# Modelling and Simulating Mobile Commerce Diffusion in China Using System Dynamics

A thesis submitted in fulfilment of the requirements for
the degree of Doctor of Philosophy


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# CANDIDATE’S CERTIFICATION

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of the work which has been carried out since the official commencement date of the approved research program; and there has been no editorial work, paid or unpaid, carried out by a third party on this thesis.

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# MODELLING AND SIMULATING MOBILE COMMERCE DIFFUSION IN CHINA USING SYSTEM DYNAMICS

# ABSTRACT

Current deployments of mobile commerce focus mostly on digital content. However, mobile commerce will grow rapidly with the increased use of portable devices such as cellular phones and personal digital assistants (PDA), increased network bandwidth, and the availability of a wider range of mobile commerce services and transactions. As the revenue generated from mobile commerce is expected to skyrocket in the coming years, strategists are turning their attention to untapped emerging markets in the developing countries. Understanding how mobile commerce will develop in countries like China, where huge market potential exists, is of paramount importance in order to develop effective strategies that will positively affect its course.

Modelling the diffusion of mobile commerce in a country is a difficult task due to the non-linear, complex and uncertain nature of its operating environment. Conventional analytical techniques are of limited use in this context, and a System Dynamics approach is more appropriate to model such a complex system. Since the diffusion of mobile commerce is influenced by a multitude of factors, some of which are yet to exist, the main objective of this study is to illustrate the process of developing System Dynamics models for simulating mobile commerce diffusion in China by using a subset of the factors involved.

In order to achieve this objective, the Chinese mobile commerce was modelled as the interaction of three subsystems (or submodels), namely: population evolution in China; mobile commerce diffusion; and the influence from the provision of mobile commerce terminals (MCT) on mobile commerce diffusion. Each subsystem was modelled by identifying the factors influencing its development as well as the interactions between the factors. The subsystems were calibrated using historical and forecasted data whenever they were available. The validation of the subsystems was also performed through extensive sensitivity analysis. The complete model was used for experimenting with some typical Chinese mobile commerce scenarios for the purpose

of analysing mobile commerce trends and designing strategies to exert positive influences on those trends.

The simulation of the submodels provided useful insights into their respective areas for controlling their development. Simulation of the population development submodel showed that, in addition to family planning policies, urbanisation rates and life quality were important factors that significantly influenced population dynamics in China. Simulation of the mobile commerce diffusion submodel showed that the time when mobile commerce is implemented will significantly influence its market expansion speed i.e.the later mobile commerce is implemented, the quicker the market will expand. The existence of floating populations in China will be a big advantage in starting up the rural market. However, if mobile commerce is implemented too late, the penetration in rural areas will be negligible. Simulation of the MCT provision submodel showed the importance of opening the Chinese market to foreign suppliers and the coordination of strategies regarding the design and supply of MCTs with strategies for the growth of mobile commerce in China.

This study is a first attempt to simulate the diffusion of mobile commerce in China using System Dynamics. The results obtained showed that the models developed were useful for understanding and controlling the future diffusion of mobile commerce in China.

# PREFACE

During the period of candidature, the following papers relating to the research topics have been published.

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# Chapter 1

# INTRODUCTION

## 1.1 Introduction

This thesis is a study of mobile commerce diffusion in China using a System Dynamics (SD) modelling and simulation approach (Sterman 2000). Mobile commerce can be simply defined as providing value-added services over networks to mobile terminals, where users can consume these services (Kuo & Yu 2006). It is believed that it will generate unprecedented business opportunities and is regarded as an important and growing sector worldwide (Yang 2005). In fact, recently the global marketplace for mobile commerce has achieved rapid expansion and will attract more and more attention in the future. Exploring the developmental trend of mobile commerce is a major challenge since it is poorly understood for several reasons. First, the development of mobile commerce seems to be influenced by a variety of factors as described in the literature (Bouwman, Carlsson, Molina-Castillo & Walden 2007). Some factors are obvious while others are hidden or not yet known. Not all of them are equally significant, thus the effect of these factors should be examined and their sensitivity should be understood. Second, mobile commerce is a new area and has a lot of uncertainties in its future (Rupp & Smith 2002). Scenario design, simulation and analysis will be useful in this regard. Designing, simulating and analysing scenarios that can illustrate the possible future of mobile commerce development is becoming necessary. Third, mobile commerce diffusion will demonstrate different behaviours under different scenarios. Some scenarios may generate desirable effects while others will have a negative impact. Developing strategies to manipulate the positive effects displayed by some scenarios and to avoid and mitigate the negative aspects of other scenarios is paramount in managing the future of mobile commerce.

This research has two purposes. First, the research will demonstrate how to develop a model for simulating mobile commerce diffusion using the System Dynamics approach. Second, this study will demonstrate how this model can be used as a platform for performing experiments to accomplish the identification of sensitive factors, the design, simulation and analysis of scenarios and the development of strategies for achieving certain goals.

For these purposes, a mobile commerce diffusion within a country's boundary is considered to be a system. Instead of using conventional analytic methods, a systemic method is used in exploring this complex system. SD modelling is used to establish the relationships between factors, events, structural changes, behaviours displayed and the changes of system state. Simulation will provide the evidence to find sensitive factors, design meaningful scenarios and experiment with useful strategies. If the relationship among influential factors, possible scenarios and effective strategies can be established, the implementation of mobile commerce will become efficient and effective and its future will be controllable.

## 1.2 Background to the research

Mobile phones are increasingly becoming an important part in the daily lives of human beings. A mobile phone is a moving terminal which a person can use to enter the digital world at any time and any place. Originally, the mobile phone was invented to replace the fixed-line telephone which provides a primitive voice service. However, with the development of new technologies, mobile phones have been further enhanced to provide short message services (SMS), multi media services (MMS), photo taking and image-transmission, location-based services, etc.

Currently, in some countries people can use their mobile phones to connect to the Internet and accomplish mobile commerce transactions (Ratsimor, Korolev, Joshi & Finin 2001) such as mobile banking, mobile shopping, etc. Through the convergence with intelligent technologies, the mobile phone of the future can be used to manage the workplace and the home. For example, from the tiny screen of the mobile phone, people can telecast what is happening at the office as well as tele-control conditions in their homes. People on their way to work can use their mobile phones to pay for train tickets and on the train they can use their mobile phones to learn about the news and the weather forecast or listen to music. Before they enter their office, they can use their mobile phones to switch on the air conditioner and their computers in advance. On their way back home, they can use their mobile phones to switch on the oven and when they arrive home, the meal is already cooked and ready to serve.

Mobile phones are attracting a huge number of users because of the benefits to ordinary people offered by mobility and the increasing number of functionalities available. They are also creating and will continuously create unlimited business opportunities with the adoption of mobile commerce. The term mobile commerce is generally used in a broad context. It refers to business transactions regarding the sale and purchase of goods and services through a network of computers accessed via a device falling into the mobile/wireless category. It also refers to any form of business activity, such as voice, SMS, mobile Internet, mobile portals and search engines, location-based service (Tewarn, Youll & Maes 2002) and receiving advertisements (Brownlow 2001). In this research, mobile commerce refers to performing business activities such as the voice, SMS, sale and purchase of goods and services through a network over mobile phones that support this functionality. Under this definition, a mobile commerce service may refer to a low-end service like mobile telephony or include a high-end service such as mobile banking, mobile shopping, mobile stock trading, etc.

Mobile commerce will be worth billions of dollars in revenue within the next five years (Dawson 2003). It is already successful in some developed countries. For example, a successful application in Japan has been adopted by the DoCoMo Company (MacDonald 2003) as its I-mode–a wireless Internet service–has been widely adopted in developed countries. Its success has caught the attention world-wide in populous countries, like China and India, of huge numbers of mobile phone users. Thus, international strategists are starting to develop interests in the emerging mobile commerce markets in developing countries because of the huge potential for business.

China is becoming the world's largest mobile phone market and is widely regarded as one of the biggest potential mobile commerce markets. The Chinese mobile phone market became the largest in the Asia Pacific in 2000 and the world's largest in 2002 (Kshetri, Williamson & Bourgoin 2006). Gartner's Dataquest puts China ahead of the rest of Asia and the Strategis Group expects China to have 334 million mobile phone users by 2007, eclipsing the US. The number of mobile phone users in early 2006 reached 400 million. In addition, China's existing high-speed cellular network in some areas is ready to exploit mobile commerce. Furthermore, China is becoming a regional economic power. *The Economist* recently forecast that, within

20 years, China would become the second-largest economy in the world (Anonymous 2001). With this great economic momentum, China has been and will continue to be the world's largest cellular market, and one of the biggest potential mobile commerce markets in the long run.

## 1.3 Problem statement

The Chinese mobile commerce market is increasingly drawing attention from Chinese Government administrators and international strategists. How to explore the dynamics of and manage mobile commerce diffusion is a great challenge with problems such as complexity, uncertainty, interconnectivity with many factors, no prior success, and no accurate information, etc.

The mobile commerce market is a new complex system. Since mobile commerce is still in its infancy no experience of success can be borrowed from. The complexity comes from the involvement of a large number of factors scattered in different sectors (horizontally) and layers (vertically) of the system. Horizontally, the factors may come from the demographic side, mobile commerce terminal industry, service provision industry, network sectors, government policy making, etc. Vertically, for example, in the demographic area, the change in the number and structure of the forecast will directly change the number of users. Factors that may change demographic dynamics, such as family planning, urbanisation and living quality, will also exert an indirect influence. So too may the factors change that influence family planning, urbanisation and living quality. Mobile commerce diffusion is becoming a far-reaching and deep system. The first challenge is how to model this system realistically. This research uses systems thinking to form a system reflecting the real world of the Chinese mobile commerce market and then adopts System Dynamics modelling techniques to simulate the real world so that it is compressed temporally and spatially into a complete model and where mobile commerce diffusion can be experimented with.

The second challenge is to determine the factors that will exert significant influence on mobile commerce diffusion from the candidates of the interwoven factors. In a developing country like China, there are plenty of existing policies and industrial regulations that are constantly changing, with new policies and regulations frequently appearing. The factors involved in these policies that affect the diffusion of mobile commerce need to be identified and studied. In addition to the factors related to national policies, there exist other factors not under the control of policies tha will also influence the diffusion of mobile commerce. Finding and analysing these factors is equally important. Some factors that appear important may turn out to be trivial and vice versa. It is equally paramount to find these sensitive factors as it is to find a suitable method to model the real world of the mobile commerce market.

The third challenge is to simulate scenarios and develop strategies if necessary. With sensitive factors identified, the model developed can be used for experimenting with different scenarios of what might happen in the future, and to help formulate strategies that are effective in controlling the diffusion of mobile commerce. Scenarios result from the combination of the identified sensitive factors. After analysing the behaviours generated under these scenarios, strategies can be developed to avoid any pitfalls or to mitigate shortcomings involved in some of the scenarios.

Last but not least the challenge will be to overcome the unavailability of accurate data and relevant information. Data is the base of research. Since mobile commerce is in its beginning, limited data and information increase the difficulty of exploring these new areas. However, the simulation technique used in this research can overcome this problem. Using common sense, realistically arriving at certain values and stochastic generation can accomplish some of the ambitions put forward by a modeller.

To sum up, the problem this research tries to solve is to provide a basic understanding of mobile commerce diffusion in China by developing an applicable simulation model, then analysing a subset of factors, designing typical scenarios and developing useful strategies for controlling the diffusion behaviours under disadvantageous conditions.

## 1.4 Justification for the research

China has not yet formally implemented its mobile commerce system except for some small-scale tentative tests conducted, but it is preparing itself for launching a large-scale mobile commerce implementation. With over 400 million subscribers in 2006, China has the largest and fastest growing number of mobile phone users and is one of the largest potential mobile commerce users in the world. How to reasonably explore this new market will be a big topic ahead. This research tries to provide useful information to the decision makers for both Chinese Government administrators and international business strategists.

Mobile commerce means an unprecedented business opportunity. Implementation of mobile commerce is a big project and is interrelated to other sectors. By the year 2008, half of all handheld mobile phones sold in the world will be produced in China. The problem is to find out whether the existing manufacturers of mobile phones can easily build the needed capacity to produce mobile commerce terminals and to strategically organise the production of mobile commerce terminals. With its entrance into the World Trade Organization (WTO), China has to open its mobile commerce to foreign companies. The problem is how to open this market to best benefit the country. Renovation of the existing network is another issue. Which option is better: to completely renovate or to gradually upgrade? or perhaps there are other options? In addition, industrialisation, family planning, education and the shifting standard of living will change the structure of the population. Will these changes generate influence? So many sectors will be involved and can exert their effects. This research will establish the complex relationship among them and demonstrate the importance of each in the process of mobile commerce diffusion. The findings from this study will provide information to the Chinese Government on how to strategically coordinate and balance the interests and reach a consensus among the different sectors.

International strategists can use this model to find and evaluate potential business opportunities brought about by mobile commerce implementation in China. On one side, the findings from the simulation will help them increase their bargaining power when some condition occurs. On the other side, experiments will assist them in avoiding unnecessary mistakes, unforeseeable risks, losses or even disaster from the vast market dynamics.

To sum up, this research will find a way to help both the Chinese Government policy makers and international strategists to examine the dynamics of mobile commerce diffusion and design their own useful strategies.

## 1.5 Methodology

This research adopts a systemic approach in general and SD simulation modelling in particular in exploring the complexity of mobile commerce diffusion. It includes a systemic approach to form a general research design, SD modelling techniques (causal loop diagramming and stock flow diagramming) to develop applicable models, and simulation techniques to conduct sensitivity analysis, scenario design and analysis and strategy formulation (Maani & Cavana 2003).

Common approaches to innovation diffusion are often derived from analytical methods with limited factors. They cannot deal with the complexity and dynamism inherent to mobile commerce diffusion (Milling 2002). As a result, an SD simulation modelling approach is being employed in this research because of these advantages.

In SD simulation modelling, model formation and simulation is integral to a clear understanding of how a system is composed and how the system changes its state both temporally and spatially. Model development unravels the complex interrelationships between the system structures, system behaviours and system states (Coyle 1996). Simulation examines how the behaviours from the model developed will change in response to both actions from decision makers and factors not subject to strategic control (Sterman 2000). SD simulation modelling is also a problem-solving and reasoning paradigm that integrates relevant knowledge to solve new problems, and can be applied for evaluating a wide range of scenarios to meet development trend analysis (Maani & Cavana 2003).

Few studies have applied SD simulation to mobile commerce diffusion, and the applicability of SD modelling to mobile commerce diffusion remains an open research question. While the application of simulation to mobile commerce diffusion issues is still in its infancy compared to other fields in which models have been extensively used for many years (Lane 1992), there is much synergy for this application in examining mobile commerce diffusion.

## 1.6 Thesis outline

The rest of this thesis is organised as follows:

**Chapter 2** reviews research on mobile commerce in general and System Dynamics simulation modelling in particular. Population dynamics modelling and innovation diffusion are also reviewed. This chapter concludes with the selective combination of these methods that motivate this research, inspire the overall research design and encourage the accomplishment of the modelling and experimenting in chapters 4, 5 and 6.

**Chapter 3** describes the general research design and the overall methods adopted. It provides an overview of the processes and embedded techniques in the SD simulation modelling. It also displays a framework to guide scenario design, simulation and analysis and strategy development using the simulation model. The chapter concludes with an explanation of how the overall research design, the processes of SD simulation modelling, the frameworks of scenario design, simulation and analysis and strategy development together pave the way for the experiments in this thesis.

Chapters 4 to 6 contain the simulation research undertaken in this thesis.

**Chapter 4** explores an SD simulation model on population development, which is the starting point to explore the consequent markets in the following chapters. It begins with a description of a dynamic population system. It then identifies the influential factors and explains the causal loops and stock flow diagramming. It theoretically and empirically establishes the logic and the mathematical relationship between the variables in the system that form the preliminary population model. The model developed is validated through historical behaviour reproduction using data collected from the National Bureau of Statistics of China and a comparison with the forecast from the United Nations. Finally, it conducts sensitivity analysis, scenario design, simulation analysis and strategy formulation.

**Chapter 5** investigates SD simulation modelling of the dynamics of mobile commerce diffusion and conducts scenario design, simulation and analysis of mobile commerce diffusion. This chapter begins with a description of a mobile commerce market system and a review of previous research. It then identifies the influential variables and explains the causal loop and stock flow diagrams used in the model. After that, it establishes the logic and mathematical relationship between the factors in the system and forms the preliminary model for mobile commerce diffusion. The model developed is validated through historical behaviour reproduction using mobile phone subscribers data collected from the database of the Chinese Ministry of Information Industry. It first identifies the key influential factors and then designs several meaningful scenarios. It then examines how the different timings in implementing mobile commerce will influence the dynamics of mobile commerce diffusion. It also examines the behaviour of mobile commerce diffusion under different urbanisation scenarios and two complex mobile commerce diffusion scenarios. As an illustration, the research also demonstrates how to form corresponding strategies to reduce the possible negative aspects of these scenarios.

**Chapter 6** explains how to develop a simulation model for the provision of mobile commerce terminals (MCT) and examines how MCT provision will influence mobile commerce diffusion. This chapter begins with a description of MCT provision in China, and discussion of variables to form a simulation model of MCT provision. The sensitive factors are identified through sensitivity analysis. After that, it demonstrates how to obtain an optimal MCT strategy and illustrates the interaction between MCT strategic planning and mobile commerce diffusion. It also finds that MCT life cycle and market openness will significantly influence mobile commerce diffusion. Two extreme scenarios are designed and examined, and countermeasure strategies are developed to mitigate the side effects of mobile commerce diffusion from these two scenarios.

**Chapter 7** concludes the thesis with a summary of the research work, findings and implications. The contributions and limitations of this study are highlighted. It also suggests directions for further research.

The thesis also contains four appendices:

**Appendix A** contains tables that list the historical data of the number of persons in the population and the changes in its composition in China from 1978 to 2003, which was collected from the database of the National Bureau of Statistics of China available at http://www.stats.gov.cn. The data was used for the validation of the population development sub-model in section 4.6 of chapter 4.

**Appendix B** contains tables that list the statistical data of the number of persons in China by age and sex on October 1st, 1995, which was also collected from the database of the National Bureau of Statistics of China available at http://www.stats.gov.cn. The data was used for formulating the time series of birth input into the population development submodel in section 4.4.2 of chapter 4.

**Appendix C** contains tables that list the historical data of the number of mobile phone subscribers in China from 1991 to 2005, which was accessed from the database of the National Bureau of Statistics of China available at http://www.stats.gov.cn and the database of the Ministry of Information Industry available at http://www.mii.gov.cn. The data was used in section 5.5 of chapter 5 for the validation of the mobile commerce diffusion submodel.

**Appendix D** contains tables that list the absolute values and the change in percentage of simulation results of the sensitivity analysis conducted in chapter 5.

**Appendix E** contains Powersim equations used in the modelling and simulation of population dynamics model in chapter 4.

**Appendix F** contains Powersim equations used in the modelling and simulation of mobile commerce diffusion model in chapter 5.

**Appendix G** contains Powersim equations used in the modelling and simulation of MCT provision model in chapter 6.

# Chapter 2

# BACKGROUND

## 2.1 Introduction

This chapter surveys the existing literature and reviews the research findings of the previous work related to this research topic. Mobile commerce, innovation diffusion, population dynamics and System Dynamics are the main areas covered. The knowledge obtained from the literature review not only contributes to the research design through displaying the relationships among the four areas but also reveals how this study links the main areas together and bridges differences between the previous research and this study, thereby confirming the significance of this study.

## 2.2 Mobile commerce: a complex world

With the development of mobile computing and wireless network technology, human beings are entering a mobile commerce era. Mobile commerce is changing the world and at the same time the world is responding by exerting its influence on mobile commerce diffusion. Plenty of evidence regarding technologies, implementation, consumer usage and future trends of mobile commerce is appearing in emerging websites, the popular press, consulting companies, conferences, journals and academia. Like many innovations throughout human history, mobile commerce is now displaying an unprecedented complexity. This complexity is partially explained by its diverse definition, the large number of players involved and the diversified services displayed.

### 2.2.1 Mobile commerce definition

The complexity of mobile commerce is reflected in its diverse definitions. The concept of mobile commerce was formed in the last decade of the 20th century when wireless technology and mobile computing appeared. In the beginning, most definitions mainly emphasised the fulfilment of monetary transactions and the expansion of electronic commerce. In Durlacher Research,[1] mobile commerce is described as a subset of electronic commerce or any transaction with a monetary value that is conducted via a mobile telecommunications network (Norman 2002). Later, the purely monetary value of such transactions is less emphasised, and instead the business commitment relating to the transaction is stressed. If mobile commerce refers to transactions, it should include any transaction of economic value through at least one kind of mobile terminal equipment on the mobile telecommunications network (Clarke 2001, Barnes 2002). Commercial transactions conducted using a variety of mobile equipment over a wireless telecommunications network is also regarded as mobile commerce (Barnes 2002, Coursaris & Hassanein 2002, Gunsaekaran & Ngai 2003). These early definitions emphasise the realisation of monetary transactions, and limit the scope of mobile commerce services.

With the development of mobile commerce, its originally narrow and rigorous definition has been relaxed. Any direct or indirect transaction conducted or facilitated through a wireless telecommunications network is considered to be mobile commerce (Yang 2005). In this definition, monetary transaction is no longer a necessary characteristic. A vague concept of service is used to replace monetary transaction within the definition. Mobile commerce is used to refer to the buying and selling of goods and services through wireless handheld devices such as cellular telephones, personal digital assistants (PDAs) and wireless computers (Michael & Salter 2006). Under this view, mobile commerce is extended to refer to a specific business activity of trading products via wireless telecommunications networks and mobile terminals. The concept of mobile commerce is further expanded to cover any auxiliary business activity accomplished through interconnected mobile networks at any mobile terminal, at any time and any place. From a systems point of view, mobile commerce is an interactive ecology system of individuals and corporations, and this ecology system is built upon the social economic background and various succeeding technologies (Mylonopoulos & Doukidis 2003). No matter how mobile commerce is defined, mobile networks, mobile devices and services constitute

[1] Durlacher Research, Mobile Commerce Report, November 1999. Available at http://www.durlacher.com/downloads/mcomreport.pdf or http://www.durlacher.com/fr-research.htm

the growing, globalising and ever morphing mobile commerce ecosystem (Dholakia, Rask & Dholakia 2006).

As a whole, mobile commerce can be considered as an ecosystem, in which any form of service is provided to consumers via a mobile telecommunications network using devices such as mobile phones, personal digital assistants (PDAs), enhanced alphanumeric handheld gadgets, and so on. The number of consumers varies with changes in the structure and quantity of the total population in this system. Mobile service can be broadly divided into two categories: information delivery, such as notification, reporting, consultation, data transfer and promotion; and monetary transactions, such as purchasing and banking. From this view, the currently used mobile commerce services should include voice communication, short message service (SMS), multimedia message service (MMS), ring tone, music download, location-based services, mobile email, and mobile global position service (GPS), and the most prospective mobile commerce services will include mobile Internet, mobile TV, mobile banking, mobile shopping, mobile stock trading, mobile auctions and mobile tele-controlling.

### 2.2.2 Mobile commerce services

The complexity of mobile commerce is also reflected in the involvement of a mixture of players. Innovative mobile commerce services, various wireless mobile networks, fast-developing mobile terminals, and the users who can access such services, networks or mobile terminals constitute the infrastructure of mobile commerce.

The mobile commerce service industry is no longer just the delivery of voice over a cellular phone. With the introduction of data services, multimedia content and advertising, there are more and more mobile commerce services arising. Forty-four potential consumer-based services are identified and shown in Table 2.1 (Mahatanankoon, Wen & Lim 2005). More and more organisations are providing tailored mobile commerce services to their recipients. For example, media companies such as Reuters now offers its business information through mobile phones. Entertainment companies like Disney sell cartoon characters and advertise via mobile devices. The high-end mobile commerce services such as payment functions require efficient and secure exchange of financial data and integration techniques. These types of services do exist in some countries. For example, some Scandinavian banks offer mobile banking solutions by directly providing billing and stock trading information to the mobile end user through wireless service providers (WSP) in the form of SMS. Mobile e-wallet aimed at payment in supermarkets, for parking and highway tolls is also available in some countries (Bradley & Scandoval 2002). It is expected that more innovative applications, as shown in Table 2.2, will become available as greater numbers of people can access more advanced networks through improved functional mobile devices (Michael & Salter 2006).

### 2.2.3 Mobile commerce networks

In addition to mobile services, another main player in the mobile commerce world is the wireless mobile networks. The Internet, local area networks (LANs) and computers are providing the preconditions for the take-off of e-commerce, wireless mobile networks (including wireless networks and telecommunications networks) and mobile terminals that are always connected to these digital communication networks and provides with the preconditions for mobile commerce. With the development of mobile network technologies, more networks will be available. Table 2.3, adopted from Barnes (2002), lists the main networks formed from newly developed technologies that have been adopted worldwide. As shown in Figure 2.1, the increase of upstream and downstream speed will make it possible for the most advanced mobile commerce services to be viable over the network system (Buellingen & Woerter 2004).

### 2.2.4 Mobile commerce terminals

Recently, mobile devices have been the fastest adopted consumer products, with more mobile phones traded annually than automobiles and PCs combined (Clarke 2001). One phenomenon is that the ever-diversified mobile commerce terminals are increasingly converging on multi-functional mobile phones. Originally, mobile phones were developed to replace fixed line telephones. Only specially tailored mobile devices were manufactured for accomplishing mobile commerce services, especially mobile transactions. With the integration of voice, multimedia and digital technology, mobile phones are now becoming the mainstream of mobile terminals. In recent years, other types of devices such as personal digital assistants (PDAs), enhanced alphanumeric communicators, watches, pens and music players have been manipulated to supplement out-of-date mobile phones to cater for mobile commerce transactions (Dholakia & Dholakia 2004). It is now more accurate to regard the mobile phone as a main terminal that provides mobile commerce services, of which voice is just one application.

Table 2.1: Mobile commerce applications (Mahatanankoon, Wen & Lim 2005)

| |
|---|
| Booking travel tickets through the Internet |
| Buying a drink from a vending machine and billing it to the mobile device |
| Calendaring and alerting Internet services (not using internal mobile functions) |
| Conducting advanced banking services (e.g. loan negotiations, ordering credit cards) |
| Controlling home appliances (heating system, car, etc.) through remote activation |
| Chatting with others on the Internet |
| Checking at airport without physical documents (e.g. mobile passport) |
| Filling out and sending damage reports (notifications of claim) to insurance companies |
| Finding the location of a new/used car of a certain model, colour and features |
| Formatting website for display on mobile device |
| Issuing electronic payment in physical shops |
| Listening to music from the Internet, including downloaded MP3 songs |
| Managing in-house and inventory-on-move |
| Managing personal appointments and meetings through Intranet/Internet |
| Performing routine banking services (pay bills, check account, etc.) |
| Paying a parking ticket on the spot |
| Playing interactive games on the Internet |
| Posting or viewing online classified ads |
| Reading and receiving news (through subscription service or browsing) |
| Reading downloaded e-books |
| Reading or sending messages from/to a specific newsgroup |
| Receiving an alert notification from an online travel company about a new lower fare |
| Receiving personal advertisements |
| Receiving personalised shopping offers |
| Receiving time-sensitive discount tickets from physical store (e.g. e-coupon based on upcoming sales) |
| Receiving location-sensitive discount tickets from physical store (e.g. e-coupon from a nearby store) |
| Receiving time-sensitive information regarding weather reports, financial, traffic information etc.) |
| Reporting (transmitting information) emergencies based on location (e.g. roadside assistance, accidents etc.) |
| Reserving a restaurant table |
| Searching for specific information on the Internet |
| Sending or receiving emails |
| Sharing digital files or personal information online with friends, family, or strangers |
| Shopping for goods on the Internet (books, flowers, groceries etc.) |
| Surfing the Internet casually |
| Taking part in Internet auctions |
| Tracking the location of product and services that are needed, including finding goods, boxes, people etc. |
| Trading stocks and initiating a request to have the money transferred |
| Transferring money from a pre-configured bank account |
| Transmitting (automatically) emergencies information (e.g. personal assistance, roadside assistance etc.) |
| Using directory services (e.g. google search, yellow pages etc.) |
| Using Internet search engines (e.g. yahoo, lycos, hotbot etc.) |
| Viewing or sending pictures via the Internet |
| Watching video clips from the Internet |
| Working with the mobile device in traffic jam, airport, or conferences |

Table 2.2: Top ten mobile commerce services today and tomorrow (Michael & Salter 2006)

| Today's top ten services | Tomorrow's top ten wish list |
|---|---|
| Voice | Travel alerts |
| SMS | Parking meter payment |
| Ring tone subscriptions | Special offers and general marketing communications |
| Calculator | Seasonal tickets |
| Taking pictures | Credit/debit cards |
| Mobile gaming | Flight check-in |
| Using operator portal | Vending machine payment |
| Mobile search | Retail checkout |
| Surfing WAP sites | Loyalty cards |
| Alert subscriptions | Mobile coupon redemption |

### 2.2.5 Mobile commerce users

The expansion of mobile telecommunications infrastructure will create a vast number of potential mobile commerce users. There are many political, economic, social, geographical, legal and demographic factors involved in adopting mobile commerce services. Thus, the focus of research must shift from a purely technical approach to a sociocultural one. It is found that cultural differences play a very important part in shaping potential consumers' choice, beliefs and attitudes about mobile commerce services. In addition to customer saturation and evaluation of services provided, education is a determining factor (Ranfit 2006). Currently, mobile commerce as an industry is still in its infancy and mobile commerce is not yet becoming a necessity in daily life. The main challenge that the industry will face does not lie in improving and refining the technology, but rather in strategically cultivating this emerging industry, for example, by creating a suitable environment, developing users' positive perceptions of mobile services and cultivating compatible lifestyles etc. Such strategic renovations will inevitably take mobile commerce growth to a new level. However, this can only occur through an appreciation of the various socio-economic dynamics that influence consumers'choices, beliefs and attitudes (Das, Wang & Lei 2006).

Table 2.3: Key mobile network technologies (Barnes 2002)

| Standard | Description | Speed[a] |
|---|---|---|
| GSM (Global System for Mobile Communication) | The prevailing mobile standard in Europe and most of the Asia-Pacific region–around half of the world's mobile phone users. | 14.4kb/s |
| PCS (Personal Communications Services) | A standard based on Time Division Multiple Access (TDMA), which divides a frequency into time slots and gives users access to a time slot at regular intervals. TDMA is used in the US, central/south America and many other countries. | 14.4kb/s |
| PDC (Personal Digital Cellular) | A standard used in Japan. Uses packet-data overlay on second-generation networks to achieve 'always-on' data communication and higher speed. | 28.8kb/s |
| HSCSD (High Speed Circuit Switched Data) | A circuit switched protocol based on GSM. Able to transmit data at around four times the speed of GSM by using four radio channels simultaneously. Some services were launched in late 1999 and early 2000. | 57.6kb/s |
| GPRS (General Packet Radio Service) | A packet switched wireless protocol as defined in the GSM standard offering instant, 'always-on' access to data networks. The speed will initially be less than the maximum burst: at first 43.2kb/s upstream and 14.4kb/s downstream, rising to 56kb/s shortly afterwards. | 115kb/s (burst) |
| EDGE (Enhanced Data rates for Global Evolution) | This is a higher bandwidth version of GPRS and an evolution of GSM. The high speeds will enable bandwidth-hungry multi-media applications. EDGE conveniently provides a migration path to UMTS by implementing necessary modulation changes. | 384kb/s |
| IMT2000 (International Mobile Telecommuni-cation) | This is a third generation (3G) standard. Three rival protocols have been developed: Universal Mobile Telephone System (UMTS) in Europe, Code Division Multiple Access (CDMA) 2000 in the US, and Time Division Synchronous CDMA (TD-SCDMA) in China. The development of the standard requires significant investment in infrastructure. | 384kb/s -2mb/s |

[a] Speed is measured in kilobits (kb) and megabits (mb) per second; 1 kb = 1024 bits; 1 mb = 1,048,576 bits

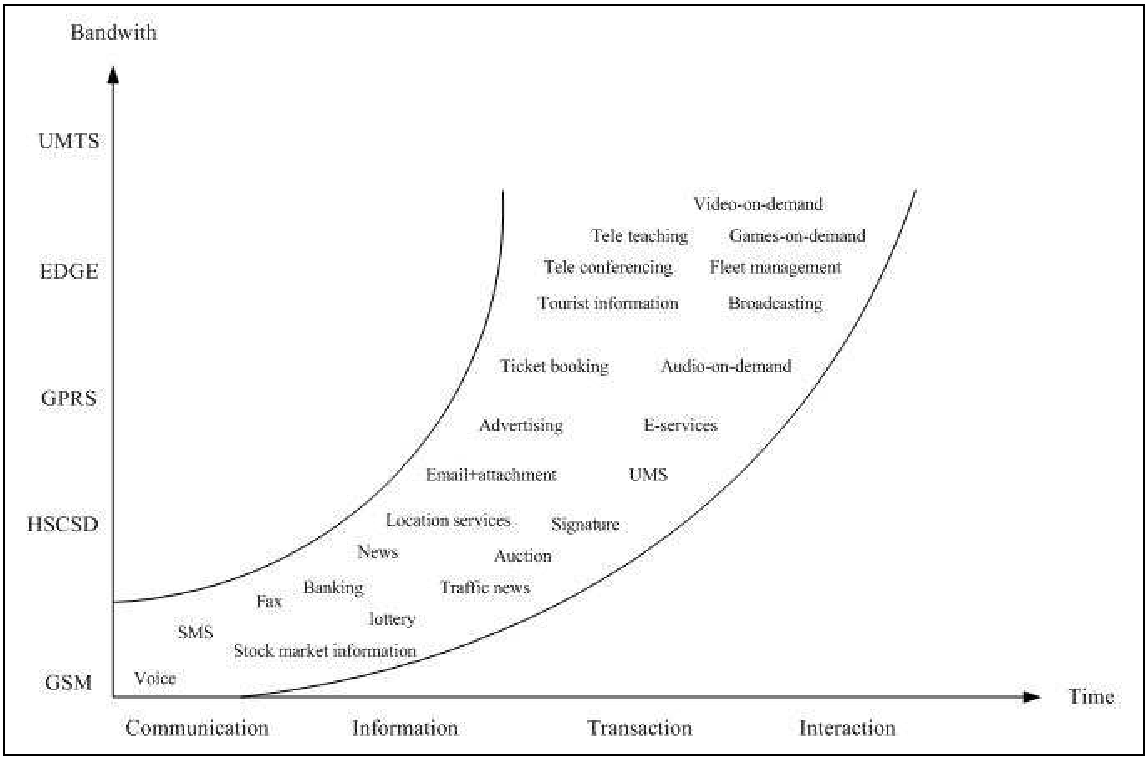


Figure 2.1: Relationship of mobile commerce services and networks (Buellingen & Woerter 2004)

### 2.2.6 Mobile commerce in China

Mobile commerce becomes even more complicated when examined in the Chinese context. China's huge mobile phone market, renovated mobile network industries, immature mobile commerce market and uneven regional development makes the future of mobile commerce uncertain.

China is the world's biggest mobile phone market in terms of its subscriber base and the fastest growing in the history of telecommunications. In 2004, China was adding five million new mobile telephone customers every month. That is the equivalent of adding the whole nation of Denmark, or Finland, every month to the mobile user base of the world's most populous country (Dholakia et al. 2006). In addition, the Chinese Government is strategically promoting mobile phones as the 'people's phone' and is actively encouraging Chinese consumers in both city and the countryside to buy mobile phones (Kshetri & Cheung 2002). As a result, China is already becoming the world centre of consumption and production of mobile phones and will emerge as a global capital of m-commerce applications.

The Chinese mobile network is the biggest in the world and has obtained the fastest growth in the history of telecommunications (Kshetri et al. 2006). China has developed its own 3G standard: TD-SCDMA. 3G refers to third generation digital mobile telecommunications, capable of data speeds high enough to support advanced mobile commerce services. Rapid development and positive prospects in the Chinese mobile telecommunications industry have increasingly attracted worldwide mobile commerce practitioners to conduct international activities in China (Kshetri 2004*b*, Kshetri 2004*a*).

Although China currently lacks advanced mobile applications as compared to Europe, North America, Japan and Korea, a number of market participants are rapidly launching sophisticated mobile applications (Kshetri et al. 2006). In the long run, it is not Europe, Japan or other Asian countries, but China who will soon be the USA's main rival. Some advanced mobile commerce services have been tentatively implemented in China and the response is encouraging. For example, a Shanghai-based company has developed a mobile commerce service called mobile billing. When a payment is due, a message displays on the screen that shows the amount due from which the user can then authorise the payment from a bank account by entering a secret code. The service attracted 90,000 users in Shanghai in nine months (Manuel 2003). Similarly, in mid 2005 The Music Engine (TME), a UK-based technology and online marketing solutions provider, was planning to provide m-payment services in China (Salz 2005). The Chinese mobile commerce market is the biggest in the world and penetration rates in some of the wealthier Chinese cities are much higher than the averages of many developed countries.

Recent mobile commerce diffusion in China can be characterized as by two extremes. On one side, low-end mobile commerce services, such as mobile voice telecommunication and SMS, obtained nationwide explosion. However, this diffusion displayed a high level of bias toward urban areas. For instance, in 1999 an average of 3.42 percent of national people owned mobile phones. By the middle of 2007, this figure was increased to 38.2 percent. In some metropolitan cities, the adoption rate of mobile phone has already reached 100 percent[2]. However, 78 percent of the total population who own mobile phones is in the three wealthy cities of Beijing, Shanghai and Guangzhou (Tsuchiyama1999a), and there are virtually no mobile phones in many Chinese villages. With the rollout in early 2004, SMS service is keeping a monthly increase of more than 35 percent[3]. On the other hand, there is no real large-scale diffusion of

[2] from http://www.stats.gov.cn/
[3] from http://www.stats.gov.cn/

high-end mobile commerce service (like mobile payment) indeed. However, the preparation for this initiative is in full swing. Applications of advanced mobile commerce services are still being trialled. In 2003, the two biggest Chinese mobile telecommunication companies, China Mobile and China Unicom, launched a one-way payment card (SinoCast 2005). In May 2005, by cooperating with ten banks, China Mobile and China UnionPay launched mobile payment in the Beijing area [4]. There is no formal large-scale implementation in China indeed.

To sum up, mobile commerce services are diversified and can appear in any form. A mobile commerce service can be regarded as a specific innovative service being diffused among a group of potential users who are viable under a certain kind of network and a certain kind of mobile terminal specific to this service. In other words, mobile commerce diffusion can be regarded as an innovation diffusion occurring in a specific temporal and spatial context. In order to explore mobile commerce diffusion, it is important to learn what kind of theories on innovation diffusion are relevant to this research topic and how innovation diffusion has been studied in academia.

## 2.3 Innovation diffusion modelling

Innovation diffusion as a traditional theory has been in existence for several decades. Its development is reflected in the diversified establishment of innovation diffusion models and the interpretation of these models through contemporary methodology.

The core models of innovation diffusion had been established by the 1970s. The famous models include the logistic model (Mansfield 1961) and the Bass model (Bass 1969). From then on, model development focused on modifying the developed models by adding greater interpretation and applicability. The main categories of these modifications include the introduction of marketing variables in the parameterisation of the models, and generalisation of the models in the context of diffusions in different countries and successive generations of technology. In practice, the main application areas are centred on the introduction of consumer durables and telecommunications innovations. As an application, there is plenty of research in the area of mobile phones for accurate forecasting methods (Rice & Katz 2003, Boretos 2005, Iimi 2005)

[4]China Mobile joins ChinaUnionPay for mobile payment service, available at URL: http://www.pacificepoch.com/newsstories/25207_0_5_0_M/

and examining their applicability to particular cases (Ishii 2004, Sangwan & Pau 2005).

### 2.3.1 Logistic diffusion model

The diffusion of many new products follows roughly logistic trajectories (Sterman 2000). The logistic model was first used and modified in early research (Mansfield 1961, Gregg, Hassel & Richardson 1964, Easingwood, Mahajan & Muller 1981, Meade 1985, Bewley & Fiebig 1988).

In whichever form it appears in practice, a basic logistic model accomplishes the following transformation. Assuming there is a certain amount of total population ($N$), the product ($ci$) of the contact rate ($c$) and adoption fraction or infectivity ($i$) can be estimated by linear regression. The solution to this logistic equation can be expressed as

$$\frac{U}{(N-U)} = \frac{U_0}{N-U_0} \exp g_0 t$$

where $U$ is the number of adopters, $U_0$ is the initial number of adopters, $N$ is the total target population, and $g_0$ is the initial fractional growth rate of the adopters, which at the initial time when there are very few adopters is equal to the number of infective contacts ($ci$) or the product of the contact rate ($c$) and adoption fraction ($i$). Taking the natural log of both sides and replacing $N - U$ with $P$, a logistic transformation is obtained.

$$\ln\left[\frac{U}{P}\right] = \ln\left[\frac{U_0}{P_0}\right] + g_0 t$$

$P$ is the number of potential adopters, and is the difference between the total population and the number of adopters.

### 2.3.2 Bass diffusion model

The logistic model of innovation diffusion has one major flaw: namely the startup problem. The logistic model cannot explain the creation of the initial adopters. The Bass model for the diffusion of innovation overcomes this problem (Bass 1969). The Bass diffusion model has become one of the most popular models for new product growth and is widely used in marketing, strategy, management of technology, and other fields. Bass solved the startup problem by assuming that potential adopters become aware of the innovation through external information sources whose magnitude and persuasiveness are roughly constant over time.

The total adoption rate is the sum of adoptions resulting from word of mouth and adoption from advertising and any other external influences. Adoptions from word of mouth are formulated exactly as in the logistic innovation diffusion model as above. Bass assumed that the probability that a potential adopter will adopt as the result of exposure to a given amount of advertising, and the volume of advertising and other external influences in each period are constant. Therefore the external influences cause a constant fraction of the potential adopter population to adopt within each time period. Hence the adoption rate, *AR*, is

$$AR = aP + ciPU/N$$

where *aP* refers to adoption from advertising, and *ciPU/N* is adoption from word of mouth. When an innovation is first introduced the initial adopter is zero, and the only source of adoption will be external influences such as advertising and propaganda. The advertising effect will be big at the very beginning of the diffusion process and will diminish as adoption from word of mouth increases and the pool of potential adopters is drained.

### 2.3.3 Progress of innovation diffusion modelling

A number of IT diffusion models have been applied to facilitate choosing the most appropriate model for a specific case (Quaddus 1995*a*, Quaddus 1995*b*). The models were subsequently classified into two main categories: implicit time dependent (i.e. stage or static models), and explicit time dependent (i.e. dynamic models).

Most IT diffusion models have been developed under the static approach, which places emphasis on phases of a diffusion process and technological impacts. IT diffusion models based on a dynamic approach deal with the time-related spread of IT usage. Generally, if a new technology adopted by early adopters is successful, a bandwagon effect will tempt potential adopters to imitate. It has been observed that technology diffusion and an imitation process over time can be modelled by a logistic or s-shaped curve (Rogers 2003). For example, the factors affecting the diffusion and substitution rate can be examined by drawing causal diagrams and developing System Dynamics models (Sharif & Haq 1979). A dynamic model was used in exploring the diffusion of spreadsheet software and it was found that this diffusion followed a dual s-curve (Brancheau & Wetherbe 1990). In addition, three types of dynamic models–internal influence, mixed influence and external influence–were also established and successfully applied to examine the diffusion behaviour of IT outsourcing (Loh & Venkatraman 1992).

With the development of computing technology, graphical notations have been used in presenting innovation diffusion models. Computer simulation assists traditional rigorous analysis. The most advanced applications are the innovation diffusion models in SD-based versions and agent-based versions (Epstein & Axtell 1996). Mathematically, an SD model is actually a system of differential equations. It is Sterman (2000) who most recently systematically redisplayed the traditional logistic, epidemic, and innovation diffusion models in the System Dynamics format. System Dynamics modelling regarding drug addiction (bad behaviour diffusion), for example, cocaine prevalence model (Homer 1993) and heroin addiction model (Richardson 1983), was successful in examining the consequences of drug use. More insightful SD models of innovation diffusion were developed and successfully implemented in anticipation of new technology growth (Homer 1996) and market forecasting (Urban, Hauser & Roberts 1996).

As shown in Figure 2.2, the Bass model can be interpreted by using SD-based notations, which are easily understood by management without compromising any rigour (Sterman 2000). In

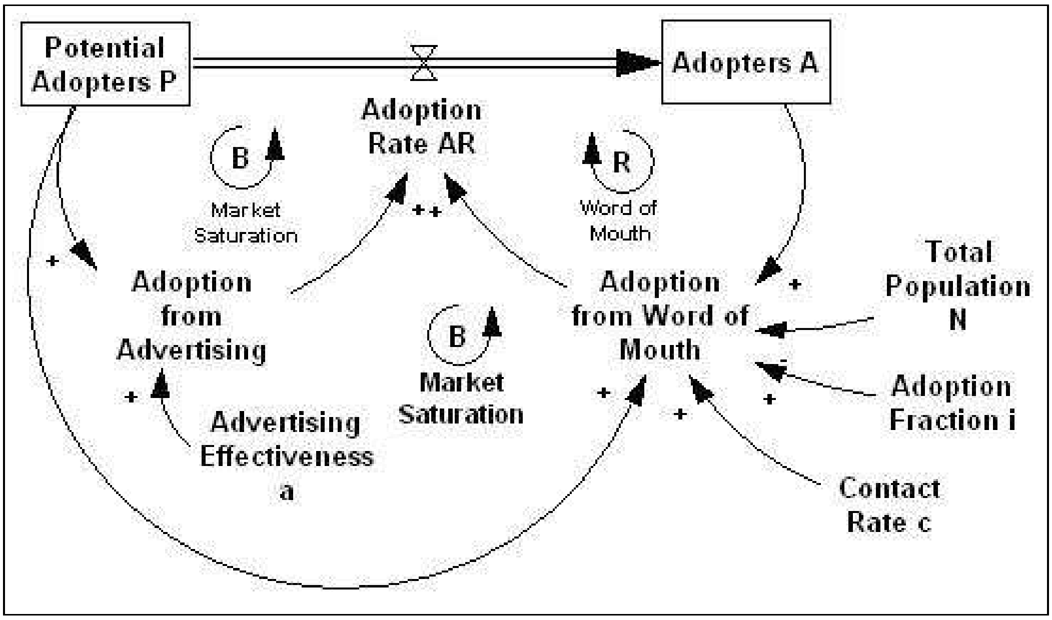


Figure 2.2: An SD-based Bass model

this diffusion model, *Potential Adopters* (P) become *Adopters* (A) at *Adoption Rate* (AR) that depends on advertising and word of mouth promotion. The impact of advertising is modelled as a constant percentage (namely, *Advertising Effectiveness* (a)) of *Potential Adopters* becoming *Adopters* at each time unit. Therefore, the corresponding summation of *Adoption Rate* equals *Potential Adopters* times *Advertising Effectiveness*. For word of mouth adoption it is assumed that everybody contacts everybody else in this population group. The number of contacts per person per time unit is *Contact Rate* (c). In case one of the two people in contact is an adopter and another one is not yet, the latter one has a probability of *Adoption Fraction* (i) to adopt the innovation. Then, during a time unit, each adopter will convert *Adopters* $*$ *Contact Rate* $*$ *Adoption Fraction* $*[$*Potential Adopters* $/($*Potential Adopters* + *Adopters*$)]$ people into *Adopters*. The expression in the square brackets is the probability of another person not being an adopter. The expression in the brackets is the *Total Population* ($N$).

No matter what kind of innovation diffusion model or interpretation method is used, among these models there is one important factor: the quantity of the total population among which an innovation will diffuse. When this population is dynamic in terms of its structure (for example, regional or sexual difference) and its quantity, this dynamic change in population needs to be examined. Hence, population dynamics is another important area under investigation.

## 2.4 Population dynamics

This section reviews the previous analytical research on demographical development in general and Chinese population dynamics in particular. The analytical research describes traditional methods that attempt to accurately forecast population elements in determining change in population. Population dynamics in China provides the basic knowledge about recent Chinese population, previous research work, issues confronted and challenged, which all demonstrates the applicability of the methodology.

### 2.4.1 Elements of population dynamics

Population change has been widely explored throughout the history of human beings. Traditionally, the number of persons is calculated as the sum of individual entities who have born or died within a specific group. The influential factors at this stage are largely related to the birth and death rates. Population research achieved unprecedented developments during the 20th century with great developments in the field of mathematics.

During the past 30 years, forecasts of the size and structural change of populations have become viewed as central to social, economic and academic activities, including short-term policy adjustment, long-term strategy planning, the provision of services to specific groups from governments or institutions, market differentiation, product positioning from business strategists, and research methodology innovation in academia. This area inevitably attracts researchers worldwide who focus their efforts on finding effective methods that can accurately forecast the key elements that control population development. The elements that most frequently appear in the literature in forecasting demographic change are mortality, fertility and migration.

#### 2.4.1.1 Mortality or death

Mortality or death have received a great deal of attention in the study of population dynamics. The simplest method of forecasting mortality is to extrapolate life expectancy, which is also called zero-factor modelling. One of the earliest models of this aspect of mortality established the logarithm transformation of observed and standard mortality (Brass 1971).

Since then, variant models have been developed to forecast mortality. A four-parameter models was used to increase flexibility and applicability (Zaba 1979, Ewbank, Gomez & Stoto 1983). At the same time, an eight-parameter model was established to estimate the age patterns of mortality in childhood, young adulthood and senescence (Mode & Busby 1982). Another eight-parameter model was established, in which senescence mortality was represented by the Gompertz function (Heligman & Pollard 1980), which refers to the linear increase in the logarithm of the age-specific mortality rates with age.

Modifications of age groups have been widely used in more recent research for the purposes of improving model fitness in forecasting mortality. For example, the childhood term can be simplified by classifying infant deaths by age (Brooks, Sams & Williams 1980, Chauhan 1997). In order to improve the fit for young adult ages, a ninth parameter was introduced to the previous eight-parameter models (Kostaki 1992).

Model fitness and flexibility later came to be emphasised. A five-parameter model from Siler is examined (Siler 1983) and it was found that this fit better than either the Heligman-Pollard or Mode-Busby models (Gage & Mode 1993). Another ten-parameter model also exhibits a better fitness (Mode & Jacobson 1984) .

The most famous method of forecasting mortality is the Lee method for long-term forecasting, in which he obtained a unique least squares solution by adopting singular value decomposition (SVD) and incorporating an adjustment of level parameter (Lee 1992). Successful applications of the Lee-Carter model were provided by other researchers. The Lee-Carter model was used to forecast mortality at a provincial level for the Canadian Government (Lee & Nault 1993). A common pattern of linear decline in the level parameter is displayed when the Lee-Carter model was applied to the G7 countries (Tuljapurkar, Li & Boe 2000). The model was also adopted to explain the reasons behind the decline in Swedish mortality decline during the 20th century (Lundstrom & Qvist 2004).

#### 2.4.1.2 Fertility and birth

It is generally accepted that fertility and birth are dynamic time series (Alho 1992, Alho 1997, Ermisch 1992). The success of forecasting fertility has been widely constrained by the difficulty in determining the structural change of the trajectory of total fertility (quantum), dynamic age patterns (tempo) and the complex interactions between the two.

As for forecasting mortality, the early, simplest and most commonly used method in fertility forecasting is the zero-factor model. Time series and functions are often used in fertility forecasting. For example, time series methods are used to forecast total births and first nuptial confinements by incorporating transfer functions linking total births to females of childbearing age and first nuptial confinements to marriages (McDonald 1979, McDonald 1981, McDonald 1983). Regression and ARIMA models are successfully applied in forecasting age-specific fertility rates (Congdon 1980, Congdon 1989).

As the Gompertz function is used to express the linear increase in the logarithm of the age-specific mortality rates with age, parameterisations, such as beta, gamma, Coale-Trussell (Coale & Trussell 1974), multi-exponential, Hadwiger and Gompertz functions have been used in modelling age-specific fertility rates. The applicability and successful implementation of these functions in fertility forecasting are widely explored. After thoroughly comparing these functions commonly used, the superiority of the gamma density, the Coale-Trussell function and the advantageous interpretability of the Coale-Trussell function in forecasting are explained (Hoem, Madsen, Nielson, Ohlsen, Hansen & Rennermalm 1981). The Coale-Trussell model was found to be superior when applied to cases of higher fertility in the 1960s, but it is a little complicated. The adoption of a double exponential function or a third term of the multi-exponential function makes the Coale-Trussell model simple (Rogers 1986).

The Hadwiger function is adopted in forecasting the four parameters involved in univariate ARIMA models (Congdon 1993), and a comparison was made later using the reduced-form

Hadwiger function for cohort fertility in London in the 1980s (Congdon 1990). The findings from these studies included: over-parameterisation of all the four-parameter functions, beta's superior fitness for the reduced-forms and the advantageous parameter interpretability of the Hadwiger function. The reduced Hadwiger function was implemented in modelling European fertility and it fits well for several countries (Chandola, Coleman & Hiorns 2000). A linear relationship between the observed fertility and a standard pattern is suitably matched in a relational Gompertz model (Brass 1974, Brass 1981). A wide fitness into the first births is witnessed by adopting the double exponential function (Coale & McNeil 1972). However, when this model is used in forecasting first births for incomplete cohorts its fitness (e.g. to young cohorts) is limited (Bloom & Trussell 1984).

Structural changes constituted another challenge in accurate forecasting of fertility. Thus variables that contribute to structural changes have attracted some attention from experts. Education is taken into account in forecasting first birthrates and childlessness using a regression model of incomplete cohort fertility (Martinelle 1993). Birth expectation is regarded as a potentially useful exogenous variable in cohort fertility forecasting, particularly in warning about changing trends (Willekens 1990). The quantum and tempo factors are considered when a linear regression is used to predict first birth fertility after the age of 25 from the proportion attaining parenthood by the age of 25 (quantum) and the ratio of fertility at 15-19-year-olds and 20-24-year-olds (tempo) (Evans 1986). To mitigate the influence from tempo, a tempo-adjusted period parity progression measure is used to forecast the fertility of incomplete cohorts that is conditional on a level of fertility and a postponement pattern derived from previous period trends (Kohler & Ortega 2002).

#### 2.4.1.3 Migration (immigration and emigration)

Migration has been largely neglected in demographic modelling and forecasting and there is less literature on this aspect than on mortality and fertility. However, this negligence and the limited availability of literature have never reduced the importance and complexity of forecasting migration. A four-term model with a multi-exponential function was developed for forecasting the age pattern of migration (Rogers & Castro 1981, Rogers, Raquillet & Castro 1978, Rogers & Watkins 1987). It comprised a constant exponential child migration, double-exponential labour migration, and retirement migration, and there were 7-11 parameters involved in their models. After examining a three-parameter bell-shaped curve used for the retirement migration (Congdon 1993), a post-retirement term is added to the four-term model (Rogers 1988). The full model modified afterwards actually includes 13 parameters (Rogers & Little 1994). The more complex migration becomes, the more parameters are involved in the forecasts. This situation inevitably limits the applicability of the established method for an increasingly complex reality.

The applications of migration forecasting have mostly focused on international migration in industrialised countries and seldom consider developing countries or domestic migration within a country. The simplest way is to make a reasonable assumption about migration rates. For example, net migration rate targets in 2050 are assumed for European countries on the basis of different economic scenarios, and then these assumptions, including five demographic patterns, are manipulated to classify European countries into different categories (De Beer & Van Wissen 1999). European countries are also grouped by using target net migration rates for intra- and extra-European migration with exponential interpolation of migrant numbers (Bijak, Kupiszewski & Kicinger 2004). Time series methods have been used in forecasting total net migration to California, in which migration is divided into domestic migration and international migration (Miller 2002). The numbers of immigrants and emigrants are also forecast for Australia through applying time series methods (Wilson & Bell 2004). No literature could be found on migration occurring in developing countries.

In addition to assumptions and time series methods, informed judgement has played a central role in migration forecasting and is increasingly used in migration forecasting in developed countries. The review on 30 industrialised countries finds that a simple assumption that the net migration is zero or would continue at the current level with a fixed age pattern is most often used (George & Perreault 1992). Combining this with informed judgement gradually enhances this assumption. As mentioned previously, De Beer-Van Wissen and Bijak-Kupiszewski-Kicinger forecast migration in European countries using scenario design, in which rational assumptions based on informed judgement on net migration rate targets in 2050 were adopted. The UK and Japan now use extrapolation based on informed judgement in their survey on projecting immigration practices, and the Netherlands combines informed judgement in its time series models in forming assumptions for 12 migrant groups (Howe & Jackson 2005).

Decomposition and disaggregation are increasingly employed in migration forecasting because this approach permits informed judgement on a specific group under certain circumstances. Decomposition includes levels and age-sex patterns forecasts for different types of migrants.

For example, based on the reason for migration, migrants can be classified as labour, dependents or asylum seekers. The importance of disaggregation in migration forecasts has been widely recognised (Hilderink, Van der Gaag, Van Wissen, Jennissen, Roman, Salt, Clarke & Pinkerton 2002). In general, as an approach, decomposition and disaggregation combined with informed judgement can increase the uncertainties for migration forecasting because of the unpredictable nature of the context, which is shaped by political, economic and social factors.

### 2.4.2 Progress of population dynamics modelling

The history of analytical population research has experienced two exciting periods. It has witnessed the methodological progression from dependence on traditional analytical methods, including deterministic projection and probabilistic approaches, to the convergence of contemporary methodology adopted from other disciplines, following a realisation of the inappropriateness and inaccuracy of the traditional analytical methodology.

#### 2.4.2.1 Traditional analytical methods

The traditional analytical methods are embedded in the long historical demographic projection (De Gans 1999). By 1980 the tradition of using the cohort-element method of population projection was well established. At this time, traditional population projections typically comprised three deterministic scenarios, based on the combinations of assumptions about mortality, fertility and migration, as described above. The problem of population projection is becoming one of requiring separate forecasting of these three elements of population change. Thus it attracts a lot of researchers to accurately forecast these elements as illustrated in the previous subsection. During 1980s this traditional deterministic scenario-based method was widely used by international organisations, such as the United Nations and the World Bank. The methods used in forecasting mortality, fertility and migration included extrapolation, expectation and explanation.

The extrapolative approach is the most widely used method in time series analysis, which is based on the assumption that the future will be a continuation of the past. The most commonly used methods of extrapolation are: the univariate autoregressive integrated moving average (ARIMA) modelling, and the generalised linear modelling (GLM) (Box & Jenkins 1976). Under the ARIMA modelling, a time series, such as birth or death, is directly forecast by zero-factor modelling or extrapolated as fitted parameters in a one-factor deterministic modelling;

however, it is difficult to forecast erratic parameter time series with accuracy. GLM is an alternative time series method, which directly models the demographic rate with time as an explicit covariate. Under the GLM framework, a zero-factor time series model is a constant; a one-factor model is a simple regression on time, and additive bivariate regression was used in the case of the two-factor model. Two or higher-level polynomials are often used for attaining a satisfactory fit, which has increased the complexity and implausibility of forecasting (Wilmoth 1993).

Extrapolation is not a theoretical method. It does not take into consideration any exogenous variables, trend alterations or structural changes. One of the fundamental weaknesses of the extrapolation method is that forecasting is based on historical patterns; changes in trends and structure are not considered for the future. Another shortcoming is that this method makes no use of exogenous variables. It also does not incorporate current knowledge about such patterns or possible intervention into actual and future trends.

Expectation methods include the use of data based on the individual's expectation about their own behaviour and experts' expectations about the population-level behaviour based on historical data research and informed judgement. Expectation methods can provide useful information for probabilistic forecasting by adopting innovative data collection methods, in which direct questions about subjective probabilities of future events are asked. But it has the limitation of subjectiveness and uncertainty.

The development of population forecasting is the process by which demographers constantly seek appropriate methods, which continuously come out by convergence with methods from other disciplines, in accurately forecasting population elements. Conventionally, mortality, fertility and migration must be forecast before the population size can be finally calculated. This increases the complexity and uncertainty of accurate population size forecasts. It is important to find simple direct methods in population size forecasting.

The applicability of logistic functions is first evaluated for this purpose, and it is found that the results from the long-term change model were much more accurate than the cohort-component method in direct population forecasts (Leach 1981). The autoregressive model was also used in forecasting population size change (Ahlburg 1987). As an application, a very general mathematical model is used for trend forecasts of population growth in China (1949-1984) by combining some basic substitution models in a new way (Xiao 1990). However, by evaluating the direct population forecasts methods, it was found that the accuracy is dependent upon the length of the base period: there are larger forecast errors for longer forecast horizons, higher base period growth rates and smaller populations (Smith 1987). It was also discovered that the length of the base period had an inverse effect on forecast errors and the relationship between forecast accuracy and forecast horizon was approximately linear (Smith & Sincich 1990, Smith & Sincich 1991). A non-linear inverse relationship was also found between small population size and forecast accuracy (Tayman, Schafer & Carter 1998). Recently, a formula for population momentum under changing fertility has been adopted in an analytical model (Li & Tuljapurkar 1999, Li & Tuljapurkar 2000), which was further extended to allow for non-replacement of ultimate total fertility and changing mortality (Goldstein & Stecklov 2002).

#### 2.4.2.2 Systemic modelling of population dynamics

Traditional population projection, extrapolation and modelling have tended to be unsystematic (Cruijsen & Eding 2001). The research methods have experienced a great transition from traditional analytic modelling to modern systemic simulation (De Gans 1999). Mainframe computers have been used in modelling and simulating world populations. The WORLD series models such as WORLD2 (Forrester 1973), WORLD3 (Meadows, Meadows & Randers 1992) and WORLD3 revisited (Meadows, Behrenns III, Naill & Zahn 1974) have been developed. The main aim of these WORLD models is to understand the effects of pollution and natural resources on the world population development. With the publishing of the Fifth discipline (Senge 1994) and significant improvements in computing power, systems thinking and SD simulation modelling have regained their relevance for examining population dynamics. For example, a model was created to illustrate the different characteristics of population dynamics under different stages of society, such as the traditional urban-agrarian and modern urban industrial stages (Ness & Low 2000). It also considered family planning. However, this model was descriptive only, as no simulation was involved.

Figure 2.3 shows a System Dynamics population model. In this model, the level of the *Population* (P) is increased by the inflow of *Birth Rate* (B) and decreased by the outflow of *Death Rate* (D). Other factors such as *Fractional Birth Rate* (FBR) and *Average Lifetime* (AL) influence the population state by directly linking to the flow rate. Using graphic notations to model and simulate population dynamics is becoming straightforward and easy for management to understand. A computer can provide friendly interfaces and undertake the rigorous calculations that

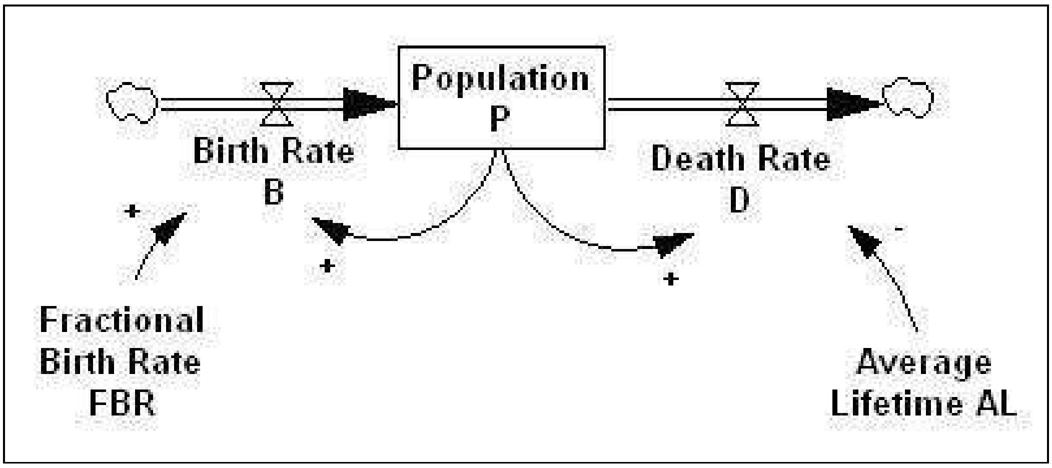


Figure 2.3: A SD-based population model

are involved.

Thus, SD-based modelling of population developments has achieved great progress, especially when used for modelling population dynamics in industrialised countries. To my best knowledge, its use for modelling and simulating population dynamics in developing countries, especially in China, is still uncommon. Since China is currently experiencing a lot of upheaval in its population development, understanding the population dynamics would be very helpful in forming general insights into population-based social or business activities. The next section will examine recent population developments in China.

### 2.4.3 Population dynamics in China

China is the most populous country in the world and its population development displays many particularities. Three stages can be identified in recent population development in China, and the government's controversial family-planning policies, and vast social changes are key points in the process of population development. These three stages are explained next.

#### 2.4.3.1 Population development in China

Recent Chinese population development has entailed the following three stages (Cao 2002, Hou 2002, Jiang 1993). The first stage started in the 1700s and ended in the 1950s, which was characterised as the constrained population development resulting from natural conditions.

Traditionally, the Chinese prefer a large family size by advocating early marriage and early childbearing. During this first stage the fertility rate was higher. However, due to natural disasters, poor healthcare and protracted periods of war, the mortality rate was also high and life expectancy was very low. High fertility, a high mortality rate and low life expectancy were thus the key characteristics during this time period, and the population obtained moderate development. The population size in this stage doubled from 250 to 500 million within about two centuries.

The second stage, which lasted roughly from 1950 to 1980, is distinguished as the population boom. The natural improvement in living conditions, preference of a large population base and late implementation of the family planning program contributed to a population explosion. In addition, the decrease in natural disasters, improvements in healthcare and the end of war greatly lowered the mortality rate and, in the meanwhile, largely improved the average life expectancy. At the beginning, the birthrate was further spurred by the policy adopted by the government which encouraged more births. In the 1970s, a tentative family planning program, which principally advocated late marriage, fewer births and spacing of births, was implemented. During this period, high fertility, lowered mortality rates and improved life expectancy were the key characteristics. An exponential population development was recorded. The population size in this period doubled again from 500 to 1000 millions within approximately three decades.

The third period refers to the period from 1980 to the present time. It is characterised by planned population development with an economy boom and great social change. In spite of the family planning program adopted in the 1970s, the large population base and annual net increase placed tremendous pressure on the Chinese Government. Sustainable development was on the agenda. China had to consider the carrying capacity of its natural resources, sustainability of its economy and harmony of its society. Economists believe that 700 million to 1 billion is the optimum population size for accelerating economic development in China. However, some experts suggest a population size of 1.6 billion is the carrying capacity for China. During this period, population development is becoming more complex than ever. Economic considerations, sustainable development and social change are increasingly playing important roles in determining population dynamics.

#### 2.4.3.2 Family planning in China

Population growth is becoming a global issue, especially in underdeveloped regions. Population reproduction falls into a vicious cycle: poorer couples want more children, yet the more children they have the poorer the couples become. Under this particular circumstance, family planning is a popular method in some countries for curbing the growth trend.

Regardless of its controversy, family planning is an effective method in controlling fertility. Unlike its two previous family planning campaigns which occurred in 1956-57 and 1962-66, China launched a third family planning campaign in 1971 that was pursued relentlessly during the following decades (Attane 2002). The aim of the campaign is to advocate late marriage and childbearing, lengthened birth spacing and reduced fertility (Banister 1987, Peng 1991). For example, in the cities, couples were encouraged to delay marriage until the age of 25 for women and 28 for men, and to have no more than two children. In the countryside, the minimum marriage ages were set at 23 and 25 respectively for women and men, and the number of children at a maximum of three. Couples had to abide by a birth-spacing period of at least three to four years.

These early measures failed to curb the population momentum. As a result, a major policy revision was made in 1979. A draconian rule, called one child per couple, was implemented both in urban and rural areas (Croll, Davin & Kane 1985). Soon after the adoption of the one-child policy, a great resistance forced the government to make the policy more lenient. Resistance to family planning was generally found to be lowest in the cities, because the push for family planning was greatly aided by the social and administrative organisation of the country. Over the past decades, the booming of the population growth in China was finally brought under control as a result of the unflagging efforts that resulted from a series of national population policies. Due to the inertia of the high birthrate of the past, however, the Chinese population will now maintain an annual growth of about 20 million people for a couple of years ahead, of which 70 percent will be born in the countryside.

#### 2.4.3.3 Social change in China

China is now experiencing extensive social change, which is characterised by a great resistance to the existing family planning policy, a change of views on having children and fast urbanisation. Under this particular circumstance, it is necessary to examine the new emerging factors concealed in this complex world.

China has long been implementing its ‘one child per couple’ family planning policy across the country. In the cities, this policy of ‘one child per couple’ is strictly applied and is successful. However, resistance to the policy is great in the rural areas, where the actual birthrate is hard to calculate. Most rural residents have more than two children, surpassing the minimum requirement of the lenient population policy, which advocates one child per couple, or two children per couple whose first child is female, and prohibits three children per couple.

This phenomenon occurs because of the imbalance in the evolutionary stages persons in urban and rural areas are reaching. Recently, the different characteristics of population dynamics under different societal stages (Ness & Low 2000) were analysed. A society will evolve from the rural-agrarian to urban-industrial. In traditional rural-agrarian society, children contributed to the household income early and supported their parents in their old age. In modern urban-industrial society, children must be educated, thereby postponing productivity for many years, and cannot be counted upon to support aged parents. This change thus alters the economic value of children from an asset to a liability. Ness also describes dynamic modelling of family planning for the first time.

Urban China has entered into a modern urban-industrial society, in which aged parents are no longer dependent upon their children and more children will increase the burden in bringing up a child without significantly lowering the quality of life in the city. However, rural China is still akin to a traditional rural-agrarian society, in which children contribute to household income early and supports parent in their old age.

All in all, family planning in countryside seems not as effective as in the urban areas for controlling population growth. Urbanisation is occurring at an even greater rate than population growth in nearly all developing countries (Ness & Low 2000). As one of the biggest developing countries, China now is experiencing unprecedented urbanisation at an uncertain speed. On the one hand, the uncertainty of urbanisation will increase the dimensions of population dynamics. On the other hand, urbanisation advances the change in society from traditional rural-agrarian to modern-urban, in which residents will change their viewpoints on having children, which in turn increases the effectiveness of family planning in the urban area.

## 2.5 Systemic approach

From the review conducted in the previous sections, it was found that the complexity of mobile commerce diffusion is process-based, multi-dimensionally integrated and time-dependent. Using mechanical analytical methods to deal with multi-layered factors is impossible. An alternative approach needs to be adopted and a systemic methodology is the optimal choice. The combination of systems thinking and System Dynamics simulation modelling forms the cornerstone of applying a systemic methodology in practice.

### 2.5.1 Systems thinking and System Dynamics

The world seems to be changing faster and faster and is globally interactive. Moreover, the problems facing the world seem to be growing ever more complex and serious. How to deal with such change and address these problems are big challenges facing human beings. As manual and power tools add to the physical power and capabilities of humans, systems thinking and system dynamics modelling may be used to add leverage to human thought and analysis of the complex world (Pidd 2003). Systems thinking is an approach that is helpful in constructing mental models which are more likely to be congruent with reality, and System Dynamics helps to formalise these mental models and simulate them accurately. Thus, systems thinking and System Dynamics increase the likelihood that the consequences of human activities can be forecast.

SD is a field of study that was founded by Jay Forrester at the Massachusetts Institute of Technology in the 1950s (Forrester 1961). Defining the concept of a system is important in understanding the basic viewpoint of System Dynamics. A system is a collection of parts which interact in such a way that the whole has properties which are not evident from the parts themselves (Coyle 1996). SD is an important systemic approach to problem solving that views a system in a holistic manner rather than analysing its elementary elements as in most conventional analytic methods. A core assumption of System Dynamics is that the world can be regarded as a set of linked systems whose boundaries depend, in part at least, on the viewpoint of the observer or analyst (Pidd 2003). The field of System Dynamics has been thriving over recent decades. Since the inception of System Dynamics, it has attracted great attention from academia and found a wide range of applications in practice by large companies, consulting agencies, innovative universities, business schools and government organisations.

The development and consumption of System Dynamics is reflected in the evolution of its definitions along the time line. Originally, Forrester defined System Dynamics as the investigation of the information-feedback characteristics of systems and the use of models for the design of improved organisational form and guiding policies. Forrester emphasised the two aspects of organisational restructuring and policy making. Afterwards, all the other definitions used are derivatives of Forrester's initial definition (Forrester 1961).

System Dynamics is regarded as a branch of control theory, which deals with socioeconomic systems, and a branch of Management Science, which deals with problems of controllability (Coyle 1979). Coyle further defines System Dynamics as a method to solve such problems as those in which time is an important factor, and which involve the study of how a system can be defended against, or made to benefit from, the shocks which fall upon it from the outside world.

System Dynamics is a rigorous method for qualitative description, exploration and analysis of complex systems in terms of their processes, information, organisational boundaries and strategies. It also facilitates quantitative simulation modelling and analysis for the design of system structure and behaviour (Wolstenholme 1990).

As an enrichment to the previous definition, Coyle claimed that System Dynamics deals with the time-dependent behaviour of managed systems with the aim of describing the system and understanding, through qualitative and quantitative models, how information feedback governs its behaviour, and designing robust information feedback structures and control policies through simulation and optimisation (Coyle 1996).

The most recent description of System Dynamics is provided by John Sterman. According to him, System Dynamics is aimed at dealing with complex issues and is a perspective and set of conceptual tools that can be used to understand the structure and dynamics of complex systems. In addition to its strength in solving complicated problems, it is a rigorous modelling method that can be manipulated to build formal computer simulations of complex systems, from which more effective policies and organisations can be designed (Sterman 2000).

In fact, systems thinking and System Dynamics are mutually interwoven. The appearance of System Dynamics gave rise to systems thinking, so systems thinking takes the principles of

Table 2.4: Qualitative and quantitative SD modelling (Wolstenholme 1993)

| Qualitative SD modelling |
| --- |
| 1. Creating and examining feedback loop structure of systems<br>2. Providing a qualitative assessment of the relationship between<br>system processes, information, organisational boundaries and strategy<br>3. Estimating system behaviour and postulating alternative strategy to improve behaviour |
| Quantitative SD modelling |
| 1. Examining the quantitative behaviour of all system variables over time<br>2. Examining the validity and sensitivity of system behaviour to changes<br>in information structure, strategies and delays/uncertainties<br>3. Designing alternative system structure and control strategies based on intuitive ideas<br>and control theory algorithms in terms of non-optimising robust policy design<br>4. Optimising the behaviour of specific system variables |

systemic behaviour that System Dynamics generated (Senge 1992). In the meantime, the establishment of systems thinking theories enhances the applicability of System Dynamics in reality. The only difference is that system dynamics with its emphasis on simulation modelling is generally seen as being more rigorous and academic. Together, these two fields are increasingly becoming allies in exploring the complexity of the world and solving complex problems.

### 2.5.2 Uses of System Dynamics

Generally, conceptualisation, formulation and simulation are the main outcomes achieved in an SD modelling approach (Richardson 1996). They are realised in two phases of SD simulation modelling: qualitative and quantitative SD modelling. Table 2.4 lists the main objectives of the two phases in SD simulation modelling (Wolstenholme 1993). Qualitative modelling uses causal loop diagrams (CLD) to depict cause and effect relationships between variables within the system boundary. Then the CLDs are converted into a quantitative model using logical relationships and mathematical equations, and simulated using computer software applications to design experiments by changing parameter values, system structures and strategies options (Wolstenholme & Coyle 1983, Senge 1992).

### 2.5.3 Elements of System Dynamics

Using System Dynamics, a system is modelled as a system of equations by which a future state of the system can be derived from its current state. Discrete time is used as an approximation for continuous time. Any kind of function can be used in SD. Graphical description languages are widely adopted in drawing SD diagrams which describe the interdependencies between the attributes of the system. The basic graphical symbols, as shown in Figure 2.4, are taken from the metaphor of streaming water or steam which flows between stocks (containers) controlled by flows (valves) (Gilbert & Troitzsch 1999). Stocks are used to contain both physical and

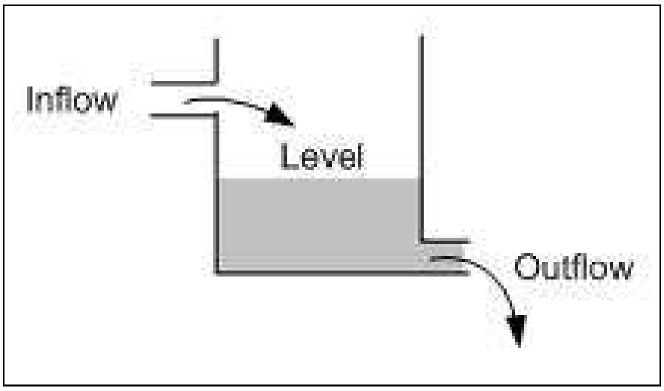


Figure 2.4: Levels and rates as stocks and flows

non-physical resources (e.g. water, money, population, energy, morale, information etc.). The level of a stock denotes the state of this stock. All the levels of stocks in a system determine the state of this system. Information passes along the closed causal loops to influence the degree of controllability of valves. Intervention can be realised through providing required information to adjust relevant valves so that the levels of stocks are amended and system states changed.

As Forrester puts it '*to model the dynamic behaviour of a system, four hierarchies of structure should be recognized: closed boundary around the system, feedback loops as the basic structural elements within the boundary, stock variables representing accumulations within the feedback loops, [and] flow variables representing activity within the feedback loops*' (Forrester 1969). In practice, causal loop diagrams represent closed loops linking resources and information and stock and flow diagrams represent levels of stocks and rates of flows. Thus, causal loop diagrams, stock and flow diagrams and the use of fully fledged software to support drawing these diagrams constitute the base on which System Dynamics is built (Pidd 2003).

A causal loop diagram is simply a map revealing the causal links among a set of variables with arrows from a cause to an effect. It emphasises the feedback structure of a system and is essentially a qualitative model which cannot be simulated. A causal loop diagram is an essential tool in System Dynamics. Not only is it a useful method for describing and understanding systems but is also the foundation on which a quantitative model can be built (Coyle 1996). An important idea in closed loop diagrams is that information links knowledge about levels of stocks to rates of flows and specifies how the rates of flow will change in the future to change the quantities of the resources in the stocks (Wolstenholme 1990). Causal loop diagrams provide '... *a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static snapshots*' (Senge 1990).

Another form of diagram used in System Dynamics is the stock and flow diagram, which uses standard symbols for the variables and links identified in causal loop diagrams. A stock and flow diagram models a system as a network of variables represented as stocks and flows interconnected by feedback loops. Figure 2.5 illustrates the simplified feedback loop in the form of stocks and flows (Forrester 1969). In a water flow analogy, the stock stays in rectangle containers and the flow moves within the pipes. Lines with arrows are used for so-called auxiliary variables, which provide information as feedback. Clouds represents the 'source', generating flow, or the 'sink', draining flow. The stocks accumulate material, money, information etc., while flows represent their movements through the system. An SFD tracks how resources are accumulated in stocks and move within a system. The stocks describe the state of the system and generate the information upon which decisions are based. The decisions then change the rates of flow which change the level of stocks by closing or opening the feedback loops of the system.

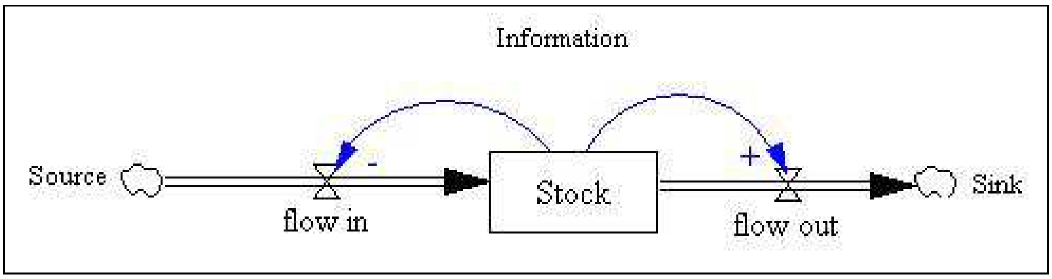


Figure 2.5: Stock and flow diagram

A causal loop diagram is a map displaying the cause-effect relationships among variables and is a qualitative model. A stock and flow diagram emphasises the underlying physical structure of the system being modelled and is a quantitative model that can be simulated. Computing experts can use contemporary computer languages to accomplish these two models. These two kinds of models can also be developed by using specialised computer packages such as VENSIM[5], SIMULINK and MATLAB[6], STELLA and *ithink*[7], POWERSIM[8] or ANYLOGIC[9].

### 2.5.4 Process of System Dynamics

SD simulation modelling achieves the objectives mentioned above as a process. This process normally starts with a problem definition, identification of key variables and their behaviours over time, and the depiction of causal links between them in a CLD. If simulation of the model is required, the qualitative CLD model has to be converted to a quantitative model. This is accomplished using an SFD which models some variables as stocks and others as flows between the stocks. Once an SFD has been created, the model has to be calibrated and validated before it can be simulated.

In practice, researchers usually design their own process with embedded stages or steps to accomplish SD simulation modelling for specific purposes. For example, a five-stage approach is developed as one of the formal processes guiding System Dynamics modelling (Coyle 1996). As shown in Figure 2.6, stage one makes clear what problems a model will solve and for what purpose and for whom this model is to be developed. Stage two develops an initial diagram, and stage three conducts qualitative analysis. In stages two and three, a system boundary is also clearly delimited and a formal influence diagram (sometimes called ‘causal loop diagram’) drawn. Stage four proceeds to construct a simulation model. In Coyle’s opinion, if the influence diagram in the previous stages is properly drawn, it is very easy in a later stage to convert the influence diagram into a simulation model. Indeed, the influence diagram, drawn using arrows and words, and the simulation model, formulated as equations and computer code, are two versions of the same model.

With the development of computer power and software engineering, SD modelling has become more acceptable in organisational learning. Flight simulators have been widely used in organisa-

[5]More details on Vensim are available at URL: http://www.vensim.com/
[6]More details on SIMULINK and MATLAB are available at URL: http://www.mathworks.com/
[7]More details on STELLA and *ithink* are available at URL: http://www.iseesystems.com/
[8]More details on POWERSIM are available at URL: http://www.powersim.com/
[9]More details on ANYLOGIC are available at URL: http://www.xjtek.com/

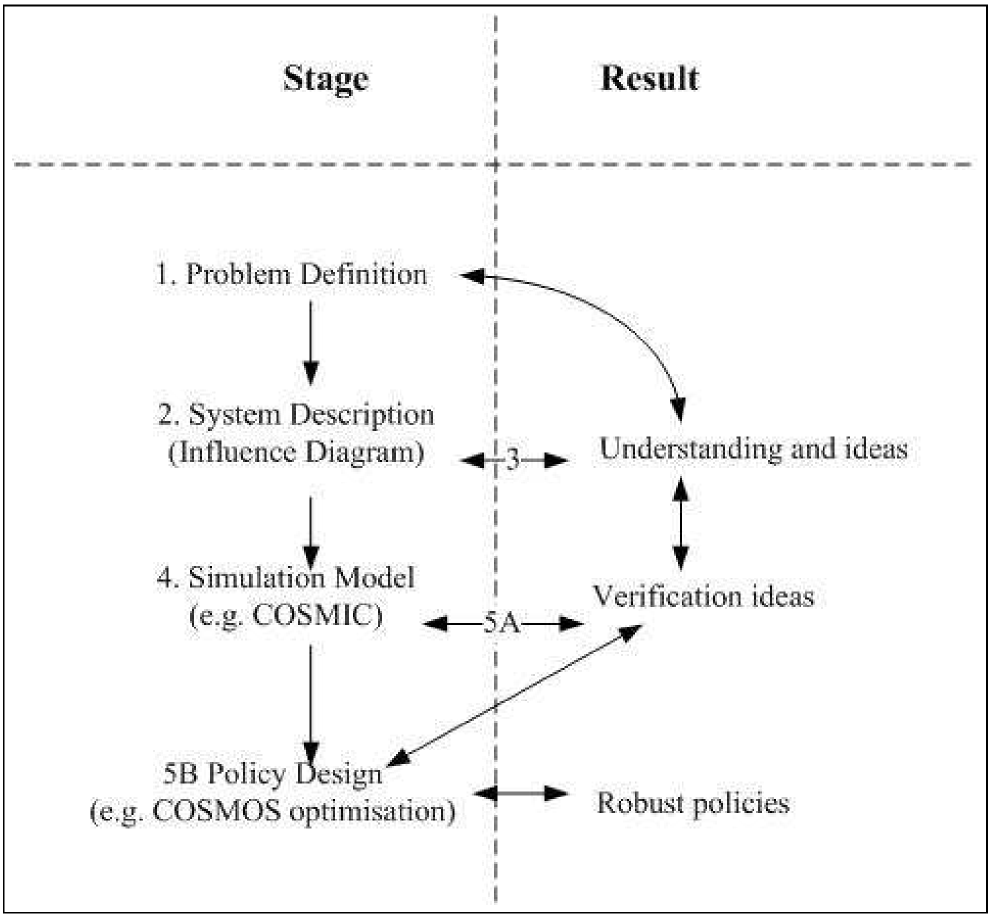


Figure 2.6: The process of System Dynamics (Coyle 1996)

tional modelling and simulation. Another five-stage process is also established (Sterman 2000). As drawn in Figure 2.7, Sterman emphasises the iteration of the modelling process and congruence between the virtual world (model or flight simulator) and the real world. The purpose of SD simulation modelling under Sterman's proposal is to build a flight simulator that can be constantly adjusted to reflect the real world. During the process of reflection, model users can gradually form insights into the real world under investigation, especially unfamiliar issues.

Maani and Cavana summarised their previous experience and also proposed five major phases in the development of a systems thinking and System Dynamics simulation modelling: problem structuring, causal loop modelling, dynamic modelling, scenario planning, and modelling implementation and organisational learning (learning lab) (Maani & Cavana 2003). These phases, including a number of steps, are accomplished as a process. Table 2.5 outlines the process and steps proposed by Maani. Maani's proposal systematically introduced the concept of scenario

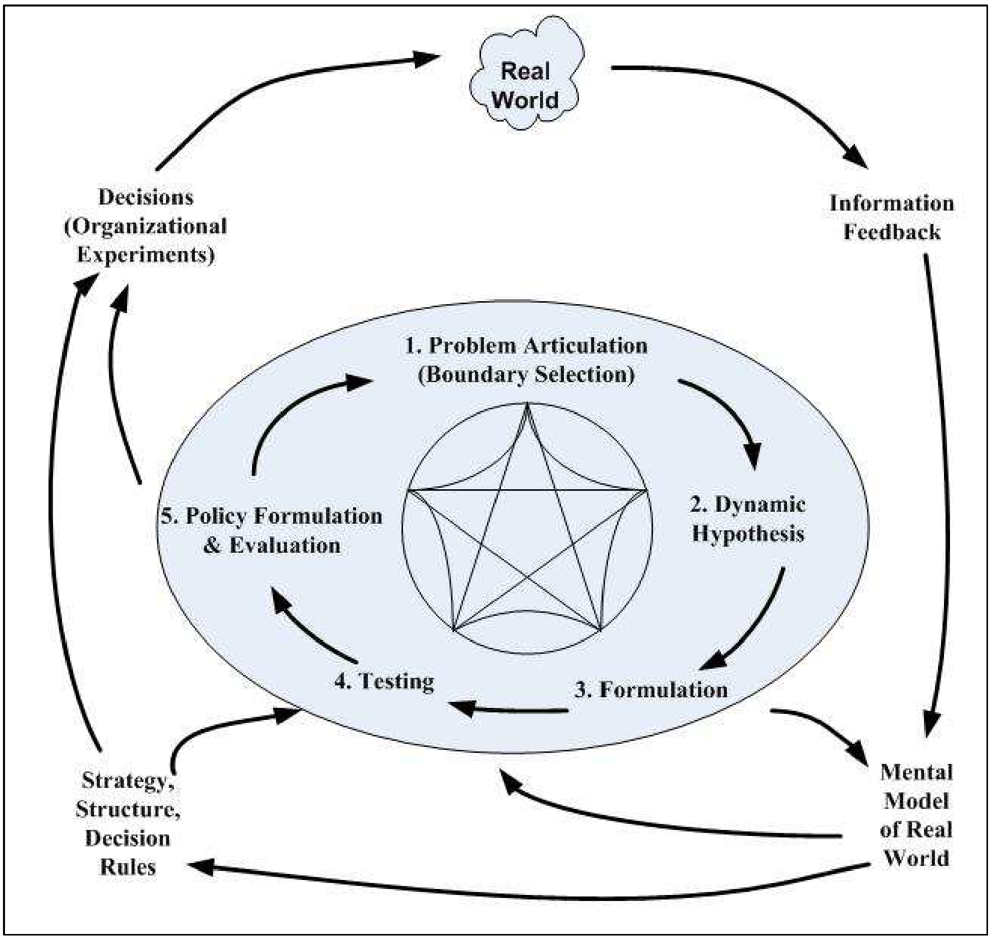


Figure 2.7: The modelling process is iterative (Sterman 2000)

planning into this field (other literature may also mention it but not in detail), which provides important clues for System Dynamicists to establish relationships among scenarios, policies and strategies using System Dynamics.

### 2.5.5 Applications of System Dynamics

System Dynamics simulation modelling plays an important role in decision making in everyday life. Not only does it integrate existing knowledge and improve our understanding of new areas relating to complex natural and socioeconomic systems, System Dynamics techniques could also be applied for evaluating a wide range of scenarios and designing better strategies or policies to meet the development trends of today's world.

Table 2.5: Systems thinking and SD modelling process (Maani & Cavana 2003)

| Phase | Steps |
|---|---|
| 1. Problem structuring | 1. Identify problems or issues of concern to management<br>2. Collect preliminary information and data |
| 2. Causal loop modelling | 1. Identify main variables<br>2. Prepare behaviour over time graphs (reference mode)<br>3. Develop causal loop diagram (influence diagram)<br>4. Analyse loop behaviour over time<br>5. Identify system archetypes<br>6. Identify key leverage points<br>7. Develop intervention strategies |
| 3. Dynamic modelling | 1. Develop a systems map or rich picture<br>2. Define variable types and construct stock-flow diagrams<br>3. Collect detailed information and data<br>4. Develop a simulation model<br>5. Simulate stead-state/stability conditions<br>6. Reproduce reference mode behaviour (base case)<br>7. Validate the model<br>8. Perform sensitivity analysis<br>9. Design and analyse policies<br>10. Develop and test strategies |
| 4. Scenario planning and modelling | 1. Plan general scope of scenarios<br>2. Identify key drivers of change and keynote uncertainties<br>3. Construct forced and learning scenarios<br>4. Simulate scenarios with the model<br>5. Evaluate robustness of the policies and strategies |
| 5. Implementation and organizational learning | 1. Prepare a report and presentation to management team<br>2. Communicate results and insights of proposed intervention to stakeholders<br>3. Develop a microworld and learning lab based on the simulation model<br>4. Use learning lab to examine mental models and facilitate learning in the organisation |

#### 2.5.5.1 SD-based decision making

Decisions can be classified as structured and unstructured. Structured decisions have clear logic and can be quantified. The factors and outcomes within structured decisions are well-defined and the decision making process is repetitive. Since unstructured decisions involve a heuristic, trial and error approach, intuition and common sense, the logic adopted is vague and qualitative. Unstructured decisions exist when decision makers deal with ad hoc and seldom repeated problems. Structured decisions are made at the lower managerial level, whereas unstructured decisions are made at the middle and top levels of management in an organisation (Licker 1997). More often than not, most decisions in daily activities involve unstructured or semi-structured decisions.

Since SD combines the strengths of computers with modelling and simulation techniques to solve semi-structured or unstructured problems (Licker 1997), decision makers are able to use suitable model structures and analytical tools, together with their own judgement, to make decisions. This leads to an extension of the scope and capability of decision making and in turn improves its effectiveness (Keen & Scott Morton 1978). In addition, with System Dynamics, decision makers are able to perform sensitivity analysis in order to understand contingencies and processes in decision making problems (Triantaphyllou & Sanchez 1997). For example, a model of interactive decision support systems for bank asset management can help decision makers conduct sensitivity analysis for urgent planning problems and objectives (Langen 1989). Combining System Dynamics with multiple criteria decision making, a System Dynamics-based support system can be successfully developed in managing policies and examining the diffusion of data warehouse in Thailand's banking sector (Quaddus & Intrapairot 2001) .

#### 2.5.5.2 Scenario analysis

The political, social, technological or industrial situation within society are all becoming increasingly uncertain, interdependent and dynamic. Information about demographic change, energy supplies, sociocultural transformation etc. is often inaccurate or even unavailable. Under these circumstances, research is now increasingly important for future decision making. System Dynamics acts as an effective scenario analysis tool in future approaches.

A scenario describes a future situation together with the progression of events leading from the base (current) situation to a future situation (Godet 1987). An SD-based scenario construction technique can detect the priority issues for study by identifying key factors, can determine the main stakeholders and examine their strategies, and describe the development of the situation under investigation by using sets of assumptions about the behaviours of the stakeholders involved. In addition, an SD-based scenario analysis can set alternative scenarios for future development along with identification of the associated risks and opportunities. It then suggests possible strategies to mitigate the risks and take advantage of such opportunities. It can also examine the consequences of such strategies under the scenario envisioned.

SD-based scenario analysis is still in its infancy. The literature on the application of System Dynamics in scenario analysis is minimal; however, this situation is now changing for the better. SD-based scenario planning is attracting more attention from both academia and business circles. Based on the procedures in traditional scenario construction (Schoemaker 1993), System Dynamics simulation modelling techniques can be manipulated to conduct scenario analysis (Maani & Cavana 2003). Maani and Cavana listed the steps involved in constructing scenarios, as shown in Table 2.6. This table is very useful in guiding System Dynamics modellers to conduct scenario analysis and planning.

#### 2.5.5.3 Strategy/policy analysis

Strategists or policy makers need reliable, event-based approaches to analyse situations, develop strategies (strategy and policy are often used interchangeably) and then implement them. They especially need to understand what drives the change of a situation through time, and what the policy resistances are. Common approaches to strategy and policy are often derived from statistical methods, and are inadequate for responding to this need for time- and event-based understanding. System Dynamics is a rigorous modelling method that enables users to build formal computer simulations of complex systems and use them to design more effective strategies (Sterman 2000).

SD is employed in forming new policies. It is not practical or cost-effective to experiment on a new policy on a large scale before it is formally operative. SD modelling can compress space and time so that experimenting on policy within a large scope and in a long time span becomes possible. For example, an SD model can be manipulated to support policy making on energy efficiency (Dyner, Smith & Pena 1995). A detailed multi-group model of the spread of AIDS in the Tanzanian population has been developed to capture complex virological and behavioural traits of the epidemic, to illustrate the medical and economic consequences, and then to set appropriate policies to prevent the spread of AIDS (Heidenberger & Flessa 1993). The effects of

Table 2.6: Steps in scenario construction (Maani & Cavana 2003)

| |
|---|
| 1. Define the issues to understand better in terms of time frame, scope and decision variables. Review the past to get a feel for the degree of uncertainty and volatility.<br>2. Identify the major stakeholders or actors who would have an interest in these issues, both those who may be affected by it and those who could influence matters appreciably. Identify their current roles, interests and power positions.<br>3. Make a list of current trends or predetermined elements that will affect the variable(s) of interest. Briefly explain each, including how and why the variable exerts an influence. Constructing a diagram may be helpful to show interlinkages and causal relationships (e.g. a causal loop diagram).<br>4. Identify key uncertainties whose resolution will significantly affect the variables of interest. Briefly explain why these uncertain events matter, as well as how they interrelate.<br>5. Construct two forced scenarios by placing all possible outcomes of key uncertainties in one scenario and all negative outcomes in the other. Add selected trends and predetermined elements to these extreme scenarios.<br>6. Assess the internal consistency and plausibility of these artificial scenarios. Identify where and why these forced scenarios may be internally inconsistent (in terms of trends and outcome combinations).<br>7. Eliminate combinations that are not credible or are impossible, and create new scenarios (two or more) until internal consistency is achieved. Make sure these new scenarios bracket a wide range of outcomes.<br>8. Assess the revised scenarios in terms of how the key stakeholders would behave in them. Where appropriate, identify topics for further study that would provide stronger support for the scenarios, or might lead to revisions of these learning scenarios.<br>9. After completing additional research, reexamine the internal consistencies of the learning scenarios and assess whether certain interactions should be formalised via a quantitative model (such as a System Dynamics simulation model).<br>10. Finally, reassess the ranges of uncertainty of the dependent (i.e. target) variables of interest, and retrace Steps 1 through 9 to arrive at decision scenarios that might be given to others to enhance their decision making under uncertainty (or used to test strategies and generate new ideas). |

eutrophication (i.e. a phenomenon observed in the bodies of water that receive large influxes of nutrients) on plankton seasonal dynamics in lakes was simulated in order to predict the effect of nutrient additions on lake biota and select policies to improve water quality (Vezjak, Savsek & Stuhler 1998).

SD has been used to examine existing policies. A System Dynamics model was adopted to rectify problems occurring in the management of a software development project (Abdel-Hamid & Madnick 1987, Abdel-Hamid 1989*b*, Abdel-Hamid 1989*a*, Abdel-Hamid 1990). The model aimed at identifying managerial factors that impacted on costs and examining the degrees of influence. These studies provided interesting insights into the existing policies for managing projects and human resource management. SD models were constructed and simulated to gain more understanding about the policy of resource allocation (Saeed 1989, Morecroft, Jarsen, Lomi & Ginsberg 1995). The analysis from Saeed enhanced the understanding of circular cause and effect relationships that shape internal trends affecting a government's commitment to economic development plans, and its ability to resolve political conflict generated over an implementation phase. Another successful application of SD modelling is to test the appropriateness of the technological development policies to economic growth and change in income distribution (Saeed & Prankprakma 1997). Yin developed a simulation model to observe the interaction among various software life cycle development activities and decision making processes, examine the trade-off of cost, schedule and functionality, and test different policies on a project's outcomes (Yin, Abdel-Hamid & Sherif 1997).

SD has also been employed to reach strategic consensus among stakeholders and reduce resistance during the implementation of a new policy. A production system and an inventory system were connected through a systems approach to investigate just-in-time policies and zero inventory management in order to coordinate suppliers in the supply chain in Japan (Gupta & Gupta 1991). It was found that conflicts often occurred in the implementation of macro-engineering projects (e.g. time and cost overruns). A better design of the project role systems and the project's interaction with its environment can be created through translating known and inferred experiential information into an SD model, and experimenting with it prior to formulating the terms of a contract (Saeed & Brooke 1996).

SD has been employed to form strategic, holistic insights, and to promote public acceptance of large-scale initiatives. In Germany, the federal railway was illustrated through a computer-based decision support system to achieve strategic planning and management (Schmidt 1989). A framework was developed in Australia to evaluate capacity and capability, technological substitution needs, resource requirements, socioeconomic impacts, and strategic planning of chemical, fuel and energy transition programs (Chambers 1991). Oil producers can strategically inspect the relationships between OPEC and non-OPEC producers on an simulation model (Morecroft & Van der Heijden 1992). In India, an SD model was established to display how successful the oil and gas exploration/exploitation industry under current strategies would be in the long run (Chowdhury & Sahu 1992) .

### 2.5.6 Evolution of System Dynamics

Recently, SD has become more accessible to practitioners such as strategists, decision makers, policy makers and academics due to developments in this field. Improvements in the symbols and software have made it easier to create system structures. Tools adopted from other disciplines, such as Delphi survey and data mining, help SD practitioners to solicit more knowledge in the process of modelling. Improvements in simulation analysis provide better insights about system behaviours. Games and computer simulations make models transparent to comprehend and friendly to interact with (Morecroft 1988).

Some significant revolutions are occurring in this discipline (Richardson 1996). The applications of SD are far beyond the circle of academic research and university training. In addition to modelling and simulation, SD improves ordinary people's mental models. SD has moved from quantitative modelling to qualitative modelling using word and arrow archetypes as represented in the Fifth Discipline (Senge 1994).

However, there is a lot of work to do before SD can be manipulated to serve mankind to its full capacity. There are eight problem areas of SD studies that are still yet to be revised: understanding model behaviour, accumulating wise practice, advancing practice, accumulating results, making models accessible, qualitative mapping and formal modelling, widening the base, increasing confidence and validation (Richardson 1996). Currently, the teaching of System Dynamics to K12 students has been initiated in developed countries like the United States and even in developing countries like China. The spread of System Dynamics knowledge is changing the way human beings think, which will further enlarge the base and rationale for using System Dynamics.

## 2.6 Summary

This chapter presented a review of the previous literature relating to the research topic, including mobile commerce, innovation diffusion modelling, population dynamics modelling and System Dynamics simulation modelling.

The literature review aimed at obtaining current information on the fast-changing mobile commerce domain, framing modelling processes and choosing appropriate research methods in developing an applicable research proposal and establishing a practical research design. These are summarised in the following paragraphs.

The analysis of definitions, players and the Chinese context of mobile commerce is used to define the research domain, to demonstrate its inherent complexity and to display the direct and indirect relationships among variables within innovation diffusion and population dynamics. The investigation of innovation diffusion and population research demonstrate the complexities, uncertainties and dynamics of the contexts and processes in which mobile commerce will appear and diffuse.

Information on innovation diffusion modelling was used to justify appropriate models that suit the research domain. The review of innovation diffusion modelling shows the importance of SD-based simulation modelling, the linkage to population dynamics and the difference between traditional, static innovation diffusion modelling and dynamic multi-factor simulation modelling of innovation diffusion. An SD-based innovation diffusion modelling appears to be more suitable than any static one. Factors that influence innovation diffusion in the previous literature were considered as variables for modelling mobile commerce diffusion under the Chinese context. Systems thinking helps to conceptualise a subsystem of mobile commerce diffusion. SD simulation helps to determine the degree of influence from these factors within the mobile commerce diffusion subsystem.

Knowledge gained from population development modelling was used to provide indications of what factors should be involved in the research, and for finding appropriate modelling methods that suit the research domain. The review of population dynamics modelling shows the importance of an SD-based simulation modelling, the relationship with innovation diffusion modelling, and the difference between the traditional static modelling and contemporary dynamic simulation modelling. The description of population development in China demonstrates its particularity. A dynamic population evolution modelling is regarded as most appropriate. Factors that influence population development in the previous literature–in China in particular– were considered as variables for model development. Systems thinking frames a subsystem for population development and sets its position within the whole system. SD simulation modelling will help to prototype the population model and determine the degree of influence from these factors within the population development subsystem.

The review of SD simulation modelling justifies its suitability and applicability for the research domain. The introduction of systemic research illustrates the endeavours of systems thinking and SD simulation modelling in understanding complexities, which not only demonstrates the complementarity of the two methods, but also provides additional reasons why an SD simulation modelling should be used. The review about SD elements, purposes, processes, applications and evolution provides the background information and rationale in choosing SD simulation modelling as an effective method in exploring such a complex, uncertain and dynamic issue as mobile commerce diffusion. It also shows the evidence for forming frameworks for general research design, SD simulation modelling and the formation of scenarios and strategies, and reminds us of what we should care about and how future research can implement SD in solving a problem. This research demonstrates the synergy brought by applying SD simulation modelling techniques in exploring the process of mobile commerce diffusion.

The research reported in this thesis differs from previous research in four regards.

1. The traditional mathematical model is isolated, analytic and static. SD simulation modelling is interconnected, systemic and dynamic. Most information communication technology (ICT) diffusions have been regarded as individual technological innovations and studied using an analytic approach in a static qualitative way in the earlier studies. This research employs a systemic approach to quantitatively study mobile commerce diffusion in a dynamic state. It provides an interactive communication for the model users to examine mobile commerce diffusion. The study puts emphasis on the dynamic analytic approach using SD simulation techniques for elaborating on the static model analysis and testing scenarios and strategies during the diffusion phase.

2. The research emphasises holism in constrast to the reductionism of analytic methods. This research not only considers most of the factors directly connected to mobile commerce but also the factors that take effect during the process of mobile commerce formation.

3. The research involves more factors. The influential factors within mobile commerce diffusion that were identified in the previous literature fall into the categories such as the users' side and technology's side at an operational level. This research explores the influence of demographic change, national policies and industrial strategic planning at a strategic level. The research design will regard mobile commerce diffusion as a complex system, which is further decomposed into subsystems with factors in different sectors. The influence on mobile commerce diffusion of these factors will be displayed by sensitivity analysis.

4. Computer simulation using software, such as Powersim, Vensim and Anylogic, is employed to tackle problems and provide sensitivity analysis, scenario design and strategy development. The model can be used as a learning tool to visualise the processes of state change and obtain an intuitive perception by running sensitivity analysis, adopting a wide range of scenarios and exerting effective strategies.

5. Traditional simulation modelling requires more technical knowledge both in mathematics and computing. The powerful computer-based simulation modelling provides a friendly interface in model development and interaction for model users who are not experts in mathematics or computing.

This proposed study will be undertaken using System Dynamics simulation modelling techniques. The research design and its methodology will be presented in the next chapter.

# Chapter 3

# METHODOLOGY

## 3.1 Introduction

This chapter begins with a description of the research design and research methodology in general. Next follows an overview of the SD simulation modelling and a description of the processes involved in detail. Then an illustration of how to conduct scenario analysis and develop strategies using an SD simulation model is presented. The chapter concludes with an explanation of how the SD simulation modelling techniques and the skills of scenario analysis and strategy development are used in the work undertaken in this study.

## 3.2 Research design

The purpose of this study is to develop a System Dynamics model for simulating mobile commerce diffusion in China by using the factors involved in different subsets: population development, mobile commerce diffusion itself and mobile commerce terminal (MCT) provision. This subdivision is helpful in unveiling the complexity and identifying the far-reaching factors involved in the process of mobile commerce diffusion. Experiments are then designed and executed on the model to obtain sensitive factors, conduct scenario design and analysis and evaluate strategies. For these purposes, a general framework, as illustrated in Figure 3.1, is designed to guide the whole research work. The research activities include system thinking, SD simulation modelling and experimentation, which are all explained in the next sections and implemented in chapters 4, 5 and 6.

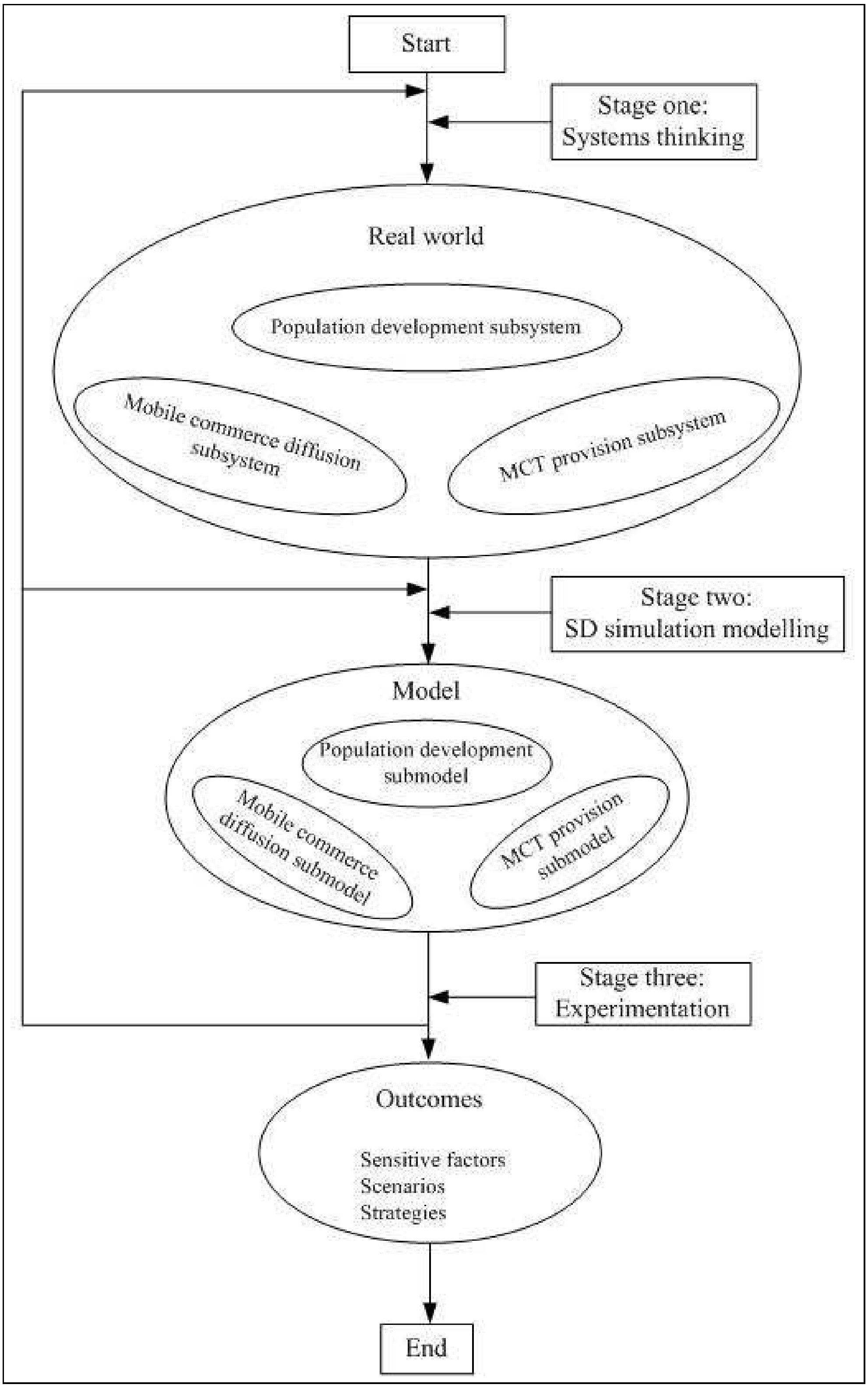


Figure 3.1: A general research design framework

### 3.2.1 Systems thinking

In the stage of systems thinking, the whole of the mobile commerce diffusion in a country is regarded as a system and decomposed into interconnected subsystems. These subsystems are further decomposed into their own elements. The real world of mobile commerce diffusion within a country is regarded as the boundary of this system, in which subsystems are identified as the co-existing components. The state of mobile commerce diffusion is the result of the interaction and interdependence of these subsystems. To simplify the situation, mobile commerce diffusion is viewed as one subsystem in a series of interdependent subsystems as illustrated in Figure 3.2. Each subsystem has its own elements, which also interact with each other within the boundary of the subsystem, and have a function to perform within the context as a whole. Because of their importance to the diffusion of mobile commerce, each subsystem is conceptualised as representing a functional imperative that has to be met if mobile commerce diffusion is to be viable. Mobile commerce diffusion must be adapted in certain ways so that it can successfully occur. The overall context in a country determines whether it appears, and this is determined in turn by the way in which the situation in a country adjusts its relationship with other components. Mobile commerce diffusion is the behaviour to be generated within this country context. The stakeholders in the system or subsystems are trying to change the behaviour in the direction they desire by exerting their influence. To apply their influence effectively, they must find their leverage points (strategies or policies) to take action.

Three subsystems are identified as the components of mobile commerce diffusion, as shown in Figure 3.1. They are the population development subsystem, mobile commerce diffusion subsystem and MCT provision subsystem. In the research, all the elements other than those that appeared in population development and MCT provision subsystems are combined into the mobile commerce diffusion subsystem as shown in Figure 3.2. The determination of the three subsystems is the result of the iterative modification of system classification and the process analysis on the formation of an actual user of mobile commerce.

The process whereby a person becomes a mobile commerce user can be described as follows. In a country system, there is a certain amount of population. The uncertainty and complexity of the population evolution forms the first subsystem of population development. Although, forecasted time series population data from well known organizations such as the United Nations could be used as input to the mobile commerce sub model, we choose to construct a system dynamics model of the population in China because of feasibility reasons. The members of the

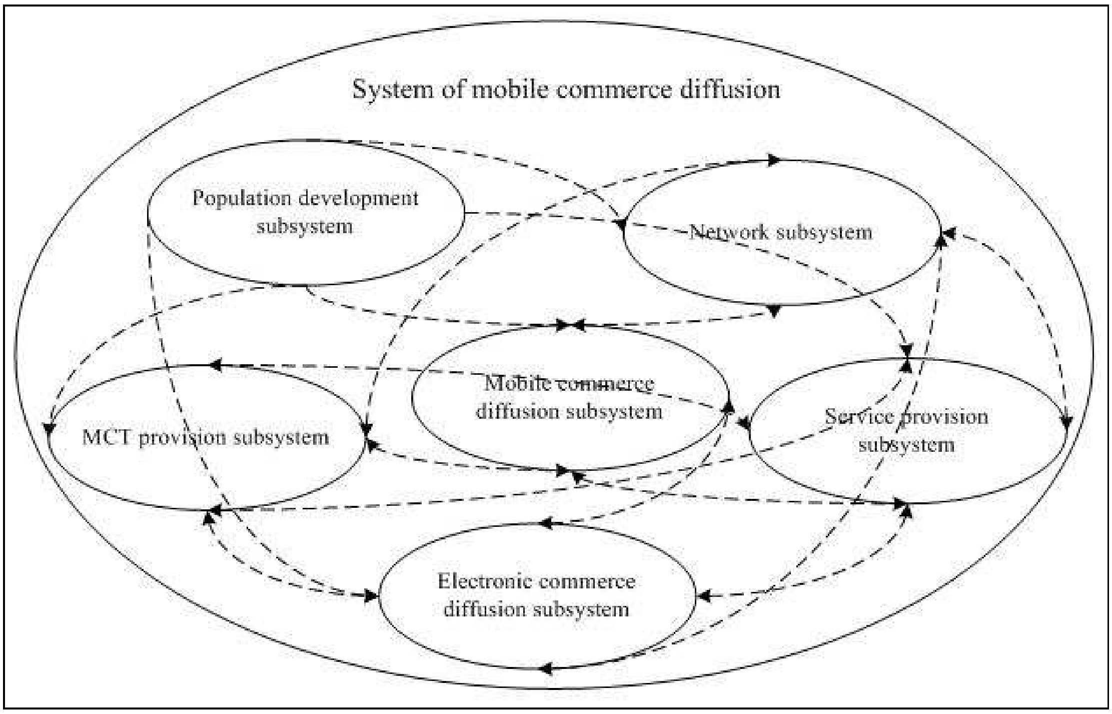


Figure 3.2: Subsystems of mobile commerce diffusion

population are the potential mobile commerce users and some of them will become actual mobile commerce users by adopting the mobile commerce service. This process of diffusion within this population will form the second subsystem of mobile commerce diffusion. However, only mobile commerce terminals can provide access to mobile commerce services for these potential users, so manufacturers start to produce and provide these kinds of terminals to the market. When potential mobile commerce users obtain their needed terminals they can become actual mobile commerce users. The supply and demand of MCTs in the market is considered as a third subsystem.

In order to facilitate the validation of the models developed for these subsystems, the overall simulation period along the time line for this research is arranged as shown in Figure 3.3.

Indicators that reflect the behaviour of the subsystems are used to evaluate the state of the subsystems. In some subsystems, historical data is available for at least one of the indicators used. For example, historical data is available for the following indicators: the numbers of total, urban and rural populations in the population subsystem, and the numbers of mobile phone subscribers in the mobile commerce diffusion subsystem. For more detail, please refer to chapters 4 and 5.

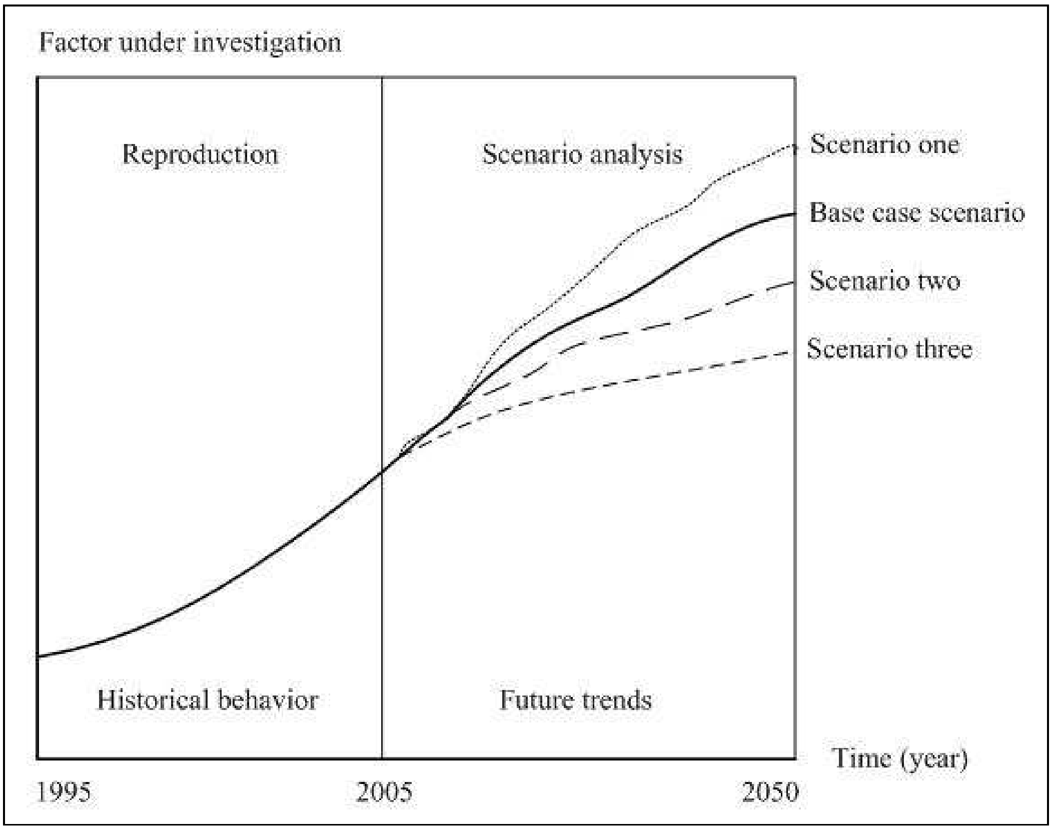


Figure 3.3: Simulation period

In other subsystems, no historical data were available for the indicators used, more especially during the simulation time period. For example, the number of high-end mobile commerce service users in the mobile commerce subsystem and the quantity of MCTs provided in the MCT provision subsystem belong to this category.

As shown in Figure 3.3, for the selected factor under investigation, the models developed are simulated using a set of scenarios to determine the evolution of the factor over time. If historical data is available during the period 1995 to 2005, the model is adjusted so that the evolution of the factor under consideration matches the historical behaviour during that period.

### 3.2.2 SD simulation modelling

In the second stage of the research, the subsystems are used for simulation. The formation of the mobile commerce market is analogous to an irrigation system, which is shown in Figure

3.4. The population is considered as a stock (or reservoir) and the level is adjusted by the total inflows and outflows of people. Logically, there is an imaginary flow from the population stock passing downstream to accumulate in the potential mobile commerce users stock. In the process, the flow is adjusted by the in, out and diffusion valves in the system. Each stock in the diagram is regarded as a subsystem and is developed as a submodel.

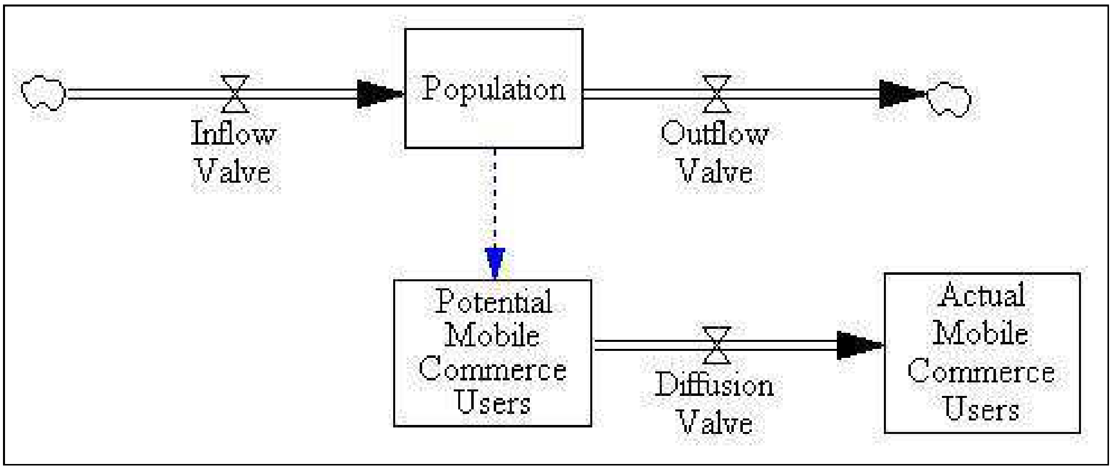


Figure 3.4: Stock and flow metaphor of mobile commerce diffusion

The first subsystem of the mobile commerce diffusion is modelled as a population submodel. The level of the population stock is determined by the net value of the total inflows and outflows. The population submodel will be developed in Chapter 4. The second subsystem represents the adoption of mobile commerce users and is modelled as a mobile commerce diffusion submodel,which will be developed in Chapter 5.

As shown in Figure 3.4, a dotted curved arrow represents a logical transformation from the population stock to the potential mobile commerce users stock. It can be seen that the level of mobile commerce users is the final stock and is only determined by the imagined inflow from the population stock if the provision of mobile commerce terminals is not a bottleneck. In the level of mobile commerce user, there is a flow between potential users and actual users, which is adjusted by a diffusion valve in the middle.

However, the level of the mobile commerce users stock may also be controlled by the provision of mobile commerce terminals especially if this provision is insufficient. A third subsystem is used to model the provision of mobile commerce terminals and is explained in Chapter 6. After the submodels are developed, they are integrated together to form a holistic mobile commerce diffusion model. More details about the process of SD simulation modelling are given in Figure 3.5 and are further explained in section 3.3.

### 3.2.3 Experimentation

This study is designed to establish the relationship among the subsystems, identify sensitive influential factors within each subsystem, and perform scenario analysis and strategy assessment for mobile commerce related events. Based on the SD simulation model developed, sensitivity analysis is designed and conducted in order to find the key influential factors. Scenarios are designed and executed so as to examine system behaviours under these perceived scenarios and design competitive strategies in case these scenarios should happen in future. Strategies are created and evaluated to select the optimal one that can change the course of mobile commerce in a positive way. The design and execution of these simulation experiments are described in chapters 4 to 6.

As a summary for the whole research, SD approach offers a means for accomplishing the tasks in stage three. This study adopts System Dynamics simulation modelling tool. Systems thinking helps to conceptualise the whole system, its subsystems, and the components in each subsystem. Whereas System Dynamics simulation modelling is used to formalise the results from systems thinking and enable simulation in support of systems thinking. In addition, two frameworks guiding the SD simulation modelling of the subsystems and the scenario analysis and strategy development applied in the ensuing chapters are explained in the next two sections.

## 3.3 A framework for SD simulation modelling

The SD modelling approach used in this study includes four phases: qualitative modelling, quantitative modelling, model testing and experimentation. During the stage of qualitative modelling, a causal loop diagram is drawn (Sterman 2000). In the quantitative modelling stage, a stock flow diagram and an SD simulation model are created (Sterman 2000). Once the model has been set up, it is calibrated and tested with historical data that is available. If it passes the testing, the model is used in experiments to generate information for system analysis. As illustrated in Figure 3.5, a complete SD simulation modelling covers these four phases and is fulfilled through the eleven steps embedded in the phases. The steps in qualitative modelling, quantitative modelling and model testing are iterative and the model is interactively compared

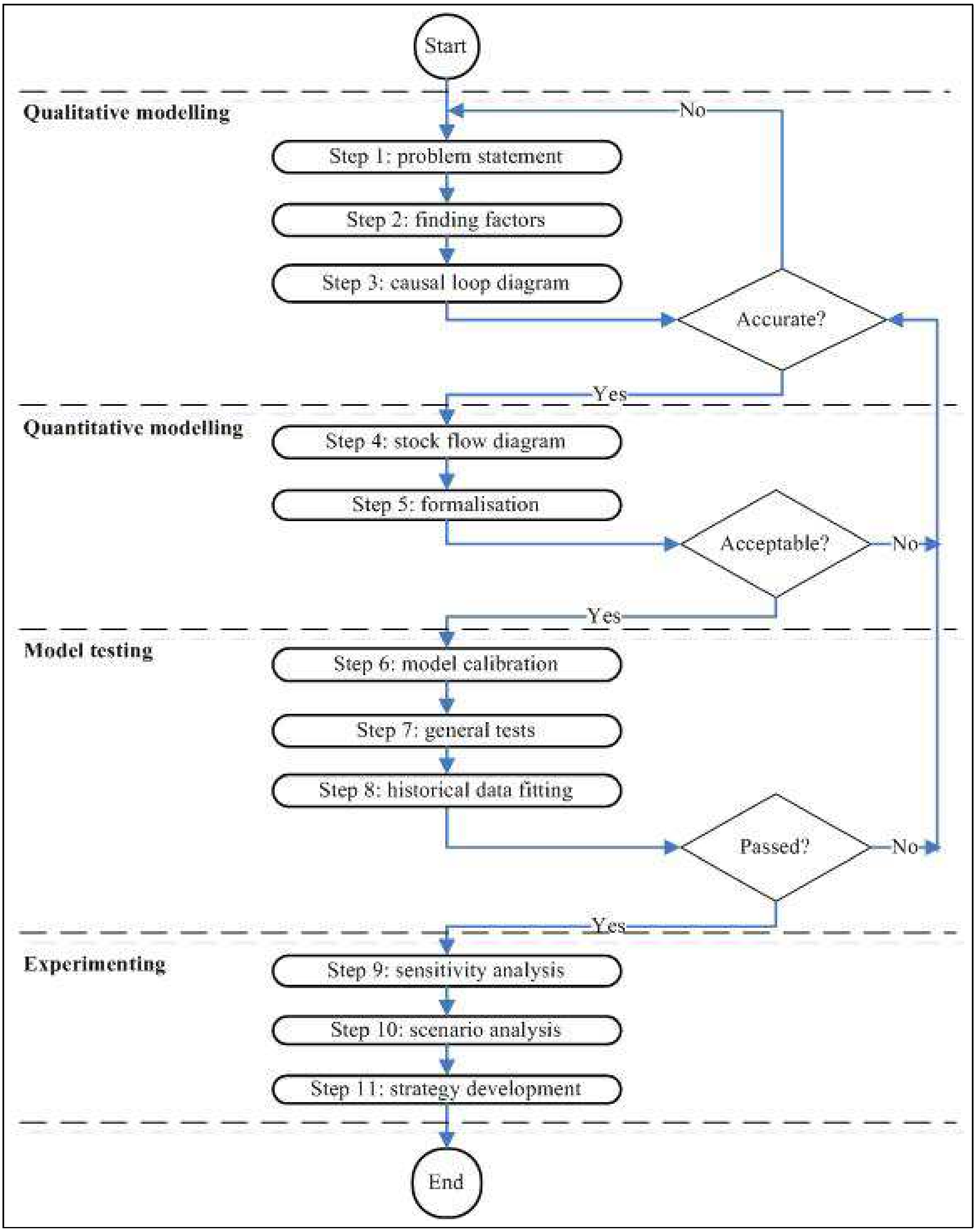


Figure 3.5: A framework of SD simulation modelling

to the real system until it is satisfactory. At each reassessment stage, the elements in both qualitative and quantitative modelling are modified until the developed model passes the testing set for the model and then experiments can be performed. Details about the steps involved in the SD simulation modelling are provided in the next subsections.

### 3.3.1 Qualitative modelling

Qualitative modelling is the starting point of the modelling process. A mental representation of the system under study is formed and then is structured, and integrated into a causal loop diagram (Forrester 1968, Forrester 1992). This is achieved by finding the relevant factors and theories through a literature survey. The qualitative modelling in this study includes the following stages: problem statement, identification of factors and drawing causal loop diagrams.

#### 3.3.1.1 Problem statement

The aim of creating the model is for exploring the dynamics of mobile commerce diffusion in China. As described in chapter 1, the main problem is how to develop an applicable SD model to simulate mobile commerce diffusion in China, and the outcomes of the research will be the identification of sensitive factors and the formulation of appropriate scenarios and strategies. The problem definition for this research can be formulated as follows:

1. How will the population develop in the future in China? What are the sensitive factors that will affect the development of the population? What are the possible scenarios that might occur in China and what are the possible strategies to influence the development of the population? These questions are addressed in chapter 4.

2. How will mobile commerce diffuse in the future in China? What are the sensitive factors that will influence the mobile commerce diffusion? What are the possible scenarios that might appear in China and what are the possible strategies to exert a positive influence on the trend of the mobile commerce diffusion? These problems are addressed in chapter 5.

3. How should MCTs be supplied in the future in China? What are the sensitive factors that affect the supply of MCTs? What are some possible scenarios that might occur in the future in China regarding the provision of MCTs? What are possible strategies that could be used to influence the supply of MCTs? These questions are addressed in chapter 6.

In order to answer these questions, three submodels are built and experimented with. These are: the population development submodel; the mobile commerce diffusion submodel; and the MCT provision submodel.

#### 3.3.1.2 Identification of factors

This is a very important step in conceptualising the SD model of a system and the first step in solving a problem (Randers 1980, Forrester 1992). The purpose is to qualitatively form a general overview of the components (an individual factor or a group of factors) and their dynamic interrelationship in the subsystem. In this research, the factors that are identified and adopted in each subsystem are obtained from the literature survey and are discussed further in chapters 4 to 6.

#### 3.3.1.3 Causal loop diagram

After the identification of the factors involved in the subsystem, a mental representation of the subsystem is formed, and is further elaborated as a causal loop diagram. No matter how complicated a system is, it is accepted that there exists a causal relationship among the components that determines the current state of the system or the changes in the state in future through interaction among the components. A causal loop diagram shows the relationships among the components of the system. Causal loop diagrams for the subsystems of population development, mobile commerce diffusion and MCT provision are discussed further in chapters 4 to 6.

### 3.3.2 Quantitative modelling

The factors identified form a mental representation, which can be translated into a causal loop diagram. A causal loop diagram is helpful in understanding a system but it is not a simulation model. To simulate the model, it must be connected to a stock and flow diagram. The steps to create a stock and flow diagram are explained next.

#### 3.3.2.1 Stock and flow diagram

Stock and flow diagrams are ways of representing the structure of a system with more detailed information than is possible in a causal loop diagram. In qualitative modelling, factors are identified and their causal relationships are established. In a stock and flow diagram, the factors are classified as stocks, flow and auxiliary. The classification of the factors helps in the process of developing the simulation model. The levels of stocks are fundamental in deciding the state of a system. The flows cause stocks to change level thereby generating dynamic states. The auxiliary variables provide useful information. Stock and flow diagrams are the most solid foundation in building a simulation model because they help with model theorisation and establish the mathematical and logical relationship in defining the types of variables that are important in changing the state. The stock and flow diagrams used in this research are discussed in chapters 4 to 6.

#### 3.3.2.2 Model formalisation

In a system, such as mobile commerce diffusion, there may exist hundreds of variables in the form of stocks, flows and auxiliaries. The aim of modelling is to establish a reasonable relationship between these variables. Each variable should be in the right place in the model, parallel to the real system. The right position is determined by establishing the proper relationships with other components. There are three methods for interconnecting variables. One of the methods is the selection of appropriate prototypes, which are small structural pieces that often appear in SD modelling. Then a group of the stocks, flows and auxiliaries can be related using these existing templates. Method two is the modification of the existing prototypes. Some of the original templates may be modified before they are applied in the model. Method three is the formulation of new prototypes. If there are no existing templates, a new theory or hypothesis is proposed to establish these relationships. Then the model will combine all the stocks, flows, and auxiliaries in the system together to form an interconnected system using logical arguments and mathematical equations. These aspects are discussed in detail in chapters 4 to 6. After this, the model is ready for tentative simulation.

### 3.3.3 Model testing

As a simulation model is built, there are various checks that must be done against reality. These checks may be explicit and take the form of tests of model behaviour or subsector behaviour under different assumptions, or they may be implicit mental simulations and analysis based on the understanding of the models and the modelling process. In either case, these checks are important in ensuring that the developed models can adequately address the problems they are being applied to.

#### 3.3.3.1 Model calibration

All the parameters in the simulation model should be calibrated before the model can be further tested. Calibration starts with the determination of ranges of values for the parameters under particular testing contexts. First of all, it must be ensured that each parameter has meaningful interpretation in reality, otherwise this parameter should be redefined or merged with other parameters. The value range of a parameter is obtained through the use of common sense or logic using possible secondary data sources.

After the range of values is determined, the parameter is randomly given a value within its range to perform a simulation. Some indicators are used to describe the performance of the model under a particular test or context that is sensitive to the change of the parameter under study. There may be hundreds of parameters in a middle-sized model. The parameters can be classified into sensitive and inertial parameters as shown in the first level of Figure 3.6, which shows sensitive and non-sensitive parameters respectively in a sensitivity analysis.

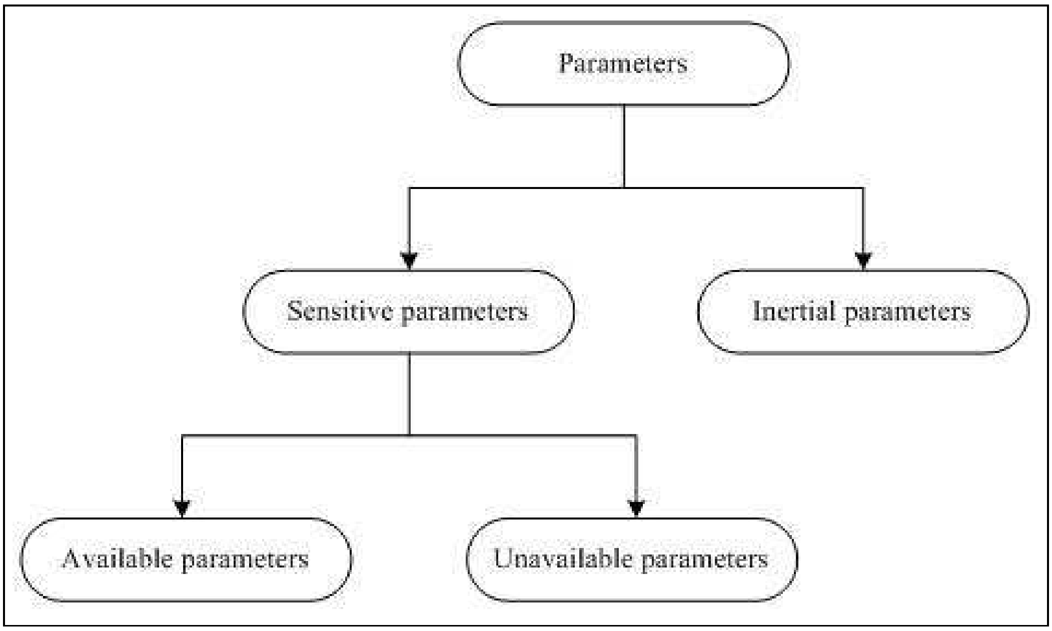


Figure 3.6: Categories of parameters

Because of their inertia, the values of inertial parameters can be arrived at by common sense or rational judgement. The sensitive parameters in the second level of the diagram are further divided into available and unavailable parameters. The values of the available parameters can be directly obtained from secondary data sources, for example, from databases, archived data or other research work. The unavailable parameters in level three of the diagram can be rationally assumed if the data is not available.

#### 3.3.3.2 Tests

Model testing is iterative and multidimensional. Since no one test is adequate, a wide range of tests can help the model builder and model consumers understand the robustness and the limitations of the developed model. There are a variety of tests that have been developed by System Dynamics modellers to uncover flaws and improve models. These tests involve direct inspection of equations and simulations of the whole model, the ability to reproduce historical behaviour and inspection of behaviour under extreme conditions. The commonly used tests for checking models are described in the following paragraphs (please refer to Sterman (2000) for more details).

**Setting test.** A setting test accesses the sensitivity of a model to the choice of a time step and the integration method to be adopted, and also checks for errors arising from a wrong choice of time step and integration method. Setting tests are carried out first so that any meaningless results generated afterward from the failure of setting tests can be avoided in advance. An SD model is normally formulated in continuous time, but often includes discrete elements such as steps, pulses, ramps, random noise or sudden shocks, and is simulated by numerical integration. A time step and a numerical integration method are chosen to yield an approximation of the underlying continuous dynamics of the factor under investigation. If the results of the model are sensitive to the choice of time step or integration method, a wrong time step or integration method can bring false dynamics into the model. In order to test for a time step error, a time step can be cut in half and the model run. If the results change significantly, the chosen time step is too large. The time step test is continued until the results no longer differ because of the choice of a different time step. Likewise, the model is tested with alternate integration methods. The use of a finite time step and the resulting approximation of the average rates over the interval can introduce integration error. The magnitude of integration error depends on how quickly the rates change relative to the time step. The longer the time step, the greater the integration error will be. In order to test for integration errors, the model is run with a best estimate of an appropriate value as time step. Then the time step is cut in half and the model is run again. If the behaviour does not change significantly then the original choice of time step and integration method are fine and the errors are within an acceptable tolerance interval. If the behaviour changes significantly, the test is continued with the time step cut in half again or an alternative integration method is used until the results are no longer sensitive to the reduced time step or an alternative integration method.

**Unit test.** A unit test is one of the most commonly used tests aimed at assessing dimensional consistency and finding errors from misused mathematical or logical relationships, missing constants/variables, misplacement of variables or denotations in equations, or identifying any involvement of meaningless arbitrary scaling factors, etc. Inconsistency in units sometimes reveals any possible significant flaws in conceptualising the structure of a system or decision rules involved in the process of modelling. There are two complementary methods for checking unit consistency: an automatic check by software and a manual check. Currently, most SD simulation modelling software can automatically accomplish a dimensional consistency check. However, a model that passes the automatic check in a dimensional consistency test is not necessarily acceptable. Every equation used in the model should be manually inspected in advance to identify any involvement of meaningless parameters, unfamiliar unit combinations, dimensionless constants, coefficients, etc.

**Boundary test.** A boundary test evaluates the adequacy of the boundary of the model set for solving the problem under investigation. The test is aimed at finding feedback loops that should be added to or should be omitted from the established model boundary. Direct experience with the system, review of the relevant literature and archived materials and interviews with key participants and outside experts are helpful in determining the addition of an endogenous feedback and the omission of an exogenous one. For example, if an additional feedback loop to the model generates a significant influence on behaviour or has obvious strategic implications then it must be included in the boundary of the model. If it has no impact, the loop can be omitted so that the resulting model is simpler and smaller.

**Structure test.** A structure test assesses the consistency of a model with the knowledge of the real system that this model reflects. Structure assessment focuses on the process and hierarchy of aggregation, the conformity of the model to basic universal theorems and laws, and the realisation of the rules about decisions for the model users. Systems thinking, subsystem diagramming and stock and flow diagramming help reveal the process and level of aggregation. Simulations of some extreme conditions or purposely designed contexts can reveal the conformity of the model. Causal loop diagramming, direct inspection of equations and partial model restructuring can reveal leverage points used for intervention from model users.

**Extreme condition test.** Models should be robust no matter how extreme conditions are. Robustness means that the model should behave realistically when the inputs take on extreme values such as zero or infinity. Extreme condition tests check for the appropriateness of the behaviours generated by the model under extreme conditions. Extreme condition tests operate in two ways: by direct inspection of the model equations and by simulation. Each equation with flow variables (possible decision rules) in the model is inspected. The feasibility and reasonability of the output of the equation are determined when each input to the equation takes on an extreme value. The reaction of the equation should be further examined when all inputs to the equation simultaneously take on their extreme values. In addition, some subtle flaws that may not be easily discovered by direct inspection will be exposed under extreme condition tests for the whole model by simulation. If the behaviour of the model under an extreme condition simulation is implausible, the formulation of the equation should be examined, the flaw source should be identified and modifications implemented until the behaviour is accountable.

#### 3.3.3.3 Historical behaviour reproduction

To enhance the reliability and confidence of the model developed, historical data of some of the factors of interest in the subsystems are collected to compare with the results of the simulation. For the population development subsystem, the numbers of the total population, urban population and rural population from 1995 to 2003 in China (see appendix A for details) are collected and plotted with the simulation results of the population development submodel. For the subsystem of mobile commerce diffusion, the number of mobile phone subscribers from 1995 to 2006 in China (see appendix C for details) are also collected and plotted with the simulation results of the mobile commerce diffusion submodel.

The ability of a model to generate appropriate patterns of behavior can be assessed qualitatively, using common sense, or statistically. A number of researcher in this area describe how these and related tools can be used to quantify the correspondence of the model and data in terms of relative amplitudes, frequencies, phase lags and other relationships (Barlas 1989, Barlas 1990, Barlas 1996). Three methods are applicable in evaluating the fitness of the historical data and the simulation data. These are described next.

**Direct comparison.** This is a primary method to compare two data sets by directly graphing the historical data and the simulation output together. This method assesses the correspondence of the model to the data by plotting the simulated and actual data together and directly checks the fitness of two plots by examining the model to see whether it captures asymmetries and other subtle features of the behaviour observed in the data. This method is straightforward but means it is hard to find the embedded problem.

**Drawing error pattern.** The differences between the simulation data and historical data are known as errors ($e_i$). Figure 3.7 illustrates a point-by-point fit computation in the measurement of the error between a historical data series $V_{H_i}$ and output of the model $V_{S_i}$ at time point $T_i$. When a time series generated from the developed model is tested with a given historical time

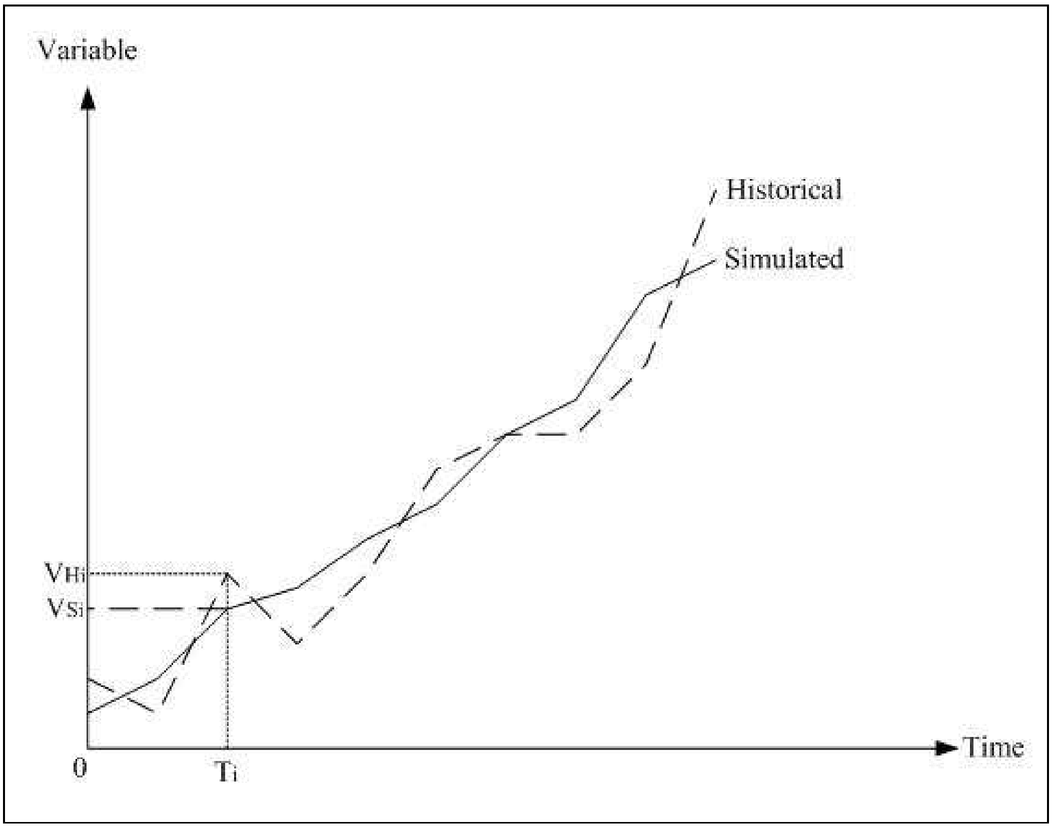


Figure 3.7: Measure of variation in testing

series, the errors are plotted over the historical periods. If the errors represent an irregular component of a time series and are therefore randomly distributed throughout the series as shown by the error pattern in Figure 3.8, it can be assumed that the model fits the historical data series adequately. If the errors follow any systematic pattern, as shown in Figure 3.9, this means that the tested model does not fit the historical data adequately. Microsoft Excel and PHStat2 make drawing the error plots easy (Levine, Stephan, Krehbiel & Berenson 2002). This research

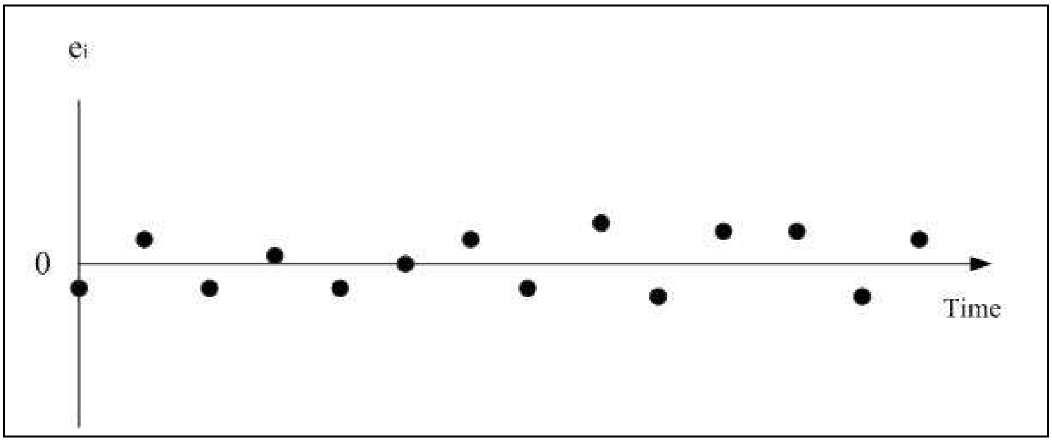


Figure 3.8: Randomly distributed error pattern

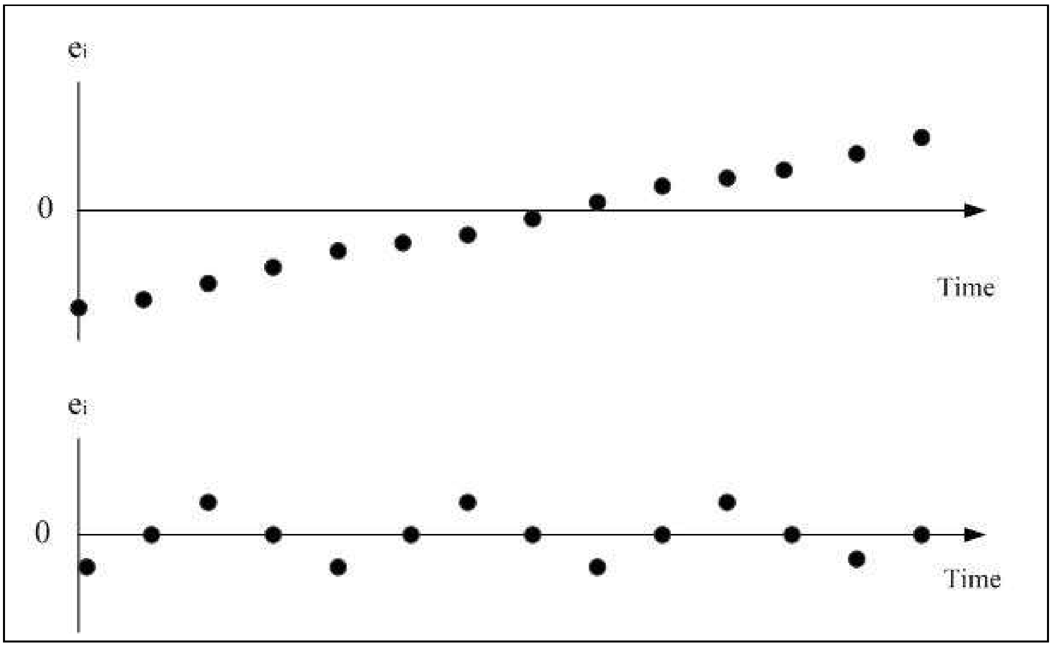


Figure 3.9: Systematic error pattern

evaluates the fitness between the historical data and the simulated data using the simulation software Anylogic[1].

### 3.3.4 Experimentation

The purpose of developing a model helps people understand the real world better. A tested model is robust enough to act as a platform, on which purposely designed experiments can

[1]Available at http://www.xjtek.com

be accomplished[2]. The experiments used in this research include sensitivity analysis, scenario analysis and strategy development.

#### 3.3.4.1 Sensitivity analysis

To conduct sensitivity analysis, indicators are first selected to describe the performance of a subsystem from the influence of a factor under study. Experiments are designed by varying the value of this parameter by a certain percentage (Maani & Cavana 2003). For example, the value of the parameter is varied by an amount of +/- 20%, that is, multiplying this parameter by a factor of 1.2 and 0.8 to generate an increase or a decrease of 20% respectively. Values of indicators are recorded and analysed to determine the sensitivity of the model to a parameter. Sensitivity analysis of the submodels of population development, mobile commerce diffusion and MCT provision are described in detail in chapters 4 to 6.

#### 3.3.4.2 Scenario simulation and analysis and strategy development

In scenario simulation and analysis, the behaviour pattern of a system under several possible future trends is determined (Maani & Cavana 2003). Scenario simulation and analysis is used to determine how the numeric value variation and model structure will change the dynamics of the system. Scenarios are created to simulate the state of most possible occurrences in future (base case scenario) and some extreme conditions. Scenario simulation and analysis are used to find the best and worst conditions for the system to generate the desired behaviour so that strategies can be developed to influence the development of best conditions and mitigate the effects of the worst situation. Most SD modelling software has the functionality to support this simulation and analysis. Scenario simulation and analysis and strategy development are discussed in chapters 4 to 6. In the next section, a detailed description about the process of accomplishing scenario design, simulation and analysis and strategy development is given.

## 3.4 A framework for scenario design, simulation and analysis and strategy development

In addition to identifying sensitive factors, analysing scenarios and establishing strategies is another important aspect of this research. A dynamic simulation model is used to design and

[2] for more details about experiment design, please refer to user guide of the software Anylogic at URL:http://www.xjtek.com

analyse the implications of policies and strategies against the backdrop of the scenarios developed (Maani & Cavana 2003). As shown in Figure 3.10, this section describes a framework that demonstrates the procedure for manipulating a simulation model to accomplish scenario simulation and analysis and strategy development. It includes three stages with ten steps that guide the research work of scenario simulation and analysis and strategy development performed in chapters 4 to 6.

## 3.4.1 Factor analysis

Factor analysis is the basis of scenario design, simulation and analysis and strategy formation. Theoretically, any random combination of factors can be used in a scenario. However, in practice, only the most meaningful and sensitive factors should be used. Before scenario simulation and analysis and strategy development can be performed, it is important to identify sensitive factors and analyse them in order to classify, quantify and interpret them.

### 3.4.1.1 Factor classification

A model may contain hundreds of factors, and some of them are sensitive to the indicators of interest while some are not. All the factors in the model are subjected to sensitivity analysis and the sensitive ones are identified as candidates for analysis in the next step. Figure 3.6 shows the flowchart used in the identification of these factors. The factors under the branch of sensitive factors are the ones of concern. According to the existing context, the influential factors are classified into different categories, as this is helpful in forming realistic scenarios and strategies in practice. For example, the sensitive factors identified in chapter 4 are classified as urbanisation, family planning and life quality categories. Using this classification, scenarios are designed using the combination of urbanisation, family planning and life quality categories to examine the behaviour of population development under these designed scenarios. Scenarios also can be designed using the combination of urbanisation scenarios and life quality categories and the strategies for family planning can be developed to adjust the behaviours under these scenarios.

### 3.4.1.2 Factor quantification

This step determines the values, or the range of values, of the factors in the real world. After the factors are classified or further interpreted and combined, it is possible to decide the values they would assume in reality. Their values, the range of values, or the development modes can

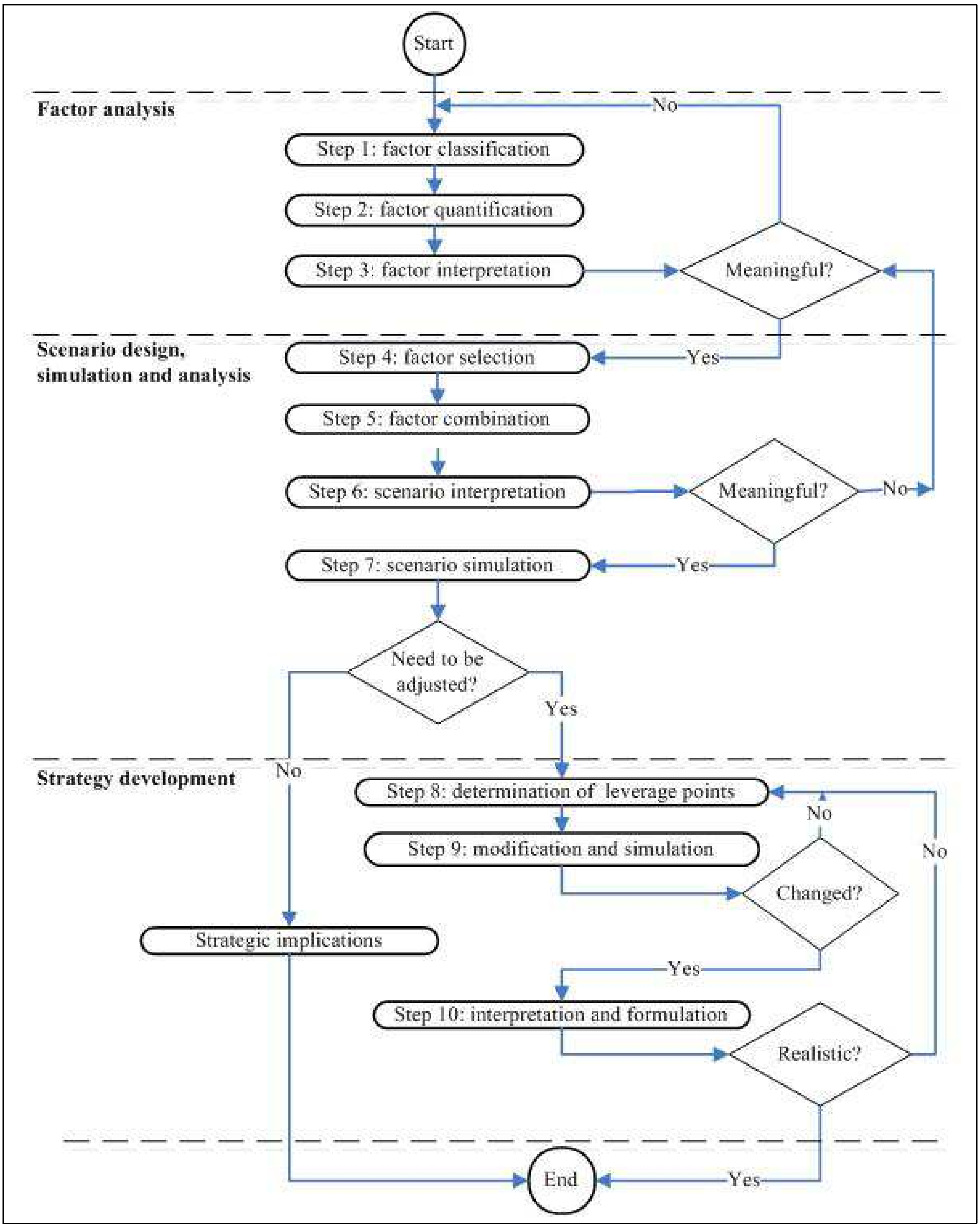


Figure 3.10: A framework of scenario design, simulation and analysis and strategy development

be further determined according to the states, the variation intervals, or the state in which they might exist in the real world in the future. As for the sensitivity analysis, the values used during simulation are normally derived using common sense or some reasonable assumptions.

#### 3.4.1.3 Factor interpretation

In this step, an individual factor or group of factors is questioned for meaningfulness or actual existence in the real world. Any factor that has no real meaning is reexamined several times until its existence in the real world can be verified. If it is still not possible, its necessity in the model is questioned. It could be merged or replaced by other factors that are considered to be more realistic and meaningful.

### 3.4.2 Scenario design, simulation and analysis

After factor analysis, scenarios can be designed for simulation purposes. Factors are selected and combined together to form possible scenarios. From these candidate scenarios, the ones that can generate unusual consequences are selected and interpreted for meaningfulness. These selected scenarios are simulated and their behaviours are thoroughly analysed.

#### 3.4.2.1 Factor selection

After the factors are quantified and interpreted, a method to select the factors is needed. To simplify the process, the factors are categorised into two groups: one is the group of basic state factors and the other one is the group of dynamic factors (Schoemaker 1995), which are illustrated in Figure 3.11. The basic state factors refer to the factors or the combination of factors that change the state of interest, but not as significantly as the dynamic factors during the time period under study. In terms of system structure, the basic state factors form the main frame of the structure of the system while the dynamic factors try to change the structure of the system. In terms of system behaviour, the basic state factors generate a basic behavioural trend line while the dynamic factors will cause variation around this basic trend line. In reality, the basic state factors fall into a relatively high-level category of factors such as those from worldwide situations or national policies, while dynamic factors belong to more low-level categories such as industrial regulations or organisational strategies.

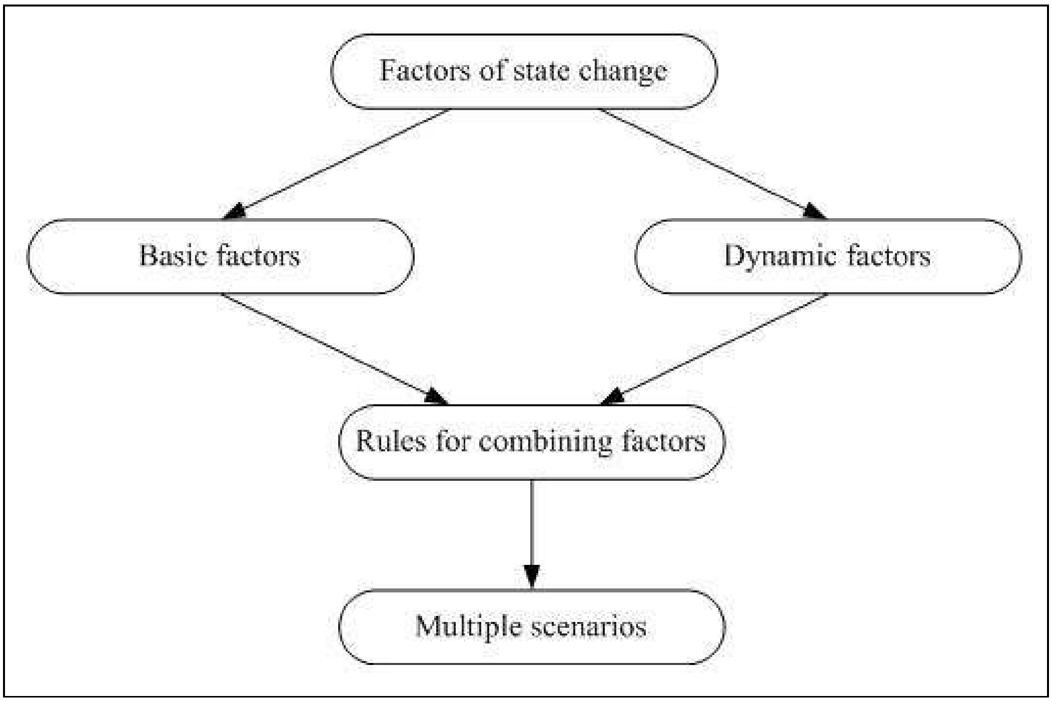


Figure 3.11: Building blocks for creating scenarios (Maani & Cavana 2003)

#### 3.4.2.2 Factor combination

When the basic state and uncertain state factors are classified, they are ready for combination to form possible scenarios. Since there are several categories ($m$) of factors and the values of each category can be set at several levels ($n$), the combination of factors and value levels will produce $C_m^n$ scenario candidates.

#### 3.4.2.3 Scenario interpretation

Theoretically, an unlimited number of scenarios can be generated. However since only a few scenarios can be simulated, it is important to select appropriate scenarios for experimentation. The meaningfulness of each scenario is established by interpreting iteratively through several interpretation rounds. If scenarios have no meaningful interpretation, they are ignored. If more than one scenario has a similar interpretation, one representative scenario is selected. Scenarios that generate different interpretations are selected for experimentation.

#### 3.4.2.4 Scenario simulation

The model is calibrated using the values of the factors set for a certain scenario. The behaviours are simulated and compared with the indicators chosen to describe the state of the system. If the generated behaviours meet certain expectations, the scenarios are analysed to identify possible strategic implications and the values of factors are recorded for simulation purposes. If the behaviours are not desirable, strategies can be developed to improve these behaviours.

### 3.4.3 Strategy development

When the consequences arising from a particular scenario are acceptable, the key elements involved in the scenario are reexamined. Strategic implications are drawn so that the conditions that influence the formation of this scenario can be cultivated in practice. When the behaviors from a scenario are undesirable, strategies must be designed and implemented in advance to positively influence the outcome of the system.

#### 3.4.3.1 Determination of leverage points

When strategies are designed to mitigate the negative effects arising from the occurrence of a certain scenario, it is important to find the leverage points that contribute to the negative effect. There may be more than one leverage point in a model. The effect from every leverage point should be examined and analysed. The leverage points that have strategic implications, called strategic leverage points, should be selected as the starting point for developing strategies.

#### 3.4.3.2 Modification and simulation

The value or the structure around a strategic leverage point is tentatively modified and simulated. The effect arising from the modification of the strategic leverage point is examined and the change from the negative behaviour is recorded. The effect arising from the combined modification of more than one strategic leverage points are also simulated. All the modifications that generate a corrective effect on the negative behaviour for a certain scenario are adopted as strategy candidates.

#### 3.4.3.3 Interpretation and formation

Some modifications may generate corrective effects but have no strategic operation in reality. These modifications cannot be elaborated as strategies. Only the modifications that exert corrective pressure and also have strong strategic interpretation and operational meanings in practice are used for formulating strategies. For example, in order to increase the proportion of urban mobile commerce users, strategies such as increasing urban fertility, increasing electronic commerce penetration rates, improving life quality in urban areas, decreasing rural birth, deteriorating living quality in rural areas and increasing urbanisation rates are effective. Increasing urban fertility is contradictory to the family planning policy aimed at total population control in China. Decreasing rural birth rates is not practical since current rural fertility is low and this further decrease will meet resistance and cause instability in these areas. The most viable strategies are: increasing electronic commerce penetration rates, improving living quality in urban regions and increasing urbanisation rates.

## 3.5 Summary

This chapter has presented the general research design, the detailed processes of SD simulation modelling and the operational steps for formulating scenarios and strategies. The research design includes three stages: systems thinking, SD simulation modelling and experimentation. Systems thinking conceptualised the three subsystems: population development, mobile commerce diffusion and MCTs provision for the whole system of mobile commerce diffusion. A framework developed for accomplishing SD simulation modelling includes eleven steps in four phases: qualitative modelling, quantitative modelling, validation and experimentation. A framework with ten steps is established for the scenario design, simulation and analysis, and strategy development in the experimentation stage. Systems thinking is the basis of the whole system development and research design, and SD simulation modelling is an effective tool to model the system and fulfil the tasks as required in research design. Two frameworks demonstrated the operationality of the overall research design.

The SD simulation modelling, scenario design, simulation and analysis, and strategy development pave the way for the deepening of this research in the ensuing chapters. More detailed SD modelling is applied to the modelling of the population development submodel, mobile commerce diffusion submodel and MCT provision submodel in China in chapters 4, 5 and 6. During the process of the SD modelling, parameters are calibrated using data from secondary sources and the model is tested using the historical behaviour reproduction of the data collected on Chinese population and mobile phone subscribers in China. Experiments related to sensitivity analysis, scenario analysis and strategy development are also designed and performed in chapters 4, 5 and 6 in order to identify sensitive factors, simulate the behaviours of possible scenarios and examine the effectiveness of the strategies formulated.

# Chapter 4

# MODELLING AND SIMULATING POPULATION DYNAMICS

## 4.1 Introduction

In Chapter 3, it was proposed to model and simulate mobile commerce diffusion in China using a System Dynamics model composed of three submodels: a population submodel, a mobile commerce diffusion submodel and a mobile commerce terminal (MCT) provision submodel. In this chapter, related work on population modelling is first reviewed followed by an explanation of the process used for constructing the population submodel.

Constructing a System Dynamics model of the population in China involves: identifying the relevant variables for use in the model, identifying and expressing the relationships between the variables as a causal loop diagram (or model), and converting the causal loop diagram to a stock and flow diagram (or model) using mathematical equations.

Before a stock and flow model can be used for simulating population dynamics in China, it must first be calibrated using appropriate parameters and then validated as a reasonable model fit for that purpose. Validation is accomplished by adjusting the parameters of the stock and flow model to reproduce the historical evolution of the Chinese population size. Sensitivity analysis is also performed on the stock and flow model to identify sensitive parameters which can be used as leverage points for exerting pressure on the system to achieve desirable outcomes such as curbing population growth in China.

Some hypothetical scenarios of what might occur in China in the future are formulated and simulated to determine their effect on the evolution of the size of the Chinese population in the future. Matching population-control strategies are also formulated and their effectiveness demonstrated through simulation.

## 4.2 Population dynamics in China

Demography is the scientific study of human population dynamics. It involves the study of changes in the numbers and composition of individuals in populations, and the biological and environmental processes influencing those changes. It can be very difficult to use a purely mathematical approach for analysing population dynamics as they are dynamical systems with very complex behaviours. A more useful approach for modelling population dynamics is agent-based modelling (ABM) (Billari 2006). Agent-based models are stochastic, micro-level models that describe systems using local and simple interactions between agents (individuals in the case of population dynamics) leading to complex patterns at a global scale (Axelrod 1997).

Another useful approach for modelling the dynamics of complex systems such as population systems is System Dynamics (SD) (Forrester 1961, Forrester 1968, Forrester 1969, Forrester 1971*a*, Forrester 1973, Forrester 1992). System dynamics models are deterministic, macro-level models that describe systems in terms of stocks and flows connected by feedback loops which create the non-linearity found in complex systems. SD models are simulated using computer software and an understanding of the system under study can be gained by testing certain policies using what-if simulations to observe the evolution of the system over time.

The aim in this chapter is to develop an SD model of human population dynamics in China. The motivation for using SD for modelling and simulating the human population in China is twofold. Firstly, an SD model of the population in China is part of the study that aims to model mobile commerce diffusion in China. Secondly, using SD to model the dynamics of such a complex system as population dynamics helps us to understand the factors that influence the growth of the population which are inherent to the Chinese environment. This allows the evolution of the Chinese population to be simulated under a range of population-control policies in order to assess the effectiveness of these policies. In addition, China is currently experiencing an unprecedented restructuring of its social economic system and this transformation will inevitably affect all walks of life. It is necessary to understand how this restructuring will affect the growth of China's population.

Initially, China's post-1949 leaders viewed a large population as an asset, but the liabilities of a large, rapidly growing population soon became apparent (Peng & Guo 2000). The Chinese population currently represents 25 percent of the world's population (United Nations Population Division 2004), and at present growth rates, that figure threatens to double in 35 years if actions are not taken to curb the growth rate. China plans to control its mainland population to within 1.36 billion by 2010 in its eleventh five-year plan (2006-2010) (Chinese State Council 2006). In the long run, China aims to control its population at 1.5 billion by 2020 and 1.6 billion by 2050 in order to build a harmonious society in which the quality of life and living environment will be improved to an ideal level (NPFPCC 2004).

### 4.2.1 Related work

Traditional demographic research is usually based on analytical approaches. Examples, as introduced in section of population dynamics in Chapter 2, are forecasting change in population using population elements such as fertility (birth), mortality (due to accidents/diseases) and/or deaths (by natural causes) and migration.

The United Nations (UN) is the authority on population research. It periodically publishes forecasts of indicators for predicting the population development trend for a country or worldwide (United Nations Population Division 2004). The UN uses mathematical and statistical methods for forecasting human population, and factors used for forecasting include: birth rate, death rate, mortality rate and life expectancy. However, mathematical models are limited for modelling such complex systems such as population dynamics. Complex systems are non-linear systems which can exhibit very complex behaviours and these behaviours cannot be adequately captured by purely mathematical models.

The world population has been simulated using large System Dynamics models such as WORLD2 (Forrester 1971*b*), WORLD3 (Meadows et al. 1992) and WORLD3 revisited (Meadows et al. 1974). The main aim of these WORLD models was to understand the effects of pollution and natural resources on world population development. A dynamic model was also created to illustrate the different characteristics of population dynamics under different stages of society such as traditional urban-agrarian and modern urban-industrial stages (Ness & Low 2000). This model also considered family planning. However, it was descriptive only, as no simulation was involved.

Thus, although SD has been used for modelling population dynamics, to the best of our knowledge it has not been used for modelling and simulating population dynamics in China. In China, the situation is different from other countries as the Chinese authorities have controlled population growth using their so-called ‘one couple one child policy’, with varying degrees of success in urban and rural areas.

## 4.3 Qualitative modelling

Developing an SD model includes several steps. The first step in creating an SD model is to identify key variables (or factors) and their behaviours over time, and show the causal links between them in a causal loop digram or model. This section describes the key variables identified, the qualitative model established and an explanation of the feedback loops identified in the system.

### 4.3.1 Factors used in model

Population dynamics is usually modelled as the interplay of birth, death and migration. Birth rates depend on the number of fertile women and the number of children a fertile woman can have. In China, births are also controlled by family-planning policies as both the age when a woman can obtain her fertility permit (i.e. allowed to give birth) and the number of children a woman can have are stipulated by the Chinese family-planning policy. In the study, the population in China is segregated into urban and rural populations as they have different characteristics.

According to the Chinese family-planning policy, an urban woman can have her only child at the age of 22 but, under the advocacy of late marriage and late fertility from government propaganda, she will normally have her baby at the age of 27. A rural woman can have her first child at the age of 22. In the study, it is assumed that rural women can have their first, second and third children at the age of 22, 25 and 28 respectively and half the number of fertile rural women will have their fourth child at the age of around 31.

Death includes natural death rates which depend on human life expectancies and mortality rates due to accidents, diseases, etc. Human life expectancy and mortality rates depend on the quality of life and the level of health in a country. Life quality and heath levels in China are assumed to be stable during the simulation period.

The population level is also affected by migration rates which consist of movement of people to and from China and within China. Immigration influence is ignored since the number of immigrants to and from China is small in comparison with the annual number of births. Migration from urban to rural areas is considered to be negligible and only migration from rural to urban areas is considered in the model. The fraction of the population living in urban areas is determined by the urbanisation increase rate which in return is a reflection of the national policy on urbanisation. An analysis of the historical data on urbanisation occurring from 1995 to 2004 in China determined the historical urbanisation rate to be stable around the value of 0.144%.

Table 4.1 lists all the variables used in the system. The table provides the following information for each variable used: abbreviation, description, type and unit.

### 4.3.2 Causal loop diagram

The starting point for establishing a qualitative model in system dynamics is to draw a causal loop diagram (CLD). The CLD identifies the relationship between variables and more importantly the feedback loops in the system, positive as well as negative. The CLD can be considered as some form of primitive representation of the target system and the CLD representing the Chinese population model is shown in Figure 4.1.

The state of the total population (the variable shown at the center of the diagram) is determined by four main causal loops. Two of the loops are positive or reinforcing feedback loops (labelled as loops R1 and R2) while two others are negative or balancing ones (labelled as loops B1 and B2)[1]. In addition to these four main causal feedback loops, there are four more feedback loops, one of them positive (labelled as loop R3) and three of them negative (labelled as loops B3, B4 and B5). The feedback loops are described next.

[1]for more detail about reinforcing/balancing feedback loops, please refer to the user guide of modelling and simulation softwares, such as Powersim, Vensim

Table 4.1: Variables used in model

| **Variable** | **Description** | **Type** | **Unit** |
|---|---|---|---|
| $T_0$ | Start Time | Constant | Year |
| $T_f$ | Final Time | Constant | Year |
| $\Delta T$ | Time step | Constant | Year |
| $FPCT_t$ | Family Planning Change Time | Constant | Year |
| $UCT_t$ | Urbanisation Change Time | Constant | Year |
| $TP_t/UP_t/RP_t$ | Total/Urban/Rural Population | Auxiliary | Person |
| $UIP_0/RIP_0$ | Urban/Rural Initial Population | Constant | Person |
| $UPI_t/RPI_t$ | Urban/Rural Population Increase | Flow | Person/year |
| $UPD_t/RPD_t$ | Urban/Rural Population Decrease | Flow | Person/year |
| $UMR_t/RMR_t$ | Urban/Rural Mortality Rate | Constant | 1/year |
| $UDR_t/RDR_t$ | Urban/Rural Death Rate | Flow | 1/year |
| $ULE_t/RLE_t$ | Urban/Rural Life Expectancy | Auxiliary | Year |
| $IULE_t/IRLE_t$ | Initial $ULE_t/RLE_t$ | Constant | Year |
| $EULE_t/ERLE_t$ | Expected $ULE_t/RLE_t$ | Constant | Year |
| $EULET_t/ERLET_t$ | $EULE_t/ERLE_t$ Time | Constant | Year |
| $UF_t/RF_t$ | Urban/Rural Fertility | Constant | Dimensionless |
| $UNWB_{t,i}$ | Urban number of fertile women to give $i^{th}$ birth, $i \in \mathbb{Z}^+$ | Time series | Person/Year |
| $RNWB_{t,i}$ | Rural number of fertile women to give $i^{th}$ birth | Time series | Person/Year |
| $UAWB_{t,i}$ | Urban age of fertile women to give $i^{th}$ birth | Constant | Year |
| $RAWB_{t,i}$ | Rural age of fertile women to give $i^{th}$ birth | Constant | Year |
| $U_t$ | Urbanisation | Auxiliary | Dimensionless |
| $EU_t$ | Expected Urbanisation | Constant | Dimensionless |
| $IMU_t$ | Interim Urbanisation | Auxiliary | Dimensionless |
| $IU_t$ | Initial Urbanisation | Constant | Dimensionless |
| $UI_t$ | Urbanisation Increase | Constant | 1/year |
| $HUI_t$ | Historical Urbanisation Increase | Constant | 1/year |
| $UDM_t$ | Urbanisation Development Mode | N/A | N/A |
| $UM_t$ | Urban Migration (from rural) | Auxiliary | Person/year |
| $UIM_t/RIM_t$ | Urban/Rural Immigration | Constant | Person/year |
| $UE_t$ | Urban Emigration | Constant | Person/year |
| $UPP_t/RPP_t$ | Urban/Rural Population Proportion | Auxiliary | Dimensionless |
| $TPI_t/UPI_t/RPI_t$ | Total/Urban/Rural Population Increase | Auxiliary | Person/year |

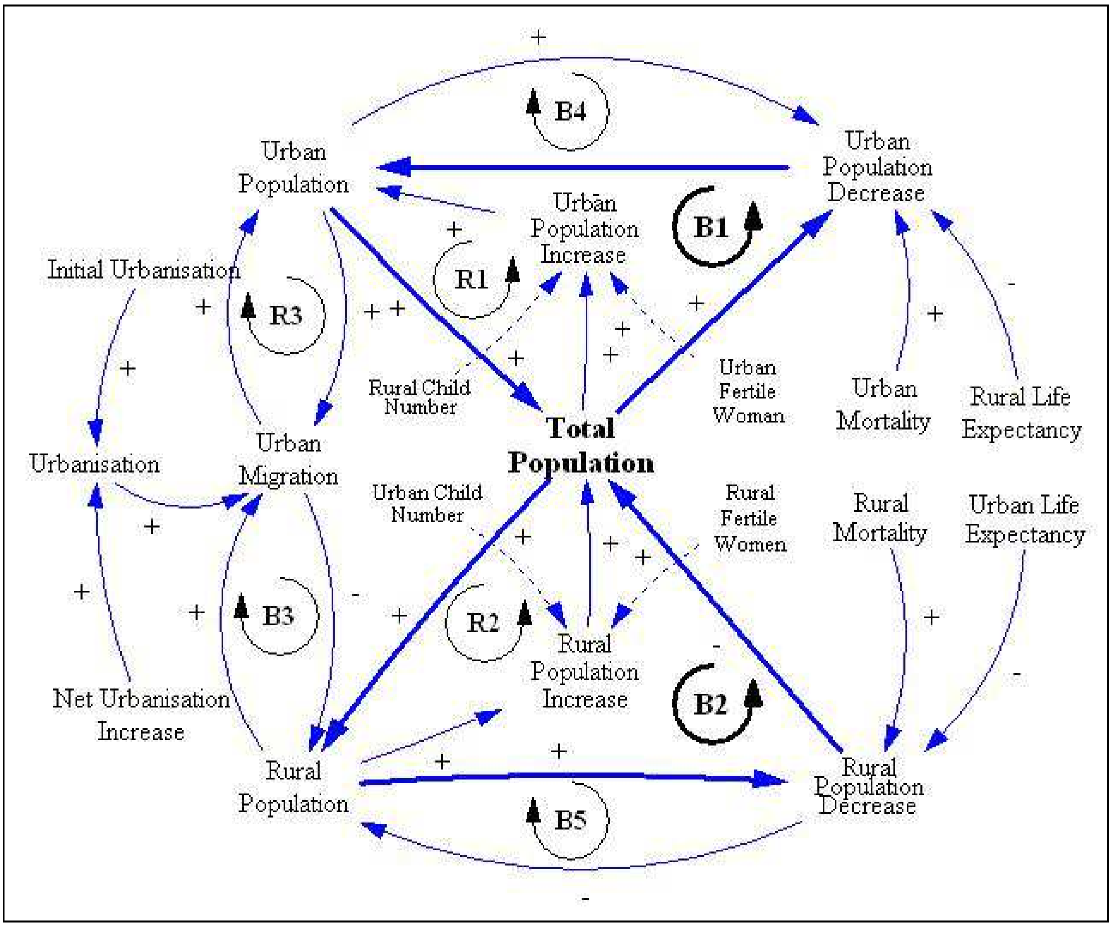


Figure 4.1: Causal loop diagram

### 4.3.3 Birth feedback loops

The birth feedback loops are represented by reinforcing feedback loops R1 and R2. Reinforcing feedback loop R1, shown in Figure 4.2, shows that an increase in total population increases the urban population which further increases the total population.

Similarly, reinforcing feedback loop R2, shown in Figure 4.3, shows that an increase in total population increases the rural population which further increases the total population. These two positive feedback loops generate a reinforcing effect to increase the level of the total population variable.

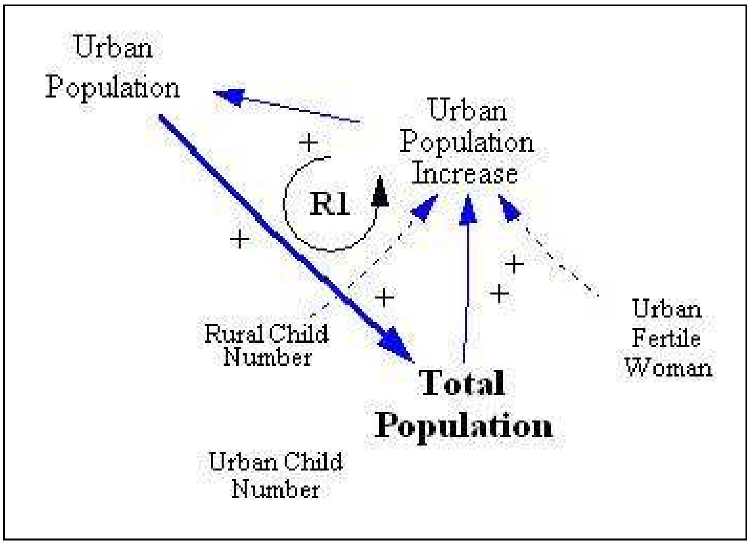


Figure 4.2: Urban increase loop (R1)

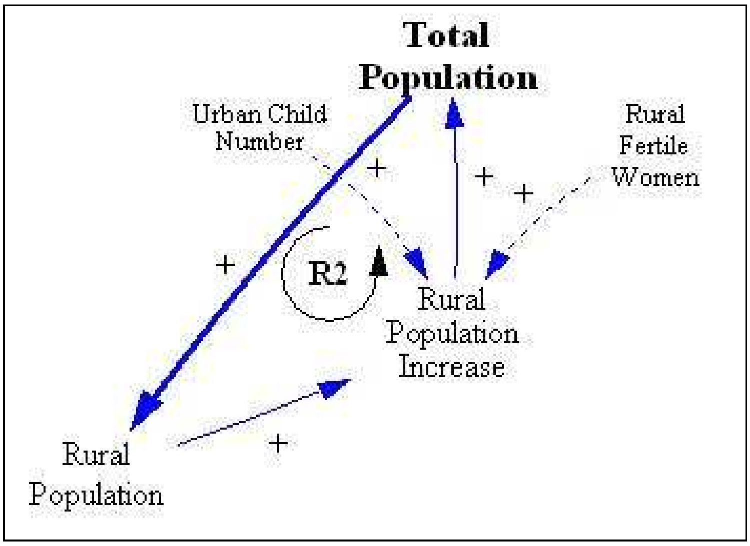


Figure 4.3: Rural increase loop (R2)

### 4.3.4 Death feedback loops

The death feedback loops describe how the population will decrease. This decrease comes from natural death (death rate) and accidental death (mortality). A death rate refers to the proportion of deaths of persons when they reach the average life expectancy. To simplify its calculation, a death rate in this population model is regarded as a reciprocal of life expectancy.

The death feedback loops are represented by balancing feedback loops B1 and B2. Balancing feedback loop B1, shown in Figure 4.4, shows that an increase in total population causes an increase in the number of deaths in the urban population which decreases urban population and hence decreases the total population.

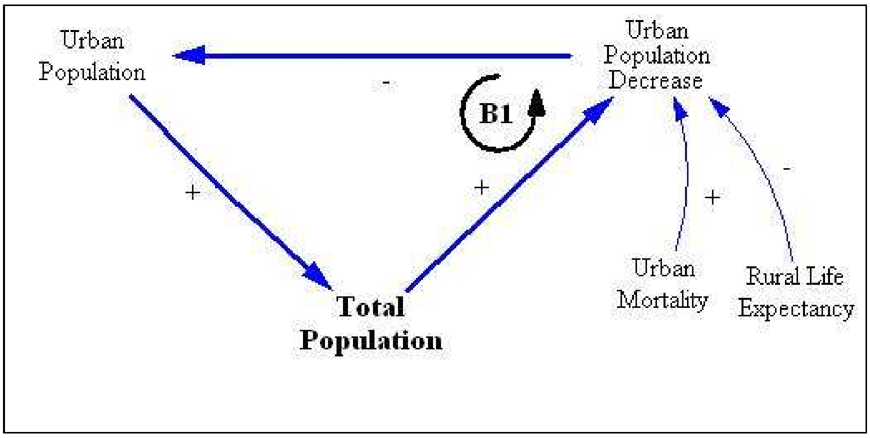


Figure 4.4: Urban decrease loop (B1)

Similarly, balancing feedback loop B2, shown in Figure 4.5, shows that an increase in total population causes an increase in the number of deaths in the rural population which leads to a decrease in the rural and total populations.

These two negative feedback loops generate a balancing effect to constrain the total population growth. The general quality of life (life expectancy and mortality rate) affects the levels of urban and rural population decrease and hence the total population level.

### 4.3.5 Migration feedback loops

Reinforcing feedback loop R3, shown in Figure 4.6, is a closed circuit from urban population to urban migration and back to urban population again. An increase in urban population results

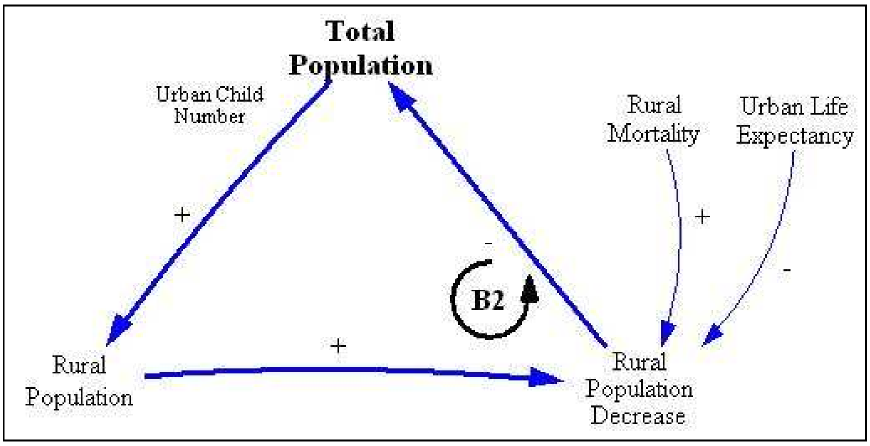


Figure 4.5: Rural decrease loop (B2)

in an increase of urban migration which eventually increases the urban population level.

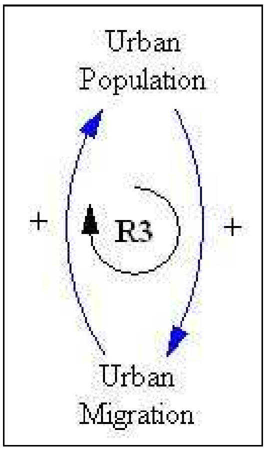


Figure 4.6: Urban migration loop (R3)

Balancing feedback loop B3, shown in Figure 4.7, runs from rural population to urban migration and back to rural population again.

An increase in rural population results in an increase of urban migration, which eventually decreases the rural population level. This negative feedback loop will generate a balancing effect to constrain the growth of the level of the rural population. Both urban and rural population levels will fluctuate with the variation of urban migration, which is further influenced by urbanisation.

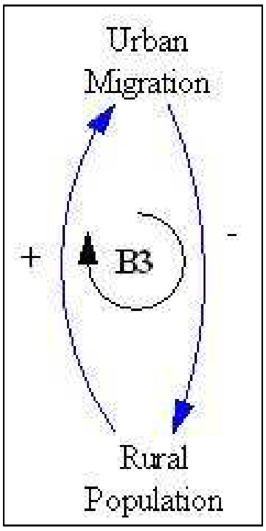


Figure 4.7: Rural migration loop (B3)

### 4.3.6 Other feedback loops

Balancing feedback loop B4, shown in Figure 4.8, loops from urban population to urban population decrease back to urban population while loop B5, shown in Figure 4.9, loops from rural population to rural population decrease back to rural population. An increase in urban population results in an increase of urban population decrease, which eventually decreases the urban population level. An increase in rural population results in an increase of rural population decrease, which eventually decreases the rural population level. Thus, these two negative feedback loops will generate a balancing effect to constrain the growth of the urban and rural population levels.

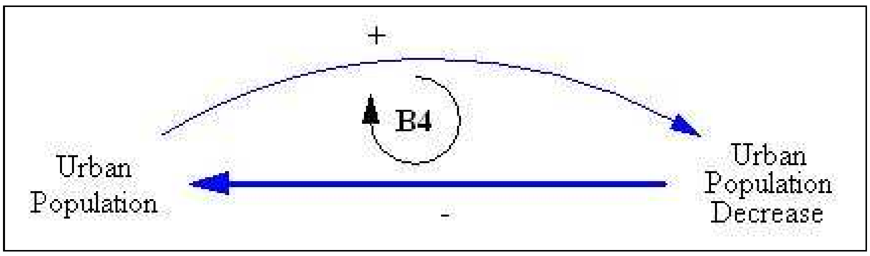


Figure 4.8: Urban decrease loop (B4)

The evolution of the total population is affected by the interplay of these eight causal loops. Demographers can exert influence on population development by closing or opening these causal feedback loops or by changing the way the factors are linked in the loops.

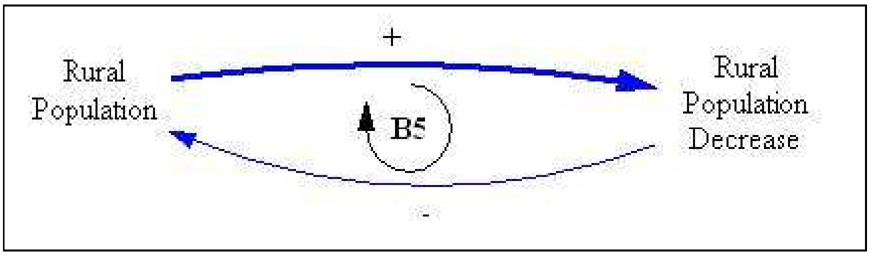


Figure 4.9: Rural decrease loop (B5)

## 4.4 Quantitative modelling

If simulation of an SD model is required, the qualitative CLD model must be converted to a quantitative model. This is accomplished using a stock and flow diagram (or model) whereby some variables are modelled as stocks and others as flows between the stocks. This section describes how a simulation model is obtained from the causal loop diagram described in the previous section. In order to simulate the model, some mathematical equations are also established.

### 4.4.1 Stock and flow diagram

A stock and flow diagram (SFD) is a quantitative model of the system. As a metaphor, a stock can be thought of as a bathtub and a flow can be thought of as a tap and piping system that fills or drains the stock. The dynamic behaviour of the system is then modelled when something (water in this case) flows through the inlet piping, accumulates in the stock (bathtub in this case) and exits through the drain.

A simplified SFD (a more detailed SFD is shown later) for modelling population dynamics in China showing the main stocks and flows is depicted in Figure 4.10. The two boxes in the diagram represent the two stocks: urban population and rural population. The level of urban (or rural) population is controlled by the inflow into and the outflow from the stock of the urban (or rural) population. The level of the two stocks is also controlled by the urban migration flow between them. The levels of the two stocks determine the state and structural change of population. The factors identified in the CLD will change the population state by affecting the flows linked to the stocks.

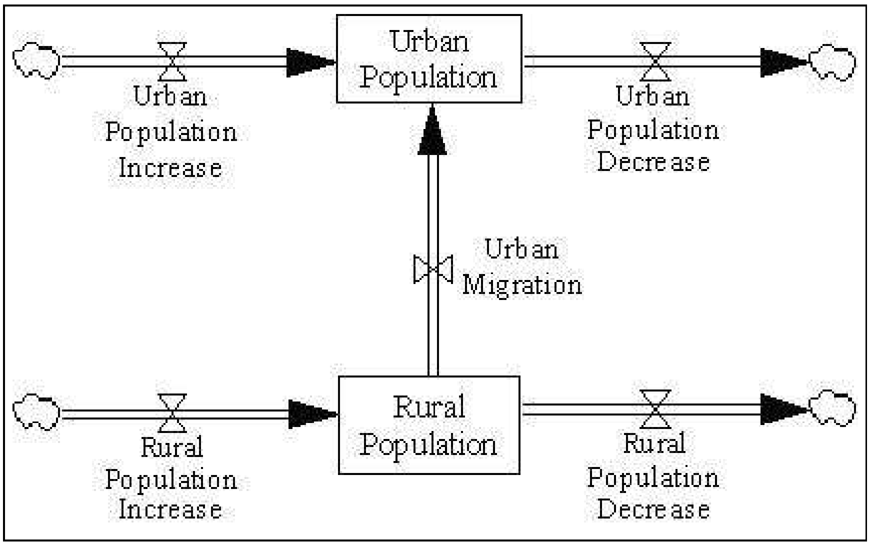


Figure 4.10: Stock and flow diagram

### 4.4.2 Equations used in model

Apart from drawing the stocks and flows and their interconnections, a set of mathematical equations or logistical relationships must also be established in the quantitative model to describe how the stocks, flows and auxiliary variables change over time. Mathematical equations are formulated for the variables classified as stock, flow and auxiliary as shown in Table 4.1. The mathematic equations used in the model are shown in Table 4.2. Appendix E lists the equations in SD format generated by Powersim software.

Equation 1 calculates the total population as the sum of urban and rural populations. Equation 2 establishes the urban population as the sum of *urban initial population* and the integration of the difference between the *urban population increase* and the *urban population decrease* plus the urban migration occurring between urban and rural areas. Similarly, equation 3 establishes the rural population as the sum of *rural initial population* and the integration of the difference between the *rural population increase* and the *rural population decrease* minus the urban migration occurring between urban and rural areas.

Equation 4 calculates the *urban population increase* as a function of factors affecting the number of births plus migration (from outside China) to urban areas. Similarly, equation 5 calculates the *rural population increase* as a function of factors affecting number of births plus migration (from outside China) to rural areas. The number of births is the result of the combination of the

Table 4.2: Equations used in model

| | |
|---|---|
| $TP_t = UP_t + RP_t$ | (1) |
| $UP_t = UIP_0 + (UPI_t - UPD_t + UM_t) * \Delta T$ | (2) |
| $RP_t = RIP_0 + (RPI_t - RPD_t - UM_t) * \Delta T$ | (3) |
| $UPI_t = C(UF_t, U_t, UNWB(t,i), UAWB(t,i)) + UIM_t$ | (4) |
| $RPI_t = C(RF_t, (1-U_t), RNWB(t,i), RAWB(t,i)) + RIM_t$ | (5) |
| $UPD_t = (UMR_t + UDR_t) * UP_t + UE_t$ | (6) |
| $RPD_t = (RMR_t + RDR_t) * RP_t + RE_t$ | (7) |
| $UDR_t = 1/ULE_t$ | (8) |
| $RDR_t = 1/RLE_t$ | (9) |
| $ULE_t = IULE_0 + [(EULE_t - IULE_0)/EULET_t] * \Delta T$ | (10) |
| $RLE_t = IRLE_0 + [(ERLE_t - IRLE_0)/ERLET_t] * \Delta T$ | (11) |
| $UM_t = UI_t * TP_t$ | (12) |
| $U_{(t,i=0)} = IU_{t=0} + HUI_t * \Delta T$, $t \leq UCT_{t,i=0}$; | (13) |
| $U_{(t,i)} = U_{t=UCT_{(t,i-1)}} + [EU_{(t,i)} - U_{t=UCT_{(t,i-1)}})/(EUT_{(t,i)} - UCT_{(t,i-1)}] * \Delta T$, $t \in \left[UCT_{(t,i)}, EUT_{(t,i)}\right], i \in \mathbb{Z}^+$ | (14) |
| $UPP_t = UP_t/TP_t$ | (15) |
| $RPP_t = RP_t/TP_t$ | (16) |
| $TPI_t = d(TP_t)/dt$ | (17) |
| $UPI_t = d(UP_t)/dt$ | (18) |
| $RPI_t = d(RP_t)/dt$ | (19) |

urban (or rural) fertility, the urbanisation fraction, the urban (or rural) number of fertile women to give birth to the $i$th child and the urban (or rural) age of fertile women giving the $i$th birth, where $i$ is a positive integer denoting the number of children a woman will have in her fertile period. The number of births during the simulation period are specified as time series inputs of fertile women giving births at the time points under consideration. The derivation of these time series inputs is explained next.

Since 1995 is used as the start time for the simulation, the age distribution of fertile women in 1995 (as shown in Figure 4.11 and the data in Appendix B) is manipulated for use as a time series input to the SD model. For modelling purposes, it is assumed that the earliest age a woman can give birth to a child is 18 years and the latest age is 44 years. Also, common sense dictates that a woman can give birth to only one child per year.

The time series used as input to the SD model is created as follows. For each birth-giving age in the range [18,44], a time series can be constructed to represent the potential number of children that could be given birth to by that age group. If fertile women are allowed to have a child in that particular age group, then the birth time series for the 18-year-old group consists of the following points: (1995, actual number of fertile women in that year), (1996, number of 17-year-old women in 1995 as they will turn 18 years in 1996), (1997, number of 16-year-old women in 1994), etc.

This time series must be added the next generations of fertile women born from this age group and who will bear children when they turn 18. If the probability of a child being a female is 0.5, then the new generation of 18-year-old fertile women consists of half the number of children given birth to by this age group when they turn 18 years. This additional number of births is represented by another birth time series that has to be added to the previous one. It consists of the following points: (2013, number of 18-year-olds in 1995/2), (2014, number of 17-year-olds in 1996/2), etc. If necessary, this time series must be added to the generation after the next generation of fertile women born from the age group of the next generation and who will bear children when they turn 18. If the probability of a child being a female is the same at 0.5, then the new generation after the next generation of 18-year-old fertile women consists of half the number of children given birth to by the next generation or a quarter of the number of children given birth to by this age group in 1995. This additional number of births is represented by another birth time series that has to be added to the previous two. It consists of the following points: (2031, number of 18-year-olds in 1995/4), (2032, number of 17-year-olds in 1996/4), etc. Thus, time series are created and added as long as the simulation requires them.

Several birth time series for fertile women in the age [18,44] from 1995 until the end of the simulation are represented as follows:

$$B_{18} = (N_{18}, N_{17}, N_{16}, ..., N_0, N_{18}/2, N_{17}/2, ..., N_0/2, N_{18}/4, N_{17}/4, ...)$$
$$B_{19} = (N_{19}, N_{18}, N_{17}, ..., N_0, N_{19}/2, N_{18}/2, ..., N_0/2, N_{19}/4, N_{18}/4, ...)$$
$$B_{20} = (N_{20}, N_{19}, N_{18}, ..., N_0, N_{20}/2, N_{19}/2, ..., N_0/2, N_{20}/4, N_{19}/4, ...)$$
$$......$$
$$B_{42} = (N_{42}, N_{41}, N_{40}, ..., N_0, N_{42}/2, N_{41}/2, ..., N_0/2, N_{42}/4, N_{41}/4, ...)$$
$$B_{43} = (N_{43}, N_{42}, N_{41}, ..., N_0, N_{43}/2, N_{42}/2, ..., N_0/2, N_{43}/4, N_{42}/4, ...)$$
$$B_{44} = (N_{44}, N_{43}, N_{42}, ..., N_0, N_{44}/2, N_{43}/2, ..., N_0/2, N_{44}/4, N_{43}/4, ...)$$

where $B_i$ represents the potential number of births for the $i^{th}$ age group in the range [18,44], $i$ refers to the age of fertile women in the age range [18,44], and $N_i$ represents the number of fertile women of age $i$. In summary, a generic equation representing the time series of births for the $i^{th}$ age group is shown below.

$$B_i = (N_i, N_{i-1}, N_{i-2}, ..., N_0, N_i/2, N_{i-1}/2, ..., N_0/2, N_i/4, N_{i-1}/4, ...)$$

Since the previous equations calculated the maximum possible number of births, the individual time series are multiplied by a weight in the range [0,1] to obtain actual births. Thus, the actual total births time series ($B_{actual}$) is the sum of all the potential births ($B_i$) of the birth time series of the age groups from 18 to 44 years multiplied by a corresponding weight $W_i$.

$$B_{actual} = \sum B_i * W_i, i = 18, ..., 44$$

$W_i$ is the weight of the $i_{th}$ time series, which is normally reflected in the family-planning policies. If it is assumed that births occur strictly according to family-planning policies (i.e. women in the countryside can have their first child at the age of 22 and they can have a total of three children after every three years), then the weights are zero for all age groups except for the 22, 25 and 28 age groups where the weight is 1.0 i.e. $W_{22} = W_{25} = W_{28} = 1.0$. Thus, the total number of actual births is

$$B_{actual} = B_{22} + B_{25} + B_{28}$$

However, in reality, not every woman will have their children according to the family-planning policies. In the SD model, it was assumed that 70% of women will have three children at the age of 22, 25 and 28; 10% at the age of 21, 24 and 27; 10% at the age of 23, 26 and 29; 5% at the age of 20, 23 and 26; and 5% at the age of 24, 27 and 30. Under this assumption, the weights are:

$(W_{20}, W_{21}, W_{22}, W_{23}, W_{24}, W_{25}, W_{26}, W_{27}, W_{28}, W_{29}, W_{30})$
$= (0.05, 0.1, 0.7, 0.15, 0.15, 0.7, 0.15, 0.15, 0.7, 0.1, 0.05)$

and the total actual number of births is:

$B_{actual} = 0.05 * B_{20} + 0.1 * B_{21} + 0.7 * B_{22} + 0.15 * B_{23} + 0.15 * B_{24} + 0.7 * B_{25}$
$+ 0.15 * B_{26} + 0.15 * B_{27} + 0.7 * B_{28} + 0.1 * B_{29} + 0.05 * B_{30}$

After the time series for each age of fertile women is determined, the next step is to calculate the number of births. The number of urban births is the sum of the selected time series multiplied by the urbanisation fraction and the number of rural births is the sum of the selected time series multiplied by the rest of the urbanisation fraction. The total urban (or rural) population increase is the urban (or rural) number of births plus the urban (or rural) immigration from outside China.

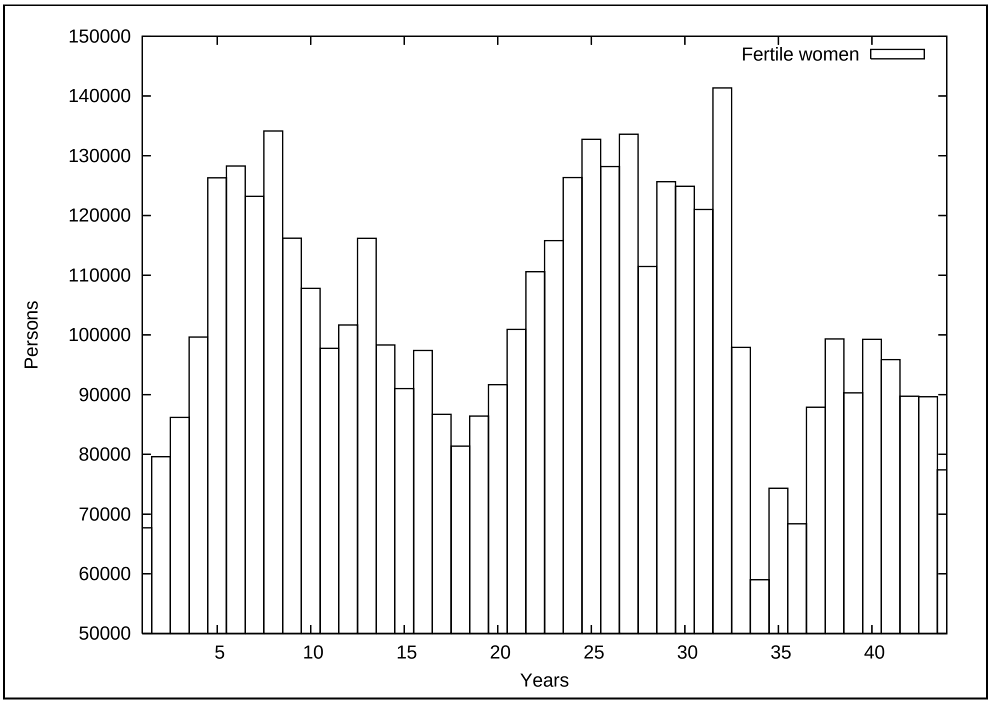


Figure 4.11: Age distribution of fertile women in China in 1995

Equation 6 describes the urban decrease as the sum of the urban mortality rate and the urban death rate multiplied by the urban population and the emigration from the urban population to other countries. Similarly, equation 7 describes the rural decrease as the sum of the rural mortality rate and the rural death rate multiplied by the rural population and the emigration from the rural population to other countries.

Equation 8 shows that the urban death rate is the reciprocal of urban life expectancy, while equation 9 shows that the rural death rate is the reciprocal of rural life expectancy. Life expectancy is simply assumed to change linearly with time. The slope is calculated as the difference of the expected value and the initial value of life expectancy divided by the time to reach the expected value. Equation 10 expresses the urban life expectancy as the sum of the initial urban life expectancy and the product of the slope and the time step. Similarly, equation 11 expresses the rural life expectancy as the sum of the initial rural life expectancy and the product of the slope and the time step.

Equation 12 calculates urban migration from rural to urban areas as the net urbanisation increase times the rural population level. Equation 13 computes the urbanisation fraction before the urbanisation increase is changed. From 1995 to the time when urbanisation first starts to change, urbanisation increases linearly at a slope representing the historical net urbanisation increase.

Equation 14 calculates the urbanisation fraction when change occurs $i$ times during the urbanisation course. $i$ is the number of times ($1, 2, 3, .., n$), by which the urbanisation fraction will reach $i$th level. During the time when the urbanisation takes the $(i - 1)$th change to the time when the urbanisation takes $i$th change, urbanisation is assumed to take a linear increase. The slope is the difference of the expected urbanisation at the $i$th change and the urbanisation at the $(i - 1)$th change divided by the time used to accomplish the change from $(i - 1)$ to $i$. During this period, urbanisation is calculated as the sum of the urbanisation at the time when the urbanisation will take the $(i - 1)$ change and the product of the slope and time interval.

Equations 15 to 19 show the calculation of miscellaneous values that have no direct influence on the structure of the model. They are used in experiments to generate meaningful outputs for analysing the results. Equation 15 calculates the urban population proportion as a fraction of the total proportion while equation 16 calculates the rural population proportion in the same way. Equations 17 to 19 define the change in speed of the total, urban and rural populations as the derivatives of the total, urban and rural populations.

The modelling software Powersim[2] was used to create the SFD and the mathematical equations were incorporated into the model. The SFD shown in Figure 4.12 is the quantitative model used for simulation purposes.

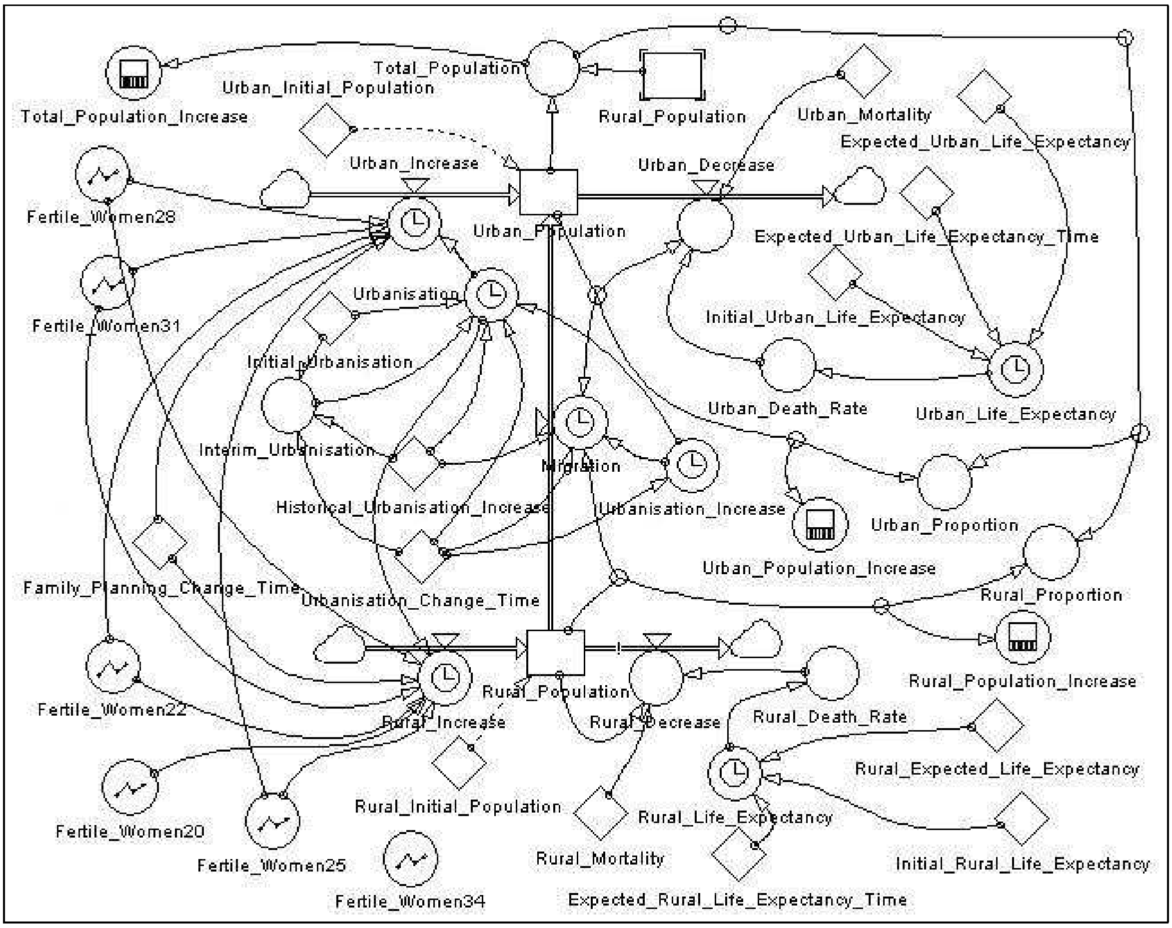


Figure 4.12: Population model

[2]Available at http://www.powersim.com

## 4.5 Model calibration

Before the SFD model can be simulated for experimentation purposes, it must be calibrated and validated. When creating a simulation model, some parameter values may not be readily available because they represent quantities that are very difficult or even impossible to measure accurately. In such a situation, it is important to determine a range of reasonable values for the variables in question and then narrow them down to specific values. The SFD model is calibrated by determining values for factors classified as constants in Table 4.1. Most of the values are derived from the 2004 Chinese Yearbook (Population chapter)[3] and the United Nations database[4]. Table 4.3 lists the values determined for the constants used in the SFD model and the following paragraphs explain how these values are obtained.

Table 4.3: Range of values for parameters

| Variable name | Unit | Value range | Variable name | Unit | Value range |
|---|---|---|---|---|---|
| $T_0$ | Year | $\geq 1995$ | $UE_t$ | Person/Year | $\cong 0$ |
| $T_f$ | Year | $\leq 2045$ | $RE_t$ | Person/Year | $\cong 0$ |
| $\Delta T$ | Year | $\leq 1$ | $ULE_t$ | Year | $\cong 71$ |
| $FPCT_t$ | Year | $\geq 8$ | $RLE_t$ | Year | $\cong 68$ |
| $UCT_t$ | Year | $\geq 8$ | $UF_t$ | Dimensionless | 0-5 |
| $IUP_t$ | Person | - | $RF_t$ | Dimensionless | 0-5 |
| $IRP_t$ | Person | - | $UNWB(t,i)$ | Person/Year | Time series |
| $UI_t$ | 1/Year | $\cong 1.44\%$ | $RNWB(t,i)$ | Person/Year | Time series |
| $HUI_t$ | 1/Year | - | $UAWB(t,i)$ | Year | 18-44 |
| $IU_t$ | Dimensionless | | $RAWB(t,i)$ | Year | 18-44 |
| $UIM_t$ | Person/Year | $\cong 0$ | $UMR_t$ | 1/Year | $\cong 0$ |
| $RIM_t$ | Person/year | $\cong 0$ | $RMR_t$ | 1/Year | $\cong 0$ |

The year 1995 was selected as the simulation starting time ($T_0$) for the model for three reasons. First, most of the relevant data to test the model were available only as far back in 1995. Second,

[3] Available at http://www.stats.gov.cn

[4] Source: Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2004 Revision and World Urbanization Prospects: The 2003 Revision, http://esa.un.org/unpp, 07 March 2006; 8:39:48 PM.

selecting 1995 as the start time leaves enough room to calibrate the model using historical data until 2003. Third, after 1995 the values of some variables were stabilised. For example, the net urbanisation increase stabilised at 1.44%.

The year 2050 was selected as the simulation final time ($T_f$) because in addition to generating the population levels over the time span from 1995 to 2003, the model also generated the population levels from 2003 to 2050. However, the final time can be modified as needed to suit the requirements of any experiment performed.

The time step ($\Delta T$) can be set to one year, a quarter, a month or a day. To select a suitable time step as discussed in the section of model testing of Chapter 3, the sensitivity of the different time steps is examined first. Tests found that a time step setting at 1 was adequate. In the simulation, one year was chosen as the time step. Since the year 2003 is the division point between the past and the future and simulation starts in the year 1995, the family-planning change time ($FPCT_t$) and urbanisation change time ($UCT_t$) should occur after 2003 and their values are set at 8 (2003-1995=8) or greater.

The range of values of the urbanisation increase ($UI_t$) is based on the analysis of the historical urbanisation increase ($HUI_t$) available from 1995 to 2003 and its extrapolation into the future. An analysis of the historical data on the urbanisation fraction occurring from 1995 to 2003 in China found the historical urbanisation increase to be stable around the value of 1.44% as shown in column 3 of Table 4.4.

The model ignores the immigration into and emigration from China as these values are negligible in comparison with the annual birth and death rates. The migration from urban to rural areas is also considered to be insignificant and only the migration from rural to urban areas is taken into consideration. Under these assumptions, the urban immigration ($UIM_t$), rural immigration ($RIM_t$), urban emigration ($UE_t$) and rural emigration ($RE_t$) are ignored.

Following the UN forecasts, the average life expectancy in urban ($UE_t$) and rural ($RE_t$) areas is set to 71 and 68 years respectively in the base simulation. The life expectancy in urban and rural areas may generate variation during the simulation time, whereas the value of urban life expectancy ($UE_t$) and rural life expectancy ($RE_t$) will vary among 60 and 80 year olds.

Table 4.4: Historical urbanisation fraction and annual urbanisation increase

| Years | Urbanisation Fraction(%)[a] | Urbanisation Increase($UI_t$)(%) |
|---|---|---|
| 1995 | 29.04 | - |
| 1996 | 30.48 | 1.44 |
| 1997 | 31.91 | 1.43 |
| 1998 | 33.35 | 1.44 |
| 1999 | 34.78 | 1.43 |
| 2000 | 36.22 | 1.44 |
| 2001 | 37.66 | 1.44 |
| 2002 | 39.09 | 1.43 |
| 2003 | 40.53 | 1.44 |
| Average Annual Urbanisation Increase | | 1.44 |

[a] Source:http://www.stats.gov.cn

Since the highest fertility (number of children giving birth) in Chinese history is 6, the urban fertility ($UF_t$) and rural fertility ($RF_t$) is assumed to be in the range [0,6]. A reasonable age span for urban fertile women ($UAWB(t,i)$) and rural fertile women ($RAWB(t,i)$) giving births is in the range [18, 44] since the natural fertility age for a woman biologically starts at 18 years and stops at 44.

Theoretically, the death rate (due to natural causes) is equal to the reciprocal of the life expectancy. As such, the urban death rate is set at 1/71 (or 1.41%) and rural death rate at 1/68 (or 1.47%). In comparison with the death rates, mortality (due to accidents/diseases) rates are small and are neglected in the model. Thus, urban mortality ($UMR_t$) and rural mortality ($RMR_t$) rates were ignored in the model.

Table 4.5 lists the values selected for the parameters in the base case of the model. Since the model is simulated from 1995, the initial urbanization should be the urbanization fraction in this year. As mentioned in Table 4.4, the value of $IU_t$ is available from the online database of the Chinese Statistics Bureau [5] and equals 0.29. The base case of the model is the version of the model that contains the parameter values that generate the most possible trend in future.

[5] Available at http://www.stats.gov.cn

Table 4.5: Parameter values used for the base state

| Variable name | Unit | Value range | Variable name | Unit | Value range |
|---|---|---|---|---|---|
| $T_0$ | Year | 1995 | $UE_t$ | Person/Year | 0 |
| $T_f$ | Year | 2045 | $RE_t$ | Person/Year | 0 |
| $\Delta T$ | Year | 1 | $ULE_t$ | Year | 71 |
| $FPCT_t$ | Year | 0 | $RLE_t$ | Year | 68 |
| $UCT_t$ | Year | 0 | $UF_t$ | Dimensionless | 1.2 |
| $IUP_t$ | Person | $3.52 \times 10^8$ | $RF_t$ | Dimensionless | 3.6 |
| $IRP_t$ | Person | $8.59 \times 10^8$ | $UNWB(t,i)$ | Person/Year | Time series |
| $UI_t$ | 1/Year | 1.44% | $RNWB(t,i)$ | Person/Year | Time series |
| $HUI_t$ | 1/Year | 1.44% | $UAWB(t,i)$ | Year | 28, 31 |
| $IU_t$ | Dimensionless | 0.29 | $RAWB(t,i)$ | Year | 22, 25, 28, 31 |
| $UIM_t$ | Person/Year | 0 | $UMR_t$ | 1/Year | 0 |
| $RIM_t$ | Person/year | 0 | $RMR_t$ | 1/Year | 0 |

According to Chinese family-planning policy, an urban woman can legitimately have her first child at the age of 22. However, under the promotion of late marriage and lower fertility from government propaganda, normally an urban woman chooses to have her first baby at the age of 28. In the simulation model, it is thus assumed that urban women will have a first child at the age of 28 and 20% of these women choose to have their second child at the age of 31. A rural woman is assumed to have her first child at 22 years, a second child at 25, a third one at 28 and 60% of these women will have their fourth child at the age of 31. These values governing the fertility parameter seem to contradict the proclamation from the Chinese authorities about their national average fertility being less than 1.6. However, the correctness of these values used in the model were confirmed through various experiments performed, and in particular the reproduction of the historical evolution of the Chinese population (as described in the next section). Many researchers (e.g. Zeng (1996)) have expressed their doubts about the authenticity and reliability of the Chinese statistical data.

## 4.6 Model validation

Before the model can be used for simulation purposes to analyse possible scenarios, it must demonstrate sufficient confidence (Forrester & Senge 1980). The process of building confidence is called validation (Maani & Cavana 2005). The SD model of Chinese population is validated using several methods. First, the parameters of the model are tuned so that the output of the model matches historical population data. Second, the output of the model is compared with the forecasts of well-known organisations such as the United Nations. Third, a number of simulations are performed with the model to identify the sensitive parameters of the model.

### 4.6.1 Historical behaviour reproduction

Historical population data was obtained on the Chinese population from 1995 to 2003 from the National Bureau of Statistics of China and the United Nations database. The parameters of the model are tuned until the output of the model matches the historical data to some acceptable degree. Normally, this is performed by trial-and-error; however, the SD simulation software Anylogic[6] provides some facilities to visually perform this. A plot of the output of the tuned model and the historical data for the total Chinese population from 1995 to 2003 is shown in Figure 4.13. From the figure, it can be seen that the simulated data reasonably approximates the historical data.

The values of the parameters of the tuned model that reproduce the general pattern of historical behaviour observed so far are shown in Table 4.6. In comparison with the base case model, listed in Table 4.5, the difference occurs in the fertility and birth age in the countryside and cities. Historical data covers the period from 1995 to 2003. During this period, family planning is more flexible than after 2003. Couples in cities can have early births for their children (at age of 25) and can have more than one child (actually 2.2 children in average); Couple in countryside can have early childbirths and can have about three children in average. When time entered the twenty-first century, the situation changed and one child policy has to be strictly coerced in China. Since urban residents are more dependent on government than its rural counterparts, urban couples have to choose late childbirths (normally at the age of 28) and have one child (1.2 in average) and rural couples can still have early childbirths and more children.

### 4.6.2 Comparison with UN forecast

To further enhance the confidence and demonstrate the soundness and usefulness of the model, the output of the model is compared with the forecasted data on Chinese population available

[6] Available from http://www.xjtek.com

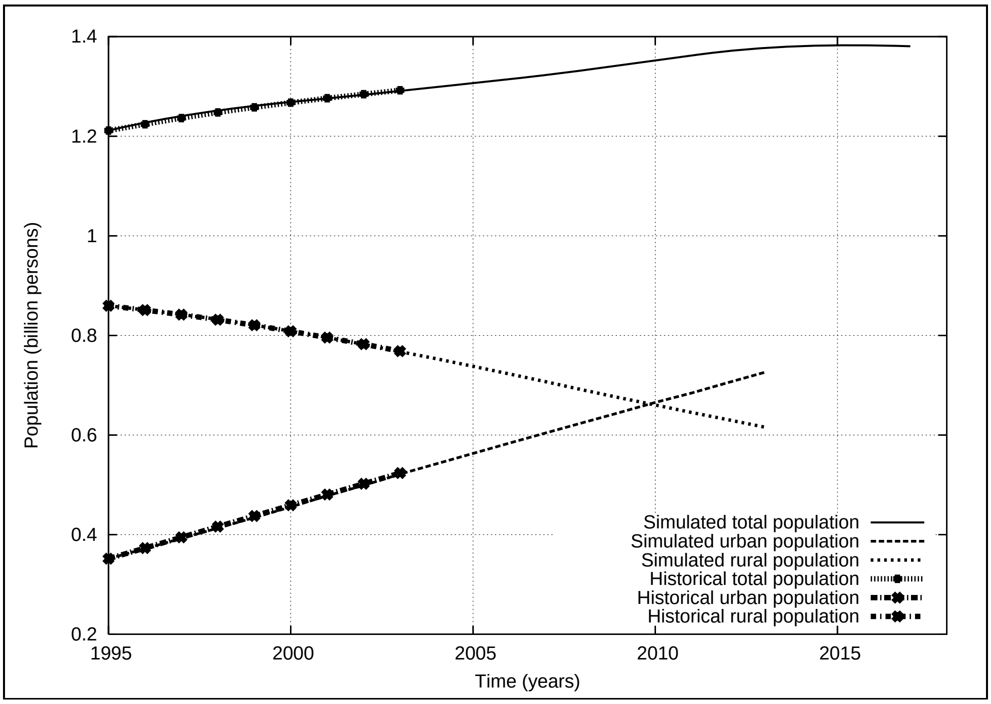


Figure 4.13: Historical behaviour reproduction (base case)

Table 4.6: Parameter values used to reproduce historical behaviour

| Variable name | Unit | Value range | Variable name | Unit | Value range |
|---|---|---|---|---|---|
| $T_0$ | Year | 1995 | $UE_t$ | Person/Year | 0 |
| $T_f$ | Year | 2045 | $RE_t$ | Person/Year | 0 |
| $\Delta T$ | Year | 1 | $ULE_t$ | Year | 71 |
| $FPCT_t$ | Year | 0 | $RLE_t$ | Year | 68 |
| $UCT_t$ | Year | 0 | $UF_t$ | Dimensionless | 2.2 |
| $IUP_t$ | Person | $3.52 \times 10^8$ | $RF_t$ | Dimensionless | 2.6 |
| $IRP_t$ | Person | $8.59 \times 10^8$ | $UNWB(t,i)$ | Person/Year | Time series |
| $UI_t$ | 1/Year | 1.44% | $RNWB(t,i)$ | Person/Year | Time series |
| $HUI_t$ | 1/Year | 1.44% | $UAWB(t,i)$ | Year | 25, 28, 31 |
| $IU_t$ | Dimensionless | 0.29 | $RAWB(t,i)$ | Year | 22, 25, 28, 31 |
| $UIM_t$ | Person/Year | 0 | $UMR_t$ | 1/Year | 0 |
| $RIM_t$ | Person/year | 0 | $RMR_t$ | 1/Year | 0 |

from the United Nations. Table 4.7 shows the data obtained from the UN database on the evolution of the Chinese population from 1995 to 2050. The numbers shown are the five-year forecasts in that time line.

Table 4.7: UN population forecast

| Year | Total population (x1000) | Urban population (x1000) | Rural population (x1000) | Year | Total population (x1000) | Urban population (x1000) | Rural population (x1000) |
|---|---|---|---|---|---|---|---|
| 1995 | 1,219,331 | 382,309 | 837,022 | 2025 | 1,441,426 | 824,914 | 616,512 |
| 2000 | 1,273,979 | 455,804 | 818,175 | 2030 | 1,446,453 | 875,162 | 571,291 |
| 2005 | 1,315,844 | 533,377 | 782,466 | 2035 | 1,442,974 | - | - |
| 2010 | 1,354,533 | 611,558 | 742,975 | 2040 | 1,433,431 | - | - |
| 2015 | 1,392,980 | 689,734 | 703,246 | 2045 | 1,416,926 | - | - |
| 2020 | 1,423,939 | 762,633 | 661,306 | 2050 | 1,392,307 | - | - |

The UN data was interpolated to obtain data at a yearly frequency and compared with the output of the SD population model (tuned to reproduce historical behaviour) as shown in Figures 4.14 and 4.15. It is evident that the output of the base case version of the model is very different to the population levels forecast by the UN. With the UN forecast, the total population will reach a maximum of 1.45 billions in the year 2030 and the predicted time when the urban population will equal the rural population is the year 2016. With the SD model tuned to reproduce historical data, the total population reaches a maximum of 1.36 billion in the year 2018, and the time when the urban population equals the rural population was found to be the year 2018. The main differences between the SD model and UN forecasts are listed in Table 4.8.

Table 4.8: Comparison of forecasts of SD model and UN forecast

| Comparison | Max total population (billion) | Time to reach the maximum (year) | Time when urban pop equals rural pop (year) |
|---|---|---|---|
| SD model forecast | 1.36 | 2018 | 2018 |
| UN forecast | 1.45 | 2030 | 2016 |

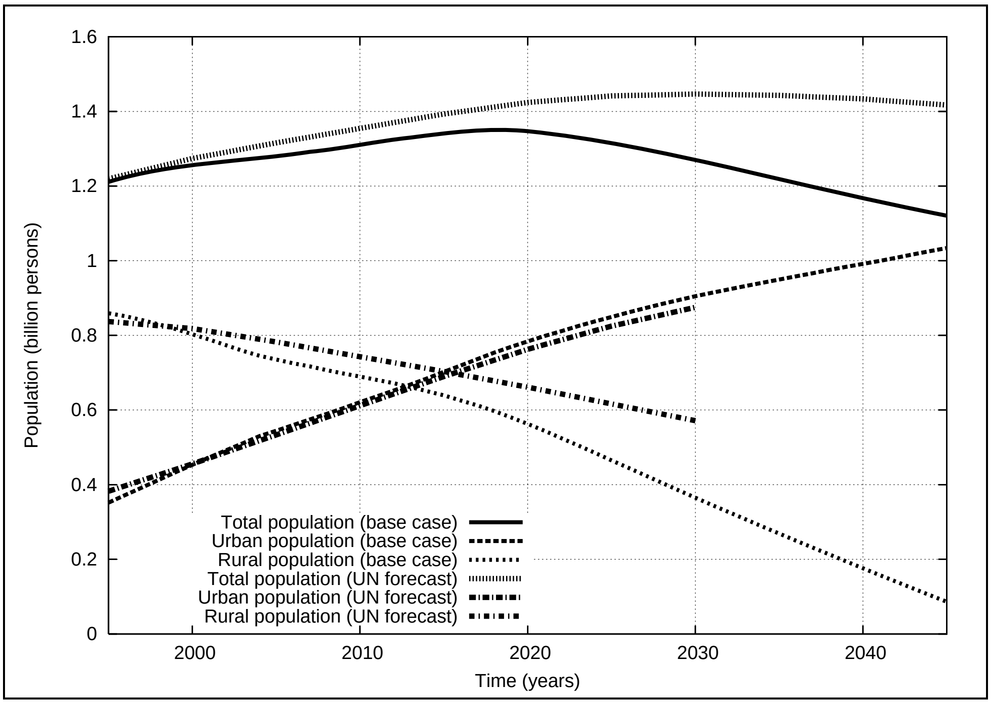


Figure 4.14: UN population forecast

It does not mean that the model is wrong because its base case scenario cannot approximate the UN data as the latter is just a forecast. Rather, the UN forecast can be considered as another possible scenario for the SD model. In order to prove the usefulness of the SD model, the model was retuned so that its output matched the UN forecast. Figure 4.15 shows a plot of the output of the tuned model to approximate the UN forecast of the total Chinese population from 1995 to 2030.

Table 4.9 lists the values of the parameters used to generate population data that approximates the UN forecast data. The UN forecast can be explained as one of the typical scenarios, since the SD population model can reproduce the UN forecast with the following parameter settings: historical urbanisation increase = 0.90%, annual urbanisation increase = 0.88%, urban fertility = 2.3 and rural fertility = 3.4.

### 4.6.3 Sensitivity analysis

As previously explained, some parameters of the SFD model are difficult to obtain or cannot be measured accurately. Since the modeller must estimate these parameter values, it is important to

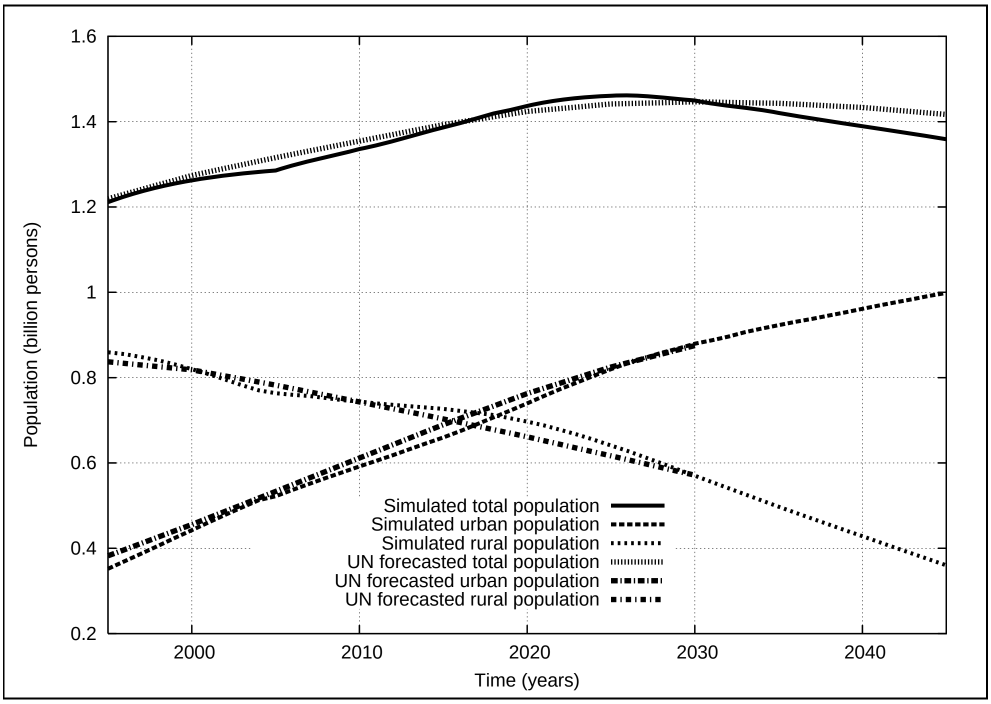


Figure 4.15: Comparison between forecasts of SD model and UN

Table 4.9: Parameter values used to simulate UN forecast

| Variable name | Unit | Value range | Variable name | Unit | Value range |
|---|---|---|---|---|---|
| $T_0$ | Year | 1995 | $UE_t$ | Person/Year | 0 |
| $T_f$ | Year | 2045 | $RE_t$ | Person/Year | 0 |
| $\Delta T$ | Year | 1 | $ULE_t$ | Year | 71 |
| $FPCT_t$ | Year | 0 | $RLE_t$ | Year | 68 |
| $UCT_t$ | Year | 0 | $UF_t$ | Dimensionless | 2.3 |
| $IUP_t$ | Person | $3.52 \times 10^8$ | $RF_t$ | Dimensionless | 3.4 |
| $IRP_t$ | Person | $8.59 \times 10^8$ | $UNWB(t,i)$ | Person/Year | Time series |
| $UI_t$ | 1/Year | 0.88% | $RNWB(t,i)$ | Person/Year | Time series |
| $HUI_t$ | 1/Year | 0.9% | $UAWB(t,i)$ | Person/Year | 31, 34, 37 |
| $IU_t$ | Dimensionless | 0.29 | $RAWB(t,i)$ | Person/Year | 25, 28, 31, 34 |
| $UI_t$ | Person/Year | 0 | $UMR_t$ | Person/Year | 0 |
| $RI_t$ | Person/year | 0 | $RMR_t$ | Person/Year | 0 |

determine the level of accuracy necessary for the parameter to make the model sufficiently useful and valid. Sensitivity analysis, in particular parameter sensitivity, is used to determine how sensitive the model is to small changes in the values of the parameters of the model. Sensitivity analysis also helps the modeller understand the dynamics of the system by experimenting with a range of values and discovering leverage points in the model i.e. parameters whose specific values can significantly influence the output of the model.

Four indicators are used to assess the effect of small changes in parameter values on the SD model. The indicators are: the maximum total population value ($P_{max}$), the time to reach the maximum total population ($T_{max}$), time when the urban and rural population have equal values ($T_{P_u=P_r}$) and the value of the total population when the simulation reaches the final time ($P_{final}$). In Figure 4.16, these four indicators are explained with the help of a hypothetical plot of the total, urban and rural populations. Table 4.10 lists the values obtained for the indicators in the base run of the SD model.

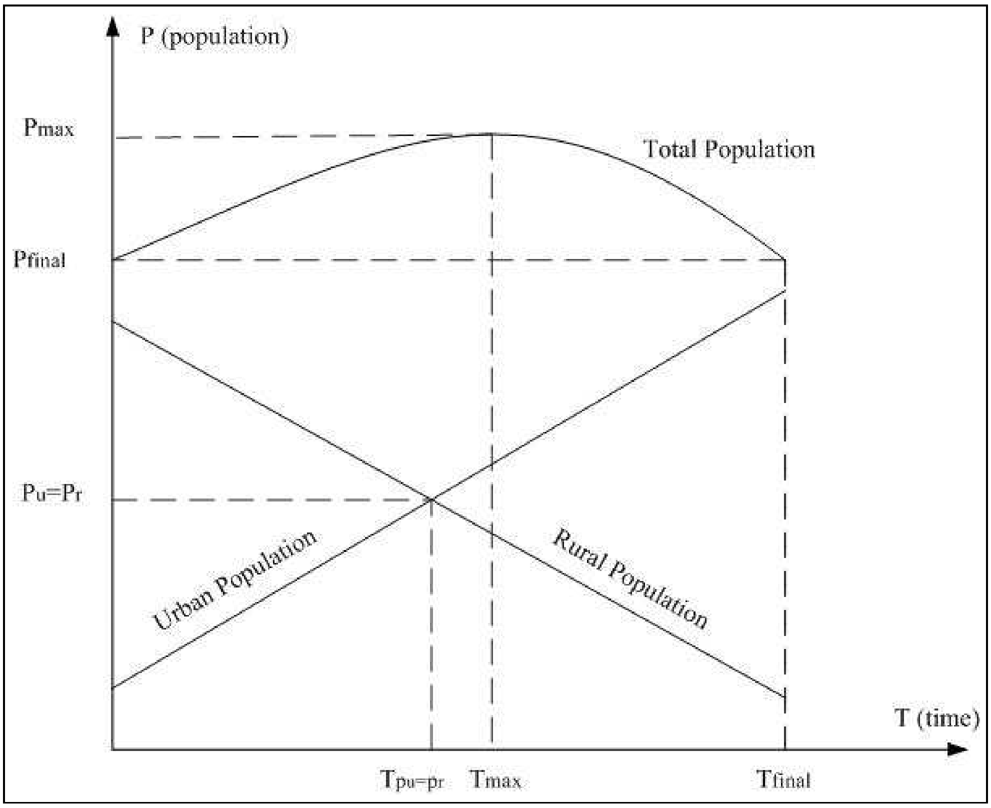


Figure 4.16: Explanation of indicators used in sensitivity analysis

Table 4.10: Values of the indicators in base state

| Indicator | $P_{max}$ (billion) | $T_{max}$ (year) | $T_{P_u=P_r}$ (year) | $P_{final}$ (billion) |
|---|---|---|---|---|
| Base state | 1.35 | 23 | 18 | 1.12 |

Sensitivity analysis is performed by varying the values of some model parameters by an amount of plus or minus 20%, that is, multiplying each parameter by a factor of 1.2 and 0.8 to give an increase and a decrease of 20% respectively. For example, the value of the urbanisation increase rate used in the base case is 1.44%. Thus, the model is simulated with urbanisation increase rate values of 1.73% and 1.15%. Table 4.11 lists the parameters whose values are varied and the values used for these parameters in the sensitivity analysis experiments.

Table 4.11: Sensitivity experiments for testing parameters

| Parameters | Base state value | 20% increase | 20% decrease |
|---|---|---|---|
| $UI_t$ | 1.44% | 1.73% | 1.15% |
| $IU_t$ | 0.29 | 0.35 | 0.23 |
| $ULE_t$ | 71 | 85 | 57 |
| $RLE_t$ | 68 | 82 | 54 |
| $UF_t$ | 1.20 | 1.44 | 0.96 |
| $RF_t$ | 3.60 | 4.32 | 2.88 |
| $IUP_t$ | $3.52 \times 10^8$ | $4.22 \times 10^8$ | $2.82 \times 10^8$ |
| $IRP_t$ | $8.59 \times 10^8$ | $1.03 \times 10^9$ | $6.87 \times 10^8$ |
| $UAWB(t,i)$ | 28, 31 | 34, 37 | 22, 25 |
| $RAWB(t,i)$ | 22, 25, 28, 31 | 26, 30, 34, 37 | 18, 20, 22, 25 |

The results for all sensitivity tests are summarised in Table 4.12, while Table 4.13 lists all the factors of the model identified as sensitive and their sensitivity to the performance indicators. An asterisk (*) in a cell of Table 4.13 indicates that the factor specified in that row of the table is sensitive to the indicator specified in the column. The sensitive factors are grouped and classified into categories: urbanisation, family planning and quality of life.

Since most of parameter values used in the SD model are reasonable estimates derived from historical data, the main aim of performing sensitivity analysis on the SD model is to identify

Table 4.12: Results of sensitivity tests (20% increase in parameter input values)

| | $P_{max}$ | | $T_{max}$ | | $T_{P_u=P_r}$ | | $P_{final}$ | |
|---|---|---|---|---|---|---|---|---|
| | (billion) | (%ch.) | (year) | (%ch.) | (year) | (%ch.) | (billion) | (%ch.) |
| Base state | 1.35 | | 23 | | 18 | | 12 | |
| $IRP_t$ | 1.47 | 8.9 | 23 | 0 | 18 | 0 | 1.12 | 0 |
| $IU_t$ | 1.33 | -1.5 | 23 | 0 | 16 | -11.1 | 1.09 | -2.7 |
| $IUP_t$ | 1.40 | 3.7 | 23 | 0 | 14.5 | -19.44 | 1.16 | 3.6 |
| $UI_t$ | 1.44 | -3.1 | 26 | -3.7 | 13.5 | -71 | 1.24 | 10.7 |
| $RAWB(t,i)$ | 1.35 | 0 | 25 | 8.7 | 17.5 | -2.8 | 1.15 | 2.7 |
| $RF_t$ | 1.40 | 3.7 | 24 | 4.3 | 18.5 | 2.8 | 1.18 | 5.4 |
| $RLE_t$ | 1.39 | 3.0 | 23 | 0 | 18.5 | 2.8 | 1.17 | 4.5 |
| $UAWB(t,i)$ | 1.35 | 0 | 23 | 0 | 17.5 | -2.8 | 1.15 | 2.7 |
| $UF_t$ | 1.38 | 2.2 | 24 | 4.3 | 17.5 | -2.8 | 1.18 | 5.4 |
| $ULE_t$ | 1.38 | 2.2 | 23 | 0 | 16.5 | -8.3 | 1.19 | 6.3 |

leverage points for exerting pressure to control the population growth in China. Factors belonging to the urbanisation and quality of life categories are identified as useful for designing future scenarios while those belonging to the family planning category are identified as leverage points for adjusting the level of the population. Therefore, one important possible use of the SD model is for assessing the effectiveness of a range of family-planning policies for controlling the influences of urbanisation and quality of life on the population level.

## 4.7 Scenario design and simulation

After having validated the model, it is now ready for simulation purposes. Although the SD population model can be used for forecasting purposes, it is more useful for experimenting with the evolution of the Chinese population under different what-if conditions or scenarios.

Scenarios are combinations of different values of parameters identified as leverage points in the SD model. Since it is not possible to simulate every possible combination of values with these parameters, only a few scenarios that are plausible or feasible are formulated for simulation purposes. In this section, typical scenarios are designed based on the sensitivity analysis of the

Table 4.13: Categories of factors to which the model is sensitive

| | $P_{max}$ (billion) | $T_{max}$ (year) | $T_{P_u=P_r}$ (year) | $P_{final}$ (billion) | Categories |
|---|---|---|---|---|---|
| $IRP_t$ | | | | * | Urbanisation |
| $IU_t$ | * | | * | * | Urbanisation |
| $IUP_t$ | * | | * | * | Urbanisation |
| $NUI_t$ | * | * | * | * | Urbanisation |
| $RAWB(t,i)$ | | * | * | * | Family planning |
| $RF_t$ | * | * | * | * | Family planning |
| $UAWB(t,i)$ | | | * | * | Family planning |
| $UF_t$ | * | * | * | * | Family planning |
| $ULE_t$ | * | | * | * | Life quality |
| $RLE_t$ | * | | * | * | Life quality |

factors that belong to the categories of urbanisation, quality of life and family planning.

### 4.7.1 Base scenario

The base state scenario is based on recent conditions identified in China from 1995 to 2003 and possibly extended to the year 2045. Table 4.5 lists the values of the parameters used in this simulation. Figure 4.17 shows the predicted evolution of the population and the structural changes occurring during the simulation of the base scenario. Basically, the trajectory of the total population evolves like a flattened parabola during the period 1995 to 2045.

The population shows growing momentum at first, reaches a maximum of 1.35 billion in the year 2018 (23 years after the start of the simulation) and then starts to decrease to reach a value of 1.11 billion in the year 2045. The urban population grows nearly linearly to reach 1.03 billion in the year 2045 while the rural population decreases nearly linearly to reach 88 million in that year. By the year 2013 (18 years after the start of the simulation), both the urban and the rural populations will be at a level of 664 million inhabitants. After 2013, the urban population is predicted to surpass the rural population and become dominant.

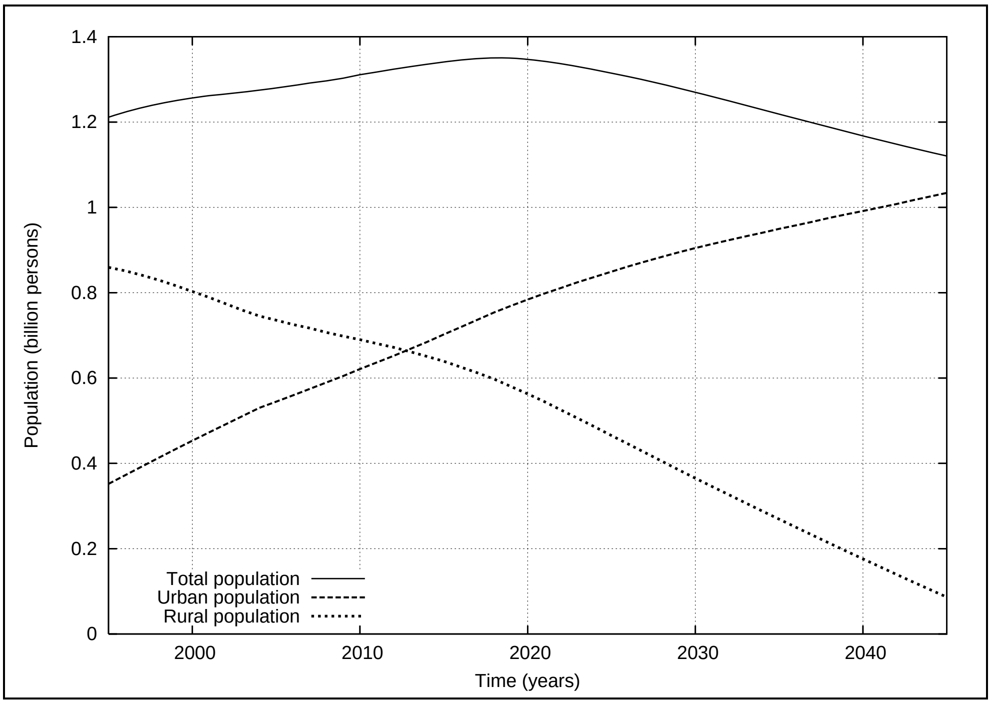


Figure 4.17: Evolution of population under base case scenario

### 4.7.2 Scenarios derived from urbanisation

Urbanisation scenarios are created using a combination of several factors which are likely to change and have an impact on the population level. In the sensitivity analysis experiments, four sensitive factors are identified in the urbanisation category. They are: $IRP_t$, $IU_t$, $IUP_t$ and $UI_t$. However, out of these four parameters, three of them ($IRP_t$, $IU_t$, $IUP_t$) are initial parameters. Since initial parameters are considered as constants, these variables cannot be manipulated to form scenarios. $UI_t$ is the only parameter that can be manipulated and hence be used in scenario design or strategy development. Urbanisation scenarios are based on how and when $UI_t$ will change. For this purpose, the urbanisation part of the model is restructured and three new variables are introduced to replace $UI_t$. The three new variables are urbanisation change time ($UCT_t$), urbanisation development mode ($UDM_t$) and expected urbanisation fraction ($EUF_t$).

Different values of $UCT_t$, $UDM_t$ and $EUF_t$ were simulated, and the indicators used for assessing sensitivity indicated that the model is sensitive to these factors and hence can be used in scenario design. Supposing that the values of each factor could be specified in three levels, theoretically these factors could be combined to form 27 ($3^3$) possible scenarios. However, since only a few scenarios can be simulated, a few scenarios that are typical, realistic and significant are formulated for simulation purposes. The framework of scenario planning developed in Chapter 3 is used to design typical scenarios and conduct scenario analysis. Four typical scenarios of urbanisation development are designed using urbanisation fractions (urbanisation levels expressed as a percentage of the total population level) illustrated in Figure 4.18 and the parameter values listed in Table 4.14.

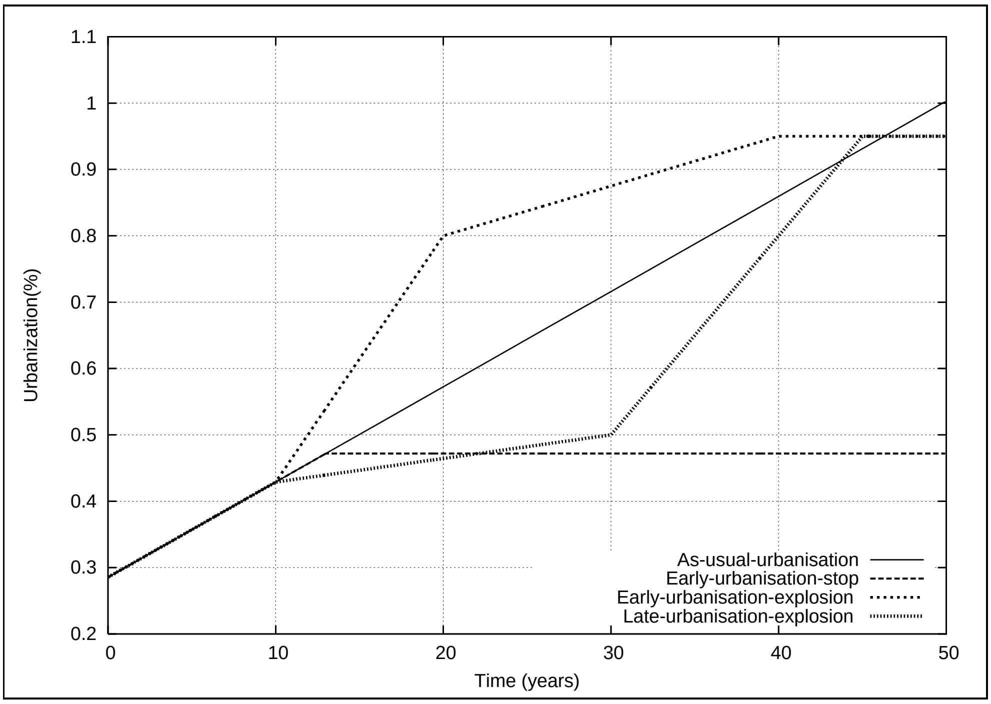


Figure 4.18: Urbanisation development used for scenario design

Table 4.14: Parameter values used for urbanisation scenarios

| Scenarios | $EU_t$% | $UDM_t$ | $UCT_t$ (year) |
|---|---|---|---|
| As-usual-urbanisation (base case) | 100 | Ramp | $> 2045$ |
| Early-urbanisation-stop | 47 | Step | 2008 |
| Early-urbanisation-explosion | 40<br>80<br>95 | Three steps | 2005<br>2015<br>2035 |
| Late-urbanisation-explosion | 40<br>50<br>95 | Three steps | 2005<br>2015<br>2035 |

#### 4.7.2.1 As-usual-urbanisation development scenario

This scenario is actually the same as the base case scenario, in which the urbanisation fraction steadily increases in a linear fashion as shown in Figure 4.18. The urbanisation fraction increases in a ramp-like mode with an annual net urbanisation increase of 1.44%. By the year 2045, the country will be totally urbanised. A summary of the values used by the factors specified in this scenario is provided in Table 4.14. A detailed description of the factors used in this scenario was provided in the previous section that described the base case scenario.

#### 4.7.2.2 Early-urbanisation-stop scenario

In this scenario, it is assumed that migration to urban areas stops when the urbanisation fraction reaches a certain level in the near future. It is assumed that the rate of urbanisation increases linearly and then the growth momentum stops so that the urbanisation fraction levels off at 47% in 2008. This scenario could be triggered by phenomena such as: deterioration of urban living; environmental problems; improvement of rural living; strict family planning in cities; high unemployment in cities; migration from urban to rural areas, etc. Figure 4.18 illustrates such a development mode. Initially, the level of the urbanisation fraction grows, then levels off with an annual urbanisation increase of zero.

The evolution of the level of the Chinese population under the early-urbanisation-stop and base case scenarios is shown in Figure 4.19 for comparison purposes. Under both the base case and early-urbanisation-stop scenarios, the urban population grows along similar levels until 2009 (14 years after 1995). After that point, the urban population evolves along a downward trend in the early-urbanisation-stop scenario while in the base case scenario the trend is upwards. In contrast, the development of the rural population follows a different pattern. It declines at the same rate under both scenarios until 2009. After that point, under the early-urbanisation-stop scenario, the rural population begins to increase in 2009, keeps a growing trend until 2023 (28 years after 1995) and then starts to decrease. Under the base case scenario, the rural population follows a downward trend from the very beginning and continues like this until the end of the simulation period. Under this scenario, the urban population decreases while the rural population increases. The increase from the rural population cannot match the decrease from the urban population and this results in a greater increase of the total population than in the base case scenario.

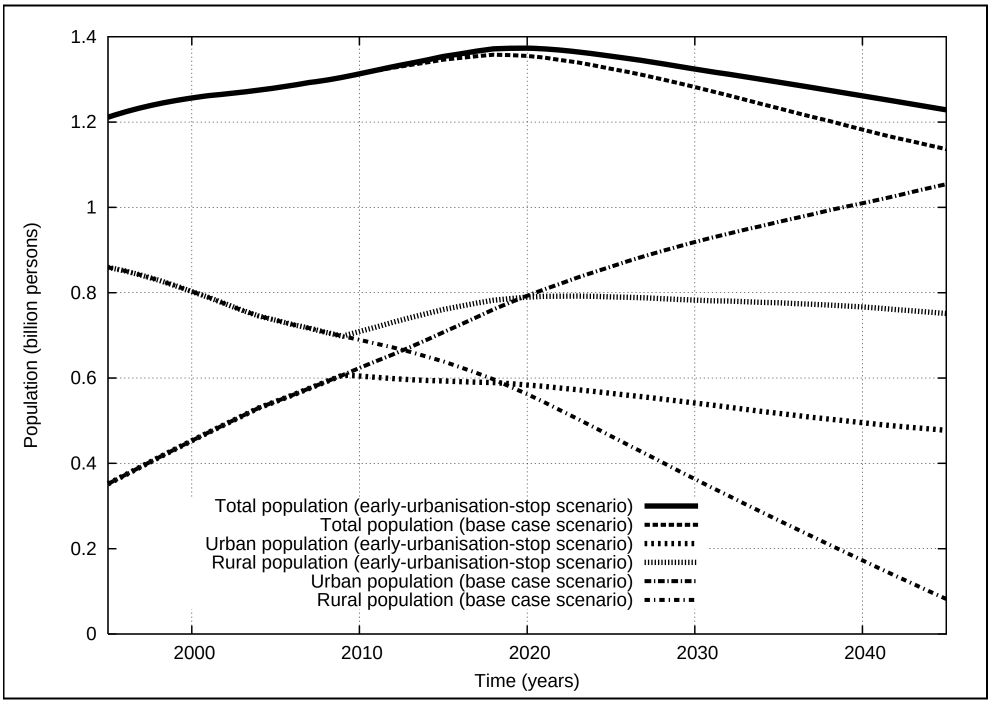


Figure 4.19: Evolution of population under early-urbanisation-stop scenario

#### 4.7.2.3 Early-urbanisation-explosion scenario

In this scenario, it is assumed that initially urbanisation increases at a normal increase rate, accelerates for some time and then slows down to reach a new plateau. Thus, it is assumed that, in 2015 and 2035, the urbanisation fraction will reach levels of 80 and 95% respectively. This scenario is a case of an early explosion in urbanisation levels in the not-too-distant future. The urbanisation development takes the shape of a fast four-step evolution mode as in Figure 4.18.

Figure 4.20 shows the different evolutions of the Chinese population under both the early-urbanisation-explosion and the base case scenarios. Under the early-urbanisation-explosion scenario, the urban population overtakes the growth rate of the urban population in the base case scenario in 2007 and the growth rate takes a parabolic shape. In the early-urbanisation-explosion scenario, the rural population shows a more pronounced decrease than in the base case scenario as after 2007, the decrease rate takes an inverse parabolic shape. In this scenario, the urban population explodes while the rural population declines with the net effect of a slightly lower total population level than in the base case.

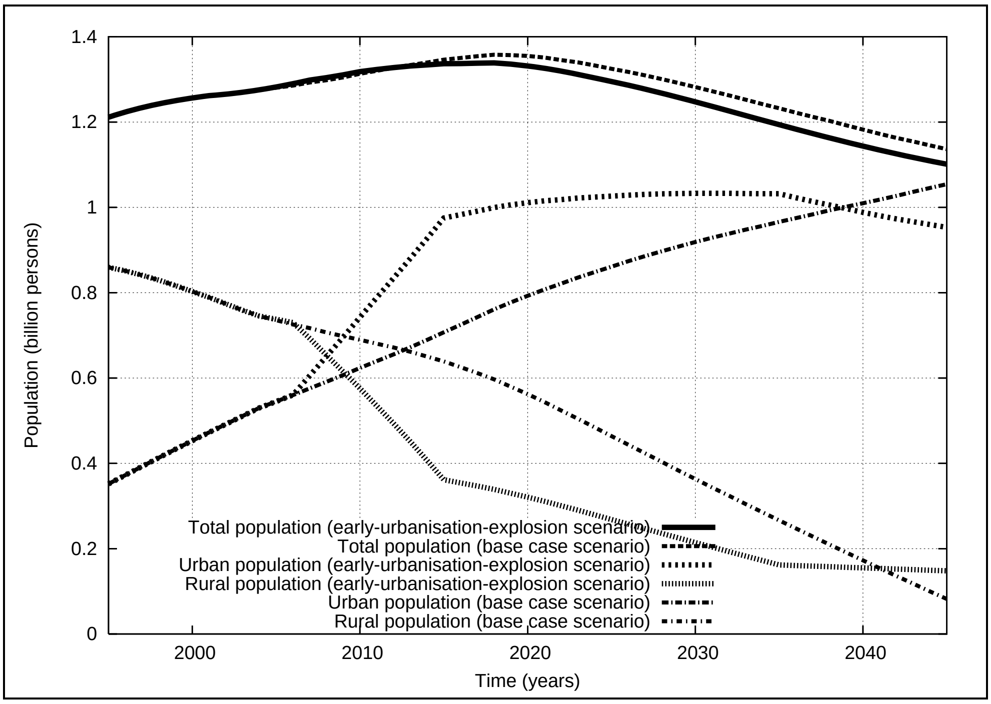


Figure 4.20: Evolution of population under early-urbanisation-explosion scenario

#### 4.7.2.4 Late-urbanisation-explosion scenario

This scenario is the opposite of the early-urbanisation-explosion scenario as an explosion of the urban population level occurs very late in the future. It is assumed that, initially, urbanisation develops at the usual rate, then it slows for a long period of time, and finally accelerates quickly until it reaches a certain level. Thus, it is assumed that in 2025 the urbanisation fraction will climb to a level of 50% while in 2040 it will reach 95%. The development of urbanisation takes a four-step delayed explosive evolution mode as shown in Figure 4.18.

Figure 4.21 shows the variations in the behaviours of the population components under the late-urbanisation-explosion and base case scenarios. In the late-urbanisation-explosion scenario, the urban population curve increases along a zigzag shape while the rural population decreases along a similar shape. Most of the time, the urban population is less than its level in the base case scenario, while the rural population is higher than its level in the base case scenario. The opposite interaction between the urban and rural populations results in the total population evolving at higher levels than in the base case scenario.

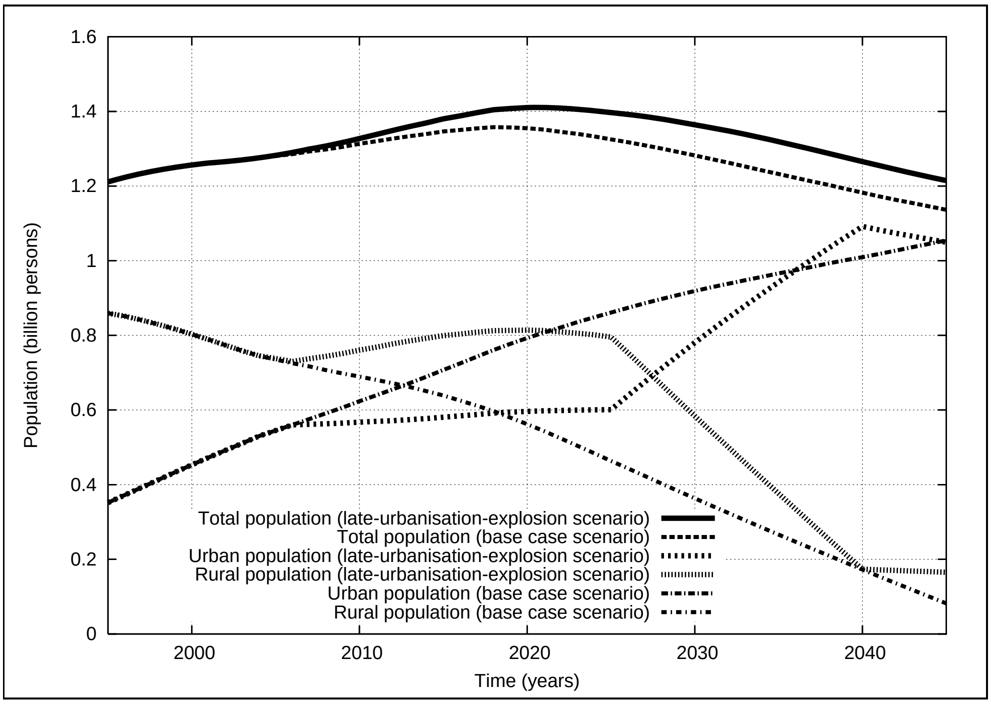


Figure 4.21: Evolution of population under late-urbanisation-explosion scenario

### 4.7.3 Scenarios derived from family planning

In the sensitivity analysis, four factors to which the model is sensitive are identified in the family planning category. These are: $UF_t$, $RF_t$, $UAWB(t,i)$ and $RAWB(t,i)$. $UF_t$ and $RF_t$ refer to the number of children a fertile woman can have while $UAWB(t,i)$ and $RAWB(t,i)$ stipulate the age at which a woman can have children. The family planning scenarios were based on when and how these factors might change in the future. For the purpose of scenario design, the population increase component of the model is restructured and a new variable named family planning change time ($FPCT_t$) introduced. Simulation performed on the model finds it to be sensitive to this new factor.

Within the family planning category, there are now five factors ($UF_t$, $RF_t$, $UAWB(t,i)$, $RAWB(t,i)$ and $FPCT_t$) that can be combined at different levels to formulate possible scenarios on how the population might evolve in the future and strategies to control the evolution of the population. If the values of each factor are specified as three levels, theoretically these factors can be combined to form 243 ($3^5$) possible scenarios. However, since only a few scenarios can be simulated, five typical scenarios are designed from the family planning category of factors. The parameter values used for the five scenarios are listed in Table 4.15. Under an early tightening scenario, the Chinese Government will tighten its current family-planning policy in the near future. This results in a decline of the values of urban fertility and rural fertility. For example, in 2003 the $UF_t$ and $RF_t$ are respectively at 1.1 and 3.6. However, if the policy changed in 2005, $UF_t$ and $RF_t$ would decrease from 1.1 and 3.6 to 1.0 and 2.0 respectively in 2005. Early liberation is the opposite to the early tightening scenario, under which $UF_t$ and $RF_t$ increase from 1.1 and 3.6 in 1995 to 3.0 and 5.0 respectively in the near future (for example in 2005).

Under an early birth scenario, regardless of the reasons, the age at which a woman can have her children is earlier than before. For example, rural women originally had their first and second children at the age of 28 and 31 respectively. But this situation can change after some time. After that year, rural women can have their first and second children at the age of 25 and 28, three years earlier than before. Late birth is the opposite scenario of early birth. Under the late birth scenario, reasons such as people changing their mind or government incentives will make women delay the time that they have children.

The purpose of the scenarios designed in this section is not for simulating them on their own. Instead, they are meant to be combined with scenarios derived from other components of the model (as described in the next sections) to form more complex scenarios for simulation.

### 4.7.4 Scenarios derived from life quality

$ULE_t$ and $RLE_t$ are the parameters that can be manipulated for designing scenarios on life quality. In this section, scenarios are designed based on the expected life expectancy and the time taken to reach the expected level. For this purpose, four new factors are introduced: expected urban (or rural) life expectancy ($EULE_t$, $ERLE_t$) and the time taken to reach the expected urban (or rural) life expectancy ($EULET_t$, $ERLET_t$). After restructuring the model, the sensitivity of the model to these four new variables (as measured by the indicators) is listed in Table 4.16. Simulation finds the model to be sensitive to the four variables such that all of them can be used to design scenarios. Table 4.17 lists the values or range of values used for the model parameters in order to form practical scenarios regarding the future evolution of the population.

Table 4.15: Parameter values of scenarios designed from family planning

| Scenarios | $FPCT_t$ | $UF_t$ | $RF_t$ | $UAWB(t,i)$ | $RAWB(t,i)$ |
|---|---|---|---|---|---|
| As-usual (base case) | $\infty$ | 1.2 | 3.6 | 28, 31 | 22, 25, 28, 31 |
| Early-tightening-late-birth | 1995 - 2003 | 2.2 | 2.6 | 25, 28, 31 | 22, 25, 28 |
| | 2003 - 2005 | 1.1 | 3.6 | 28, 31 | 22, 25, 28, 31 |
| | 2005 -2045 | 1.0 | 2.0 | 31 | 28, 31 |
| Late-tightening-early-birth | 1995- 2003 | 2.2 | 2.6 | 25, 28, 31 | 22, 25, 28 |
| | 2003- 2015 | 1.1 | 3.6 | 28, 31 | 22, 25, 28, 31 |
| | 2015- 2045 | 1.0 | 2.0 | 25 | 22, 25 |
| Early-liberation-early-birth | 1995-2003 | 2.2 | 2.6 | 25, 28, 31 | 22, 25, 28 |
| | 2003-2005 | 1.1 | 3.6 | 28, 31 | 22, 25, 28, 31 |
| | 2005-2045 | 3.0 | 5.0 | 22, 25, 28 | 20, 22, 25, 28, 31 |
| Late-liberation-late-birth | 1995-2003 | 2.2 | 2.6 | 25, 28, 31 | 22, 25, 28 |
| | 2003-2015 | 1.1 | 3.6 | 28, 31 | 22, 25, 28, 31 |
| | 2015-2045 | 3.0 | 5.0 | 28, 31, 34 | 25, 28, 31, 34, 37 |

Under the as-usual scenario, the urban (or rural) life expectancy is unchanged at a value of 71 (or 68). Under the fast-urban-rural-improvement scenario, the quality of life and the health system is envisaged to greatly improve in the near future, and thus the average life expectancy reaches 80 years for both urban and rural residents. The slow-urban-rural-improvement is the same as the fast-urban-rural-improvement scenario. The difference is that the process time for the life expectancy to be improved under the slow-urban-rural-improvement scenario is much longer than under the fast-urban-rural-improvement scenario. The fast-urban-rural-deterioration scenario is the opposite to the fast-urban-rural-improvement scenario. Under the fast-urban-rural-deterioration scenario, the quality of life quickly deteriorates because of potential causes such as: inadequate health and social welfare system, environmental problems, natural disaster, war, infectious disease etc. In such a situation, the average life expectancy will decline to about 60 years for rural residents. The fast-rural-deterioration scenario is a typical case of the fast-urban-rural-deterioration scenario occurring in the countryside.

Table 4.16: Life quality parameters to which the model is sensitive

| Factor | $P_{max}$ (billion) | $T_{max}$ (year) | $T_{P_u=P_r}$ (year) | $P_{final}$ (billion) |
|---|---|---|---|---|
| $EULE_t$ | | | | * |
| $ERLE_t$ | * | | * | * |
| $EULET_t$ | * | | * | * |
| $ERLET_t$ | * | * | * | * |

Table 4.17: Parameter values of scenarios designed from quality of life

| Scenario | $EULE_t$ | $ERLE_t$ | $EULET_t$ | $ERLET_t$ |
|---|---|---|---|---|
| As-usual (base case) | 71 | 68 | $\geq 50$ | $\geq 50$ |
| Fast-urban-rural-improvement | 80 | 80 | 10 | 10 |
| Slow-urban-rural-improvement | 80 | 80 | 20 | 20 |
| Fast-urban-rural-deterioration | 65 | 65 | 10 | 10 |
| Fast-rural-deterioration | 71 | 60 | 0 | 10 |

### 4.7.5 Complex scenarios on future population development

In theory, the various combinations of the three categories of scenarios previously discussed can give rise to 100 (four urbanisation scenarios times five family planning scenarios times five quality of life scenarios, listed in Tables 4.14, 4.15 and 4.17) possible more complex scenarios. Furthermore, if the factors listed in Tables 4.14, 4.15 and 4.17 are assumed to have two possible values, then $3^{14}$ possible scenarios can be formulated for the future evolution of the population in China. In this study, two typical scenarios, namely population explosion and population decline are formulated for simulation and analysis purposes. Table 4.18 shows the components of the two scenarios formulated.

Table 4.18: Population elements used in scenario formulation

| Scenario | Urbanisation | Family planning | Life quality |
|---|---|---|---|
| As-usual (base case) | As-usual | As-usual | As-usual |
| Explosion | Early-urbanisation-stop | Early-liberation-early-birth | Fast-urban-rural-improvement |
| Decline | Early-urbanisation-explosion | Early-tightening-late-birth | Fast-urban-rural-deterioration |

#### 4.7.5.1 Simulation of population explosion scenario

The story for this futuristic scenario of population explosion in China is described as follows. China continues to urbanise its countryside at the current speed for about a decade and then stops when the urbanisation fraction reaches 50%. The Chinese Family Planning Committee changes its controversial family-planning policy in 2007. Under the new policy, urban couples are allowed to have 3 children on average and rural couples are allowed to have as many children (up to a maximum of 5) as they wish. The traditional concept of ‘more children, happier families’ still has great influence on residents of both urban and rural areas. With the development of the Chinese economy, the living environment improves. Social welfare and medical systems that cover the whole of Chinese society are established and within a decade, the standard of living greatly improves. The average life expectancy increases to 80 years.

This futuristic scenario can be broken into sub-scenarios and simulated using the SD population model by adjusting the values of the variables involved and restructuring the corresponding components in the model. In order to simulate this scenario of population explosion, simulation experiments are performed on a combination of the following sub-scenarios: early-urbanisation-stop scenario from the urbanisation component of the model, early-liberation-early-birth scenario from the family planning component, and the fast-urban-rural-improvement scenario from the life quality component. The parameters used for these sub-scenarios are listed in Tables 4.14, 4.15 and 4.17.

Figure 4.22 shows the evolution of the Chinese population under the base case and population explosion scenarios, while Figure 4.23 shows the evolution of the change in population proportion under the population explosion scenario. Table 4.19 shows the changes in the values of the key indicators of the model under the base case, population explosion and population decline (explained in the next section) scenarios. Under the population explosion scenario, the maximum population value shows a 7.4% increase reaching 1.64 billion people and the time to reach this maximum population is delayed by 17 years. The level of the rural population will always be higher than the urban population. In fifty years, the total population will reach 1.61 billion people, a 43.8% increase leading to an additional half a billion people.

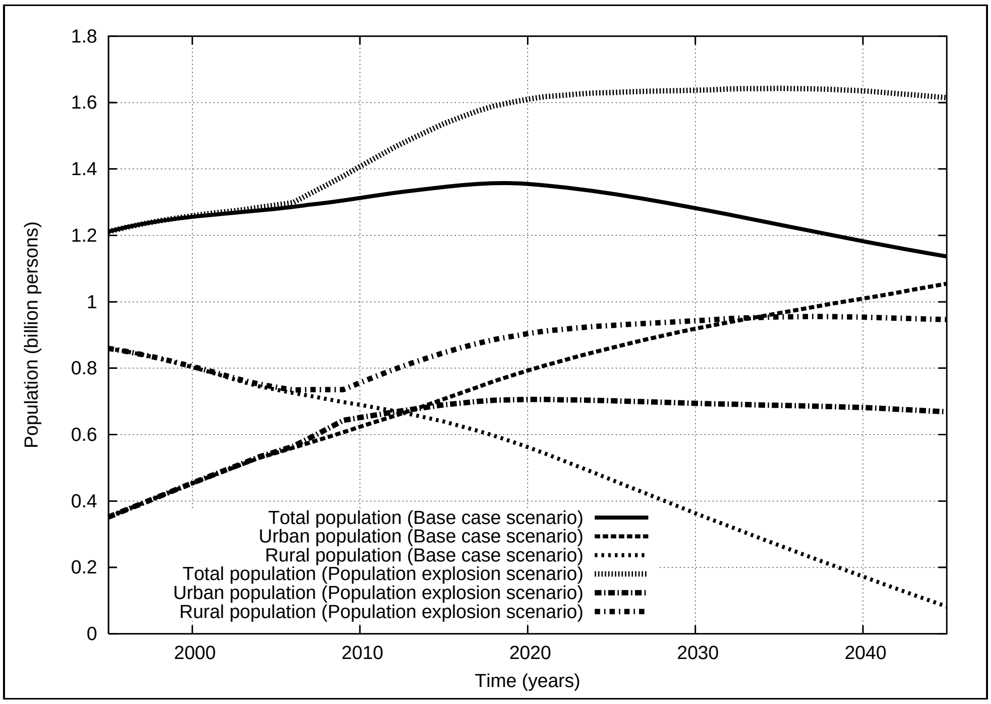


Figure 4.22: Evolution of population under population explosion scenario

Table 4.19: Results of simulation of population scenarios

| Scenario | Maximum population (billion) | Time to maximum (year) | Even point (year) | Final population (billion) |
|---|---|---|---|---|
| As-usual | 1.35 | 23 | 18 | 1.12 |
| Population-explosion<br>(% change from base scenario) | 1.64<br>7.4% | 40<br>74.0% | Never<br>- | 1.61<br>43.8% |
| Population-decline<br>(% change from base scenario)<br>(% change from explosion scenario) | 1.28<br>-5.2%<br>-22.0% | 11<br>-52.2%<br>-72.5% | 12.5<br>-30.6%<br>- | 0.95<br>-15.2%<br>-41.0% |

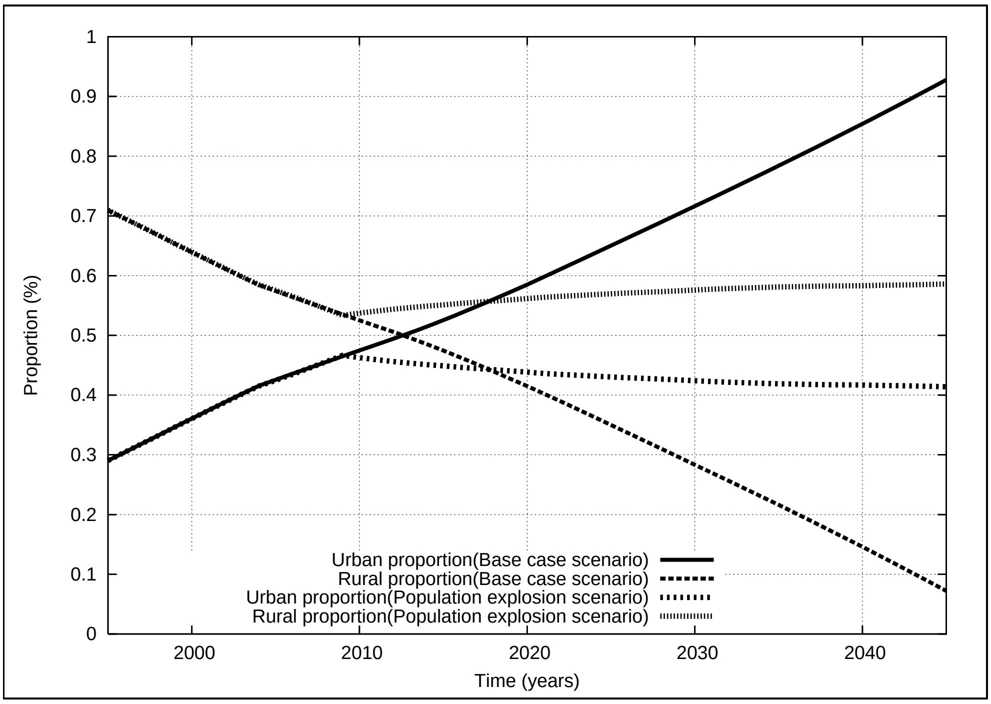


Figure 4.23: Evolution of population proportion change under population explosion scenario

#### 4.7.5.2 Simulation of population decline scenario

The futuristic scenario of population decline is the opposite of the population explosion scenario. It is described as follows. The reform in the countryside will relieve Chinese peasants from their dependence on the land. Privatisation will cause the land in the countryside to be owned by a small number of elite peasants. A large number of peasants will need to rush into the cities to make a living there. Industrialisation will absorb most of the cheap labour from the countryside. At the same time, local governments will purposely create small-to-middle-sized towns to urbanise its rural residents. It is presumed that urbanisation in China will be in full swing in the coming decades as it will experience accelerated increase from the current 40% in 2005 to around 80% in 2015 or so. After that time, urbanisation will further expand until only a small non-urbanisation fraction is left.

The Chinese Family Planning Committee will continue its controversial family-planning policy. Its implementation will be stricter because fewer births and later births are advocated for urban residents; most of the urban residents will be former peasants who are increasingly dependent on the administration of government policies. Industrialisation intensifies competition, increasing the cost of bringing up children and causing changes in the minds of people who believe that their children will look after them when they are old. Most couples will choose to have fewer children, and even no children in some cases. Since so much social change will have occurred in a small amount of time, social life will become unstable. The side effects of this social change such as cultural shock, worries, unemployment, crime, drugs etc. will greatly offset any improvement of the quality of life brought about by industrialisation. Generally speaking, the standard of living will not have improved but instead it may have deteriorated. The average life time will be a little shorter than previous values.

In order to simulate this scenario of population decline, simulation experiments were performed on a combination of the following sub-scenarios: early-urbanisation-explosion scenario from the urbanisation component of the model, early-tightening-late-birth scenario from the family planning component, and the fast-urban-rural-deterioration scenario from the life quality component. The parameters used for these sub-scenarios are listed in Tables 4.14, 4.15 and 4.17.

Figure 4.24 shows the evolution of the Chinese population under the base case and population decline scenarios, while Figure 4.25 shows the evolution of the change in population proportion under the population decline scenario. Table 4.19 shows the changes in the values of the key indicators of the model under the base case, population explosion and population decline scenarios. Under the population decline scenario, the maximum population value shows a 5.2% decrease reaching 1.28 billion people, and the time to reach this maximum population is reduced by half i.e. 12 years earlier. The time when the urban population will exceed the rural population is also greatly reduced from the original 18 years to 12.5 years i.e. a 30.6% reduction. In fifty years, the total population will reach 0.95 billion of people, a 15.2% decrease leading to a reduction of 170 million people.

#### 4.7.5.3 Comparison of population scenarios

A comparison of the differences between the two population explosion and population decline scenarios revealed some interesting characteristics and consequences. Figure 4.26 shows the difference in population levels on an annual basis from 2005 to 2045. Under the population explosion scenario, both the total and rural populations are greater than their corresponding levels in the population decline scenario. However, under the population decline scenario, the level of the urban population exceeds its corresponding levels in the population explosion scenario. The increase of the total population in the population explosion scenario occurs because

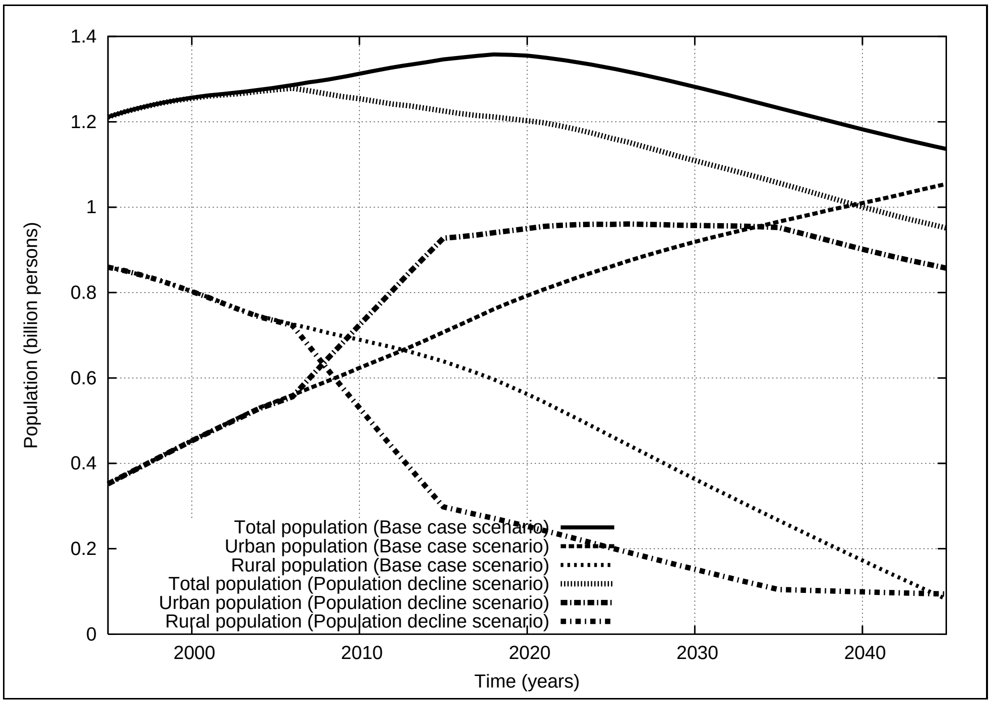


Figure 4.24: Evolution of population under population decline scenario

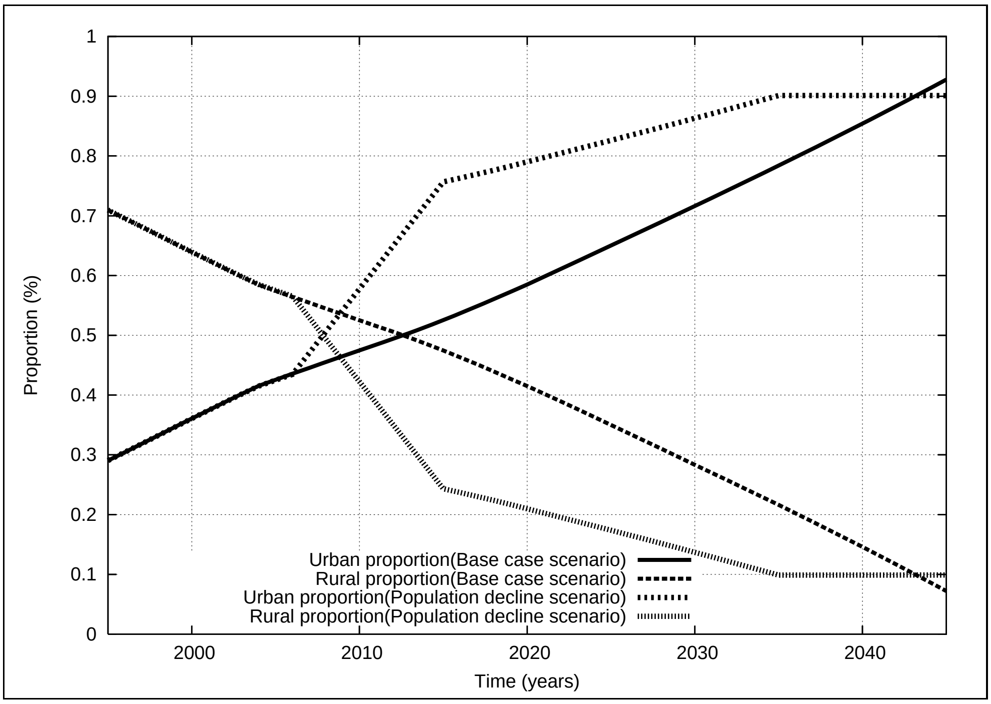


Figure 4.25: Evolution of population proportion change under population decline scenario

the increase of the rural population is much greater than the decrease of the urban population in that scenario. Table 4.20 lists the difference between the annual net change in total, urban and rural populations between the two scenarios. The positive (negative) value denotes the net increase (decrease) of total, urban and rural population under the population explosion scenario compared to decline scenario in that year. The bottom row shows the accumulated population change from the period of 2005 to 2045. In comparison with the population explosion scenario, after fifty years the population decline scenario will cause a reduction of inhabitants at a total number of about six hundred million, including a reduction of rural persons at eight hundred million and an addition of urban persons at two hundred million.

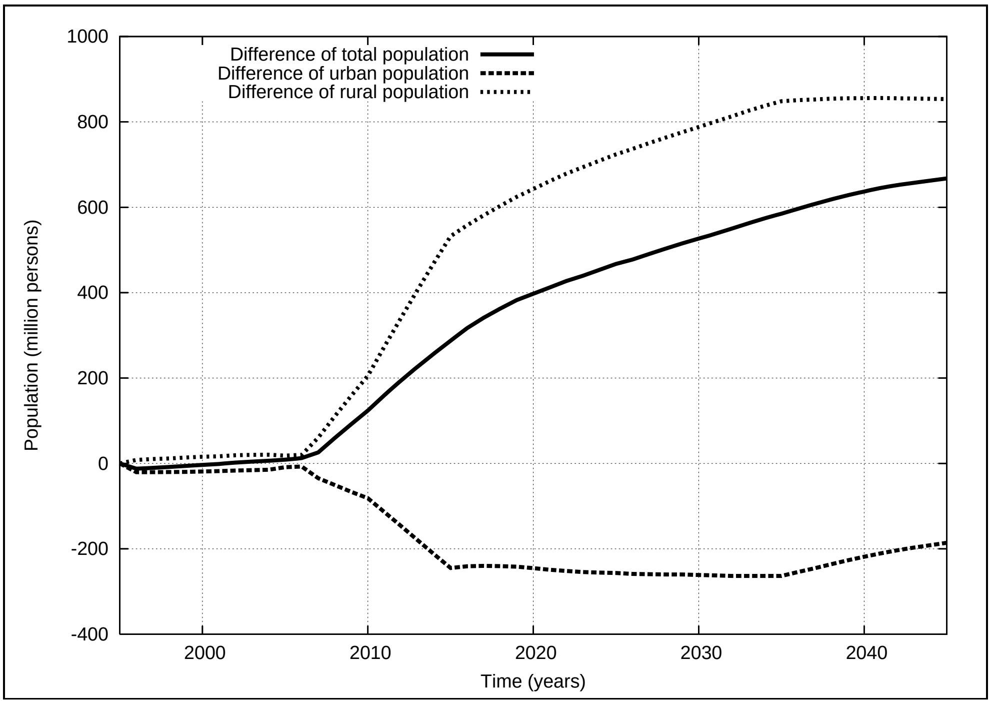


Figure 4.26: Evolution of differences in population levels under explosion and decline scenarios

## 4.8 Strategy formulation and simulation

The factors to which the SD model is sensitive can be combined to form both scenarios of how the population will evolve in the future as well as strategies for controlling the evolution of the population to achieve certain objectives. In general, factors that are not controllable are used for designing scenarios while those that are controllable are used for formulating strategies that

Table 4.20: Differences in annual population levels under explosion and decline scenarios

| Time (year) | **Total population change** (person per year) | **Urban population change** (person per year) | **Rural population change** (person per year) | Time (year) | **Total population change** (person per year) | **Urban population change** (person per year) | **Rural population change** (person per year) |
|---|---|---|---|---|---|---|---|
| 2005 | 3,803,564 | 6015343 | -2211779 | 2026 | 10,404,899 | -2,337,554 | 12,742,452 |
| 2006 | 3,320,716 | 1,412,217 | 1908,499 | 2027 | 12,898,870 | -629,359 | 13,528,229 |
| 2007 | 13,086,954 | -27,136,520 | 40,223,474 | 2028 | 12,453,580 | -471,084 | 12,924,663 |
| 2008 | 34,094,372 | -16,281,087 | 50,375,458 | 2029 | 12,299,465 | -262,026 | 12,561,490 |
| 2009 | 32,271,348 | -16,002,797 | 48,274,145 | 2030 | 11,316,668 | -1,139,694 | 12,456,362 |
| 2010 | 31,909,243 | -14,559,215 | 46,468,459 | 2031 | 11,412,466 | -1,039,312 | 12,451,778 |
| 2011 | 35,645,355 | -32,635,730 | 68,281,085 | 2032 | 11,404,928 | -1,055,836 | 12,460,764 |
| 2012 | 34,411,447 | -32,728,650 | 67,140,097 | 2033 | 13,196,684 | -1,084 | 13,197,768 |
| 2013 | 32,401,359 | -32,996,281 | 65,397,640 | 2034 | 11,144,570 | -199,276 | 11,343,846 |
| 2014 | 31,070,724 | -32,980,325 | 64,051,049 | 2035 | 10,925,113 | 234,563 | 10,690,550 |
| 2015 | 29,942,184 | -32,309,074 | 62,251,258 | 2036 | 11,917,548 | 9,096,094 | 2,821,453 |
| 2016 | 29,355,718 | 3,996,956 | 25,358,762 | 2037 | 10,377,182 | 8,810,333 | 1,566,850 |
| 2017 | 24,328,173 | 904,610 | 23,423,563 | 2038 | 11,090,784 | 9,198,001 | 1,892,783 |
| 2018 | 21,355,585 | -443,379 | 21,798,964 | 2039 | 10,192,135 | 9,298,491 | 893,644 |
| 2019 | 20,262,708 | -1,149,055 | 21,411,763 | 2040 | 8,506,338 | 8,395,661 | 110,677 |
| 2020 | 14,735,984 | -3,649,034 | 18,385,019 | 2041 | 8,180,586 | 7,894,430 | 286,157 |
| 2021 | 14,692,639 | -3,779,439 | 18,472,078 | 2042 | 6,653,507 | 7,106,150 | -452,644 |
| 2022 | 15,019,383 | -2,732,918 | 17,752,301 | 2043 | 5,607,153 | 6,408,730 | -801,577 |
| 2023 | 12,482,274 | -2,491,370 | 14,973,644 | 2044 | 5,087,708 | 5,612,727 | -525,019 |
| 2024 | 13,877,337 | -1,325,981 | 15,203,318 | 2045 | 5,004,372 | 5,606,536 | -602,164 |
| 2025 | 13,791,940 | -864,598 | 14,656,539 | | | | |
| Accumulated total population change | | | | | 661,933,563 | -171,209,836 | 833,143,398 |

can be used to adjust the population level to desirable levels should a particular scenario occur. In this section, a description is provided of how the factors of the family planning component of the model are used for formulating alternative family-planning strategies. The strategies are useful for controlling the evolution of the Chinese population in order to achieve the predefined targets specified under typical projected urbanisation scenarios. Simulation of the SD population model is performed to observe its behavioural response to inputs of different scenarios. The behaviours of the model generated by the base case scenario are used as benchmarks and the behaviours under the urbanisation scenarios are compared and their differences with those from base state analysed. These simulation experiments provided useful insights about possible adjustments to the current family-planning policies to achieve some predefined goals.

An as-usual-urbanisation scenario was used as a base case scenario to demonstrate how to design effective strategic family planning (SFP) without significantly altering the behaviour of the total population development. Simulation experiments with strategies of family planning under other scenarios to achieve the same result allowed the discovery of suitable family planning factors in the model. The values of the SFP under different urbanisation scenarios are summarised in Table 4.21.

Under an as-usual-urbanisation scenario, the behaviour of the population development is actually the same as in the base state. As illustrated in Figure 4.18, the population shows a growing momentum at first, reaching a maximum in the middle and then starts to decline until the end of the simulation. As illustrated in Figure 4.27, the challenge is to obtain an effective SFP that will change the structural composition of the existing urban and rural population without significantly changing the total population behaviour. In other words, after the SFP adjustment, the yearly number of the total population will be the same as in the as-usual-urbanisation scenario.

Table 4.21 lists the factors that need to be adjusted in order to form effective strategic propositions under the four urbanisation scenarios. In order to maintain the current population development trend in the future, i.e. as-usual-urbanisation scenario, it is found through simulation that the SFP can be amended in 2020 (26 years after the start of the simulation) in two ways. Urban fertility can be increased from the original value of 1.2 children per couple to 1.6 and at the same time rural fertility must be reduced from 3.6 children to 2. Figure 4.27 shows the behaviours of the total population before and after this adjustment.

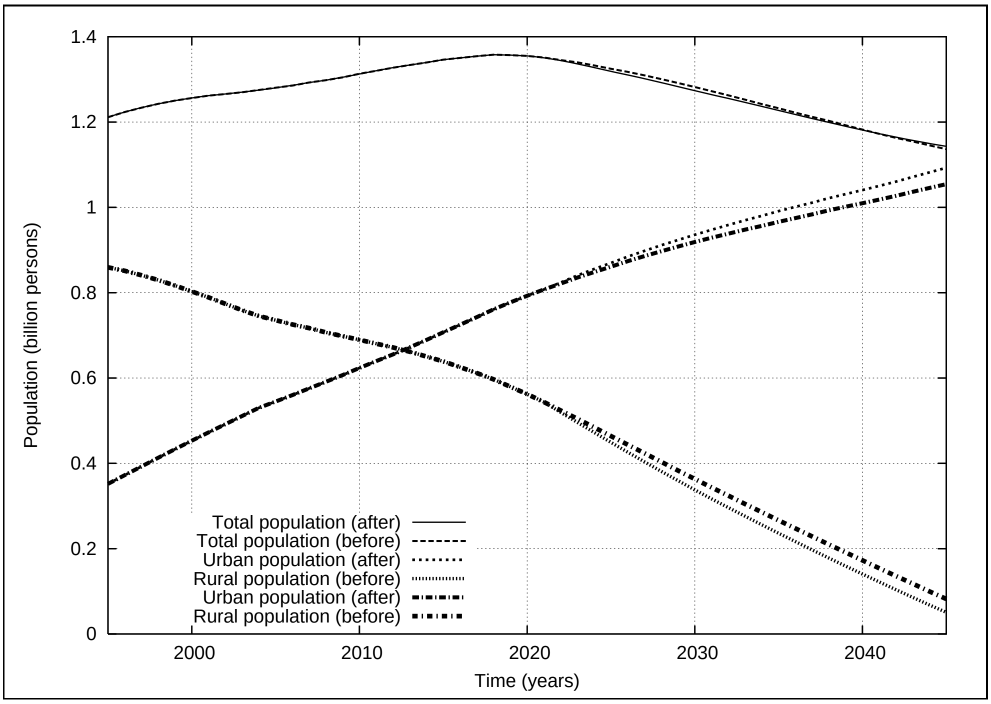


Figure 4.27: Evolution of population before and after adjustment using family planning strategy

Table 4.21: Parameter values used for family planning scenarios

| Urbanisation scenarios | Strategic family planning | |
|---|---|---|
| | Factors | Adjusted values |
| As-usual-urbanisation | $FPCT_t$ (year) | In 2021 (26 years after 1995) |
| | $UF_t$ | From 1.2 to 1.6 |
| | $RF_t$ | From 3.6 to 2.0 |
| Early-urbanisation-stop | $FPCT_t$ (year) | In 2017 (22 years after 1995) |
| | $UF_t$ | From 1.2 to 1.5 |
| | $RF_t$ | From 3.6 to 2.2 |
| Early-urbanisation-explosion | $FPCT_t$ (year) | In 2007 (12 years after 1995) |
| | $UF_t$ | From 1.2 to 1.5 |
| | $RF_t$ | From 3.6 to 4.0 |
| Late-urbanisation-explosion | $FPCT_t$ (year) | In 2013 (18 years after 1995) |
| | $UF_t$ | From 1.2 to 1.4 |
| | $RF_t$ | From 3.6 to 2.8 |

An explanation of the effectiveness of this policy adjustment is as follows. The amendment meets the requirements of the expectation for more children in the city and also alleviates the burden of too many children for rural residents, and thus possibly improves the quality of life of the population in general, such as levels of education and health. Since this SFP can be implemented in 2021, this leaves policy makers plenty of time to prepare for its implementation. For example, less resistance would be met if rural couples were educated/influenced to have less children. As illustrated in Figure 4.18, it should be noted that the adjustment would alter the original composition of the urban and rural population, resulting in a lower proportion of urban population and a higher rural population percentage. However, this alteration is not significant.

In order to obtain SFPs for other scenarios, further simulation experiments are performed. Table 4.21 lists the values of the SFPs used for all the urbanisation scenarios. Under the early-urbanisation-stop scenario, in order to keep the total population behaviour unchanged, the family-planning policy has to be amended in 2017 (22 years after 1995). Urban fertility should be increased from 1.2 children per couple to 1.5 while rural fertility should be reduced from 3.6 to 2.2. Under the early-urbanisation-explosion scenario, the family-planning policy should be changed in 2007 (12 years after 1995); urban fertility should be increased from 1.2 to 1.5 and rural fertility to as many as four children. In fact, under these circumstances, the birth-control policy could be abolished. Under the late-urbanisation-explosion scenario, 2013 (18 years after 1995) would be the right time to adjust the existing policy; urban and rural couples can then on average have 1.4 and 2.8 children respectively.

## 4.9 Summary

In this chapter, a System Dynamics model was developed for simulating the evolution of the Chinese population. The dynamics of the population was modelled as the interplay of birth, death and migration. In addition, the peculiarities of the Chinese family-planning policies were also included in the model and this required the segregation of the population into urban and rural components. Thus, the model included factors such as family-planning policies, urbanisation and quality of life, as these are known to significantly influence the course of population evolution in China. The model was calibrated using data available on the Chinese population, and it was validated by reproducing historical behaviour, comparing the results with UN forecasts and performing extensive sensitivity analysis.

The uncertainties from urbanisation, family planning and quality of life were used to formulate sub-scenarios which were then combined to form more complex scenarios, i.e. a population explosion and a population decline scenario. These two scenarios were simulated and their behaviours compared with each other as well as with the base case scenario of population development. The family planning component of the model was further utilised as a control method in the strategic planning for various urbanisation scenarios. Four strategic family-planning proposals were provided for the purpose of meeting the different requirements of family size in urban and rural areas without significantly changing the behaviour of the total population.

The simulation model developed provides an experimentation platform for examining population dynamics and for making effective strategic family planning under different scenarios. Strategists can also use this model to examine the behaviour of the population development under different scenarios and design corresponding family-planning strategies for appropriate responses. The dynamics of the Chinese population demonstrated in this subsystem will be utilised by the mobile commerce diffusion subsystem to be developed in the next chapter. In the next chapter, a System Dynamics model of the diffusion of mobile commerce in China will be built and will use the output of the population model as input.

# Chapter 5

# MODELLING AND SIMULATING MOBILE COMMERCE DIFFUSION

## 5.1 Introduction

In Chapter 4, a System Dynamics model of the population in China was developed. In this chapter, a System Dynamics model is developed to explore the dynamics of mobile commerce diffusion. The mobile commerce diffusion model is the second submodel that was proposed in Chapter 3.

As mentioned in Chapter 4, the steps for constructing a System Dynamics model of mobile commerce diffusion in China include: identifying variables for qualitative modelling; establishing the relationships between these variables in the form of a causal loop diagram; creating a stock and flow diagram from the causal loop diagram using mathematical equations; and validating the model. The model is validated using mobile telephony diffusion in China from 1995 to 2006 as mobile telephony is regarded as a primitive form of mobile commerce services. A base case is proposed and its behaviour is examined. The model is further validated through sensitivity analysis and the factors to which the model is sensitive are then determined.

The sensitive factors identified are further used as leverage points for simulation analysis related to mobile commerce diffusion. The influence from the timing of implementation of mobile commerce and the existence of floating populations, that is rural residents who make a living in urban areas, is experimented upon. The behaviours of mobile commerce under four urbanisation scenarios are examined. Two complex scenarios involving most factors are designed, simulated and analysed. Finally, a strategy that can mitigate the negative effects of fast market expansion from a carry-away scenario is developed.

## 5.2 Modelling mobile commerce diffusion

Electronic commerce (e-commerce) is widely regarded as an innovation created during the last two decades. Mobile commerce is an extension of e-commerce from the wired to wireless medium and from fixed to mobile environments. In this sense, mobile commerce is an innovation made possible after the advent of e-commerce. Modelling mobile commerce diffusion is actually equivalent to modelling innovation diffusion.

The core models of innovation diffusion were established during the 1970s. The most famous models are the logistic model and the Bass model (Bass 1969, Mahajan & Peterson 1985, Rogers 2003). From that time on, model developments focused on modifying the developed models by adding greater interpretation and applicability. The main categories of these modifications include the introduction of marketing variables in the parameterisation of the models and generalisation of the models in the context of diffusions in different countries and successive generations of technology. In practice, the main application areas are centered on the introduction of consumer durables and telecommunication innovations. As an application of these models, there is plenty of research in the area of mobile service for accurate forecasting methods (Rice & Katz 2003, Boretos 2005, Iimi 2005) and examining their applicability to particular cases (Ishii 2004, Sangwan & Pau 2005). The traditional modelling of innovation diffusion uses a purely mathematical approach. With the increase in the number of parameters involved, it is hard to use this analytic method to deal with an innovation diffused in a complex world. It is necessary to find an alternative method instead.

Systemic approaches have appeared recently and one of these methods is System Dynamics simulation modelling. Researchers use System Dynamics techniques to develop models to display the behaviours of both the logistic model and the Bass model (Sterman 2000) and extend these models to consider market factors, such as total market size, pricing, learning curve, abandonment, replacement, life cycle of products, etc. (Sterman 2000). This SD-based innovation diffusion model is finding its application in the mobile commerce service area. SD has been used for modelling innovation of diffusion in the area of telecommunication but to date there are no applications in the modelling of mobile commerce diffusion. Since China is becoming one of the biggest potential mobile commerce markets, modelling mobile commerce diffusion in China will not only fill the research blank in this area but also produce useful business implications.

## 5.3 Qualitative modelling

Qualitative modelling is the first step in setting up an SD model to deal with a complex issue like mobile commerce diffusion in China. It includes the identification of key variables and the establishment of causal loop relationships among them.

### 5.3.1 Identification of variables

Like most products and services of the information telecommunication technology (ICT) , a mobile commerce service diffusion will presumably experience three phases before it finally occupies the total Chinese market. The first stage is characterised by a high price and service fee targeting specific groups, such as highly educated persons, rich people etc. The added values like luxury consumption, symbols of wealth, convenience, high social status brought by this mobile commerce service are obvious to these specific groups. They are the first adopters. Initially the adoption rate may be low and the discard rate may be high within a period. After a period of adaptation, the adoption rate will begin to recover to a normal rate, the discard rate will be greatly reduced and adoption will spread around. This occurs concurrently in urban areas and the developed countryside.

With the reduction in cost and improvement of service quality, a widespread diffusion over the urban area and the developed countryside is possible. The existence of a floating population,who are moving around within China, will accelerate the process of mobile commerce service diffusion, especially in the countryside.

The third phase is characterised by a further decreased cost, improved service, and a large-scale diffusion into untapped areas. The development of the economy will make rural residents richer. The overall entrance threshold is further lowered. The maturation of the new digital generation and the prevalence of new knowledge will make mobile commerce service much more acceptable. The renovation of the infrastructure and technological innovation will make these services more and more accessible to people. By that time, a mobile commerce service will become popular similar to what telephony has become today.

First of all the start time, time step and finishing time of simulation are determined. The timing depends on which mobile commerce service is examined and when it is supposed to be implemented in reality. For example, mobile telephony, which can now be regarded as a primitive mobile commerce service, was implemented in China in the late 1980s. Mobile banking as an advanced mobile commerce service has not yet formally been put into use. The same start time, time step and finishing time as in the population model are used for examining mobile telephony diffusion so that they are synchronous with each other. However, for the mobile commerce services that are not yet implemented in China, the start time will be non-synchronous with the population model.

In accordance with the decomposition of the population in chapter 4, the users of a mobile commerce service in China are also segregated into urban and rural categories under the assumption that they have different characteristics. In each category, a mobile commerce diffusion is modelled as user transform from potential users into actual users.

The total number of users in China consists of the number of urban users plus the number of rural users. Its diffusion occurs in three dimensions. The first dimension refers to diffusion within urban areas; the second refers to diffusion between urban and rural areas; and the third includes diffusion within rural areas. The innovator first occurs and diffuses in the urban and rural areas because of initiatives such as institutional propaganda and commercial promotion. The floating population will enhance the process of diffusion between urban to rural areas. In both urban and rural areas, the early adopters will expose their friends, families and acquaintances to mobile services through word of mouth (WOM) (Gilbert, Jager, Deffuant & Adjali 2007). WOM refers to contacts between actual users and potential users. The potential users are the group of persons within the population who have common characteristics with this mobile commerce service. For example, for the mobile banking service, the potential users are the number of persons who are users of the on-line banking system from the population pool. How much adoption will occur is determined by the contact rate (number of contacts between an adopter and potential users in a certain time period) and the adoption fraction from these contacts. Table 5.1 lists all the possible variables that are responsible for the diffusion of a mobile commerce service diffusion.

Table 5.1: Description of variables

| Variable | Description | Type | Unit |
|---|---|---|---|
| $T_0$ | Start Time | Constant | Year |
| $T_f$ | Final Time | Constant | Year |
| $\Delta T$ | Time Step | Constant | Year |
| $IT_t$ | Implementation Time | Constant | Year |
| $TU_t$ | Total User | Auxiliary | Person |
| $UP_t/RP_t$ | Urban/Rural Population | Stock | Person |
| $UPU_t/RPU_t$ | Urban/Rural Potential User | Stock | Person |
| $UEF_t/REF_t$ | Urban/Rural E-commerce Fraction | Constant | Dimensionless |
| $UU_t/RU_t$ | Urban/Rural User | Stock | Person |
| $IUU_t/IRU_t$ | Initial Urban/Rural User | Constant | Person |
| $UA_t/RA_t$ | Urban/Rural Adoption | Flow | 1/year |
| $UAWM_t/RAWM_t$ | Urban/Rural Adoption from WOM | Flow | 1/year |
| $UAP_t/RAP_t$ | Urban/Rural Adoption from Propaganda | Flow | 1/year |
| $UD_t/RD_t$ | Urban/Rural Discard | Flow | 1/year |
| $UDF_t/RDF_t$ | Urban/Rural Discard Fraction | Constant | Dimensionless |
| $UCR_t/RCR_t$ | Urban/Rural Contact Rate | Constant | 1/year |
| $RUCR_t$ | Rural Urban Contact Rate | Constant | 1/year |
| $UPE_t/RPE_t$ | Urban/Rural Propaganda Effectiveness | Constant | Dimensionless |
| $FPF_t$ | Floating Population Fraction | Constant | Dimensionless |
| $UAF_t/RAF_t$ | Urban/Rural Adoption Fraction | Constant | Dimensionless |
| $RUAF_t$ | Rural Urban Adoption Fraction | Constant | Dimensionless |
| $UNC_t/RNC_t$ | Urban/Rural Network Coverage | Constant | Dimensionless |
| $UUP_t/RUP_t$ | Urban/Rural User Proportion | Auxiliary | Dimensionless |
| $TUI_t$ | Total User Increase | Auxiliary | Person/year |
| $UUI_t/RUI_t$ | Urban/Rural User Increase | Auxiliary | Person/year |

### 5.3.2 Causal loop diagram

A causal loop diagram (CLD) for a mobile commerce system is shown in Figure 5.1. It illustrates how diffusion occurs within the three layers or dimensions previously discussed and the feedback loops involved. Diffusion within the urban area is the result of combined actions from word of mouth (WOM), propaganda and discard. Diffusion between urban and rural areas is shown as acceptance within the floating population. Diffusion within rural areas is the interplay of adoption from the floating population, adoption from WOM, adoption from propaganda and discard.

There are fourteen feedback loops within the two blocks that interplay to determine the states of mobile commerce diffusion. Within the urban cluster, the number of the urban users is determined by six feedback loops whereas in the rural cluster the number of rural users is determined by eight feedback loops. There are three positive feedback loops (R1, R2 and R3) and three negative feedback loops (B1, B2 and B3) for the urban block while there are four positive feedback loops (R4, R5, R6 and R7) and four negative feedback loops (B4, B5, B6 and B7) for the rural block. According to their causes, these feedback loops are classified into three categories: WOM feedback loops, propaganda feedback loops and discard feedback loops.

#### 5.3.2.1 WOM Feedback loops

WOM is one medium that forms feedback loops in the mobile commerce diffusion system. It includes WOM feedback loops within urban areas,WOM feedback loops within rural areas and WOM feedback loops between urban and rural areas.

WOM feedback loops within urban areas include one reinforcing feedback loop and one balancing feedback loop. The positive feedback loop R1, shown in Figure 5.2, is the urban adoption resulting from WOM. An increase of adoption due to the urban adoption rate increase from WOM will result in an increase of the number of mobile commerce users, and the increase of mobile commerce users will further raise the adoption rate due to WOM and hence boost adoption. This positive loop contributes to an exponential growth in the number of urban mobile commerce users. The negative feedback loop B1 is the adoption due to the urban adoption rate from WOM attracting urban potential mobile commerce users. An increase in the urban adoption rate from WOM will result in a decrease of the number of potential mobile commerce users, and the decrease of the number of potential urban mobile commerce users will further reduce the adoption rate from WOM. This negative loop contributes to a reverse exponential

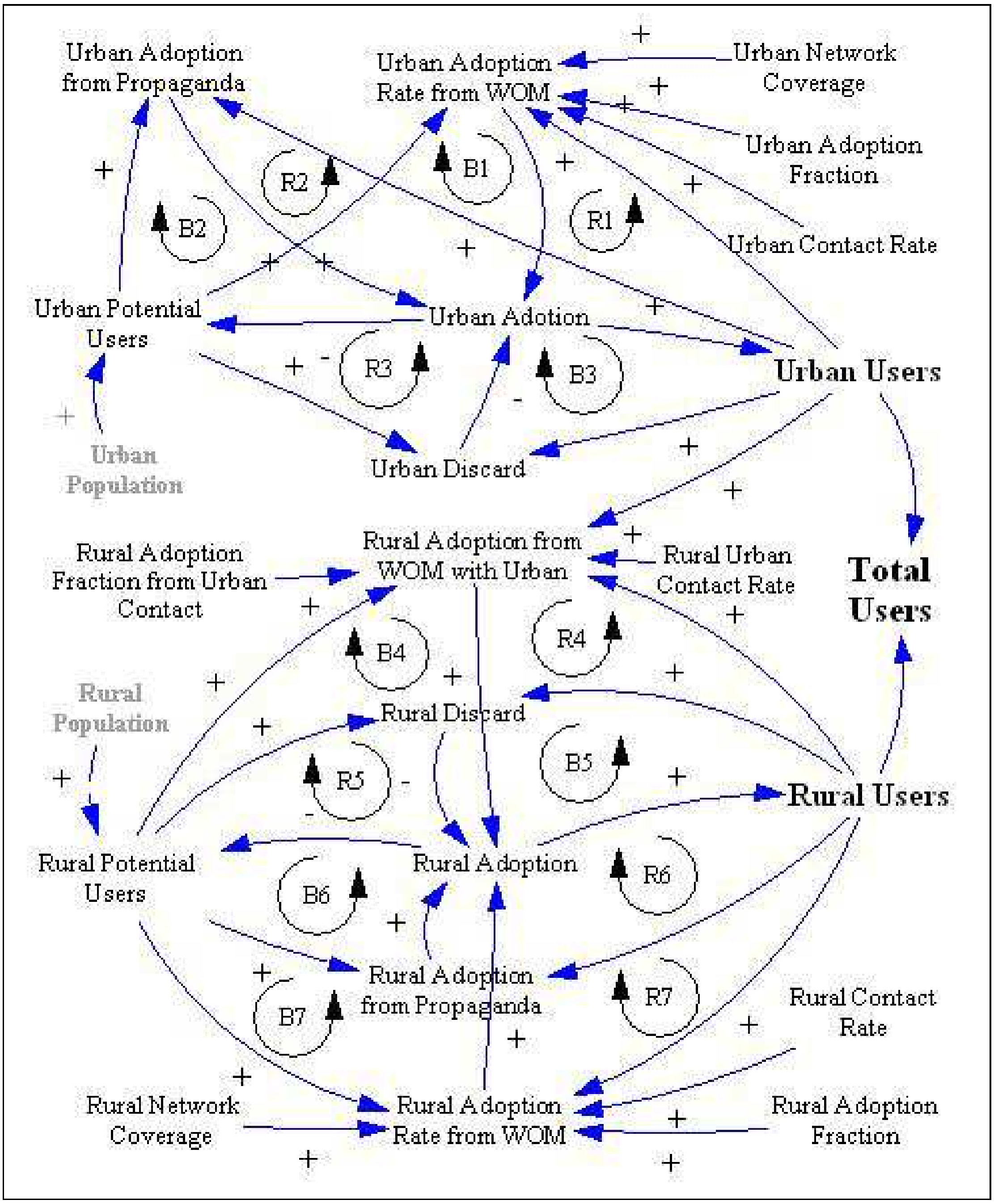


Figure 5.1: Causal loop diagram for mobile commerce diffusion

decay in the number of urban mobile commerce users. The adoption from WOM in the urban areas is the result of the interplay from these two feedback loops.

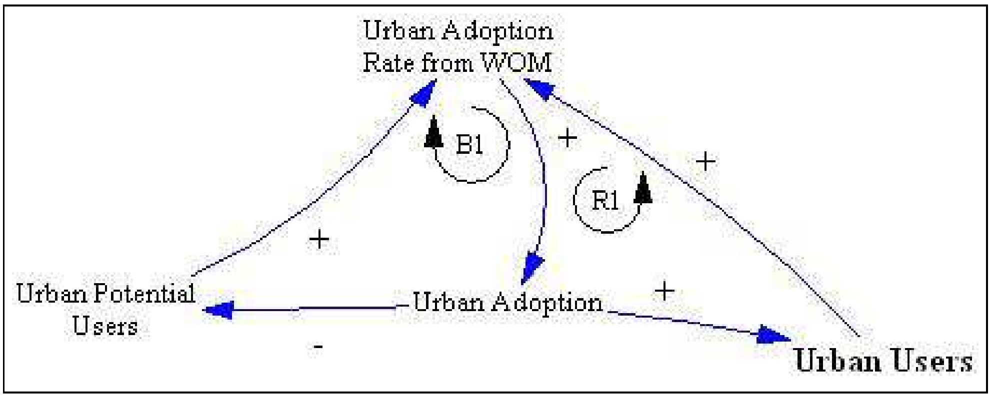


Figure 5.2: Urban WOM feedback loops

Similarly for the WOM feedback loops in urban areas, there is one positive WOM feedback loop and one negative WOM feedback loop within rural areas. Figure 5.3 illustrates the positive feedback loop R7, the rural adoption resulting from the flow of rural adoption of WOM to rural mobile commerce users. This positive loop contributes to an exponential growth in the number of rural mobile commerce users. Figure 5.3 also shows the negative feedback loop B7, which is the rural adoption resulting from the rural adoption rate from WOM to rural potential mobile commerce users. This negative loop contributes to a reverse exponential decay in the number of rural mobile commerce users. These two feedback loops determine the way adoption from WOM operates in the rural areas.

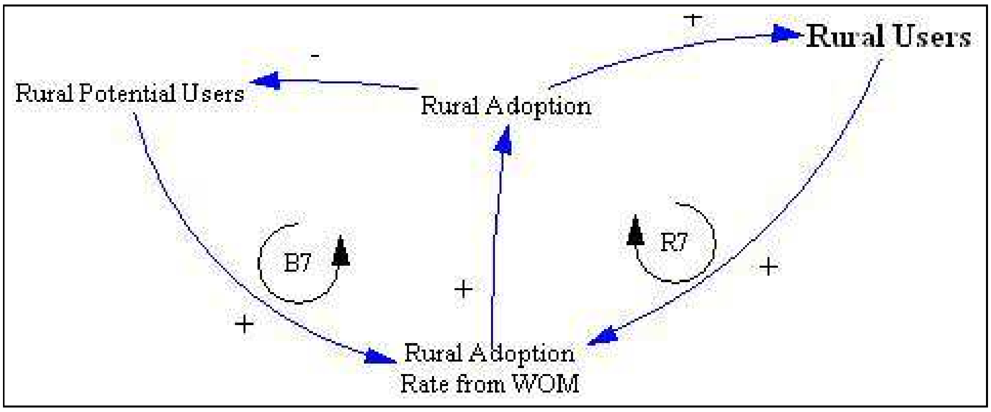


Figure 5.3: Rural WOM feedback loops

Figure 5.4 shows the WOM feedback loops between urban and rural areas. There are also two feedback loops: a positive feedback loop R4 from the flow of rural adoption of WOM from the urban area to rural mobile commerce users, and a negative feedback loop B4 from the rural adoption rate from WOM by contact with urban users to the variable rural potential mobile commerce users. The adoption from WOM between urban and rural areas is the summation of the exponential growth of the rural mobile commerce users from loop R4 and the reverse exponential decay of the number of rural mobile commerce users created by loop B4.

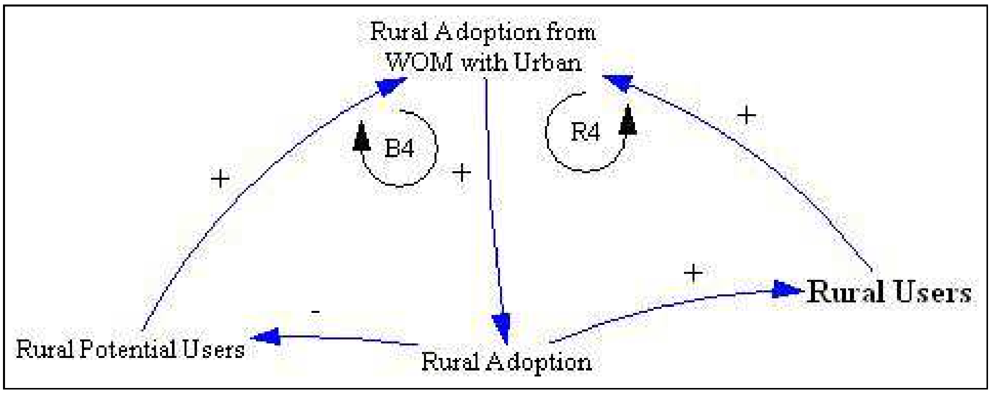


Figure 5.4: Rural WOM feedback loops from urban

### 5.3.2.2 Propaganda feedback loops

Similarly to WOM, propaganda is another medium that creates feedback loops in the mobile commerce diffusion system. Propaganda feedback loops exist within both urban and rural areas.

As shown in Figures 5.5 and 5.6, the positive feedback loop R2 (or R6) is the urban (or rural) adoption resulting from the flow of urban (or rural) adoption of propaganda to urban (or rural) mobile commerce users. An increase of urban (or rural) adoption due to urban (or rural) adoption rate increase from propaganda will result in an increase of the number of mobile commerce users, and the increase of mobile commerce users will further raise the adoption rate due to propaganda and hence boost adoption. This positive loop contributes to an exponential growth in the number of urban (or rural) mobile commerce users.

The negative feedback loop B2 (or B6) is the urban (or rural) adoption resulting from the urban (or rural) adoption rate from propaganda to urban (or rural) potential mobile commerce users. An increase in the urban (or rural) adoption rate from propaganda will result in a decrease

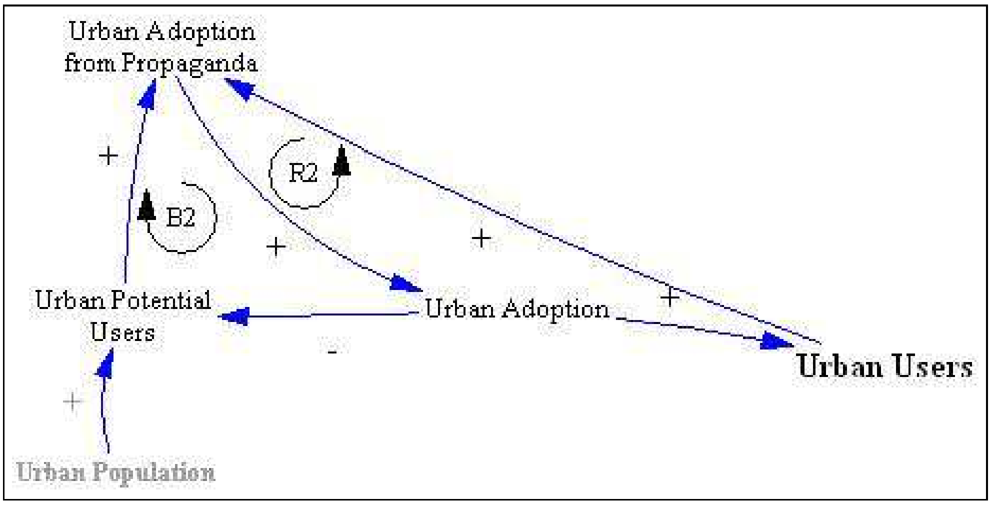


Figure 5.5: Urban propaganda feedback loops

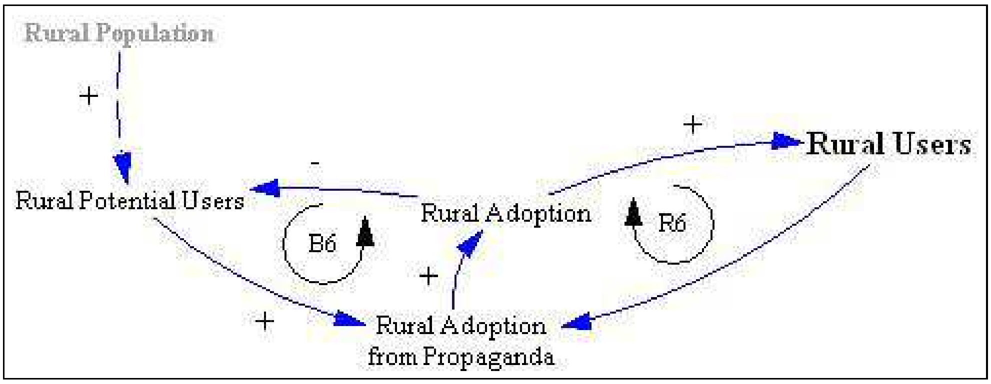


Figure 5.6: Rural propaganda feedback loops

in the number of potential urban (or rural) mobile commerce users, and the decrease in the potential urban (or rural) mobile commerce users will further reduce the adoption rate from propaganda. This negative loop contributes to a reverse exponential decay in the number of urban (or rural) mobile commerce users. Loops B2 (or B6) determine the behaviour of adoption from propaganda in urban (or rural) areas.

#### 5.3.2.3 Discard feedback loops

Opposite to adoption, discard refers to the phenomenon whereby a mobile commerce user gives up an adopted mobile commerce service and returns back to the state of being a potential mobile commerce user. Accompanying adoption of mobile commerce, discard of mobile commerce also exists within urban and rural areas. Figures 5.7 and 5.8 show the discard feedback loops within urban and rural areas.

The negative feedback loop B3 is the change in urban adoption resulting from the urban discard to urban mobile commerce users, and the positive feedback loop R3 is the urban adoption change resulting from the flow of urban discard to urban potential mobile commerce users. The negative feedback loop B5 is the rural adoption change resulting from rural discard to the variable rural mobile commerce users, and the positive feedback loop R5 is the rural adoption change resulting from the flow of rural discard to rural potential mobile commerce users. They determine the state of user discard of mobile commerce in urban and rural areas.

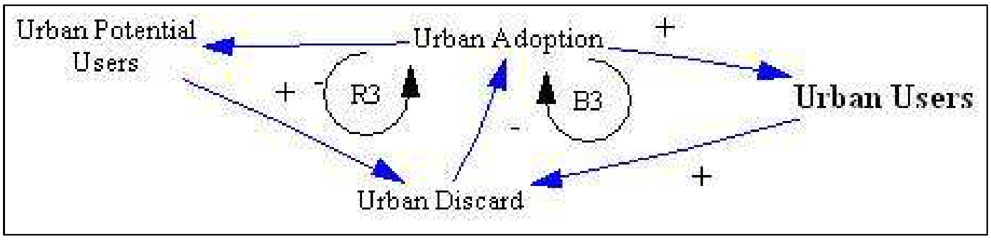


Figure 5.7: Urban discard feedback loops

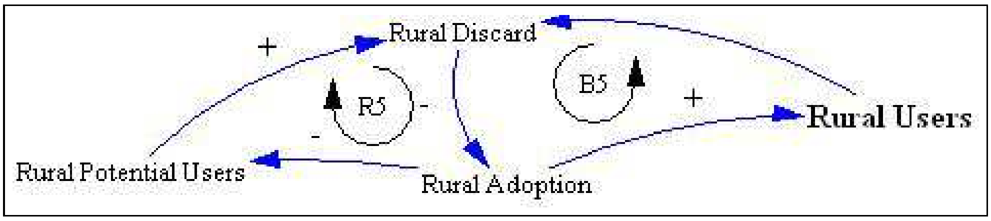


Figure 5.8: Rural discard feedback loops

To sum up, the evolution of a mobile commerce service diffusion is affected by the interplay of mobile commerce diffusion in both urban and rural areas, which is further determined by the interaction of fourteen feedback loops from WOM, propaganda and discard occurring in or between the two areas.

## 5.4 Quantitative modelling

SD simulation has been suggested as the ideal quantitative complement to qualitative modelling approaches. In order to establish an SD simulation model for mobile commerce diffusion, a stock and flow diagram is established to link the identified variables and reflect the causal relationships described in qualitative model. Mathematical equations, plus some logical arguments, are used to establish these relationships.

### 5.4.1 Stock and flow diagram

An SFD for modelling the evolution of users of mobile commerce service in China showing the main stocks and flows is depicted in Figure 5.9. The four boxes in the diagram represent stocks:

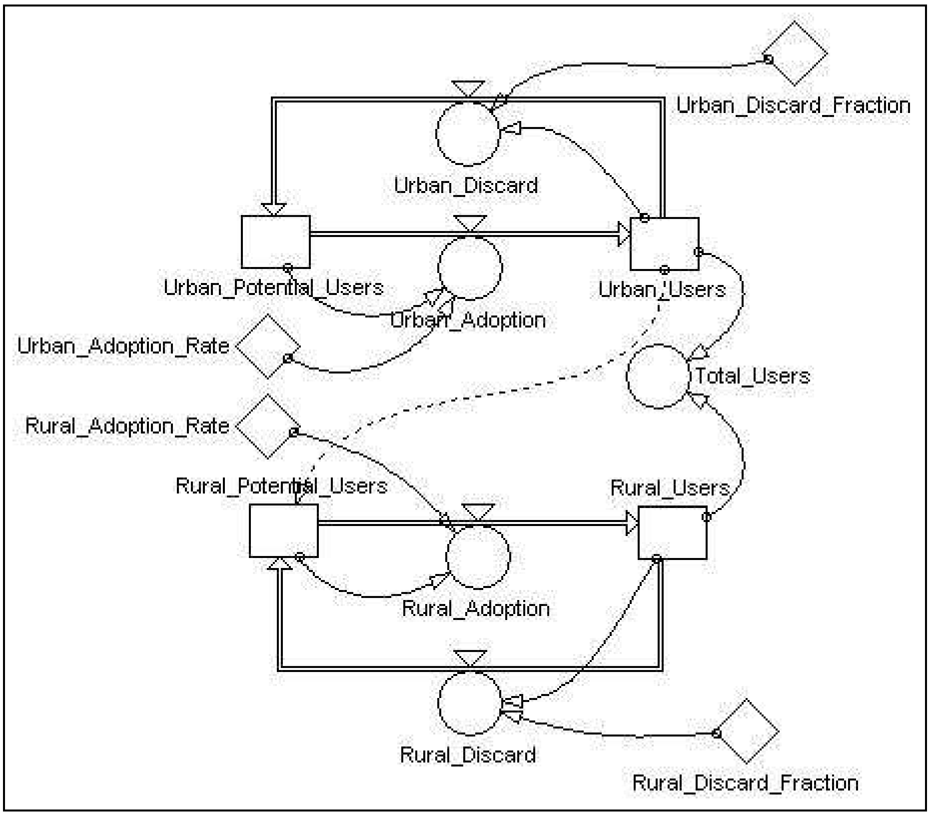


Figure 5.9: Stock flow diagram

potential urban and rural users, and urban and rural mobile commerce users. The level of mobile commerce users is controlled by the sum of inflow of users generated by the adoption and pressure from the stock of the potential mobile commerce users and outflow of users incurred from the discard and pressure form the stock of the existing mobile commerce users. The level of the stock representing potential mobile commerce users is exogenously determined by the urban or rural population (an input from the population model) and the level of e-commerce penetration fraction. The levels of potential users and users are constantly adjusted by the flow of the adoption and discard between the stocks. The dotted line linking urban users and rural potential users denotes the floating population plays a crucial role in ensuring the diffusion can surpass the divide existing between urban and rural areas. The levels of the four stocks determine the state and the structural change of mobile commerce users. The variables identified in the CLD change the state by affecting the flows linked to the stocks.

### 5.4.2 Equations used in model

Apart from drawing the stocks and flows and their interconnections, a set of mathematical equations or logistical relationships are established in the SFD to describe how the stocks, flows and auxiliary variables change over time. As illustrated in Table 5.1, all the variables classified as stock, flow and auxiliary are described using mathematical equations. The equations used in the model are shown in Table 5.2 and analysed afterwards. More details about the equations in SD format generated by Powersim software are listed in Appendix F.

Equation 1 denotes the total number of mobile commerce service users as the sum of urban users and rural users. Equations 2 and 3 indicate that the number of urban (or rural) potential mobile commerce service users is the product of urban (or rural) population and urban (or rural) electronic commerce fraction minus the difference of urban (or rural) users and urban (or rural) discard. Urban (or rural) electronic commerce fraction represents the proportion of persons who have adopted a certain service of electronic commerce within the urban (or rural) population.

Equations 4 and 5 calculate the number of urban (or rural) users as the integration of the difference between the urban (or rural) user adoption and urban (or rural) discard plus the initial value of urban (or rural) users.

Equations 6 and 7 determine the number of urban (or rural) discard as the product of the urban (or rural) user and urban (or rural) discard fraction.

Equation 8 is the calculation of urban adoption from WOM. Urban adoption from WOM is the product of urban population, urban electronic commerce fraction, the number of urban users, urban contact rates between urban potential user and actual urban user, urban network coverage and the urban adoption fraction, divided by the product of urban population and urban education

Table 5.2: Equations used by model

| | |
|---|---|
| $TU_t = UU_t + RU_t$ | (1) |
| $UPU_t = UP_t * UEF_t - UU_t + UD_t$ | (2) |
| $RPU_t = RP_t * REF_t - RU_t + RD_t$ | (3) |
| $UU_t = IUU_{t=0} + (UA_t - UD_t) * \Delta T$ | (4) |
| $RU_t = IRU_{t=0} + (RA_t - RD_t) * \Delta T$ | (5) |
| $UD_t = UDF_t * UU_t$ | (6) |
| $RD_t = RDF_t * RU_t$ | (7) |
| $UAWM_t = UPU_t * UU_t * UCR_t * UNC_t * UAF_t/(UP_t * UEF_t)$ | (8) |
| $RAWM_t = [RPU_t * FPF_t * UU_t * RUCR_t * UNC_t * RAFU_t]$ $+ [RPU_t * (1 - FPF_t) * RU_t * RCR_t * RNC_t * RAF_t] / (RP_t * REF_t)$ | (9) |
| $UAP_t = UPU_t * UPE_t$ | (10) |
| $RAP_t = RPU_t * RPE_t$ | (11) |
| $UA_t = UAWM_t + UAP_t$ | (12) |
| $RA_t = RAWM_t + RAP_t$ | (13) |
| $UUP_t = UU_t/TU_t$ | (14) |
| $RUP_t = RU_t/TU_t$ | (15) |
| $TUI_t = d(TU_t)/dt$ | (16) |
| $UUI_t = d(UU_t)/dt$ | (17) |
| $RUI_t = d(RU_t)/dt$ | (18) |

fraction.

Equation 9 computes rural adoption from WOM and consists of two components. One component is the adoption arising from the contact between a fraction of the potential rural users and urban users. It is the product of rural potential users, the floating population fraction, urban users, the rural urban contact rate, urban network coverage and the rural adoption fraction from urban, divided by the product of the rural population size and rural electronic commerce fraction. The other component refers to adoption resulting from contact between the rest of the potential rural users and rural users. It is the product of rural potential users, the rest of the floating population fraction, rural users, the rural contact rate, rural network coverage and the rural adoption fraction, divided by the product of the rural population size and rural electronic commerce fraction. The rural adoption is the sum of the two components.

Equations 10 and 11 calculate adoption from propaganda in the urban (or rural) areas. Urban (or rural) adoption from propaganda is the product of urban (or rural) potential users and the urban (or rural) propaganda effectiveness.

Equations 12 and 13 calculate the urban (or rural) adoption , which is equivalent to the sum of the urban (or rural) adoption from WOM and the urban (or rural) adoption from propaganda.

Equations 14 to 18 calculate the outputs of the simulation model. They have no direct influence on the behaviour of the model but will generate meaningful information for the experiments and for analyzing the results. Equations 14 and 15 show how to calculate the proportion of urban (or rural) mobile commerce users. The proportion of urban (or rural) mobile commerce service users is the number of urban (or rural) mobile commerce users divided by the total number of users. Equations 16, 17 and 18 describe how to compute the change in the number of total (or urban, or rural) mobile commerce users. They are expressed as the derivatives of total (or urban, or rural) mobile commerce service users.

Figure 5.10 shows the simulation model of mobile commerce diffusion created using Powersim modelling software. It connects with the population model from the previous chapter through the variables ‘Urban Population’ and ‘Rural Population’ and with mobile commerce terminal (MCT) model in the ensuing chapter through the variable ‘Total Users’. After validation, the developed model is used for conducting sensitivity analysis, scenario analysis and strategy development.

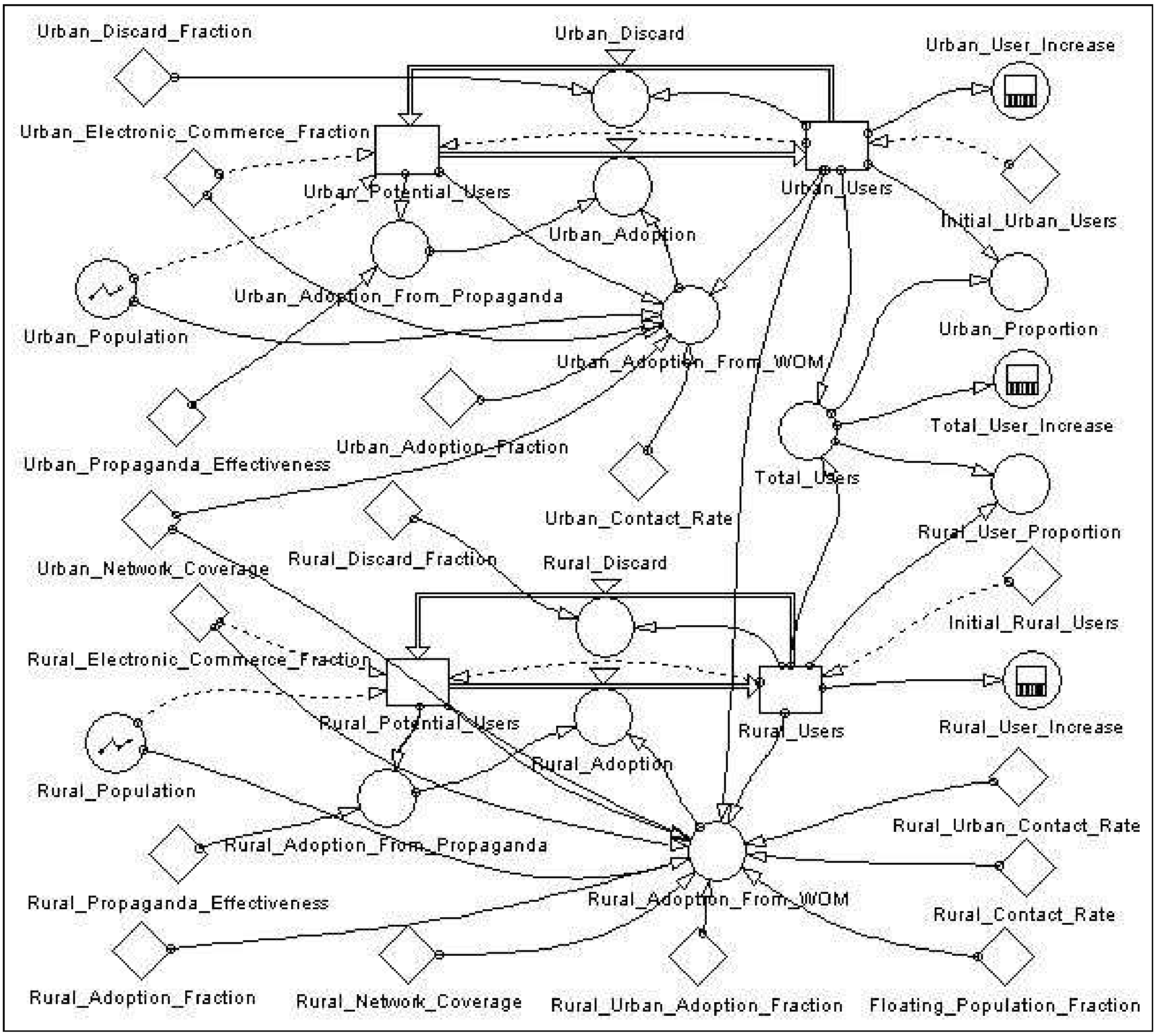


Figure 5.10: SD simulation model of mobile commerce diffusion

## 5.5 Model validation

The mobile commerce diffusion model is validated using data on mobile telephony service subscribers in China. Since the data for specific urban and rural mobile phone users is not available, this validation is only based on total mobile phone users rather than urban and rural users as distinct variables. The reason for choosing to validate the mobile commerce diffusion model with mobile telephony data is that mobile phone service is considered to be a form of primitive or simplified mobile commerce service. Mobile commerce service is any service provided over a network and a mobile terminal to a specific group of recipients. Different mobile commerce services have different requirements in terms of the network, mobile terminals and potential users. For example, voice telecommunication service, as a form of low-end services in the spectrum of mobile commerce services, can operate over existing networks, through cellular terminals (mobile phones) and to ordinary people. However, mobile banking, as one of the high-end mobile commerce services, has special requirements. For example, the existing networks are currently in their first generation (1G), second generation (2G) and other generation (e.g. 2.75G). These networks provide low-speed, low-volume, analog and low-security data transmission and support voice service. In order to implement a high-end mobile commerce service, these networks need to be renovated to a third-generation (3G) or post-3G generation, in order to meet the requirements of high-speed, high-volume, digital and secure data transmission from high-end mobile commerce services. The existing voice-centric mobile phones are also replaced by the third (3G) terminals, which provide multiple functions such as an on-line browser, high-pixel screen display, e-wallet, identification, security, etc.

The different requirements between mobile telephony and a high-end mobile commerce service are listed in Table 5.3. In terms of network, the existing 1G, 2G and 2.5 G networks are sufficient to provide the analog voice service over the telephone. However, a high-end mobile commerce service needs the existing networks to be renovated to 3G or post-3G to meet high volumes of data transmission and security requirements. Terminals have to be improved to meet screen displays and specific functions required for high-end mobile commerce services. In terms of users, mobile telephony is aimed at the ordinary population. A high-end mobile commerce service is targeted towards a specific group of people rather than the ordinary population. Another difference is that mobile telephony is already in use but high-end mobile commerce services are not yet operational in China.

Despite the great differences between the mobile commerce services in their different stage of development, the developed model is still applicable to model and simulate the diffusion of these mobile commerce services in general. In order to calibrate the model for each specific mobile commerce service (for example, diffusion of voice telecommunication service over mobile phones), the range of values of the parameters in the model needs to be determined first and then narrowed down to specific values to simulate the diffusion of each service. The range of

Table 5.3: Differences between mobile commerce services

| Mobile commerce service | Differences | | | |
|---|---|---|---|---|
| | Network | Terminal | User | Existence |
| Mobile telephony | 1G, 2G, 2.5G, 2.75G, 3G, 4G | Mobile phone | Ordinary people | Already exists |
| High-end mobile commerce services | 3G or post 3G | Multi-functional terminal | Specific group of people | Not yet |

values of the parameters in the model are shown in Table 5.4.

Table 5.4: Range of values for parameters of model

| Variable | Value range | Variable | Value range |
|---|---|---|---|
| $T_0$ | $\geq 1995$ | $UPE_t$ | $[0, 1]$ |
| $T_f$ | $\geq 1995$ | $RPE_t$ | $[0, 1]$ |
| $\Delta T$ | $\leq 1$ | $UCR_t$ | $\geq 0$ |
| $IT_t$ | $(-\infty, +\infty)$ | $RCR_t$ | $\geq 0$ |
| $IUU_t$ | $\geq 0$ | $RUCR_t$ | $\geq 0$ |
| $IRU_t$ | $\geq 0$ | $UAF_t$ | $[0, 1]$ |
| $FPF_t$ | $[0, 1]$ | $RAF_t$ | $[0, 1]$ |
| $UEF_t$ | $[0, 1]$ | $RUAF_t$ | $[0, 1]$ |
| $REF_t$ | $[0, 1]$ | $UNC_t$ | $[0, 1]$ |
| $UDF_t$ | $[0, 1]$ | $RNC_t$ | $[0, 1]$ |
| $RDF_t$ | $[0, 1]$ | | |

The values of the parameters used in the base state (a state which produces the historical behaviour of the system and is extrapolated into the future) of mobile telephony diffusion are shown in Table 5.5. The following paragraphs provide an explanation of how the mobile commerce diffusion model for modelling the diffusion of mobile telephony services was calibrated.

Mobile phones have been used in China since the early 1980s, so the implementation time of mobile commerce service is before its start time in this simulation. The simulation covers the period from 1995 onwards. During this period, China has already developed a nationwide network for mobile phone users, so both urban network coverage ($UNC_t$) and rural network coverage ($RNC_t$ ) are assumed to be 1 (or 100%).

In 1995, China had $3.69 \times 10^6$ mobile phones[1]. It is assumed that this number of mobile phone users comes mainly from urban areas. Under this assumption, initial urban users ($IUU_t$) are set at $3.69 \times 10^6$ while initial rural users ($IRU_t$) are set at 0. China not only produces mobile phones for its own market but also exports worldwide (Kshetri et al. 2006), such that it is assumed that there can be no shortage of mobile phone provision during the simulation period. The diffusion model does not consider a possible shortage in the provision of mobile phones. Mobile phones in China are promoted as the 'people's phone (Kshetri & Cheung 2002) as ordinary people are targeted. There are no special requirements on the potential mobile phone users, so urban electronic commerce fraction ($UEF_t$) and rural electronic commerce fraction ($REF_t$) are all set to 1 (or 100%).

Mobile telephony is a mature service and it is assumed that the rate of discard is not high during the simulation period. Since there is almost no discard occurrence the urban discard fraction ($UDF_t$) and the rural discard fraction ($RDF_t$) are all set to zero. Since the effects from propaganda are small in comparison to the effects from WOM (especially after mobile phone diffusion passes its initial stage), propaganda is not taken into consideration. Urban propaganda effectiveness ($UPE_t$) and rural propaganda effectiveness ($RPE_t$) are all set to zero. Table 5.5 lists the values set for the parameters when calibrating the model for mobile telephony diffusion. The values used in calibrating the model for fitting historical data were rationally arrived at. For example, it is assumed that the adoption fraction in cities is much bigger than in countryside and both of them are still at a low level. Hence, the values of $UAF_t$ and $RAF_t$ were set at 0.015 and 0.005 to reproduce the historical behaviour.

The performance of the mobile commerce diffusion model was evaluated by comparing the output generated by the model with the historical data on Chinese mobile phone users. Table 5.6 lists the actual mobile phone users and the simulated results from 1995 to 2005. Figure 5.11 shows the plot of the historical data and the simulated values of mobile telephony subscribers.

[1] Available at the on-line database from the National Bureau of Statistics of China (http://www.stats.gov.cn) and the Ministry of Information Industry (http://www.mii.gov.cn)

Table 5.5: Values for parameters used to simulate mobile telephony service diffusion

| Variable | Value | Variable | Value |
|---|---|---|---|
| $T_0$ | 1995 | $UPE_t$ | 0 |
| $T_f$ | 2045 | $RPE_t$ | 0 |
| $\Delta T$ | 1 | $UCR_t$ | 65 |
| $IT_t$ | Before 1995 | $RCR_t$ | 30 |
| $IUU_t$ | $3.69 \times 10^6$ | $RUCR_t$ | 30 |
| $IRU_t$ | 0 | $UAF_t$ | 0.015 |
| $FPF_t$ | 1/5 | $RAF_t$ | 0.005 |
| $UEF_t$ | 1 | $RUAF_t$ | 0.01 |
| $REF_t$ | 1 | $UNC_t$ | 1 |
| $UDF_t$ | 0 | $RNC_t$ | 1 |
| $RDF_t$ | 0 | | |

Table 5.6: Actual versus simulated number of mobile phone users

| Time (year) | Actual number of subscribers[a] | Simulated number of subscribers |
|---|---|---|
| 1995 | 3,629,000 | 3,629,000 |
| 1996 | 6,853,000 | 7,729,000 |
| 1997 | 13,233,000 | 15,433,000 |
| 1998 | 23,860,000 | 29,298,000 |
| 1999 | 43,300,000 | 52,867,000 |
| 2000 | 84,530,000 | 89,907,000 |
| 2001 | 144,812,000 | 142,272,000 |
| 2002 | 206,616,000 | 207,297,000 |
| 2003 | 268,693,000 | 277,649,000 |
| 2004 | 334,824,000 | 34,5176,000 |
| 2005 | 393,428,000 | 405,167,000 |

[a] Available from http://www.mii.gov.cn or http://www.stats.gov.cn

It can be seen that the simulated data closely follows the historical data.

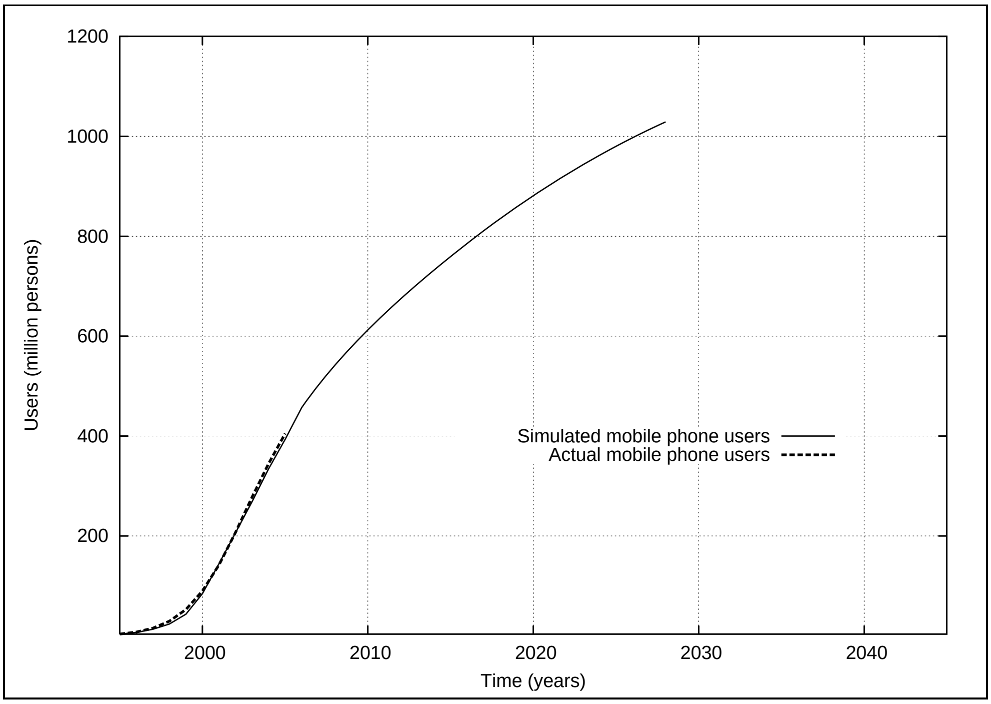


Figure 5.11: Actual versus simulated mobile telephony diffusion

As a form of mobile commerce service, mobile telephony diffusion fits historical data very well. Because most of the high-end mobile commerce services are not yet implemented in reality, it is impossible to collect sufficient historical data to validate this model for the diffusion of other mobile commerce services. However, considering the technology analogy (Thomas 1985, Ilonen, Kamarainen, Puumalainen, Sundqvist & Kalviainen 2006) and for the purpose of providing a general understanding (not accurate forecasting), the fitness of mobile phone diffusion will greatly enhance the reliability of using this developed model to simulate the general behavior of mobile commerce diffusion in its high-end spectrum as long as the model is reasonably calibrated with the values confined in Table 5.4.

## 5.6 Base case behaviour

After the mobile commerce diffusion model has been successfully calibrated by reproducing the diffusion of mobile phone diffusion in China, it is assumed that it can be used to explore the diffusion of other mobile commerce services such as high-level mobile commerce services.

An understanding of the diffusion of a high-end mobile commerce service can be obtained by manipulating the parameters whose range of possible values are shown in Table 5.4. Table 5.7 shows the actual parameters used for the base state of a simulation model for high-end mobile commerce services. For convenience, hereafter all high-end mobile commerce (service) is simplified as mobile commerce (service).

Table 5.7: Value of parameters used in a base state of mobile commerce service diffusion

| Parameter | Base value | Parameter | Base value |
|---|---|---|---|
| $T_0$ | 2010 | $UPE_t$ | 0.05 |
| $T_f$ | 2060 | $RPE_t$ | 0.01 |
| $\Delta T$ | 1 | $UCR_t$ | 60 |
| $IT_t$ | 2010 | $RCR_t$ | 30 |
| $IUU_t$ | $5.0 \times 10^5$ | $RUCR_t$ | 40 |
| $IRU_t$ | $5.0 \times 10^5$ | $UAF_t$ | 0.03 |
| $FPF_t$ | 1/5 | $RAF_t$ | 0.01 |
| $UEF_t$ | 0.1 | $RUAF_t$ | 0.02 |
| $REF_t$ | 0.05 | $UNC_t$ | 0.2 |
| $UDF_t$ | 0.05 | $RNC_t$ | 0.1 |
| $RDF_t$ | 0.1 | | |

Unlike mobile telephony, which has already been implemented, mobile commerce is not yet in use. A base state of mobile commerce diffusion is based on reasonable assumptions, as shown in Table 5.7. Mobile commerce is presumably to be implemented in 2010. As a campaign, 500000 mobile commerce users are initiated, which will be acting as early adopters. Mobile commerce will diffuse among the electronic commerce users. The fraction of electronic commerce users, discard rate, propaganda effectiveness, contact rate, adoption rate and network coverage in the urban areas are greater those rural areas. Their values are listed in Table 5.7. In comparison with mobile telephony (see Table 5.5), the calibration for the base state of mobile commerce diffusion has following implications. The implementation will occur in future. Mobile telephony diffuses among total population but mobile commerce diffuse among electronic commerce users. In addition, mobile commerce diffusion will be constrained by renovated network coverage, which supports mobile commerce, and influenced by propaganda campaign. Mobile commerce diffusion also incurs higher discard rate and adoption fraction among its potential users.

### 5.6.1 Number of users

Simulation of the base case scenario shows that the course of mobile commerce diffusion follows a quasi-s-shape explosion as depicted in Figure 5.12. The evolution of the number of mobile commerce users shows a remarkable development in the first 40 years, from an initial value of one million in the implementation year (2010) to an equilibrium value of 96 million in the final year when the diffusion stops.

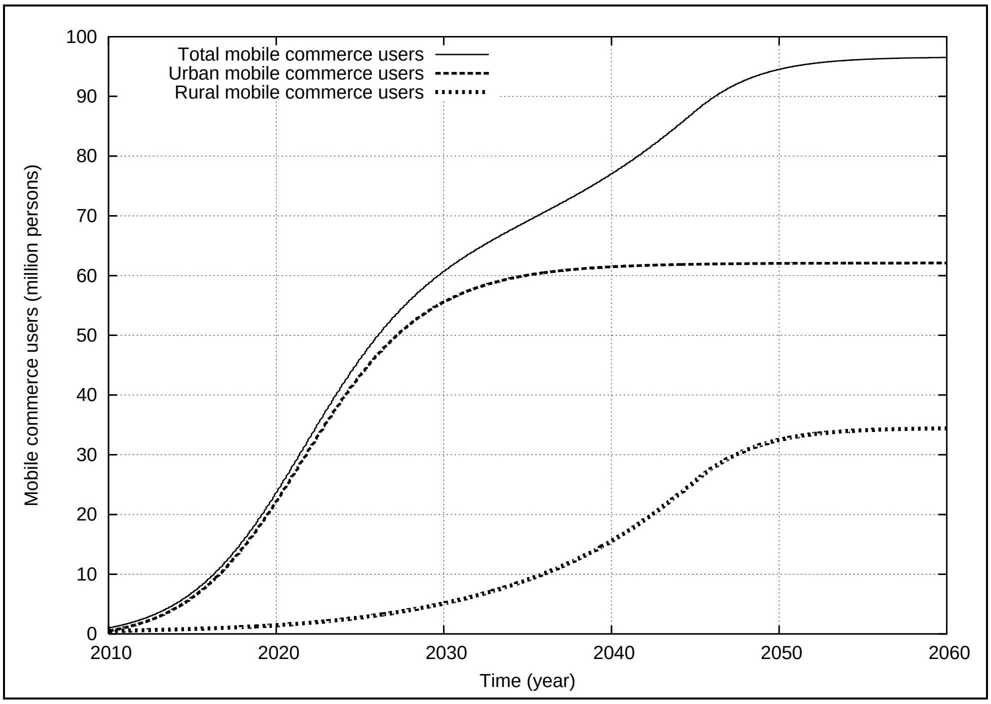


Figure 5.12: Number of mobile commerce users

The total number of mobile commerce users is determined by the urban and rural diffusion behaviours, both of which demonstrate an s-shape expansion like the total diffusion. The diffusion of urban mobile commerce users takes place at a fast pace in the first twenty years, and the diffusion of rural mobile commerce users takes place at a fast pace in the second twenty years, during a fifty-year period from 2010 to 2060. As shown in Figure 5.12, the number of urban mobile commerce users starts from an initial value of half a million in 2010 and increases to a value of 62 million before stopping. The progression of rural mobile commerce users shows a slow expansion in comparison with its urban counterpart from an initial value of half a million in 2010 to a final equilibrium value of 34 million.

### 5.6.2 Annual increase in mobile commerce users

Annual increase of mobile commerce users is an indicator adopted in measuring the rate of market expansion. The simulated annual increase in mobile commerce users is shown in Figure 5.13. The curve shows a dynamic wave with two crests and one trough. The first highest point occurs in 2022, or 12 years after the implementation time of this mobile commerce service at a maximum speed value of 4.68 million new users per year. The second culminating point appears in 2045, or 35 years after the implementation year at a speed value of 2.35 million new users per year. The trough appears in the year 2035 at a value of 1.48 million new users per year.

The increase in the total number of mobile commerce users is the sum of the urban and rural components. The curve of the annual increase in urban mobile commerce users follows a symmetrical bell-shape. The maximum increase in urban users occurs in the year 2022, with a value of 4.56 million users per year, which contributes to the first crest in the increase in the total number of users. In comparison, the curve of the increase in annual rural mobile commerce users displays a right-skewed bell-shape. The maximum increase in rural users occurs in the year 2040 with a value of 2.31 million users per year. This contributes to the second crest in the increase in the number of total users. The trough in the increase in the number of total users is formed by the declined increase in the number of urban users and the slow increase in the number of rural users.

Since there are ups and downs in the evolution of the annual increase of the total mobile commerce users, the market expansion will experience five stages in general. Stage one, called market expansion, occurs from the beginning of implementation to the first climax. During this stage, the increase in the number of users will experience its first explosion by growing at an accelerated speed. Expansion comes mainly from the urban side.

Stage two, named market consolidation, covers the period from the first climax to the trough. Within this stage, the number of users will further expand but at a decelerated speed and will eventually slow down. The expansion comes from the decreasing urban market expansion and the increasing rural market expansion. However, the increase from the rural side cannot offset the decrease, and this causes the total market to expand at a decelerated speed.

Stage three, called market re-expansion, occurs in the period from the trough to the second climax. During this stage, the mobile commerce market will explode again at an accelerated speed. This stage is similar to stage one, with the difference being that the expansion now comes mainly from the rural market. The urban market becomes saturated and market expansion in the urban area completely stops.

Stage four, called market reconsolidation, starts from the second climax to the point at which the increase in the number of users becomes zero for the first time. In this stage, the number of users will further expand but at a decelerated speed and will eventually slow down. As in stage two, the market is further expanded and consolidated for the second time. During this period, the expansion and consolidation comes mainly from the rural side.

After stage four, market expansion enters a final stage of market saturation. As Figure 5.13 shows, during this stage the total, urban and rural increase in users become zero. It means that the total, urban and rural markets become saturated and enter a stable state. It signals the end of the market expansion of mobile commerce user in China.

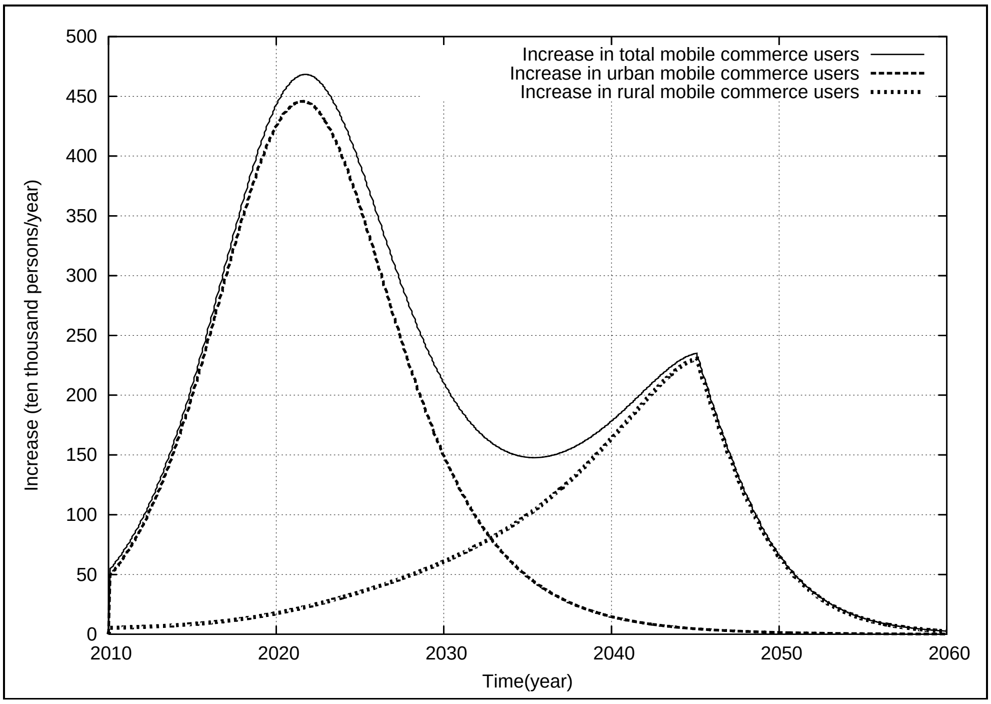


Figure 5.13: Annual increase in mobile commerce users

### 5.6.3 Proportion of users

User proportion is another indicator used for measuring the change in market structure. The analysis of the market in terms of its structure can help obtain useful business implications arising from changes in the market. In the model, the mobile commerce market is segmented into an urban and a rural submarket. During the various stages of the evolution of the market, the composition of the total market will constantly change. Experiments find that market restructuring will experience different stages during its simulation period. Figure 5.14 shows the change in proportion of users occurring between the urban and rural markets. The change of user proportion can be divided into three stages.

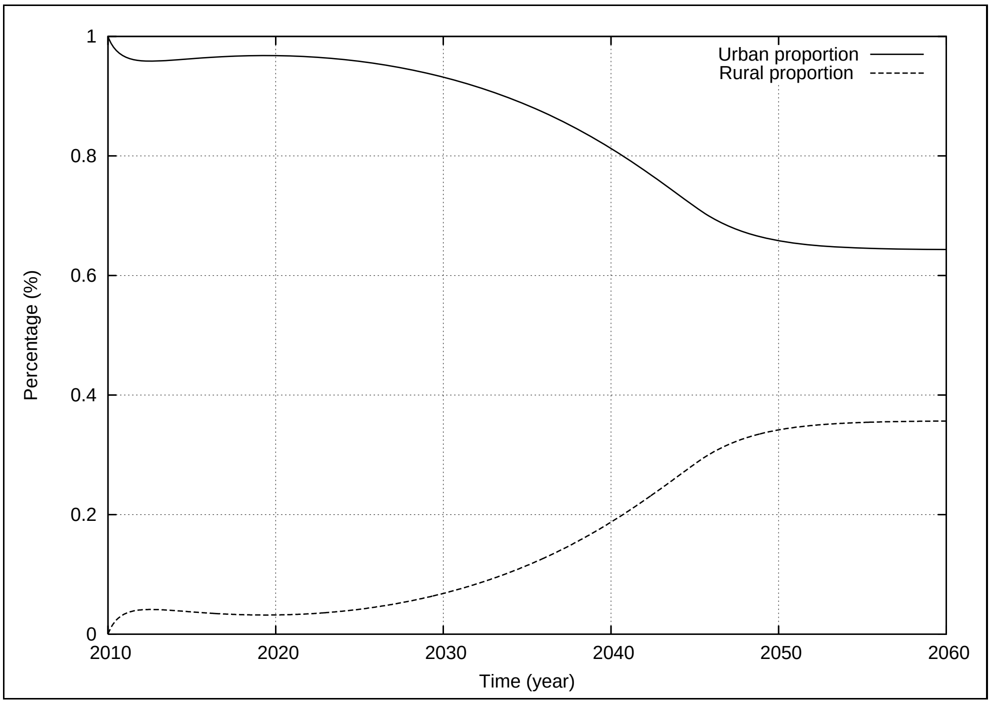


Figure 5.14: Proportion of mobile commerce users

Stage one, called urban dominance, roughly covers the first 20 years. The main characteristic of this stage is that the urban submarket dominates the whole market. In this time span, the urban submarket contributes to over 90% of the total market as shown in Figure 5.14.

Stage two, called the rural take-off, occurs when the urban proportion decreases and the rural proportion increases. The rural submarket gradually gets its weight in the total market fraction. This stage starts from the point at which the urban (or rural) proportion starts to decline (or increase) to the point at which both of them start to level off. The market share of the urban submarket decreases from an initial value of over 90% in 2030 to 65% in 2050 and finally stabilizes at 65%. On the other hand, the market share of the rural submarket increases from an initial value of less than 10 % in 2030 to 36% in 2050 and finally reaches 35%.

Stage three denotes a stable stage. As illustrated in Figure 5.14, the urban submarket retains a constant market share of 65% while the rural market has a share of 35%.

The structural changes of the market will have the following business implications. During stage one, it is more advantageous to tailor marketing activities for the urban submarket. Marketing strategies relating to placing, promotion, positioning and pricing of mobile commerce terminals and services should be urban-oriented. Losses might be encountered if marketing strategies focus too much on the rural submarket.

In stage two, the focus of marketing strategies has to change from the urban to the rural area. On the one hand, the urban submarket has been saturated and the potential of the urban submarket has been fully exploited. On the other hand, the rural submarket is emerging and its potential needs to be exploited. Efforts targeted towards the rural area will thus be more effective than the urban area. Early business entrants, in addition to sustaining the existing urban submarket, which was formed in stage one, should waste no time in penetrating the rural submarket concurrently. For new business entrants, the rural area is the gold rush opportunity.

In stage three, both the urban and rural submarkets have obtained maximum penetration. Strategically, this period is not the right time for new entrants to penetrate the already occupied territory. However, existing businesses should protect themselves from the threat of new entrants by increasing the total threshold cost of market entry. Existing businesses can gain more market share from their competitors by providing more attractive mobile commerce services to customers.

## 5.7 Sensitivity analysis

A high-end mobile commerce diffusion is more dynamic than mobile telephony. A high-end mobile commerce needs advanced networks, terminals and knowledgeable users. All these factors will shape the uncertain future of the diffusion of the mobile commerce service. These uncertainties may come from the implementation time, the development of the network, the discard situation, propaganda, e-commerce penetration levels, adoption rates, the floating population fraction, contact rates, demographic change and terminal provision (terminal provision will be discussed in chapter 7). In order to examine the effects of these uncertainties on mobile commerce diffusion, sensitivity experiments are designed and the sensitivities arising from these uncertain variables are analysed.

### 5.7.1 Design of sensitivity experiments

Based on the base case behaviours, eight indicators are selected to measure the behaviours of mobile commerce diffusion. These indicators include: urban mobile commerce users in equilibrium ($UU_e$); rural mobile commerce users in equilibrium ($RU_e$); maximum urban mobile commerce user increase ($UUI_m$); maximum rural mobile commerce user increase ($RUI_m$); time taken to maximum urban mobile commerce user increase ($UUIT_m$); time taken to maximum rural mobile commerce user increase ($RUIT_m$); maximum urban proportion ($UP_m$) and urban proportion in equilibrium ($UP_e$).

In order to design the sensitivity experiments, the range of variation of the parameters involved is first determined. Table 5.8 lists the values used in the sensitivity analysis. Each parameter is increased/decreased by 20% from its value in the base case to examine the outcomes of the indicators.

### 5.7.2 Findings of sensitivity analysis

The results of sensitivity tests are summarised in Appendix D while Table 5.9 lists the factors of the model identified as sensitive and the degree of their sensitivity to the performance indicators. An asterisk (*) in a cell of Table 5.9 is used to show that the factor specified in that row of the table is sensitive to the indicator specified in the column of the table. The more asterisks a factor has, the more sensitive the model is.

In Table 5.9, the sensitive factors are also grouped and classified into categories. The implementation timing category, $IT_t$, which denotes when the mobile commerce service will be put into use, is one of the most sensitive factors. It influences the level of urban users in equilibrium, the

Table 5.8: Sensitivity experiment design

| Parameters | Base value | Increase (20%) | Decrease (20%) | Parameters | Base value | Increase (20%) | Decrease (20%) |
|---|---|---|---|---|---|---|---|
| $T_0$ | 2010 | 2013 | 2007 | $RCR_t$ | 30 | 36 | 24 |
| $T_f$ | 2060 | N/A | N/A | $RUCR_t$ | 40 | 48 | 32 |
| $\Delta T$ | 1 | N/A | N/A | $UAF_t$ | 0.03 | 0.036 | 0.024 |
| $IT_t$ | 2010 | 2013 | 2007 | $RAF_t$ | 0.01 | 0.012 | 0.008 |
| $IUU_t$ | $5.0 \times 10^5$ | $6.0 \times 10^5$ | $4.0 \times 10^5$ | $RUAF_t$ | 0.02 | 0.024 | 0.016 |
| $IRU_t$ | $5.0 \times 10^5$ | $6.0 \times 10^5$ | $4.0 \times 10^5$ | $UNC_t$ | 0.2 | 0.24 | 0.16 |
| $FPF_t$ | 0.2 | 0.24 | 0.16 | $RNC_t$ | 0.1 | 0.12 | 0.08 |
| $UEF_t$ | 0.1 | 0.12 | 0.08 | $UI_t$ [a] | 1.44% | 1.73% | 1.15% |
| $REF_t$ | 0.05 | 0.06 | 0.04 | $UF_t$ | 1.20 | 1.44 | 0.96 |
| $UDF_t$ | 0.05 | 0.06 | 0.04 | $RF_t$ | 3.60 | 4.32 | 2.88 |
| $RDF_t$ | 0.1 | 0.12 | 0.08 | $ULE_t$ | 71 | 85 | 57 |
| $UPE_t$ | 0.05 | 0.06 | 0.04 | $RLE_t$ | 68 | 82 | 54 |
| $RPE_t$ | 0.01 | 0.012 | 0.008 | $UAWB(t,i)$ | 28, 31 | 34, 37 | 22, 25 |
| $UCR_t$ | 60 | 72 | 48 | $RAWB(t,i)$ | 22, 25 | 26, 30 | 18, 20 |
| | | | | | 28, 31 | 34, 37 | 22, 25 |

[a] $UI_t, RF_t, ULE_t, RLE_t, UAWB(t,i)$ and $RAWB(t,i)$ are from the population model created in chapter 4

maximum value of the increase in urban users and the time taken to reach the maximum value of the increase in rural users. Factors $IUU_t$, $IRU_t$, $UPE_t$ and $RPE_t$, which belong to the market start-up group, are not sensitive. $FPF_t$ is sensitive and influences the increase in rural users. Within the e-commerce penetration category, $UEF_t$ and $REF_t$ are sensitive and respectively influence the number of users in equilibrium, the increase in users and the proportion of users.

$UDF_t$ and $RDF_t$, from the discard category, are not sensitive. In the contact category, $UCR_t$, $RCR_t$ and $RUCR_t$ are sensitive. They are sensitive by influencing the increase in urban and rural users. In the acceptance category, $UAF_t$ is sensitive but $RAF_t$ and $RUAF_t$ are not. The network coverage factors $UNC_t$ and $RNC_t$ are sensitive to user increase in the urban and rural areas respectively. $UNC_t$ also influences the increase in rural users.

The sensitive factors in the population model have the following characteristics. In the urbanisation area, urbanisation increase ($UI_t$) will significantly influence mobile commerce diffusion in

Table 5.9: Summary of sensitive factors

| | $UU_e$ | $RU_e$ | $UUI_m$ | $UUIT_m$ | $RUI_m$ | $RUIT_m$ | $UP_m$ | $UP_e$ | Classification |
|---|---|---|---|---|---|---|---|---|---|
| $IT_t$ | *[a] | | ** | | | * | | | Implementation timing |
| $IUU_t$ | | | | | | | | | Market startup |
| $IRU_t$ | | | | | | | | | Market startup |
| $UPE_t$ | | | | | | | | | Market startup |
| $RPE_t$ | | | | | | | | | Market startup |
| $FPF_t$ | | | | | * | | | | Floating population |
| $UEF_t$ | *** | | *** | | * | | | * | E-commerce level |
| $REF_t$ | | ** | * | | *** | | | * | E-commerce level |
| $UDF_t$ | | | | | | | | | Discard |
| $RDF_t$ | | | | | | | | | Discard |
| $UCR_t$ | | | *** | ** | | | | | Contact |
| $RCR_t$ | | | | | * | | | | Contact |
| $RUCR_t$ | | | | | * | | | | Contact |
| $UAF_t$ | | | *** | ** | | | | | Acceptance |
| $RAF_t$ | | | | | | | | | Acceptance |
| $RUAF_t$ | | | | | | | | | Acceptance |
| $UNC_t$ | | | *** | ** | ** | | | | Network |
| $RNC_t$ | | | | | ** | * | | | Network |
| Variables from population model | | | | | | | | | |
| $UI_t$[b] | | | * | | **** | ** | | | urbanisation |
| $UF_t$ | | | | | * | | | | Family planning |
| $UAWB(t,i)$ | | | * | | | | | | Family planning |
| $RF_t$ | | | | | | * | | | Family planning |
| $RAWB(t,i)$ | | | | | | | | | Family planning |
| $ULE_t$ | | | | | * | | | | Life quality |
| $RLE_t$ | | | | | | | | | Life quality |

[a] *, ** and *** denote change within $[5\%, 10\%)$, $[10\%, 20\%)$ and $[20\%, +\infty)$ respectively

[b] simulation period is within 31 years

terms of an increase in users and the time taken to reach a maximum increase in rural users. In the family planning category, there are four factors: $UF_t$, $UAWB(t,i)$, $RF_t$ and $RAWB(t,i)$. The former three are sensitive by influencing the increase in urban and rural users and the time taken to reach a maximum increase in rural users. In the life quality category, only $ULE_t$ will influence the increase in rural users.

The findings from the sensitivity analysis have two practical meanings. First, they provide the evidence for simulation analysis described in the next section. For example, the sensitivity analysis of the factors from the population model provides the evidence for experimenting on mobile commerce diffusion under the urbanisation scenarios. Second, it provides guidance for more accurate exploration of the sensitive variables for future research.

## 5.8 Scenario analysis

After having identified the factors that will significantly influence mobile commerce diffusion through sensitivity analysis, these factors are combined to form scenarios. Possible scenarios are designed and the consequences are analysed to determine business implications.

### 5.8.1 Implications from implementation timing

Sensitivity analysis found that the implementation time will significantly influence the behaviour of mobile commerce diffusion. In this section, the influence of implementation timing on market behaviours is determined. 1995, 2000, 2005, 2010, 2015, 2020, 2025, 2030 and 2035 are selected as the implementation times and their effects on mobile commerce diffusion are examined.

A delay in implementing the mobile commerce service will have the same effect on the total number of users and the number of urban users. The number of the total (or urban) mobile commerce users in equilibrium increases and the time to reach the maximum advances during the simulation period (see Figures 5.15 and 5.16). Initially the effects are significant. With further postponement of implementation, the influence decreases. Eventually, the plot of the total (or urban) number of users approaches a curve, as the one denoting ‘Implemented in 2035’ in Figure 5.15 (or the one denoting ‘Implemented in 2035’ in Figure 5.16). For example, if a mobile commerce service is implemented after 2030 this timing has no significant effect on the number of total (or urban) users. Under this situation, the evolution of the total (or urban) number of users is similar to that of 2030. However, the evolution of rural users behaves differently. With the postponement of the implementation time, the number of rural mobile commerce users in equilibrium decreases, and the time taken to reach the equilibrium moves ahead, as shown in Figure 5.17. During the simulation period, this influence is always significant.

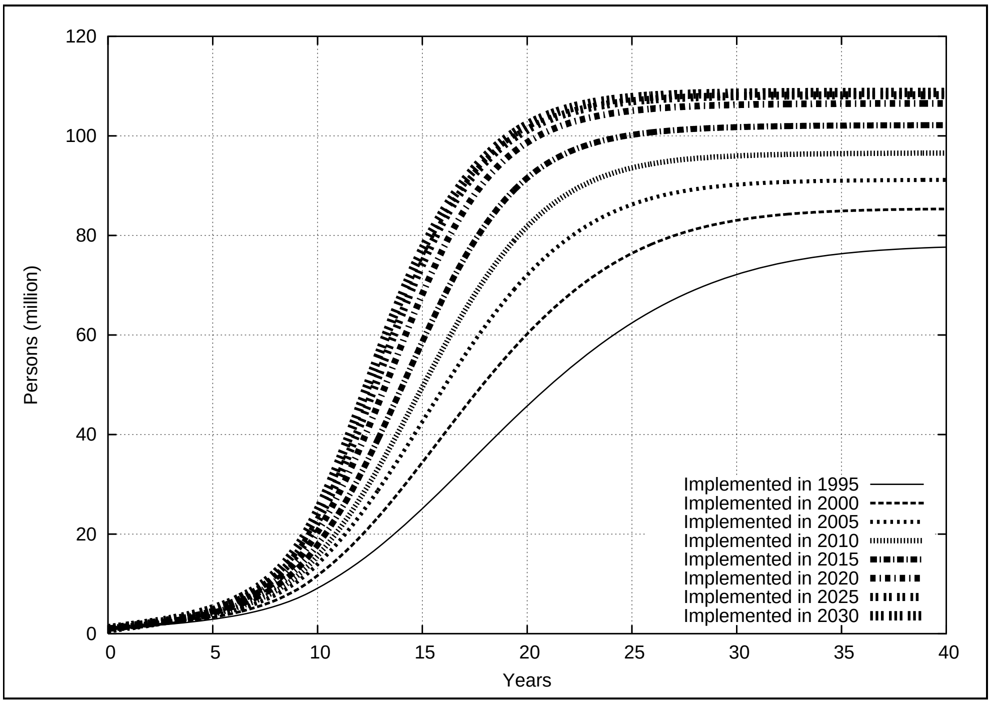


Figure 5.15: Total number of mobile commerce users

The curve of the annual increase in rural mobile commerce users is bell-shaped, as shown in Figure 5.18. The earlier mobile commerce is implemented, the more flattened the bell shape becomes and the nearer to the y-axis the crest of the bell shifts. This means that the later a mobile commerce service is implemented, the shorter will be the period for the rural market to become mature. The maximum value of the increase in the rural area under the implementation scenarios appears 13 years after a mobile commerce service is implemented in 2030. The time period under which a maximum rural increase occurs after a mobile commerce service is implemented is between 12 to 18 years.

The graph of the annual increase in urban users also follows a bell-shaped pattern, as displayed in Figure 5.19. The difference with the rural area is that all the graphs are symmetrical around a vertical line (*x=13*) parallel to the y-axis with a different maximum value. The earlier mobile

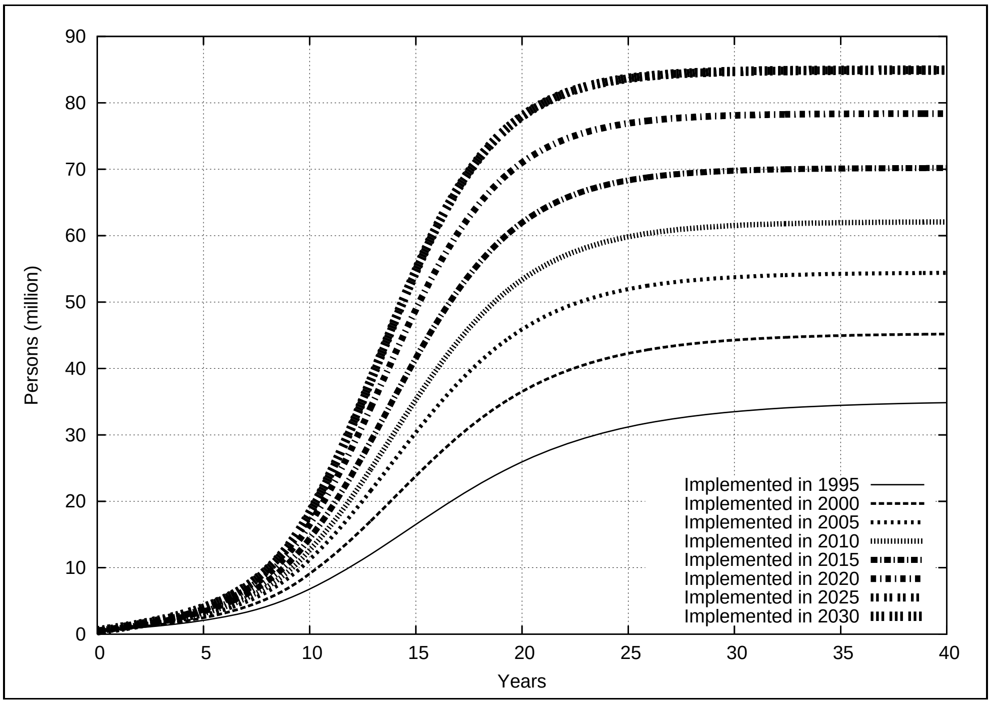


Figure 5.16: Number of urban mobile commerce users

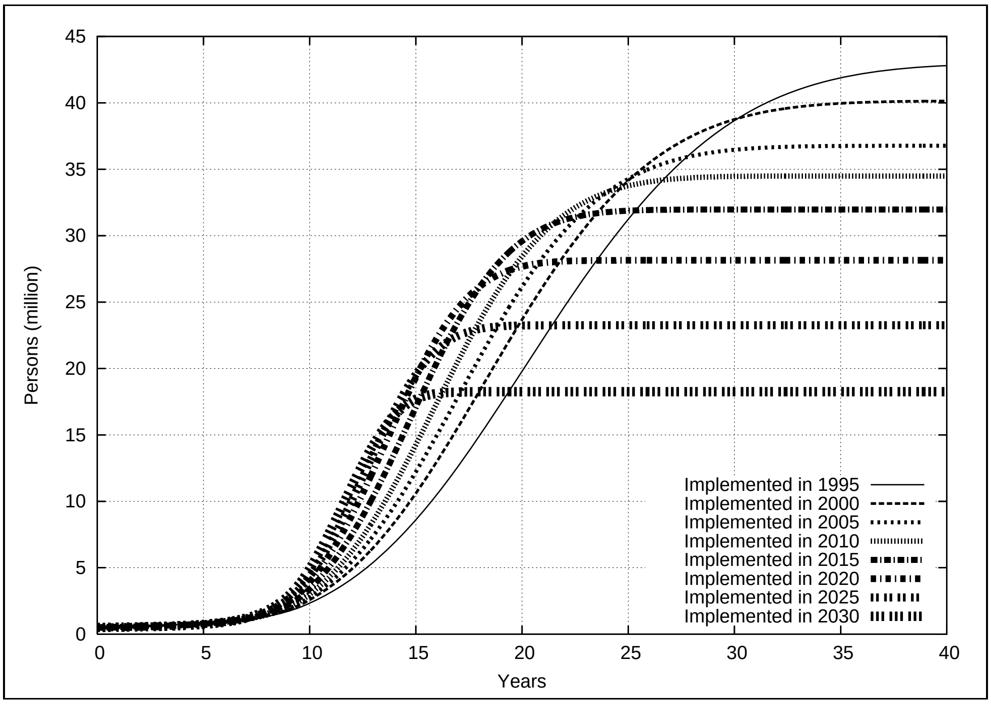


Figure 5.17: Number of rural mobile commerce users

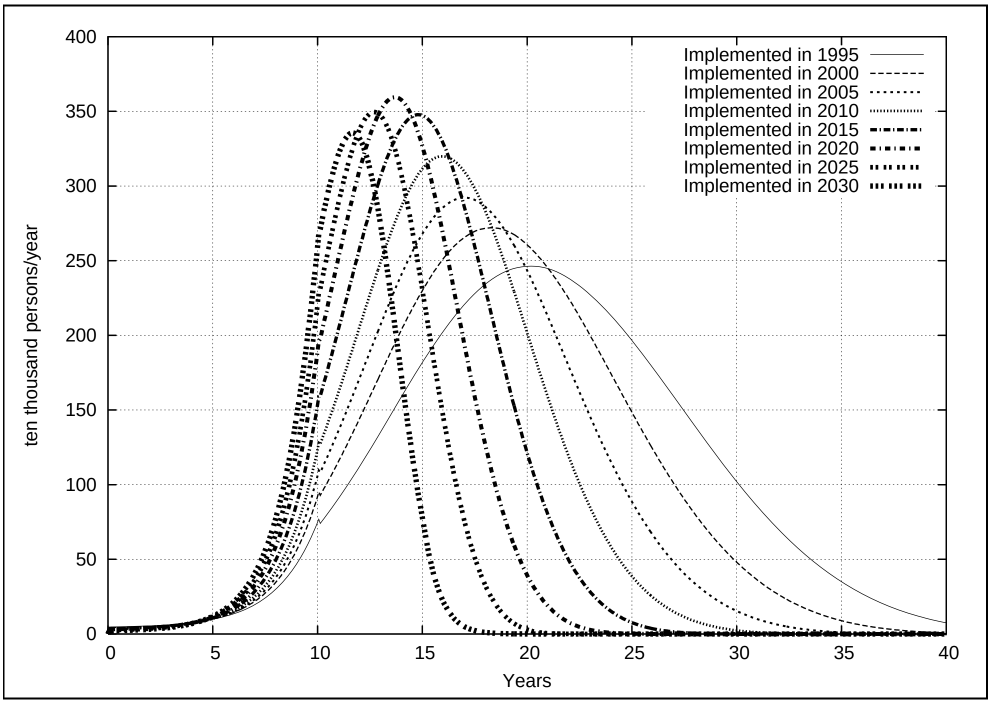


Figure 5.18: Annual increase in rural mobile commerce users

commerce is implemented, the more flattened the bell shape becomes. This means that no matter when a mobile commerce service is put in use, the time taken to reach a maximum level is the same. For example, in Figure 5.19 the time taken to reach a maximum urban increase occurs 13 years after the implementation of the service. For the urban market, the later a mobile commerce service is adopted, the stronger it will develop.

The annual increase in total mobile commerce users also follows a bell-shaped plot which is slightly left-skewed (see Figure 5.20). The earlier mobile commerce is implemented, the more flattened and more left-skewed the bell shape becomes. With a delay in implementation, the maximum value of total mobile commerce users increases. However, this increase is not significant when the delay is further increased. The maximum value of annual increase in total mobile commerce users is in the range of 48-118 million no matter when a service is implemented, and the time period in which the annual increase reaches its maximum is between 13 and 16 years after the implementation time.

As described in the base case behaviour analysis, the proportion of users between urban and rural areas will experience three stages: urban dominance, rural take-off and stability. With a delay in implementation, the curve becomes flattened. This means that the later the service is

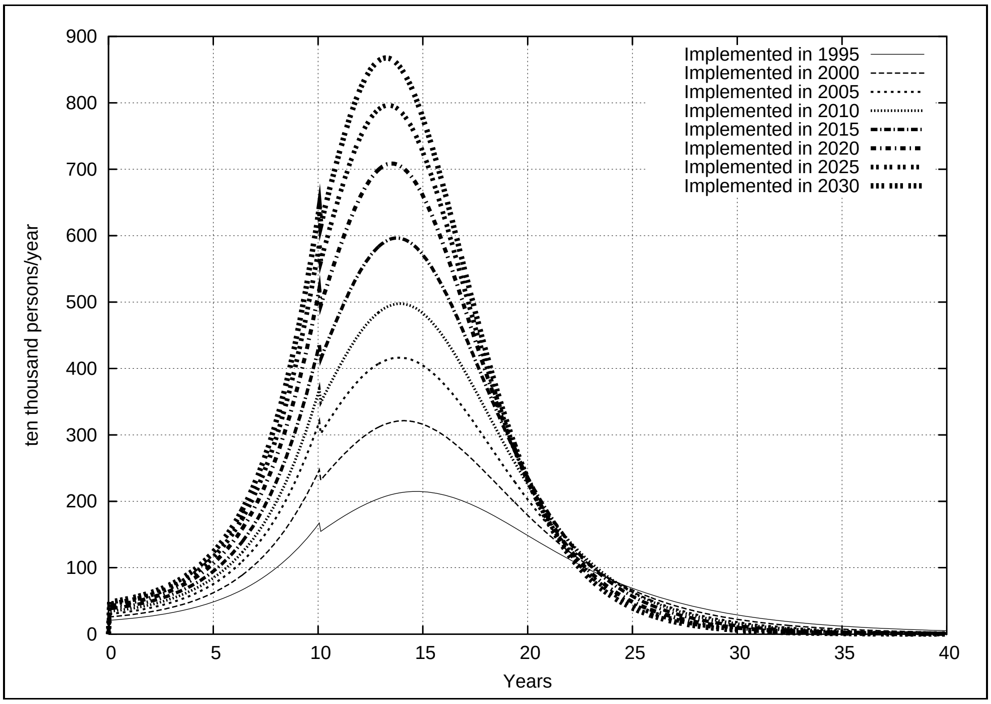


Figure 5.19: Annual increase in urban mobile commerce users

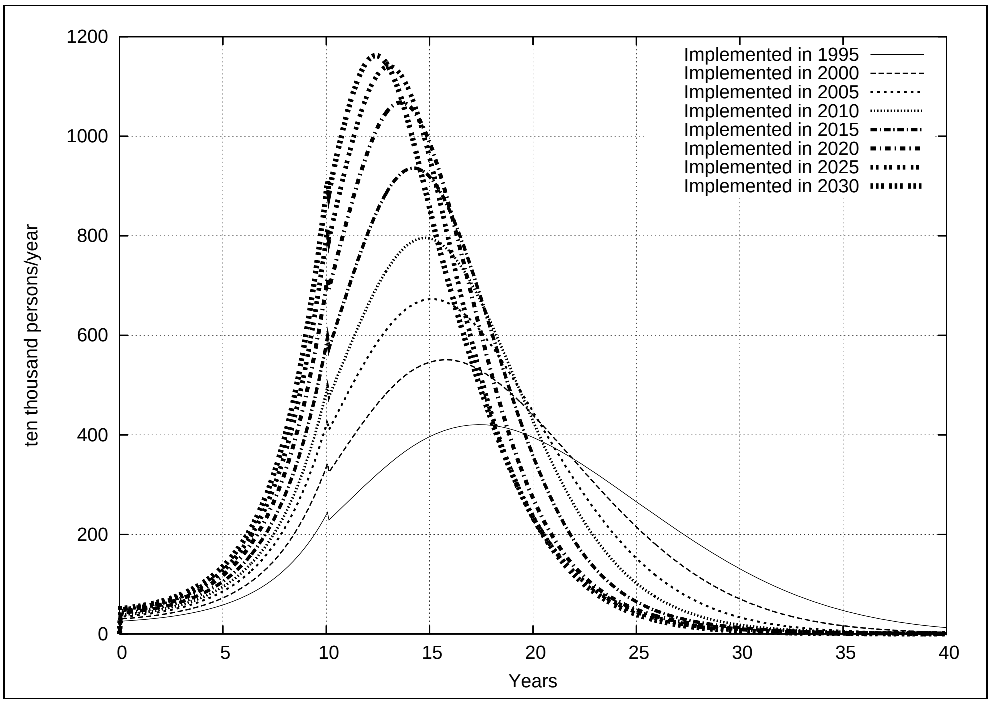


Figure 5.20: Annual increase in total mobile commerce users

implemented, the more weight the urban market gets. When the implementation time is later than 2030 the proportion of the rural market becomes very small. Under this situation, the urban market is the only focus of strategic planning. The rural market can be neglected during the simulation period.

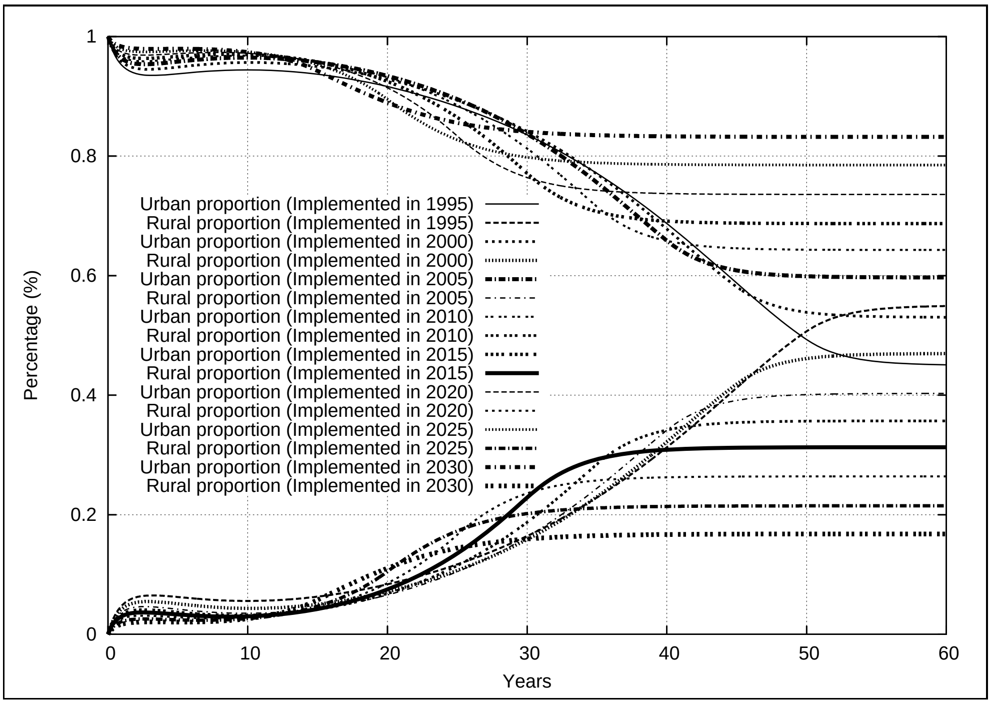


Figure 5.21: Proportion of mobile commerce users

### 5.8.2 Implications from the floating population

There exists a large amount of the population which moves around in China, which is a typical phenomenon in the process of industrialisation. The existence of a floating population implies an advantage to be manipulated in exploring the Chinese rural mobile commerce market.

To start up a new market, two methods can be used in practice. One method is called free-use, in which a certain number of potential users are selected and given priority to try the mobile commerce service for free. After a period of use, the service is accepted by the users and spreads around. Another method is advertising promotion, which uses advertisements to attract potential customers to try the service. Whichever method is adopted, a considerable amount of investment and effort is required in operation. Fortunately, simulation of the model demonstrates that the existence of a floating population can save financial resources in initiating a rural market in China.

The Chinese rural area is a huge potential market for mobile commerce. Cultivating this market is a big challenge when considering its low e-commerce penetration, large territory and the time it will take. To examine the effectiveness of the floating population in starting up the Chinese rural market, three scenarios (see Table 5.10)are simulated in this regard.

Table 5.10: Scenarios of floating population

| Scenarios | one | two | three |
|---|---|---|---|
| $FPF_t$ | 0.20 | 0 | 0 |
| $IRU_t$ | 1,000,000 | 0 | 5,000,000 |
| $RPE_t$ | 0 | 0.70 | 0 |

Scenario one recognises the existence of a floating population and assumes $FPF_t$ equals to 0.20. A free-use method is used. Simulation finds that only when the number of free mobile commerce users reaches a value of over one million that it generates a significant effect on the behaviour of rural mobile commerce diffusion. Otherwise it is a waste of money in the long run. This means that, with the existence of a floating population, free-use or advertising initiatives are not necessary. If these are adopted, their effects are not significant.

A second scenario assumes that there is no floating population. As a substitute, advertisement will be used to promote a mobile commerce service to penetrate the new market. Simulation of this scenario showed that, in order to obtain the same effects created by the existence of a floating population, marketers must launch advertising campaigns with an annual effectiveness of 70%. It is impossible to achieve an effectiveness of 70% from advertisement. Simulation finds that the existence of floating population is the most efficient and effective advertisement.

A third scenario also assumes that there is no floating population and requires that a certain amount of free mobile service be offered to the Chinese rural population in 2008. Experiments find that, to generate the equivalent effect of the existence of a floating population, about 5 million mobile commerce terminals have to be sent to targeted users as an initiative. If each mobile commerce terminal is priced at AUD $50, the direct cost of the terminal is $250 million.

As a suggestion, in practice strategy planners should carefully examine the effectiveness of a floating population before taking any action in initiating the rural mobile commerce market. If there is no floating population or there is no influence from this population, a free user or advertisement initiative is necessary. If there does exist a large proportion of floating population, any attempt in starting rural markets by providing free users or advertisement is worthless.

### 5.8.3 Implications from urbanisation

Sensitivity analysis finds, in addition to its influence on demographic dynamics as examined in chapter 4, that urbanisation is the most sensitive factor influencing mobile commerce diffusion from the population model. This section examines how mobile commerce behaves under the urbanisation scenarios listed in Table 4.14 of chapter 4.

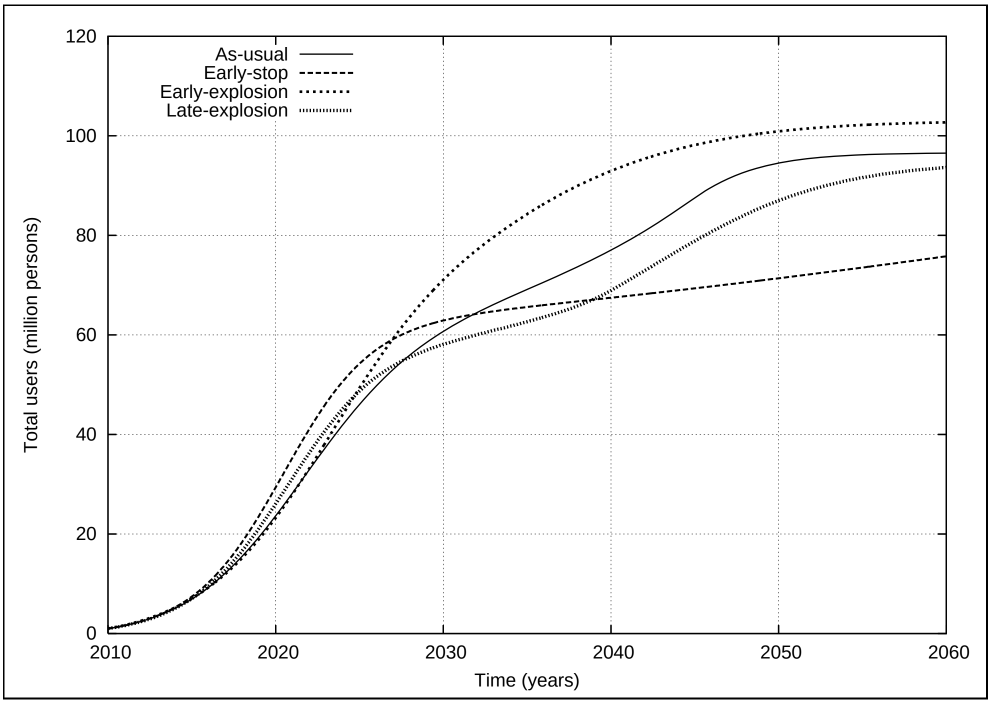


Figure 5.22: Total number of users under different urbanisation scenarios

Graphically, the curves for the total number of users under the early-stop and early-explosion urbanisation scenarios show an obvious s-shaped characteristic as depicted in Figure 5.22. The curve of the total number of users for the late-explosion scenario is very similar to the base

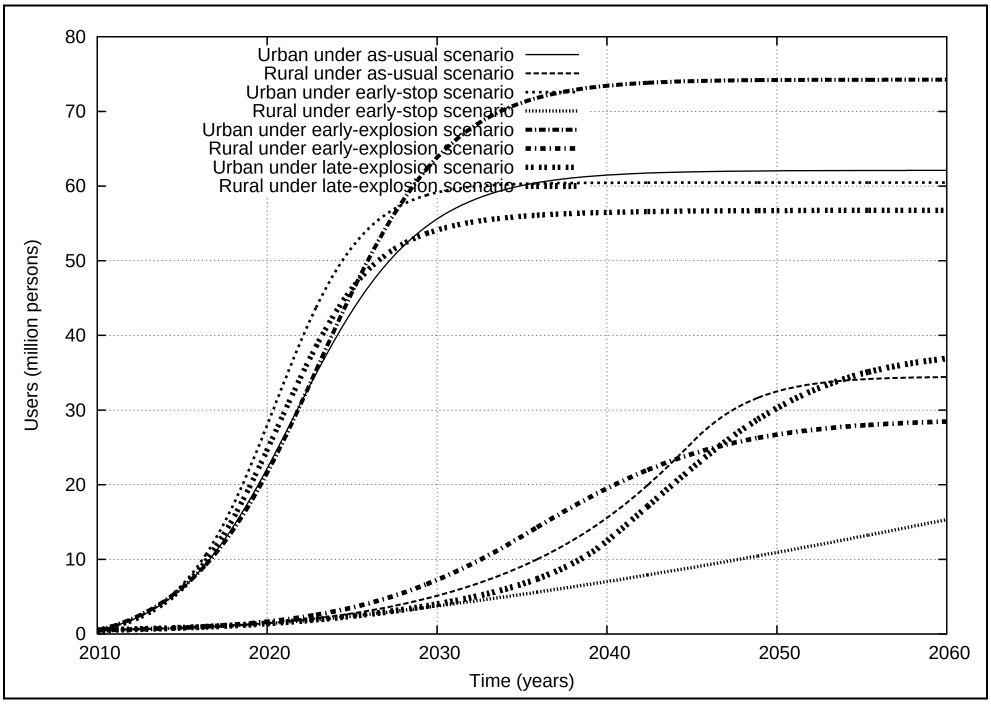


Figure 5.23: Number of urban and rural users under different urbanisation scenarios

case scenario which is a linear increase in the first forty years. The evolution of the urban and rural users are illustrated in Figure 5.23. Obviously, the diffusion of the urban user under the urbanisation scenarios all take an s-shape evolution. However, the evolution of the rural user is different. The diffusion of rural users under the early-stop scenario follows a linear increase during the simulation period while diffusion under the early-explosion and late-explosion urbanisation scenarios still follow a quasi-s-shaped development.

Compared with the base case, the early-explosion urbanisation scenario will greatly change the value of the total number of users, urban number of users and rural number of users to 102.71 million, 74.25 million and 28.46 million respectively, in the condition of equilibrium. This represents a 6.7% increase, 19.57% increase and 17.32% decrease respectively from the base case scenario (see Table 5.11). The opposite to an early-explosion urbanisation scenario, the early-stop urbanisation scenario will bring a low value to the total number of users and rural number of users to 75.80 million and 15.34 million respectively in the condition of equilibrium, a reduction of 21.47% and 55.43%. The influence on the urban number of users is not significant, the scenario only causing a 2.64% decline from the base case.

Under the late-explosion urbanisation scenario, the curve of the annual increase in total mobile

Table 5.11: Evaluation of mobile commerce diffusion under different urbanisation scenarios

| Indicators | As-usual (base case) | Early-stop (change) | Early–explosion (change) | Late-explosion (change) |
|---|---|---|---|---|
| $TU_e$ (million) | 96.52 | 75.80 (-21.47%) | 102.71 (6.41%) | 93.65 (-2.97%) |
| $UU_e$ (million) | 62.10 | 60.46 (-2.64%) | 74.25 (19.57%) | 56.76 (-8.60%) |
| $RU_e$ (million) | 34.42 | 15.34 (-55.43%) | 28.46 (-17.32%) | 36.89 (7.18%) |
| $UUI_m(\times 10^6)$ | 4.58 | 5.80 (26.64%) | 5.04 (10.04%) | 5.00 (9.17%) |
| $RUI_m(\times 10^6)$ | 2.31 | 0.46 (-80.09%) | 1.37 (-40.69%) | 1.99 (-13.85%) |
| $UUIT_m$ (years) | 11.56 | 10.44 (-9.69%) | 13.13 (13.58%) | 10.69 (-7.53%) |
| $RUIT_m$ (years) | 35.06 | 50 (42.61%) | 25.06 (-28.52%) | 32.69 (-6.76%) |
| $UP_m$ (%) | 94.30 | 95.80 (1.59%) | 93.20 (-1.17%) | 95.20 (0.95%) |
| $UP_e$ (%) | 64.30 | 79.80 (24.11%) | 72.3 (12.44%) | 60.60 (-5.75%) |

commerce users shows a dynamic wave with two crests and one trough as in the base scenario. The difference is that the values of the peaks and troughs are higher than for the base case. As shown in Figure 5.24, the five stages of market development analysed in the base scenario are more obvious under the late-explosion urbanisation scenario. Under the early-stop and early-explosion urbanisation scenarios, the curve of the annual increase in the number of total mobile commerce users is a left-skewed bell-shaped curve. There is no sign of the five-stage market development pattern as displayed in the base scenario.

The curves of the annual increase in urban mobile commerce users under the urbanisation scenarios are bell-shaped, as shown in Figure 5.25. As listed in Table 5.11, the maximum values of annual increase in urban users under the early-stop, early-explosion and late-explosion scenarios are greater at 5.80 million per year, 5.04 million per year and 5.00 million per year. These represent an increase of a 26.64%, 10.04% and 9.17% respectively from the 4.58 million per year in the base scenario (see Table 5.11). There is no big difference among the times taken to reach these maximum values, and they all fall in the period from 2020 to 2024 or from 10 to 14 years after the implementation of the service.

The annual increase in rural users under the early-stop urbanisation scenario takes a linear increase, as shown in Figure 5.25. There is no extreme value appearing within the simulation period. The annual increase in rural users for the early-explosion and late-explosion urbanisation scenarios are bell-shaped. The maximum values of the annual increase in rural users under

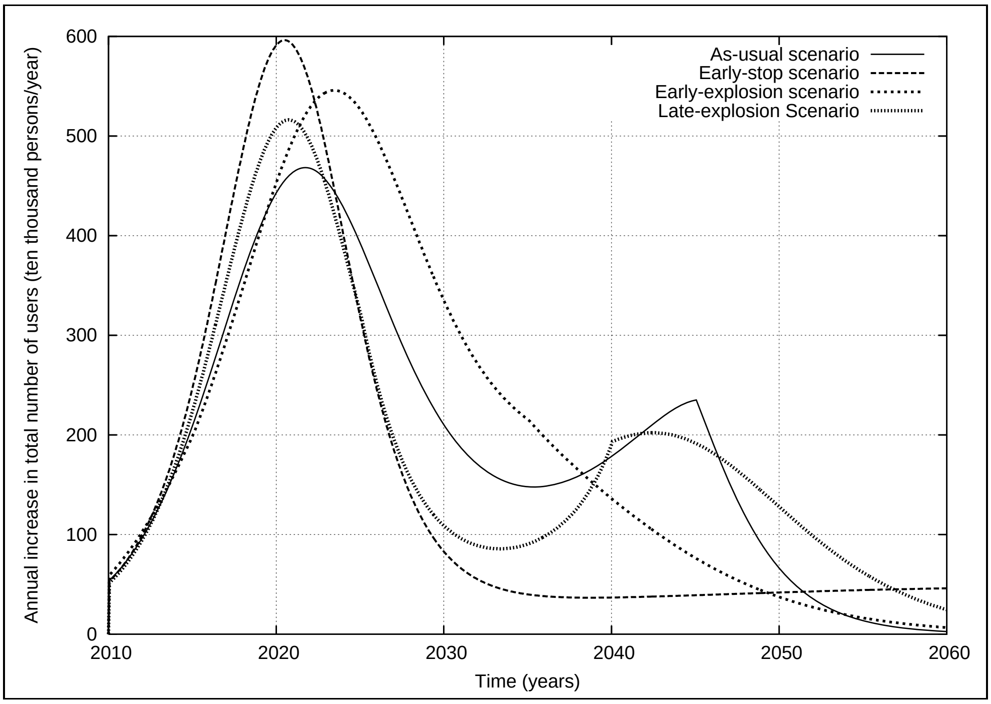


Figure 5.24: Annual increase in number of total users under different urbanisation scenarios

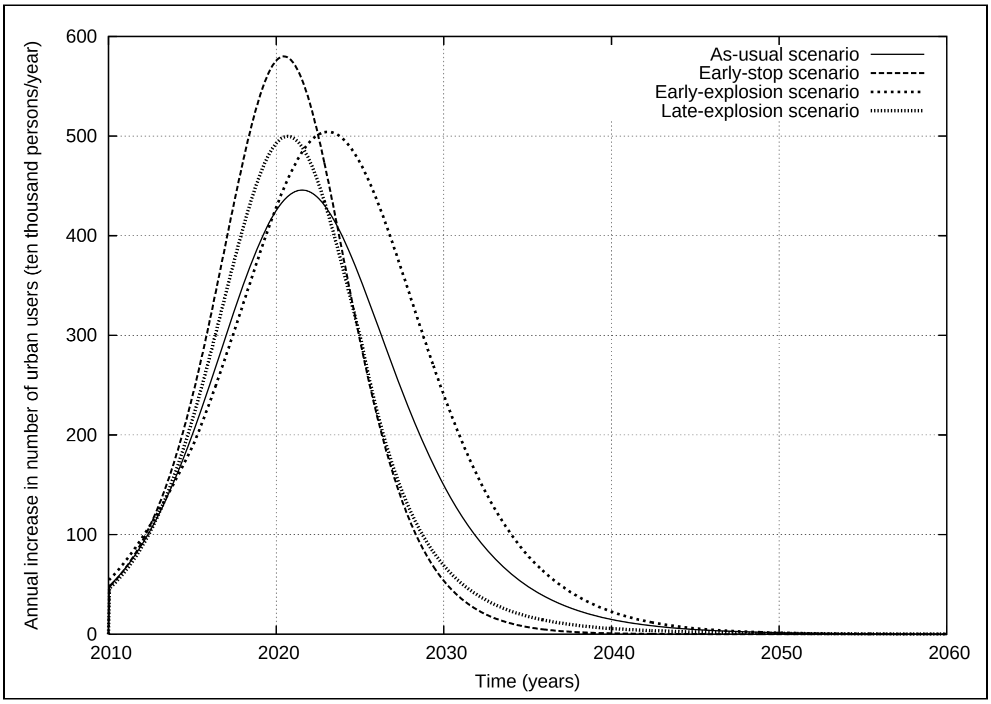


Figure 5.25: Annual increase in number of urban users under different urbanisation scenarios

the early-explosion and late-explosion urbanisation scenarios are at 1.37 million per year and 1.99 million per year respectively, a 40.69% and 13.85% decline from the 2.31 million per year in the base scenario, as shown in Table 5.11. The times taken to reach these maximum values are up to the year 2036 (25.06 years after implementation) and 2043 (32.69 years after implementation). These represent roughly 10 and 2 years earlier than the period to the year 2046 (35.06 years after implementation) of the base scenario.

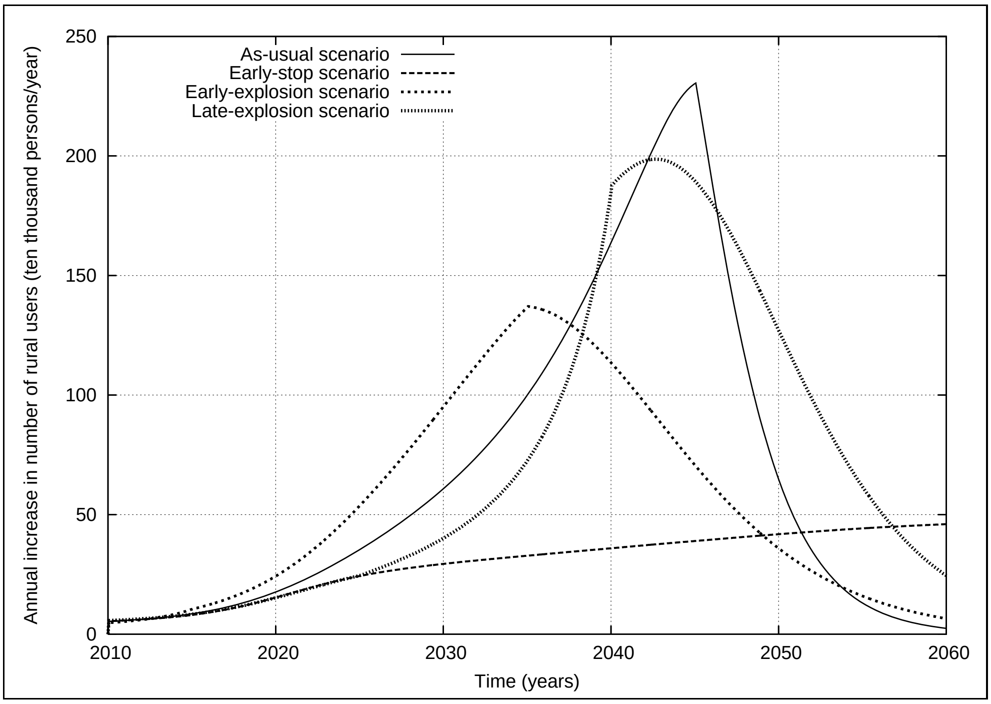


Figure 5.26: Annual increase in number of rural users under different urbanisation scenarios

As shown in Figure 5.27, the proportions under the different urbanisation scenarios are stable in the first 20 years but change afterwards. The evolution of proportions under the late-explosion urbanisation scenario follows the same course as in the base case scenario. The urban proportions for the base case scenario and the late-explosion urbanisation scenarios are around 60% at the equilibrium level. The urban proportions under the early-stop and the early-explosion urbanisation scenarios are much greater than in the base case scenario. As listed in Table 5.11, the urban proportion under the early-stop and early-explosion urbanisation scenarios are higher than 79.80% and 72.3% respectively, an increase of 24.11% and 12.44% from the base case scenario.

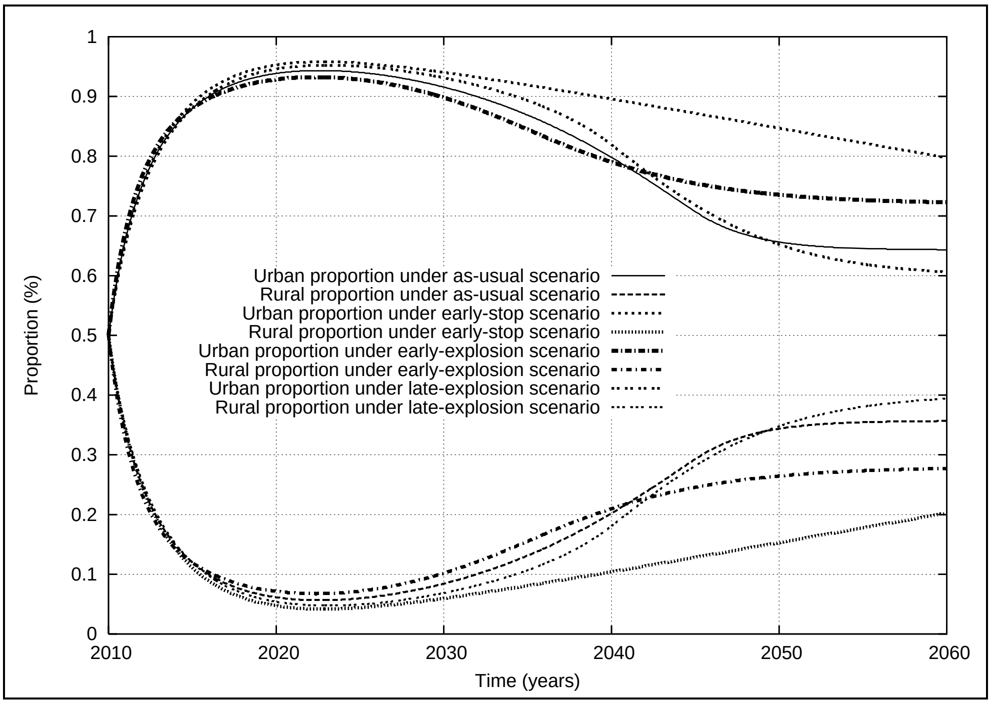


Figure 5.27: Market proportions under different urbanisation scenarios

### 5.8.4 Typical scenarios of mobile commerce diffusion

The previous subsections describe how sensitive factors from one sector influence mobile commerce diffusion. More complex scenarios can be designed to examine the diffusion dynamics under these conditions. Theoretically, the combinations of the twelve factors in three levels listed in Table 5.9 at three levels per factor can produce $3^{12}$ possible scenarios. Two extreme scenarios, the carry-away scenario and the cautious scenario, are designed and simulated for illustration and analysis purposes. Table 5.12 shows the values used in these scenarios.

#### 5.8.4.1 Simulation of the carry-away scenario

Carry away is termed here as no constraint placed on mobile commerce diffusion. The story for this scenario of mobile commerce development in China is described as follows. Mobile commerce is unanimously regarded as an unprecedented business opportunity by the Chinese administration, stakeholders and users. The value of mobile commerce is exaggerated. To make full use of this opportunity, the government decides to implement mobile commerce as soon as possible. This decision is acknowledged nationwide from all walks of life. In addition, communist China uses its powerful propaganda machine to mobilise all possible resources to promote

Table 5.12: Values used in different mobile commerce scenarios

| Scenarios | Base case | Carry-away | Cautious |
|---|---|---|---|
| $IT_t$ | 2010 | 2007 | 2020 |
| $FPF_t$ | 0.2 | 0.3 | 0.1 |
| $UEF_t$ | 0.10 | 0.30 | 0.15 |
| $REF_t$ | 0.05 | 0.15 | 0.05 |
| $UCR_t$ | 60 | 80 | 30 |
| $RCR_t$ | 30 | 40 | 15 |
| $RUCR_t$ | 40 | 50 | 20 |
| $UAF_t$ | 0.03 | 0.035 | 0.024 |
| $RAF_t$ | 0.01 | 0.015 | 0.008 |
| $RUAF_t$ | 0.02 | 0.025 | 0.016 |
| $UNC_t$ | 0.2 | 1 | 0.5 |
| $RNC_t$ | 0.1 | 0.8 | 0.3 |
| $UI_t$ | 1.44% | determined as in early-explosion and early-stop urbanisation scenarios respectively | |
| $UF_t$ | 1.2 | 3 | 1 |
| $UAWB(t, i)$ | 28, 31 | 22, 25, 28 | 31 |
| $RF_t$ | 3.6 | 5 | 2 |
| $RAWB(t, i)$ | 22, 25, 28, 31 | 20, 22, 25, 28, 31 | 28, 31 |
| $ULE_t$ | 71 | 80 | 65 |
| $RLE_t$ | 68 | 80 | 65 |

this campaign. As an encouragement, the Ministry of Information Industry quickly issues its 3G licences to as many operators as possible. Financially, the nationwide subsidiaries of the central government are used to support the producers of mobile commerce terminals, operators of networks and users. People, institutions and governments are greatly motivated. A renovated network is established covering most of the urban and rural areas. Mobile phones that can support mobile commerce services are quickly produced from the Chinese domestic production line and marketed. Cheap terminals and service fees attract a huge number of mobile commerce users. Despite the low popularity of e-commerce in China, people are taught and motivated to directly use mobile commerce.

During this period, the Chinese economy still keeps two-digit percentage increases. Economic fortune for the whole society quickly accumulates. It is the right time for China to lift its tight control on family planning as the standard of living greatly improves.

This scenario was simulated using the parameter values listed in Table 5.12 and the results obtained are listed in Table 5.13. The total number of users, urban number of users and rural

Table 5.13: Evaluation of different scenarios

| Indicators | As-usual (base case) | Carry-away (change) | Cautious (change) |
|---|---|---|---|
| $TU_e$ (million) | 96.52 | 287.33 (197.69%) | 155.14 (60.73%) |
| $UU_e$ (million) | 62.10 | 177.01 (185.04%) | 142.52 (129.50%) |
| $RU_e$ (million) | 34.42 | 110.32 (220.51%) | 12.62 (-63.34%) |
| $UUI_m(\times 10^6)$ | 4.58 | 113.97 (2388.43%) | 13.10 (186.03%) |
| $RUI_m(\times 10^6)$ | 2.31 | 41.92 (1714.72%) | 1.00 (-56.71%) |
| $UUIT_m$ (years) | 11.56 | 2.19 (-81.06%) | 11.31 (-2.16%) |
| $RUIT_m$ (years) | 35.06 | 2.81 (-91.99%) | 15.06 (-57.05%) |
| $UP_m$ (%) | 94.30 | 84.60 (-10.29%) | 96.20 (2.01%) |
| $UP_e$ (%) | 64.30 | 61.60 (-4.20%) | 91.90 (42.92%) |

number of users in equilibrium are nearly double the numbers in the base case scenario. The large change in the indicator values indicates an intensive boom in use. The maximum annual increase in urban and rural users are 24 and 17 times higher. The time taken to reach the urban (or rural) maximum is greatly reduced from 11.56 (or 35.06) years to 2.19 (or 2.81) years, a reduction of 81.06% (or 91.99%). Figure 5.28 shows that the market expansion for both the urban and rural areas is finished within 8 years after the implementation time. In terms of market proportion, both urban and rural markets still have important weights.

The following characteristics can be found under the carry-away scenario: a large increase in the number of users, quicker market expansion and simultaneous expansion in both urban and rural areas. A great challenge with the carry-away scenario is to deal with this fast market expansion. The number of users exposed within a five-year period of time. In the strategy development section, strategies will be developed to deal with such a market explosion as occurs under the carry-away scenario.

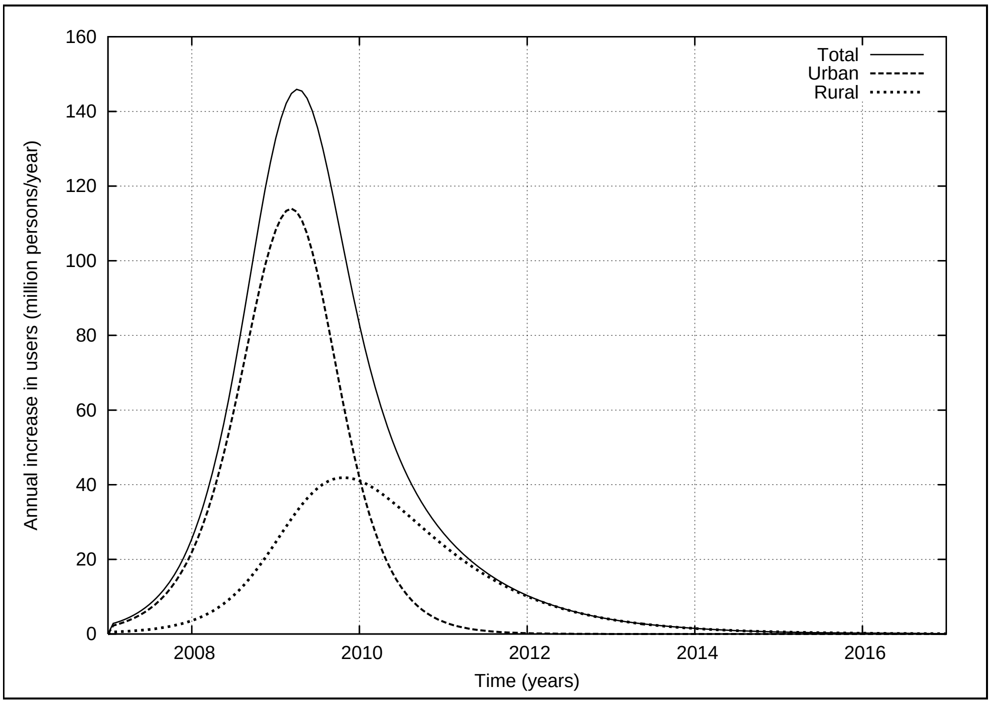


Figure 5.28: Market expansion under the carry-away scenario

#### 5.8.4.2 Simulation of the cautious scenario

This scenario of mobile commerce development in China occurs as follows. China takes great precautions in mobile commerce adoption because of negative factors such as unsuccessful cases in foreign countries, the break-up of the e-commerce bubble at the end of the last century, investment risk and waiting for the domestic industry to catch up. The government is cautious in implementing mobile commerce. Hence, the Ministry of Information Industry delays the issue of 3G licences. The network operating companies renovate their existing networks gradually. Networks that cover metropolitan cities are tentatively improved first. Then the networks are developed to cover middle-sized cities, counties, towns and the countryside. A lot of work needs to be done to deal with problems regarding compatibility with network-dependent services before terminal manufacturers can provide proper mobile commerce terminals to markets.

Despite the low initial e-commerce penetration in both urban and rural areas, time changes everything. Ordinary people begin to know about mobile commerce and become involved in mobile commerce. Mobile commerce becomes popular through word of mouth and obtains increased acceptance.

After several years of booming, the Chinese economy cools down and is at an all-time low level of growth. Urbanisation slows down. With a long-time high-level of unemployment, environmental problems and poor social welfare, the living standards do not improve very much. Under these circumstances, people are reluctant to have more children than ever before.

This scenario is created by using the parameter values shown in Table 5.12. Table 5.13 shows the results of the simulation. Under this scenario, the number of total users increases by 60.73%, the number of urban users increases by 129.50% and the number of rural users decreases by 63.34% at the equilibrium level compared to the base case scenario. The change in the number of users is not as large as in the carry-away scenario. From Figure 5.29, it is found that the urban market proportion is always at a high level of 91.90% and the rural market proportion at a low level of 8.10%.

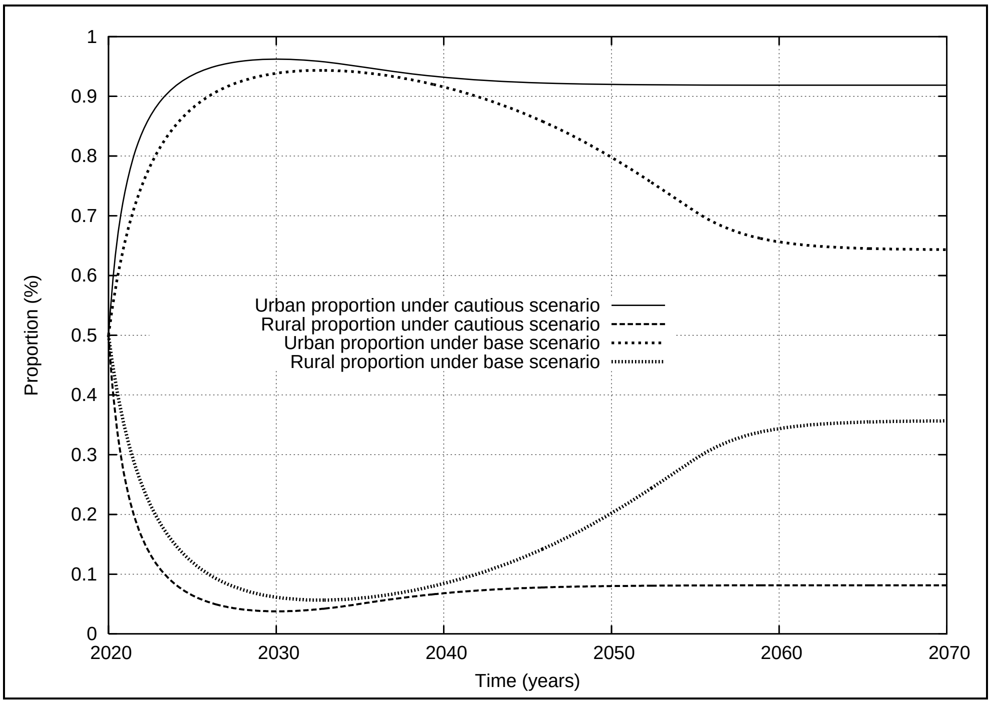


Figure 5.29: Market proportion under the cautious scenario

Mobile commerce diffusion under the cautious scenario has the following characteristics in comparison with the carry-away scenario. In terms of implementation timing, a late implementation as in the cautious scenario wins plenty of time for China to develop related industries and cultivate a suitable market environment. During this interval, success and failure in the other countries also provides useful experience. Because of the absolute dominance of the urban market, there is no need to consider the rural areas when planning. From the very beginning of the implementation, planning can only focus mainly on urban areas and this will save on resources required in opening the rural market as in other scenario. For example, network renovation can only focus on urban areas. To sum up, the cautious scenario is more desirable and strategists can choose this scenario as an example to control the growth of a mobile commerce market.

## 5.9 Strategy development

Market expansion under the carry-away scenario shows an exponential increase in the number of users. The expansion is so intensive and quick that it increases the difficulty of mobilising resources to meet the demand in such a short time. Strategists must find methods to cool down the hottest market and control the behaviour of the market development. This section describes how to realise this aim by developing alternative network renovation strategies.

Under the carry-away scenario, two problems exist: first, the large annual increase in the number of users and, second, the short time taken to reach this value. A strategy of delayed network renovation can be developed to reduce the increase in annual users and prolong the time taken to reach that value.

As illustrated in Figure 5.30, the network coverage ($NC_t$) factor increases from its initial value ($NC_0$) to the fully covered value ($NC_t = 1$). Experiments can be performed to determine the influence of the time taken when the $NC_t = 1$ on mobile commerce diffusion. Then a suitable network strategy for the carry-away scenario can be designed.

Figures 5.31 and 5.32 show the relationship between the different timings of network renovation ($t_{NC_t=1}$) and explain the effects on mobile commerce diffusion. Simulation found that, when prolonging $t_{NC_t=1}$, the maximum annual increase in the number of total users will decrease and the time taken to reach the maximum shifts to the right. However, further prolonging this phenomenon is not obvious. This means that there exists an issue in determining the suitable timing for network renovation. Observation found that the most suitable $t_{NC_t=1}$ for an urban network to be fully renovated is around 25 years and the most suitable $t_{NC_t=1}$ for a rural network to be

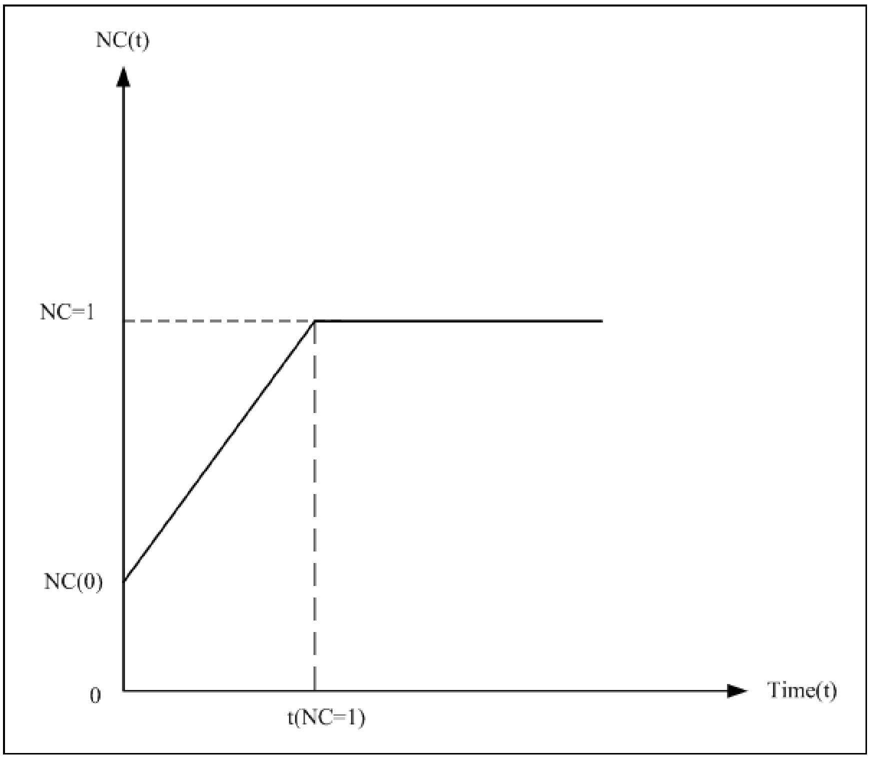


Figure 5.30: Network development strategy designed to mitigate the market explosion

fully renovated is about 20 years.

A delayed network renovation strategy can be designed as follows. It takes 25 years for the urban network to be renovated from the initial coverage of 20% to a full coverage and it takes 20 years for the rural network to be developed from the initial value of 5% to a full coverage. This strategy, shown in Figure 5.33, is very effective, since the maximum values for the total, urban and rural users are greatly reduced and the time taken to reach these values is further delayed.

Table 5.14 lists the values of indicators under the carry-away scenario and the delayed network strategy. Under the delayed network strategy, the total, urban and rural users in equilibrium and the maximum urban proportion and urban proportion in equilibrium show no difference as compared to the carry-away scenario. The annual increase in the number of total users is reduced from a peak of 145.92 million per year to 53.77 million per year, a decline of 63.15%. The annual increase in the number of urban users shows a 58.35% reduction from $113.97 \times 10^6$ per year to $47.47 \times 10^6$ per year. The annual increase in the number of rural users decreases 59.90% from $41.92 \times 10^6$ per annum to $16.81 \times 10^6$. The time taken to reach the maximum

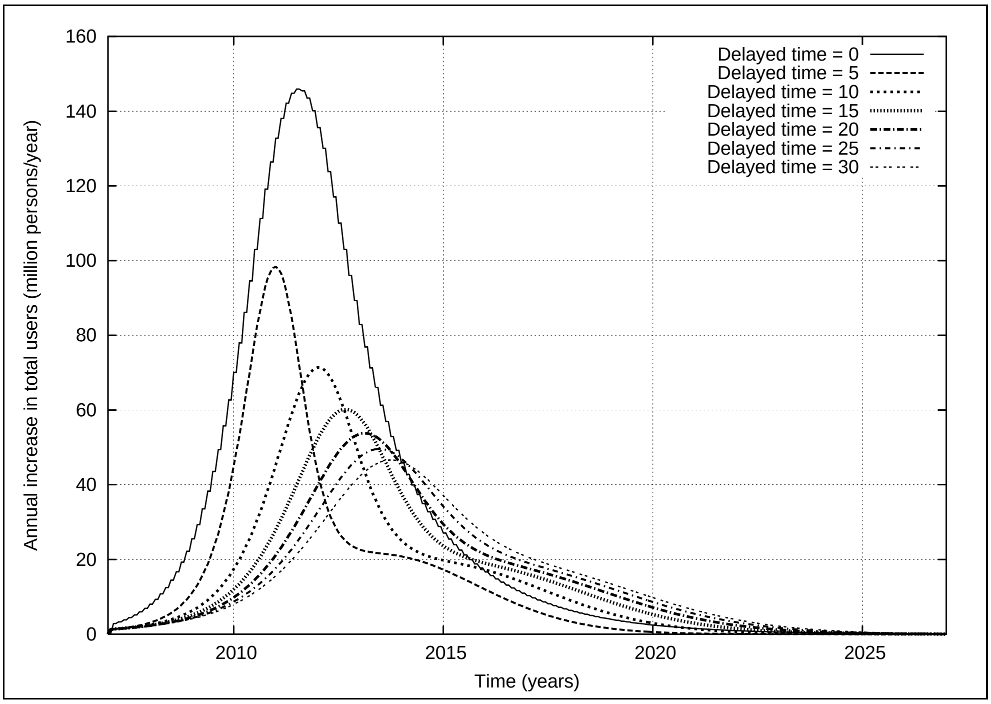


Figure 5.31: Market expansion under different renovation of urban network timing

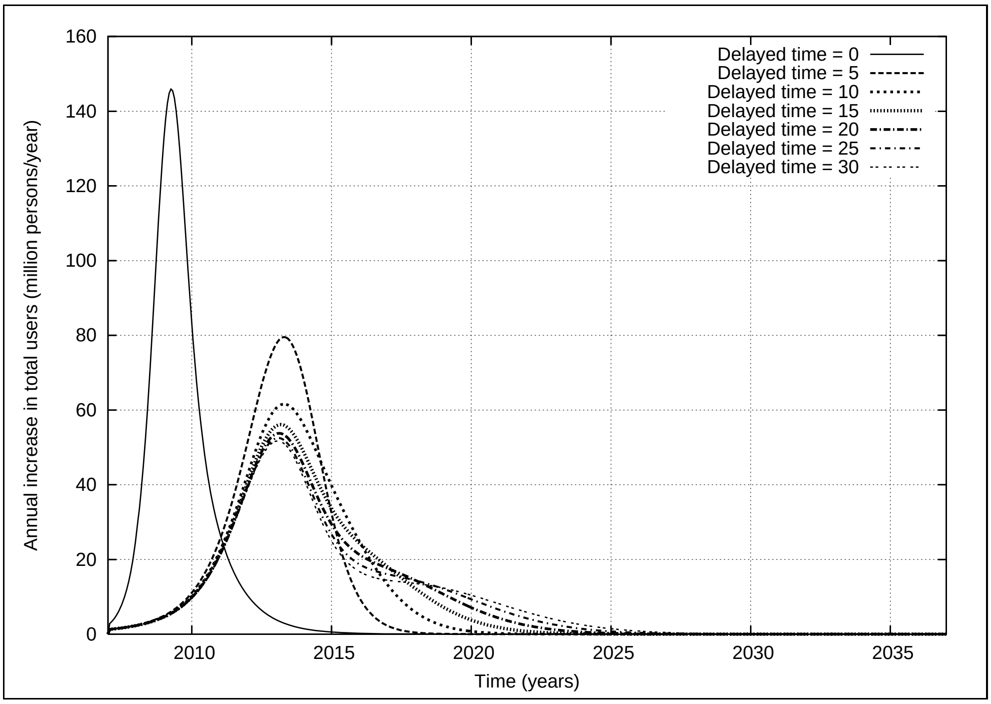


Figure 5.32: Market expansion under different renovation of rural network timing

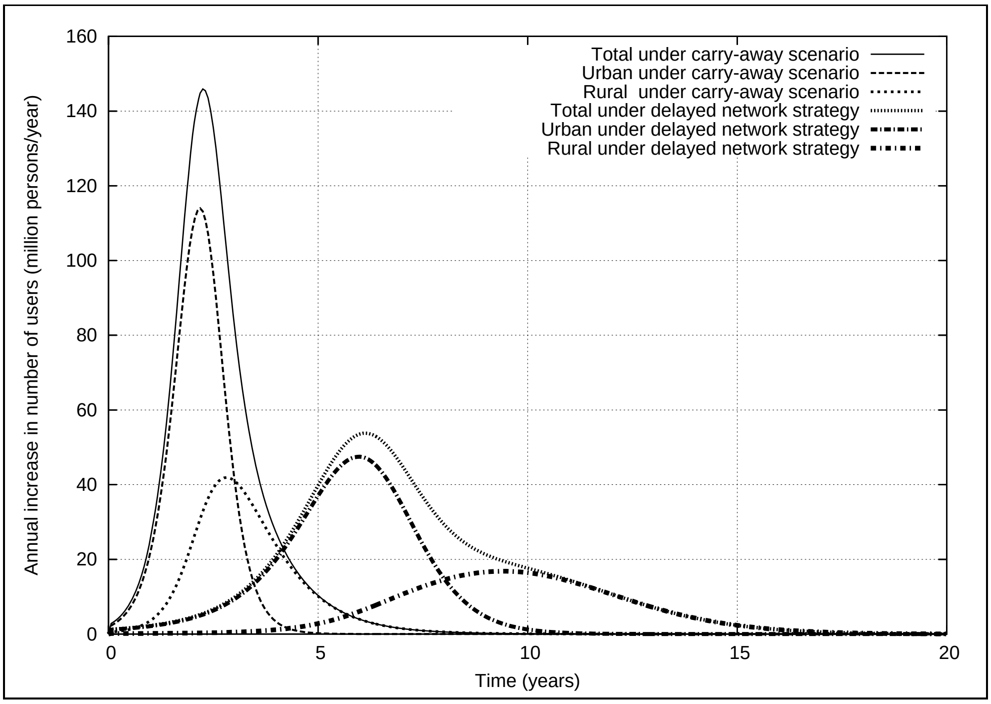


Figure 5.33: Market expansion under delayed network renovation strategy

Table 5.14: Effects of delayed network strategy

| Indicators | Carry-away scenario | Delayed network strategy (change) |
|---|---|---|
| $TU_e$ (million) | 287.33 | 287.33 (0%) |
| $UU_e$ (million) | 177.01 | 177.01 (0%) |
| $RU_e$ (million) | 110.32 | 110.32 (0%) |
| $TUI_m(\times 10^6)$ | 145.92 | 53.77 (-63.15%) |
| $UUI_m(\times 10^6)$ | 113.97 | 47.47 (-58.35%) |
| $RUI_m(\times 10^6)$ | 41.92 | 16.81 (-59.90%) |
| $TUIT_m$ (years) | 2.25 | 6.13 (172.44%) |
| $UUIT_m$ (years) | 2.19 | 6.00 (173.97%) |
| $RUIT_m$ (years) | 2.81 | 9.44 (235.94%) |
| $UP_m$ (%) | 84.60 | 84.60 (0%) |
| $UP_e$ (%) | 61.60 | 61.60 (0%) |

annual increase in the number of total users is prolonged from 2.25 years to 6.13 years, an increase of 172.44%. The time taken to reach the maximum annual increase in the number of urban users has been extended from the original 2.19 years to 6.00 years, a delay of 173.97%. The time taken to reach the maximum annual increase in the number of rural users shows a delay of 235.94% from 2.81 years to 9.44 years.

## 5.10 Summary

An SD simulation modelling approach was presented in this chapter to explore the dynamics of mobile commerce diffusion in China. Variables were identified, causal loops established and finally an SD model was developed for simulating mobile commerce diffusion in general. The model developed was validated using data on mobile telephony subscribers in China from 1995 to 2006. The model was then simulated to experiment with the diffusion of a general mobile commerce service. A base case scenario was simulated and its behaviour was described. Sensitivity tests were also designed and performed to identify sensitive factors.

The uncertainties identified by the model are: implementation timing, electronic commerce penetration, floating populations, contact rates, acceptance, network development and demographic dynamics. As an illustration, the influence of timing of implementation on the formation of the mobile commerce market was also examined. The importance and business implications of the existence of the floating population in starting up the rural market was also analysed. Experiments were also conducted to determine the behaviours of mobile commerce diffusion under four urbanisation scenarios that were identified in chapter 4. Two typical scenarios, i.e. a carry-away scenario and a cautious scenario, which involve most of the sensitive factors, were designed, simulated and their behaviours are analysed. The carry-away scenario generates an instant market explosion and, to avoid such potential explosive market expansion, planners can instead adopt a strategy of controlled network renovation. Market behaviour under the cautious scenario was found to be highly desirable. When planning and cultivating for this type of new market, strategists can make use of the advantages of the cautious scenario.

The simulation model created can be used for experimentation purposes for examining the dynamics of mobile commerce diffusion. It can be used to demonstrate the future of mobile commerce under different scenarios and strategies. The outcomes from the mobile commerce diffusion model in this subsystem will be manipulated by the subsystem of the mobile commerce terminal (MCT) provision described in the next chapter. In the next chapter, a simulation model of MCT provision in China will be developed and will use the output of the mobile commerce diffusion model as input.

# Chapter 6

# MODELLING AND SIMULATING MCT PROVISION

## 6.1 Introduction

In Chapters 4 and 5, simulation models were established for population evolution and mobile commerce diffusion The process modelling of mobile commerce formation should have been finished here. However, as mentioned in research design of Chapter 3, the provision of mobile commerce terminals in the market will possibly influence mobile commerce user market. This chapter will describe how to construct a simulation model for mobile commerce terminal (MCT) provision and then examining its impact on mobile commerce diffusion.

The purpose of developing a model for MCT provision is to examine how the supply of MCTs will influence the diffusion of mobile commerce. The modelling process proceeds along the same line as described in the previous chapters. Variables are found and equations are identified for creating the model. Sensitivity analysis is performed on the MCT provision model to identify sensitive parameters, which are then used as leverage points for scenario analysis and strategy development relating to MCT provision and mobile commerce diffusion.

## 6.2 MCT provision

In the previous chapters, an SD model for simulating mobile commerce diffusion under different scenarios was developed. However, it did not take into consideration possible bottlenecks in the supply of MCTs. In reality, the supply of mobile commerce terminals may constrain the development of mobile commerce diffusion if their provision is not appropriately planned. An ideal provision occurs when the supply of mobile commerce terminals exactly meets the demand of mobile commerce users at each time point during the simulation. In fact, it is difficult to obtain this ideal provision. This is a coordination problem among mobile commerce users, MCT manufacturers and marketers. When the supply of mobile commerce terminals exceeds the demand from mobile commerce users, mobile commerce users can get their mobile commerce terminals and become actual mobile commerce users. When the provision of mobile commerce terminals is less than the actual demands of mobile commerce users, not all of the mobile commerce users are able to obtain their mobile commerce terminals and thus the persons who already have a mobile commerce terminal can become actual mobile commerce users.

In order to achieve harmony in the provision of MCTs, it is important to identify the factors that will influence MCT provision and how to coordinate among the stakeholders influencing these factors. The MCT manufacturing industry is regarded as one of the important components of the Chinese domestic industry in the future. In order to cultivate its domestic MCT industry, which is still in its infancy stage, the Chinese Government is currently strictly controlling the process of opening this market to foreign companies. Currently, the government is providing incentive policies to foster the growth of its domestic MCT industry. However, since China has joined the World Trade Organization (WTO) in 2001, it has to open this market to foreign enterprises under the WTO framework (Division 2004). A big challenge facing the decision makers of the Chinese Government is how to balance the relationship among Chinese MCT providers, foreign MCT providers and mobile commerce development without compromising WTO promises, while at the same time maximising benefits for the country. The model developed in the next section will establish these relationships and examine the effectiveness of some proposed strategic coordination.

## 6.3 Modelling MCT provision

There can be many MCT providers in the Chinese mobile commerce market. According to their ownership, they can be classified into two counterparts: Chinese MCT companies and foreign MCT companies (see Figure 6.1). In this market, the amount of mobile commerce terminals is co-provided by these two counterparts. The amount of MCTs provided by foreign companies at a certain time depends on the degree of market openness and the capacity domestic providers can supply at this point in time. Market openness is the proportion of the amount of MCTs

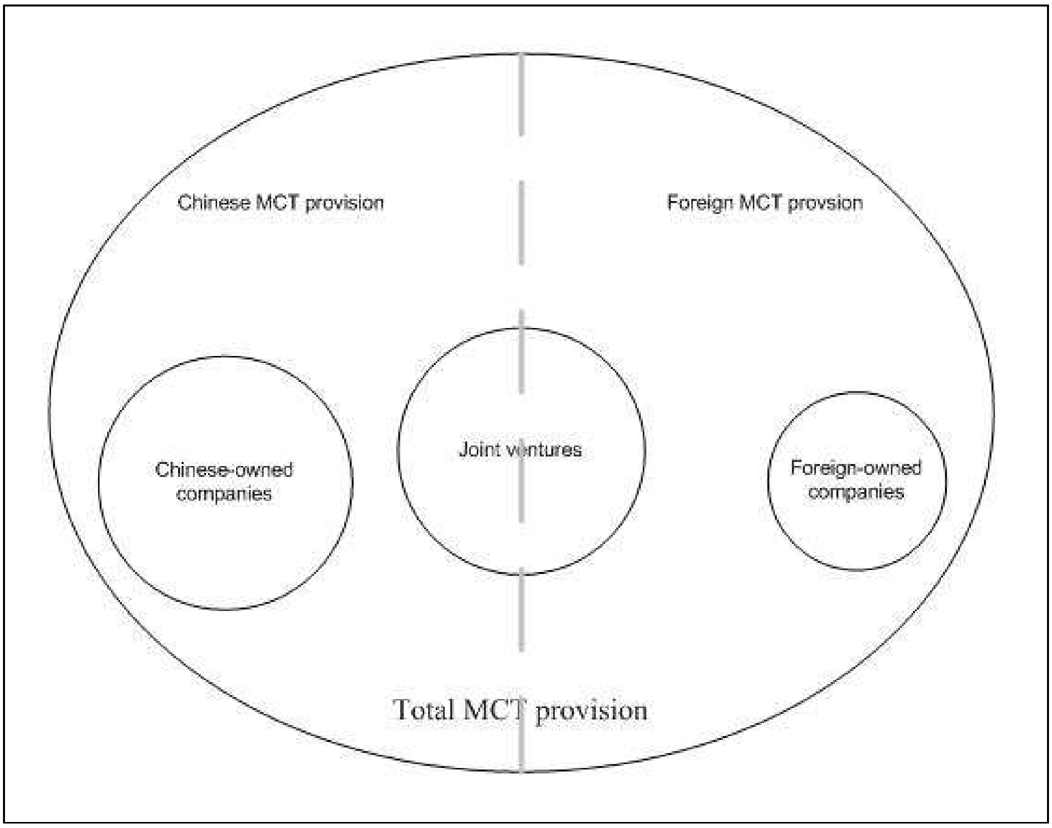


Figure 6.1: MCT provision

supplied by foreign manufacturers over the total amount of MCTs supplied. In a monopoly economy, the level of market openness is commonly controlled by domestic country policies. Whereas in a market economy, the degree of market openness depends on negotiation between the country in question and its foreign partners as stipulated by the World Trade Organization (WTO).

The degree of market openness, the way to open the market, the domestic manufacturing capacity, the time to build the capacity and the way to engage in effective strategic planning are uncertainties in determining the dynamic state of MCT provision. The variables that are manipulated in modelling MCT provision are listed in Table 6.1 and in Appendix G.

Seven equations, listed in Table 6.2, are used in the model to establish the logic and mathematical relationship among these variables. Appendix G also lists SD equations in the model generated by Powersim software. Equation (1) establishes the relationship between the MCT demand from mobile commerce users and the MCT supply from MCT providers in the mar-

Table 6.1: Variables and their characteristics

| Variable | Description | Unit | Type |
|---|---|---|---|
| $T_0$ | Start Time | Year | Constant |
| $T_f$ | Final Time | Year | Constant |
| $\Delta T$ | Time Step | Year | Constant |
| $AU_t$ | Actual Mobile Commerce Users | Person | Auxiliary |
| $TU_t$ | Total Users | Person | Auxiliary |
| $D_t$ | Difference between Total Users and Actual Mobile Commerce Users | Person | Auxiliary |
| $AI_t$ | Annual Mobile Commerce User Increase | Person/year | Auxiliary |
| $TP_t$ | Provided Mobile Commerce Terminal | Unit | Stock |
| $ITP_t$ | Initial Provided Mobile Commerce Terminal | Unit | Constant |
| $P_t$ | Provision | Unit/Year | Flow |
| $O_t$ | Obsolescence | Unit/Year | Flow |
| $MCTLC_t$ | Mobile Commerce Terminal Life Cycle | Year | Constant |
| $MO_t$ | Market Openness | Dimensionless | Auxiliary |
| $IMO_t$ | Initial Market Openness | Dimensionless | Constant |
| $MMO_t$ | Max Market Openness | Dimensionless | Constant |
| $MT_t$ | Market Monopoly Time | Dimensionless | Constant |
| $DMC_t$ | Domestic Manufacturing Capacity | Unit/Year | Auxiliary |
| $IDMC_t$ | Initial (Domestic Manufacturing) Capacity | Unit/Year | Constant |
| $FDMC_t$ | Final (Domestic Manufacturing) Capacity | Unit/Year | Constant |
| $TI_t$ | Time to Reach Initial Capacity | Year | Constant |
| $TIF_t$ | Time to Build Capacity from $IDMC_t$ to $FDMC_t$ | Year | Constant |

Table 6.2: Equations in modelling MCT provision

| | |
|---|---|
| $AU_t = TU_t$, when $TP_t > TU_t$;<br>$TP_t$, when $TP_t <= TU_t$ | (1) |
| $D_t = AU_t - TU_t$ | (2) |
| $AI_t = d(AU_t)/dt$ | (3) |
| $TP_t = P_t - O_t$ | (4) |
| $P_t = DMC_t/(1 - MO_t)$ | (5) |
| $O_t = DELAY(TP_t, MCTLC_t)$ | (6) |
| $MO_t = IMO_t + RAMP\,[(MMO_t - IMO_t)/MT_t, 0]$, when $0 \leq T \leq MT_t$<br>$MMO_t$, when $T \geq MT_t$ | (7) |
| $DMC_t = RAMP(IC_t/TI_t, 0)$, when $T \leq TI_t$;<br>$IC_t + RAMP\,[(FC_t - IC_t)/TIF_t, TI_t]$, when $TI_t \leq T \leq (TI_t + TIF_t)$;<br>$FC_t$, when $T \geq (TI_t + TIF_t)$ | (8) |

ket of mobile commerce terminals. When the provision of MCTs exceeds the number of total mobile commerce users, the actual number of mobile commerce users is equivalent to the total number of mobile commerce users, generated from mobile commerce diffusion model in Chapter 5, otherwise it is determined by the number of the MCTs supplied.

Equations (2) and (3) provide the calculation of $D_t$ and $AI_t$. $D_t$ is an indicator denoting the difference between the actual number of mobile commerce users and the total number of mobile commerce users. The value of $D_t$ is equal or less than zero. If it takes a negative value, it means that the MCT provision is not enough. $AI_t$ is the derivative of the actual number of mobile commerce users.

Equation (4) computes the number of MCTs provided to generate new mobile commerce users. It is the difference between the total number of MCTs manufactured ($P_t = DMC_t/(1-MO_t)$) and the replacement amount of obsolete MCTs ($O_t = DELAY(TP_t, MCTLC_t)$).

Equation (5) shows the relationship between MCT provision and domestic MCT manufacturing capacity. $P_t$ is the total provision of MCTs to the market. $DMC_t/(1-MO_t)$ is the total number of MCTs co-produced by foreign and domestic manufacturers.

Equation (6) computes the annual number of MCTs that are obsolete from the market. It is the exact total number of MCTs provided in the market a period of time ago. This time is equivalent to $MCTLC_t)$.

Equation (7) establishes the relationship between MCT provision and MCT obsolescence. $O_t$ is the total number of obsolete MCTs outflowing from the market when they reach the end of their life cycle. The amount of $O_t$ is that of $P_t$ delayed by a time of $MCTLC_t$, i.e., DELAY ($P_t$, $MCTLC_t$). $MCTLC_t$ refers to a time period during which an MCT can be normally used before it is replaced by a new one.

Equation (8) describes the process of opening the mobile commerce terminal market in China. The market is originally opened at a value of $IMO_t$. After a time period of monopoly ($MT_t$), market openness will increase from the initial value ($IMO_t$) to a maximum market openness value ($MMO_t$), which is commonly reached by negotiation as stipulated by the WTO.

Equation (8) defines the process of building domestic MCT manufacturing capacity. Since in the previous chapter, it was shown that mobile commerce user diffusion demonstrates an s-shape, this study chooses a three-step development mode for building MCT capacity to match the s-shape. As shown in Figure 6.2, it is assumed that MCT production will undergo three periods in China. In the introductory period, from the beginning to the time it reaches initial capacity, capacity will increase from nil to the initial value set by industry planners. In the increase period, from the time taken to reach initial capacity to the time taken to reach final capacity, capacity will rise further from the initial capacity to a final capacity. After that, the capacity will be stabilised. In the section on strategy development, the parameters involved will be determined.

The equations described are used for developing a simulation model for MCT provision. Figure 6.3 is a simulation model for MCT provision created by the modelling software Powersim. MCT provision model connects mobile commerce model in Chapter 5 through the variable 'Actual Mobile Commerce Users', which is further determined by two variables 'Provided Mobile Commerce Terminal' and 'Total Users'. 'Total Users' framed in Figure 6.3 is a variable from

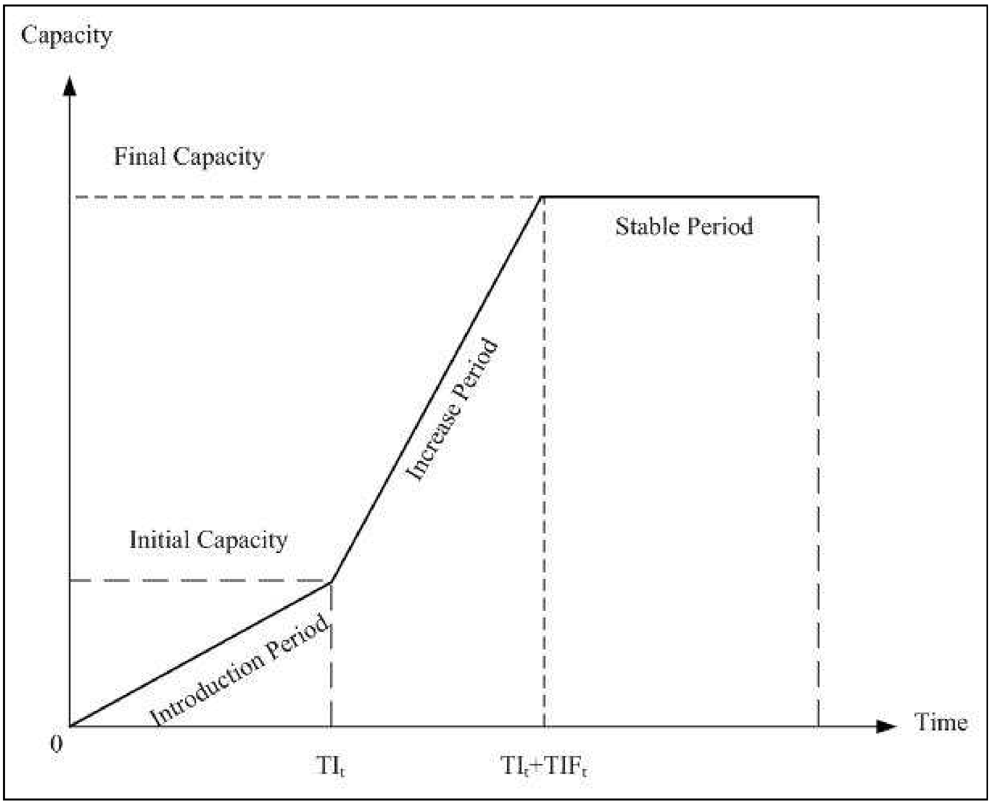


Figure 6.2: Proposed mode for building domestic MCT production capacity

mobile commerce diffusion model of chapter 5. In the mobile commerce diffusion model, the ‘Total Users’ is the sum of urban users and rural users, which are derived respectively from urban population and rural population in population model of chapter 4.

Since mobile commerce market does not yet exist in the system under investigation and there is no data available for MCT provision, it is impossible to validate the developed model. However, simulation is an effective tool in dealing with the issue with no data. The MCT provision model is then used for conducting a sensitivity analysis and identifying sensitive variables.

## 6.4 Sensitivity analysis

Three indicators are used to measure the level of sensitivity. These indicators include: the final number of mobile commerce terminals provided ($TP_{final}$); the final number of actual mobile commerce users in final ($AU_{final}$); and the visual observation from the graphs of the behaviours between the total users ($TU_t$) and the actual mobile commerce users ($AU_t$); and the annual

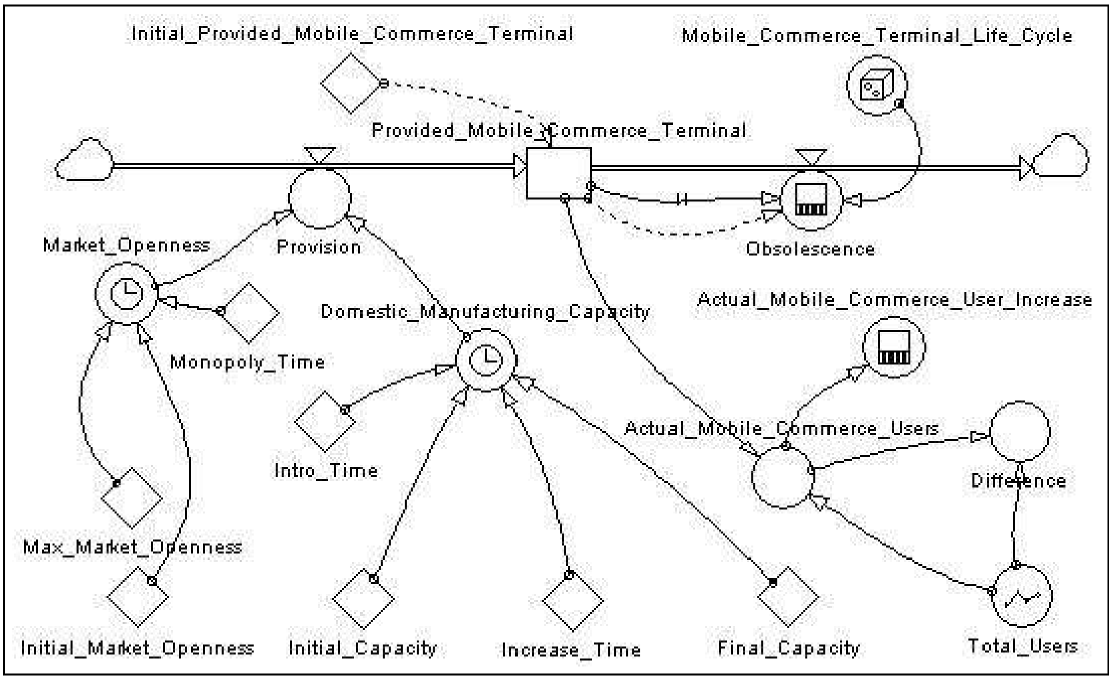


Figure 6.3: MCT provision model

increase in the total number of mobile commerce users ($TUI_t$); and the annual increase in the number of actual mobile commerce users ($AI_t$).

Experiments are designed for sensitivity analysis in the same way as in the previous chapters. Table 6.3 lists the factors of the model identified as sensitive and their sensitivity to the performance indicators. As shown in Table 6.3, a factor with an asterisk (*) indicates that the factor is sensitive to the indicator specified in the column. The sensitive factors are grouped and classified into five categories: mobile commerce diffusion, terminal design, market openness, initial MCT market and MCT strategic planning.

$TU_t$ is a factor connected to the submodel of mobile commerce diffusion in chapter 5. This means that mobile commerce diffusion under the scenarios examined in chapter 5 will have significant influence on the indicators used in this chapter. Hence the scenarios designed in chapter 5 can be used in both scenario analysis and strategy development in this chapter. $MCTLC_t$ is based on the design of the life-span of a terminal by manufacturers (MCT design strategy), and how to recycle this terminal in the markets (MCT marketing strategy). It will generate oscillation in the provision of MCTs and in the actual diffusion of mobile commerce. This is further examined in the next section. $IMO_t$, $MMO_t$ and $MT_t$ are sensitive factors related to market openness. This means that how the MCT market is opened to the outside world will be important in examining MCT provision and mobile commerce diffusion. Thus scenarios that are based on market openness can be designed and analysed further in the next section. $IDMC_t$, $FDMC_t$, $TI_t$ and $TIF_t$ are sensitive factors that belong to domestic MCT manufacturing. These factors can be used to design and experiment with more complete scenarios and strategies for MCT strategic planning and mobile commerce diffusion.

Table 6.3: Categories of factors to which the model is sensitive

| Indicator | $TP_{final}$ (million) | $AU_{final}$ (ten thousand) | Visual Observation | Classification |
|---|---|---|---|---|
| $IDMC_t$ | * | * | * | MCT strategic planning |
| $FDMC_t$ | * | * | * | MCT strategic planning |
| $TI_t$ | * | * | | MCT strategic planning |
| $TIF_t$ | * | * | | MCT strategic planning |
| $TU_t$ | | * | * | Mobile commerce diffusion |
| $MCTLC_t$ | * | * | * | Terminal design |
| $IMO_t$ | | | | Market openness |
| $MMO_t$ | * | * | * | Market openness |
| $MT_t$ | | | | Market openness |
| $ITP_t$ | | | | Initial MCT market |

## 6.5 Scenario design and analysis

In this section, several scenarios of MCT provision are designed and their influence on mobile commerce diffusion analysed. From sensitivity analysis, it is found that MCT strategic planning, MCT life cycle and market openness are the factors that can be manipulated to create scenarios for MCT provision. Scenarios using different combinations of values of factors such as MCT strategic planning, MCT life cycle and market openness are designed and analysed. In addition, two extreme conditions of MCT provision are examined.

### 6.5.1 Scenario analysis of MCT strategic planning

The base case scenario of mobile commerce diffusion described in section 5.6 is selected for designing strategies for domestic production of MCTs and for analysing the influence of the MCT strategies under different scenarios on mobile commerce diffusion. The results of a simulation run of the scenario with a time span of 50 years under three typical strategies of the MCT industry are described in the next subsections and shown in Figures 6.5 to 6.9.

In order to model the development of the Chinese domestic MCT industry (the strategies for manufacturing and supplying MCTs in China), a development mode should be determined first. Several modes, such as linear increase or an s-shape increase, can be adopted for the Chinese MCT industry. Based on the behaviours generated under the base case scenario of mobile commerce diffusion, a three-step mode is used in modelling the Chinese MCT provision, as illustrated in Figure 6.2. The simulation found other modes can be approximated using this three-step mode after the model is established.

Presumably the formation of domestic manufacturing capacity will undergo three strategic stages: an introduction period, an increase period and a stable period. In order to form a production strategy, four parameters–including initial capacity ($IDMC_t$ ), final capacity ($FDMC_t$), the introduction time ($TI_t$) and the increase time ( $TIF_t$)–have to be determined first.

In the introduction stage, the domestic manufacturing capacity will increase linearly from nil at the very beginning to the initial capacity at the end of the introduction stage. The slope of the increase line indicates the annual increase rate of the domestic manufacturing capacity set for the introductory period, which is determined by the value of the preset initial capacity and the preset value of the time needed to reach that initial capacity. During the increase stage, the domestic manufacturing capacity will further increase from the initial capacity to a final capacity. Similar to the introduction stage, the slope of the increase line indicates the annual increase rate of the domestic manufacturing capacity in this stage, which is determined by the value (the time this stage lasts) and the values of the preset initial and final capacities. The difference between the two stages lies in the values set for the slopes. After the increase stage comes the stable stage, in which the domestic manufacturing capacity is kept at an appropriate level.

Whichever development mode is used in designing an MCT industry strategy, in practice an MCT industry strategy will fall under one of the following strategic planning scenarios elaborated next. For illustration purposes, the base case scenario of mobile commerce diffusion is used to examine the change in behaviour under the three MCT strategic planning scenarios.

#### 6.5.1.1 Scenario of liberal MCT strategic planning

Under liberal conditions, the introductory period is less than 9 years, the total initial capacity of domestic mobile commerce terminal production is set to more than 8,000,000 terminals per year, the increase period is less than 10 years and the total full capacity of domestic mobile commerce terminal production is set to over 50,000,000 terminals per year. This strategy has no constraint on the mobile commerce diffusion under the base case scenario. Mobile commerce will obtain maximum diffusion because MCT provision under a liberal planning ensures that there is surplus supply of MCTs in the market. This strategic planning will generate positive effects on mobile commerce diffusion and is called liberal strategic planning.

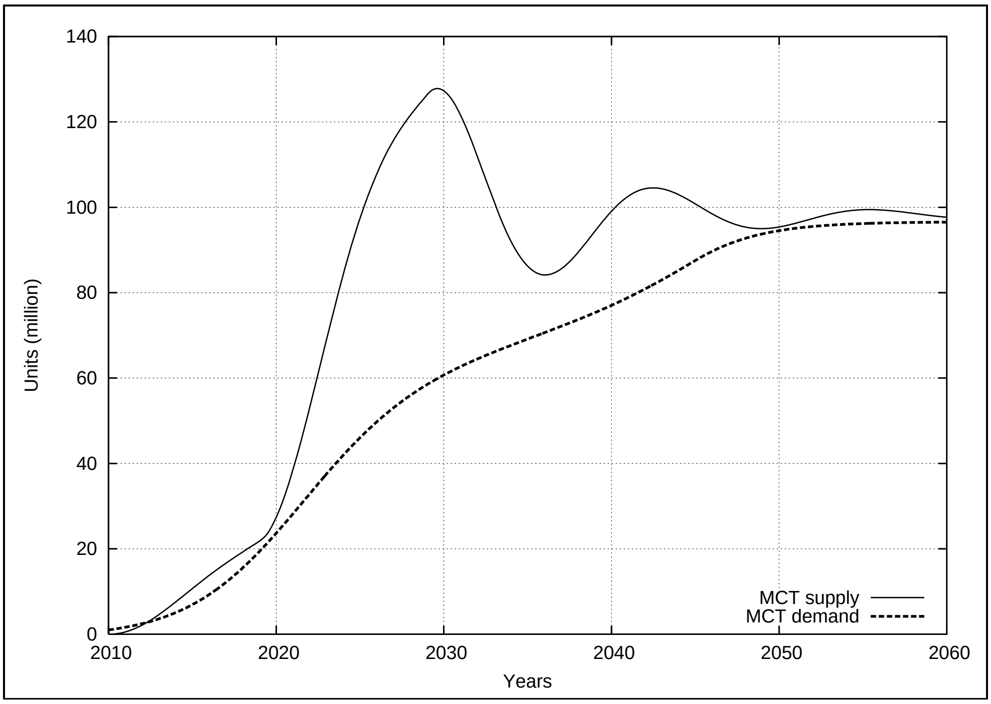


Figure 6.4: Supply and demand of MCTs under liberal strategic planning

The supply and demand of MCTs under liberal strategic planning is shown in Figure 6.4. Under this strategy, the supply of mobile commerce terminal always exceeds the market demand. The market in this case is called a buyer's market. Mobile commerce diffusion is not influenced by the strategy of the MCT industry in a buyer's market. Mobile commerce will diffuse without being impacted by the strategy of the MCT industry as long as the supply exceeds the demand of MCTs.

It is important to differentiate between the actual number and the total number of mobile commerce users. The total number of mobile commerce users was computed in the previous chapter without considering the bottleneck of MCT provision. When MCT provision is in surplus, the actual number of mobile commerce users is the same as the total number of mobile commerce users; otherwise the actual number of mobile commerce users is less than the total number of mobile commerce users. As illustrated in Figure 6.5, the graph of the actual number of mobile commerce users overlaps the graph of the total number of mobile commerce users. It means that under a liberal MCT production strategy, all mobile commerce users can easily obtain their mobile commerce terminals and become actual mobile commerce users. The general behaviour of the mobile commerce diffusion illustrated in Figure 6.5 is similar to what was identified in chapter 5.

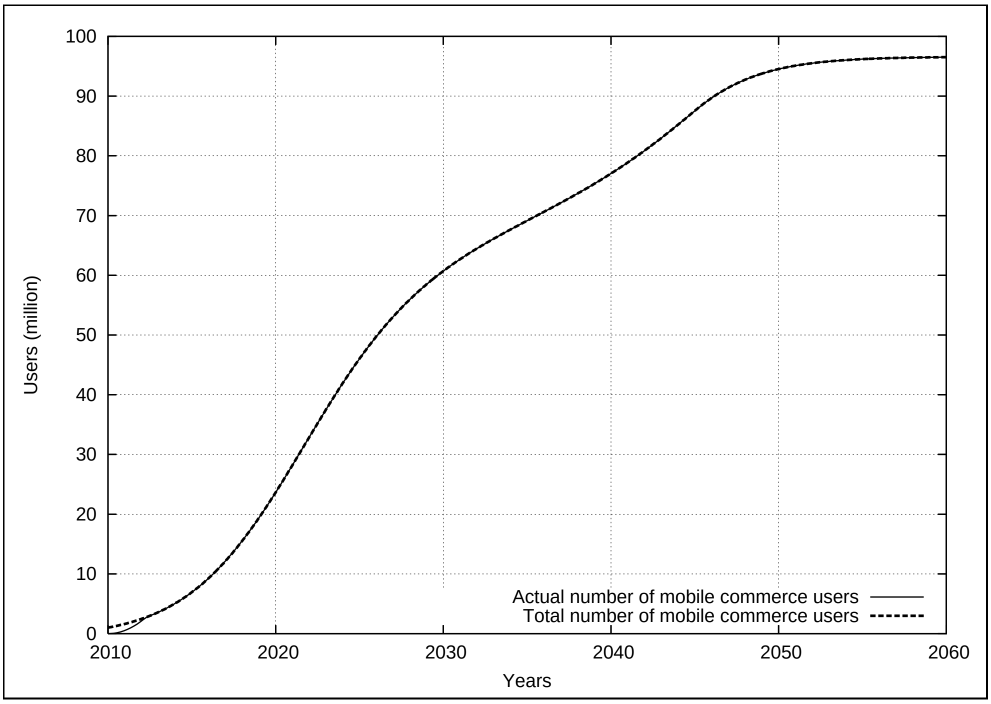


Figure 6.5: Mobile commerce diffusion under liberal MCT strategic planning

#### 6.5.1.2 Scenario of conservative strategic planning

Under conservative conditions, the introductory period is more than 16 years, the total initial capacity of domestic mobile commerce terminal production is set to less than 4,000,000 terminals per year, the increase time is over 21 years and the total full capacity of domestic mobile commerce terminal production is set to under 40,000,000 terminals per year. This strategy will generate constraining effects on mobile commerce diffusion and is called conservative strategic planning.

The behaviour of MCTs supplied under a conservative strategic planning as described by the previously mentioned conditions is illustrated by the graph shown in Figure 6.6. Any strategy

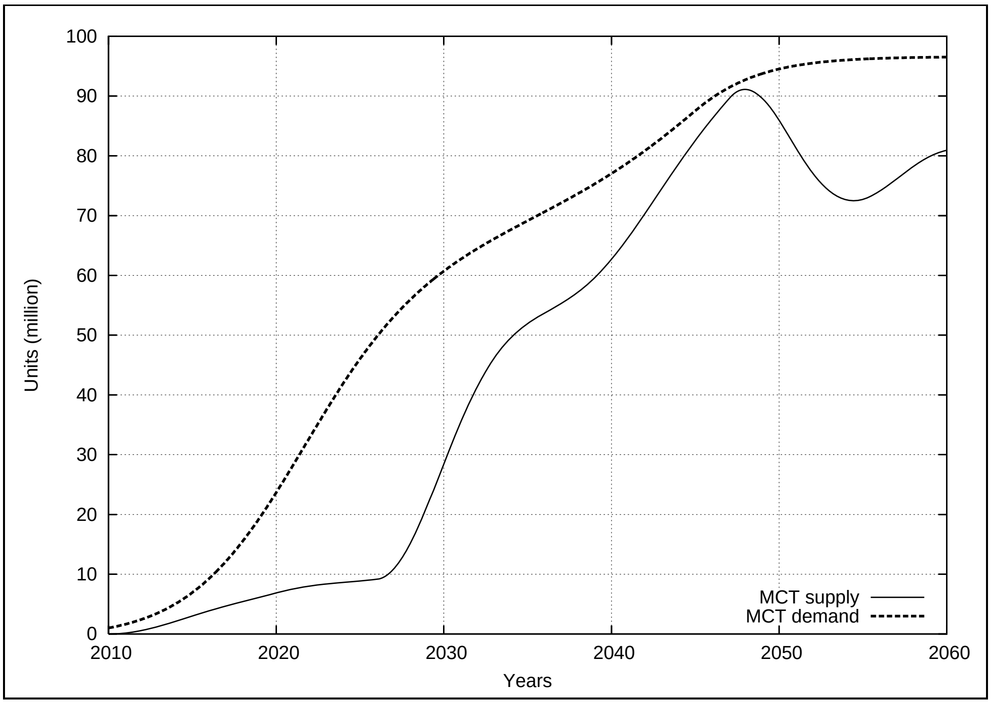


Figure 6.6: Supply and demand of MCTs under conservative MCT strategic planning

which meets the conservative conditions will fall below the mobile commerce diffusion curve and will constrain mobile commerce diffusion. Under this development strategy of MCT provision, the market demand will always exceed the total provision of mobile commerce terminals. This kind of market is called a seller's market. The supply of MCTs is a bottleneck to the mobile commerce diffusion in the seller's market. Under these circumstances, mobile commerce diffusion is constrained by the domestic mobile commerce terminal manufacturing capacity.

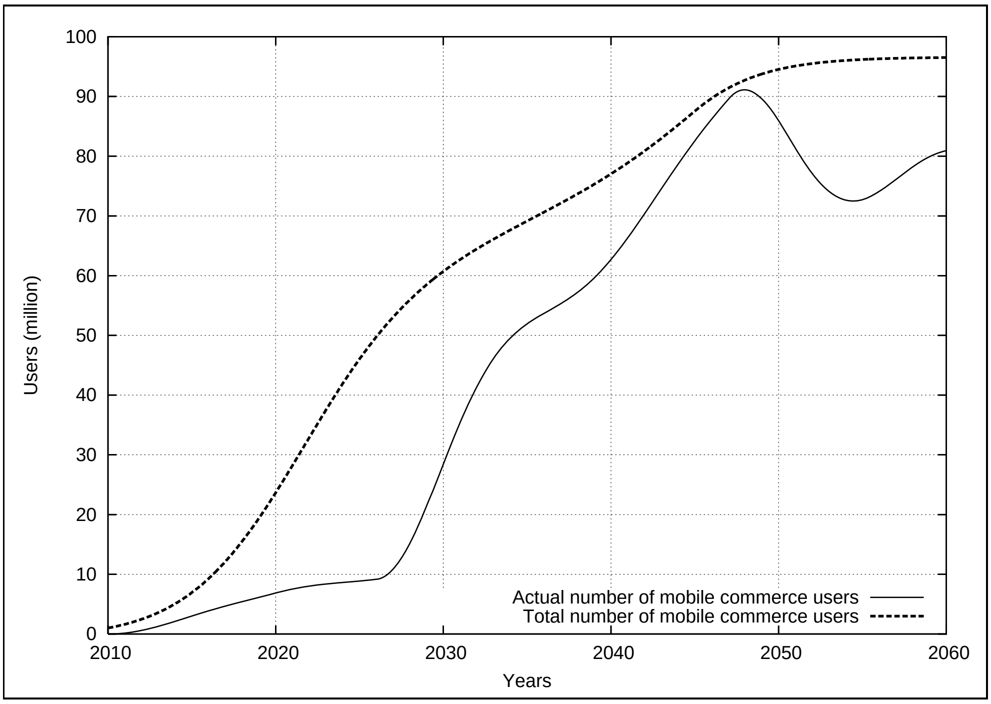


Figure 6.7: Mobile commerce diffusion under conservative MCT strategic planning

As illustrated in Figure 6.7, the growth in the actual number of mobile commerce users will almost follow the curve of the supply of the mobile commerce terminals. The curve of the mobile commerce terminal supplied is the curve of the actual number of mobile commerce users. It means that only the number of mobile commerce users (equivalent to the number of mobile commerce terminals supplied in the time interval) can manage to obtain their mobile commerce terminals and hence become actual mobile commerce users.

Figures 6.6 and 6.7 look at the same event from different perspectives. Figure 6.6 is from the angle of marketing and Figure 6.7 from the transformation of users. If the total number of mobile commerce users want to become actual number of mobile commerce users, MCT manufacturers have to produce a certain amount of MCTs. Ideally, this amount of MCTs is exactly the same as the total number of mobile commerce users and constitutes the total demand in MCT market. From this sense, the curves of MCT demand and the total number of mobile commerce users are the same. However, under conservative MCT strategic planning, the MCT provision is not enough. Only the number of persons from the total number of mobile commerce users can get their MCT and become the actual number of mobile commerce users. Theoretically, the actual number of mobile commerce users is exactly the same as the amount of MCT supply. Hence, the curves of actual number of mobile commerce users and MCT supply are identical under a conservative MCT strategic planning.

#### 6.5.1.3 Scenario of mixed strategic planning

Under a mixed strategy (a mixture of liberal and conservative strategies), the introductory period is set to around 12 years, the total initial capacity of domestic mobile commerce terminal manufacturing is set to between 4,000,000 and 8,000,000 terminals per year, the increase time is set to about 15 years, and the total full capacity of domestic mobile commerce terminal manufacturing is set to between 40,000,000 and 50,000,000 terminals per year. This is a mixed strategy, which will sometimes exert constraining effects on the mobile commerce diffusion. Under this development strategy, the market demands sometimes exceeds the total supply of mobile commerce terminals and vice versa. The market in this situation is called a mixed market. Under these circumstances, the actual mobile commerce diffusion is co-determined by the quantity of the mobile commerce terminals supplied and the number of mobile commerce users, as illustrated in Figure 6.8.

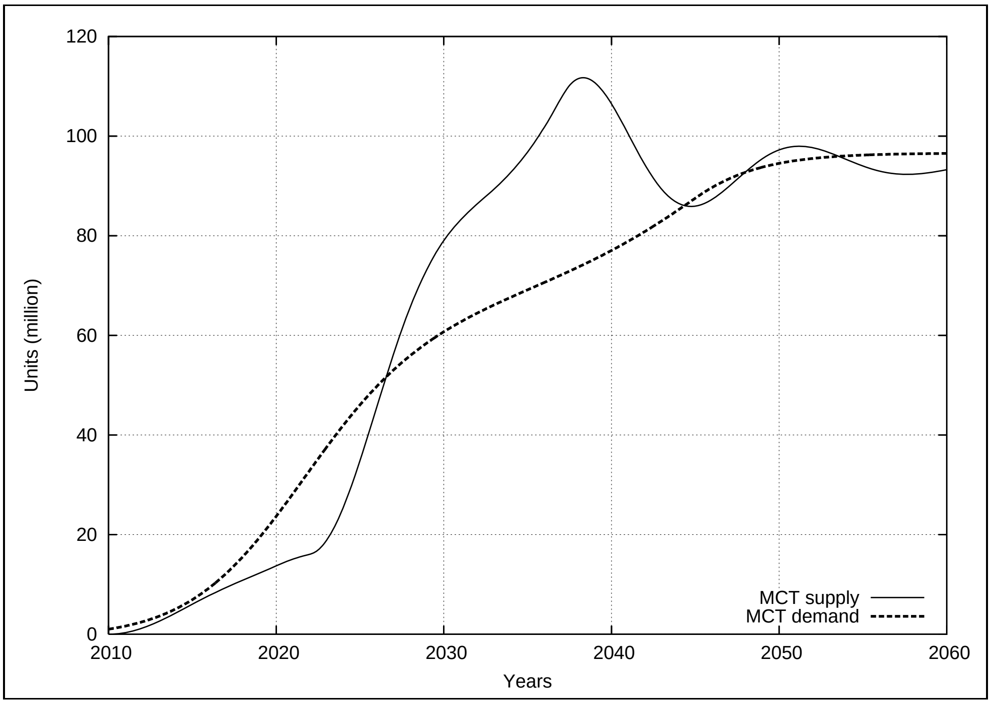


Figure 6.8: Supply and demand of MCTs under mixed MCT strategic planning

As shown in Figure 6.9, the growth of the actual mobile commerce users will be a combination of the curve of the number of mobile commerce terminals supplied and the curve of the number of mobile commerce users. The curve of the actual number of mobile commerce users will always appear in the area between the corresponding curves produced by the liberal strategic planning under minimum conditions and the conservative strategic planning under maximum conditions (see Figure 6.16).

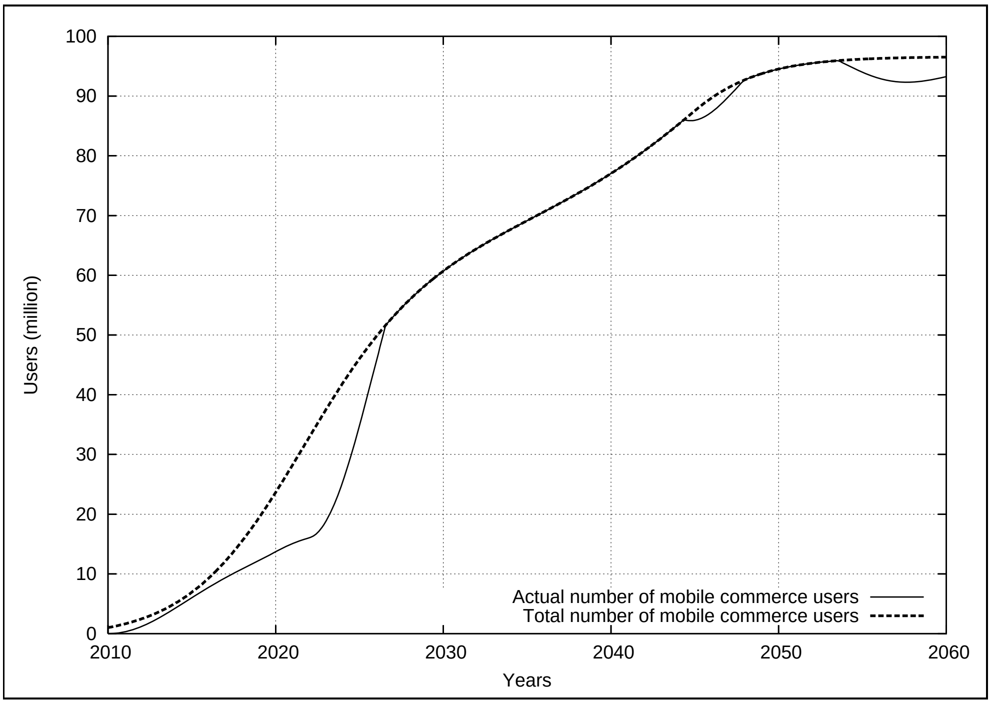


Figure 6.9: Mobile commerce diffusion under mixed MCT strategic planning

Figure 6.9 depicts one of these combinations. During the process of mobile commerce diffusion, three phenomena occur. Phenomenon one is the mini conservative strategic planning, under which the provision of mobile commerce terminals cannot meet the market demand. During this time period, only a number of mobile commerce users equivalent to the number of mobile commerce terminals can obtain their mobile commerce terminals and become actual mobile commerce users. During this stage, the MCT industry constrains mobile commerce diffusion and the market is in the seller's hand.

Phenomenon two is the mini liberal strategic planning, under which the provision of mobile commerce terminals exceeds the requirements of the market. During this time interval, mobile commerce users can always obtain their mobile commerce terminals and become actual mobile commerce users. As in the liberal strategy, the MCT industry provides enough space for mobile commerce to develop and the market is in the buyer's hand. Phenomenon three occurs when the provision of mobile commerce terminals corresponds exactly with market demand. In this case, the behaviour of mobile commerce diffusion is the same as that of MCT provision.

In general, under mixed strategic planning, mobile commerce diffusion grows very slow during the introductory period. After that period it takes on fast growth in the next phase and eventually reaches a plateau. The general behaviour illustrated in Figure 6.9 is a trimmed s-shaped in comparison with that in liberal strategic planning.

#### 6.5.1.4 Strategic implications of MCT strategic planning

Figures 6.16 and 6.17 show the different behaviours of the number of actual mobile commerce users and the annual increase in the number of actual mobile commerce users under the three typical strategies of mobile commerce terminal manufacturing. The following implications can be drawn from the experimentation performed.

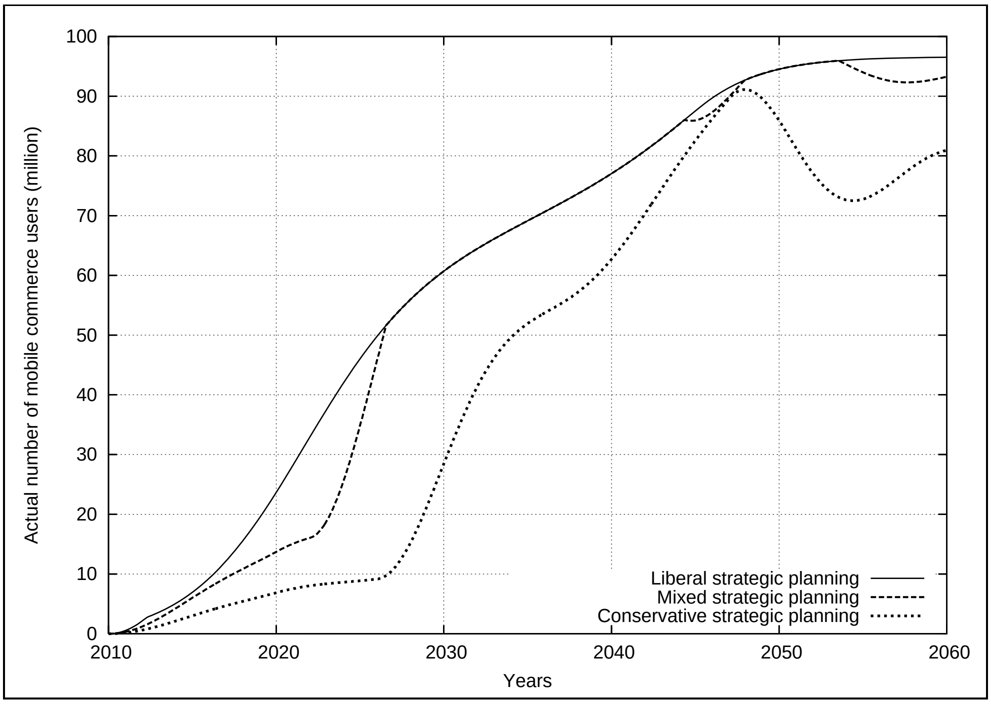


Figure 6.10: Number of actual mobile commerce users under different strategies

In order to reduce the oscillation of MCT provision in the MCT strategic planning, first of all, the MCT life cycle should be set to two years. In this way, the curve of the mobile commerce

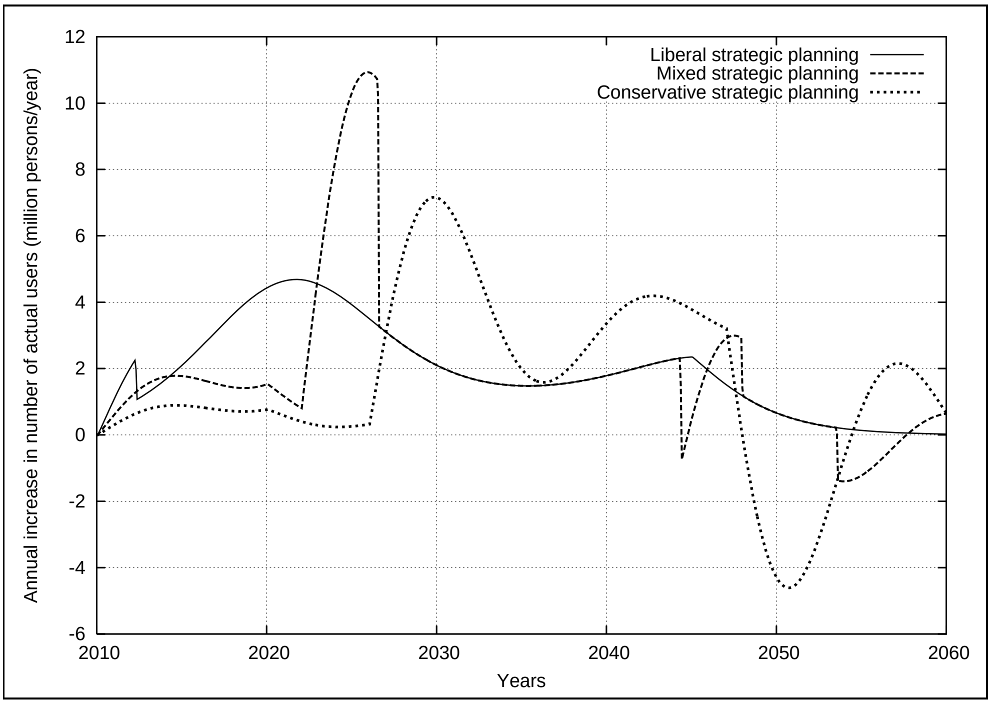


Figure 6.11: Annual increase of actual mobile commerce users under different strategies

diffusion under any strategic plan of MCT provision will be smoother and the width of the mixed area will become narrower.

The liberal strategic planning will always generate a standard s-shaped mobile commerce diffusion at a faster pace and with a bigger magnitude than that generated from conservative and mixed strategic planning.

When liberal strategic planning is used, the mobile commerce diffusion pattern, including total quantity and market expansion, cannot be changed by increasing its initial and final capacities, decreasing the time needed to reach the capacities or reducing the opening level of the monopoly market. Under the liberal strategic planning, an appropriate lowering of the preset capacities, extension of time or decrease of market openness will not influence the diffusion of mobile commerce.

When conservative strategic planning is used, the speed and magnitude of mobile commerce diffusion can be quickly improved by increasing the initial and final capacities, decreasing the time needed to reach the capacities or opening more of the market to outsiders. In conservative planning, the mobile commerce diffusion is similar to the provision of mobile commerce terminals in the market.

When mixed strategic planning is used, a small increase in the initial and final capacities, a small decrease in the time needed to reach the capacities or a small increase of market openness will change the strategy into a liberal strategy. On the contrary, a small decrease in the initial and final capacities, a small increase in the time needed to reach the capacities or a small decrease in market openness will change the strategy into a conservative one.

In the next section, these implications are used to design effective strategies that can be manipulated by adjusting the supply-demand relationship among market participants.

### 6.5.2 Scenario analysis of the length of the MCT life cycle

Simulation experiments found that the length of the MCT life cycle would significantly influence the stability of MCT provision and consequently influence the dynamics of mobile commerce diffusion. Figure 6.12 illustrates the disturbances to the actual mobile commerce diffusion brought about by differences in the length of the MCT life cycle.

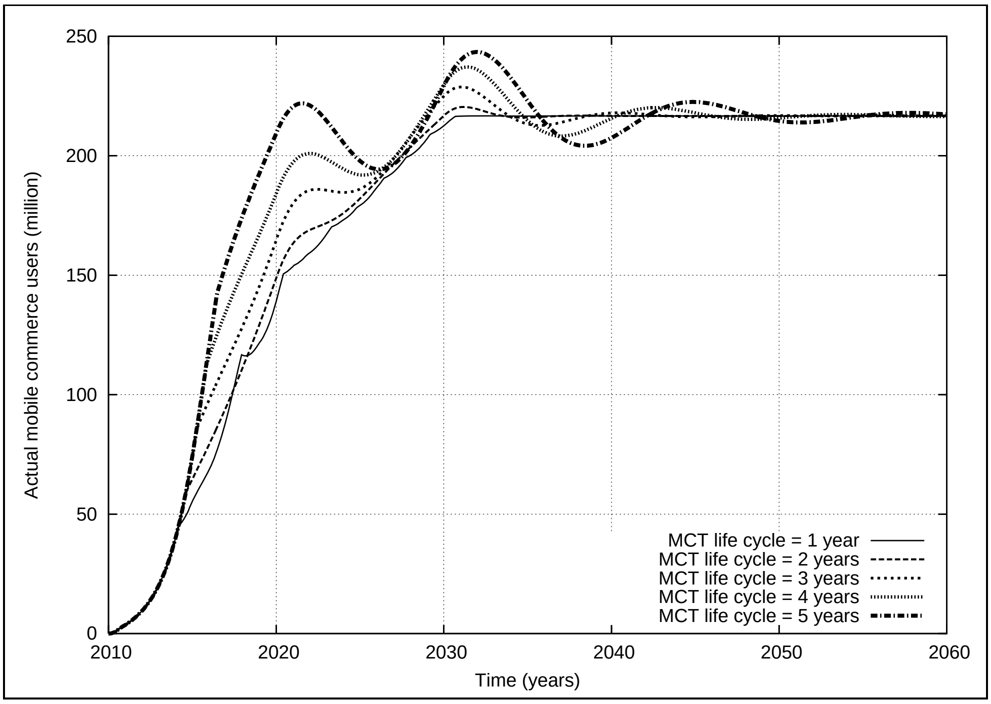


Figure 6.12: Disturbances caused by different lengths of the MCT life cycle

The curves denoted as ‘MCT life cycle = 1 year’, ‘MCT life cycle = 2 years’, ‘MCT life cycle = 3 years’, ‘MCT life cycle = 4 years’ and ‘MCT life cycle = 5 years’ are the curves of the actual number of mobile commerce users in the market generated from the simulations when the length of the MCT life cycle is set to one, two, three, four and five years respectively.

The simulation found that the length of the MCT life cycle would cause turbulence in MCT provision, which would pass the dynamics to actual mobile commerce diffusion. Generally the variations in the amplitude of oscillation caused by a certain length of MCT life cycle are very high at the beginning and gradually attenuate as time elapses to finally stabilise. The greater the length of the MCT life cycle, the greater the oscillations it will generate. The variation even reaches a value as high as 50% of the normal quantity, which increases the difficulty of market planning.

If this problem cannot be adequately handled in advance, it will not only complicate MCT provision but it will also further influence mobile commerce diffusion. Figure 6.13 illustrates the constrained expansion of the mobile commerce market when the length of the MCT life cycle is set to four years. In this case, the market expansion is not following the simple two-crest and

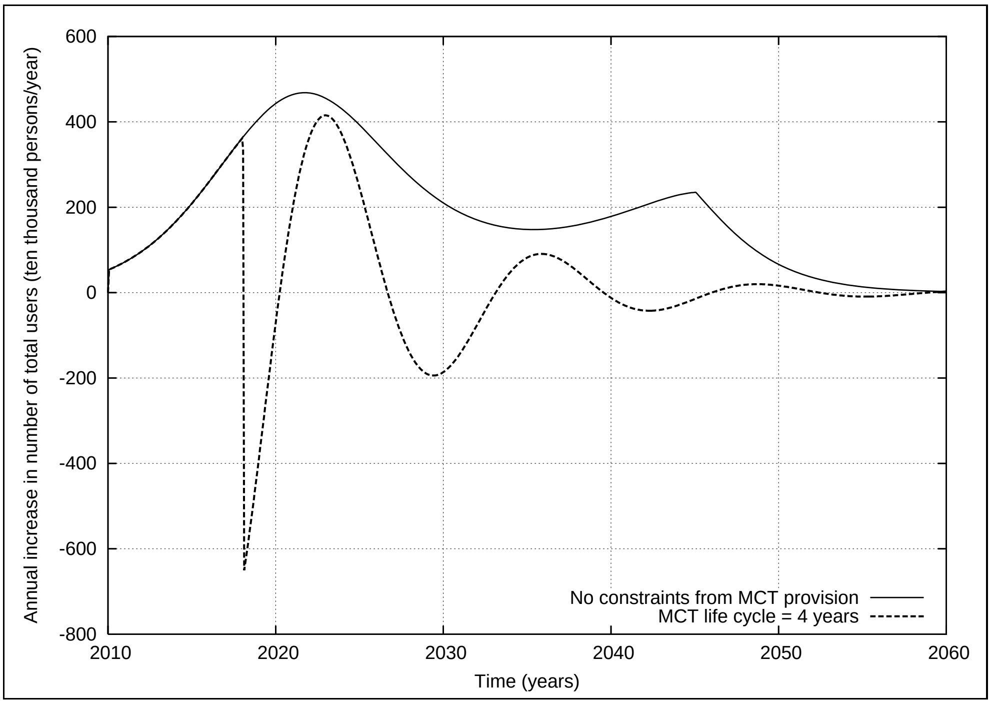


Figure 6.13: Turbulence from MCT life cycle

one-trough shaped curve as in the base scenario. It will generate oscillations around the x-axis.

The larger amplitude and higher frequencies of the oscillations increase the level of difficulty in market planning. To reduce these negative effects, two strategic countermeasures are proposed.

When the MCT industry forms a mixed or conservative strategy, the only method that can be used is to reduce the magnitude of the oscillations. With the reduction in the length of the MCT life cycle the oscillation will decline. Theoretically, the shorter the MCT life cycle is, the less oscillations will occur. Since the oscillation will reach its maximum when the MCT life cycle approaches two years, the best MCT life cycle is around two years long. From the perspective of MCT manufacturing, a two-year-long MCT life cycle is a good choice. In addition, MCTs should be positioned as frequently renovated fashionable goods and should not be considered as durable products when manufacturers design their MCT models. From the perspective of MCT marketing, a 24-month contract with free MCTs to the mobile commerce user, which is currently very popular in mobile phone marketing, is the preferred method.

As discussed in the previous section, avoiding the use of a mixed or conservative strategy is one choice in mitigating the influence of MCT provision on mobile commerce diffusion. The most effective method is to plan the MCT supply using a liberal strategy, which essentially dampens the fluctuations caused by the MCT life cycle. Using a liberal strategy may avoid the disturbances brought by the MCT life cycle. However, this method is undertaken at the cost of the MCT industry. The guarantee that mobile commerce development will be in full swing is based on a constant surplus of MCT provision in the market. Under these circumstances, the MCT industry has to bear the cost caused by producing excess products.

### 6.5.3 Scenario analysis of market openness

Market openness is the process of opening a market to outsiders. The influence of this process is determined by the initial market openness, the maximum market openness, the monopoly time and the method adopted to change from the initial market openness. Sensitivity analysis found that the maximum market openness is a sensitive factor. However, in the sensitivity analysis market openness development was assumed to be linear. This section examines the effects of the different strategies of market openness and their influence on mobile commerce diffusion.

Figure 6.14 displays the graphs of the actual number of mobile commerce users influenced by different values of the maximum market openness. For the scenario of mobile commerce diffusion, with the increase of market openness the actual number of mobile commerce users in

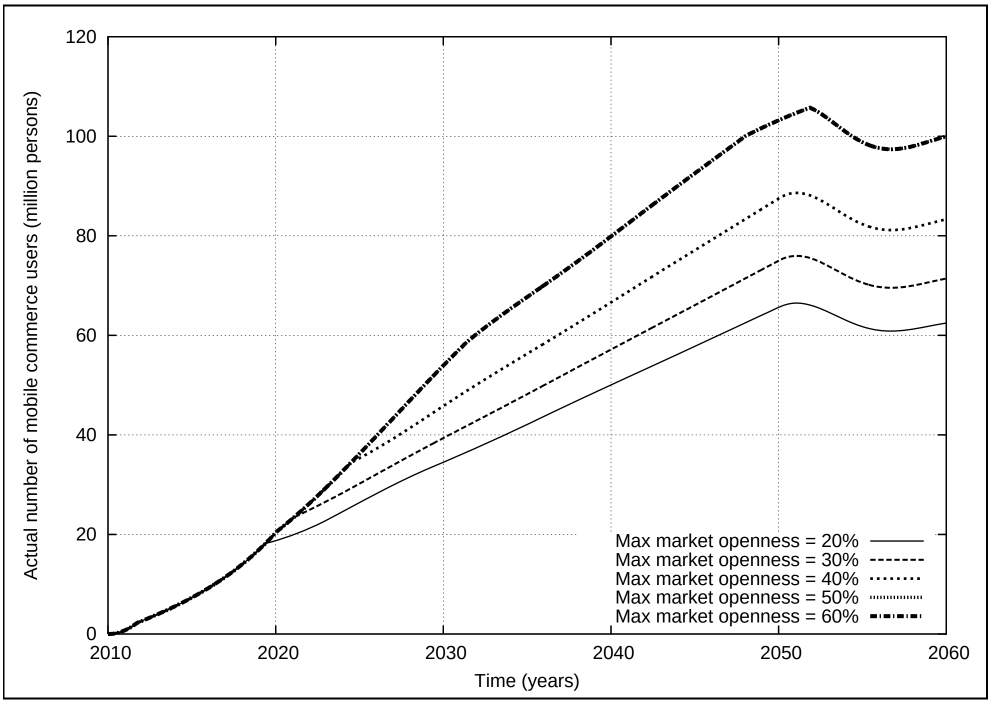


Figure 6.14: Influence of market opening level on mobile commerce diffusion

equilibrium will improve. However, this improvement is limited. When the maximum market openness is increased to a certain level, the increase in the actual number of mobile commerce users will cease. For example, in Figure 6.14, when the maximum market openness reaches a value of 50%, the curve will not change any more.

Figure 6.15 illustrates the two development modes for market openness: linear and two-step. Under a linear mode, the market will be opened linearly from an initial value of 20% to a maximum of 40 within 20 years. Under a two-step mode, the market in the first 20 years will be opened at a constant level of 20% and then suddenly will be opened to a maximum level of 40%.

As shown in Figure 6.16, the actual number of mobile commerce users under the linear mode will approximately increase linearly but the curve from the two-step mode will generate oscillations. Market expansion under the two-step mode, shown in Figure 6.17, will produce wider variations and increases the difficulty in managing the MCT market.

In practice, market openness is often manipulated. In one scenario, a country may strictly abide by its promise made when negotiating entry into the WTO. As a requirement, the country must open its monopolised mobile market from its current fraction (e.g. 20%) to a maximum fraction

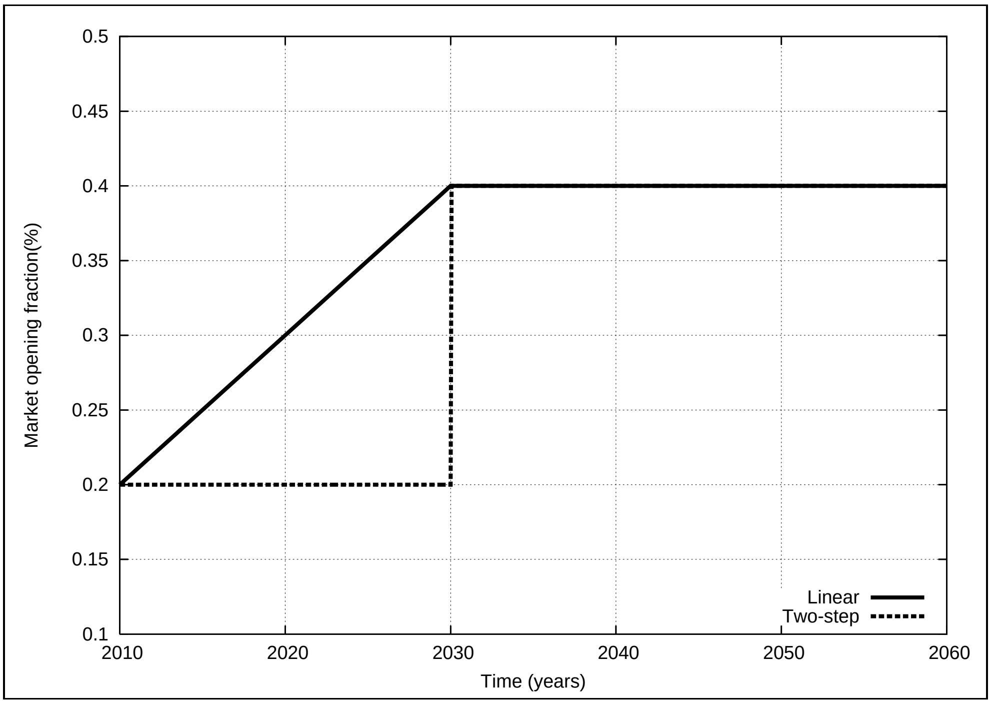


Figure 6.15: Different ways to open an MCT market

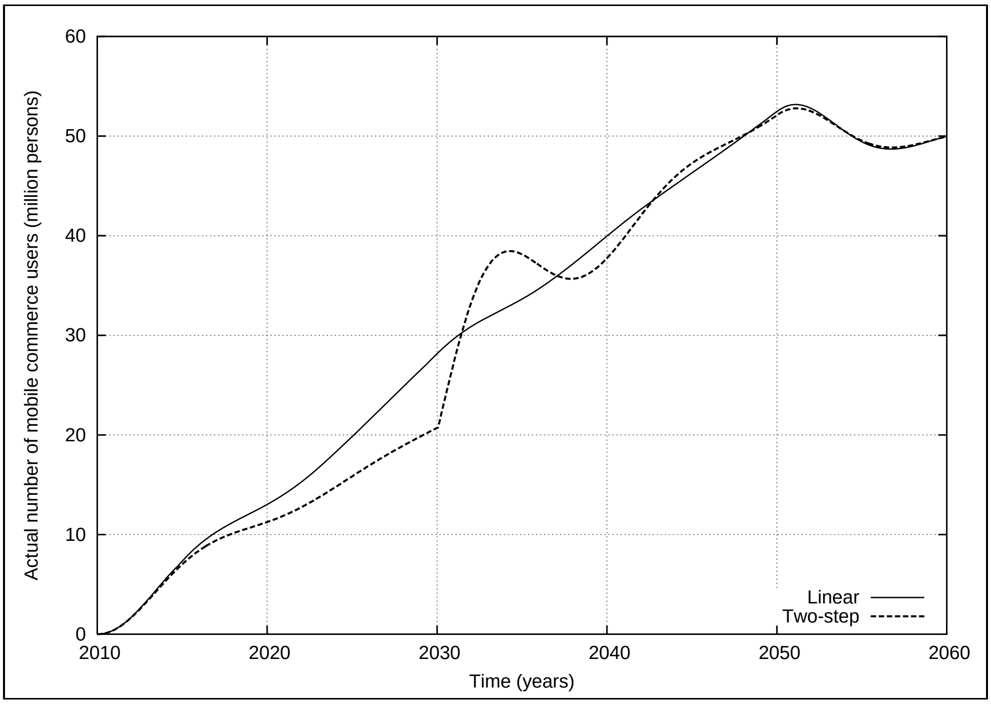


Figure 6.16: Actual number of users under two market opening modes

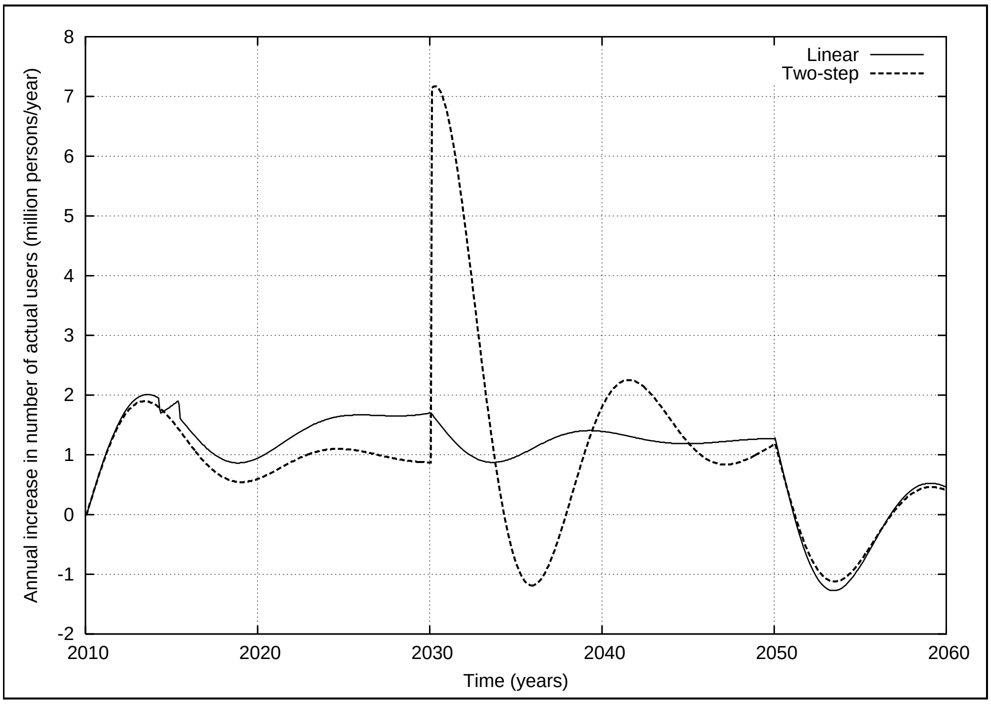


Figure 6.17: Increase in actual number of users under two market opening modes

of 49% five years after it becomes a WTO standing member. In another scenario, the government will presumably manipulate hidden barriers to prevent international competitors. Suppose that the actual market openness only reaches a 30 percentile five years after it enters the WTO. Simulations find that this manipulation will bring instability into mobile commerce diffusion, and experiments also show the effectiveness of possible actions that policy makers can take to avoid these disturbances.

Figure 6.18 shows two curves created under scenarios one and two. Under scenario two, mobile commerce diffusion does not follow a smooth quasi-s-shaped course as in scenario one. The variation from the s-shaped line will not only raise the degree of uncertainty in the mobile commerce market but will also increase the level of difficulty in mobile commerce industry planning. If not cautiously handled in advance, this causes negative effects on the emerging mobile commerce industry.

To solve this problem, an effective strategy is to increase supply capacities and reduce the time needed to build these capacities. In essence this is liberal MCT strategic planning which can be used to avoid the oscillations created.

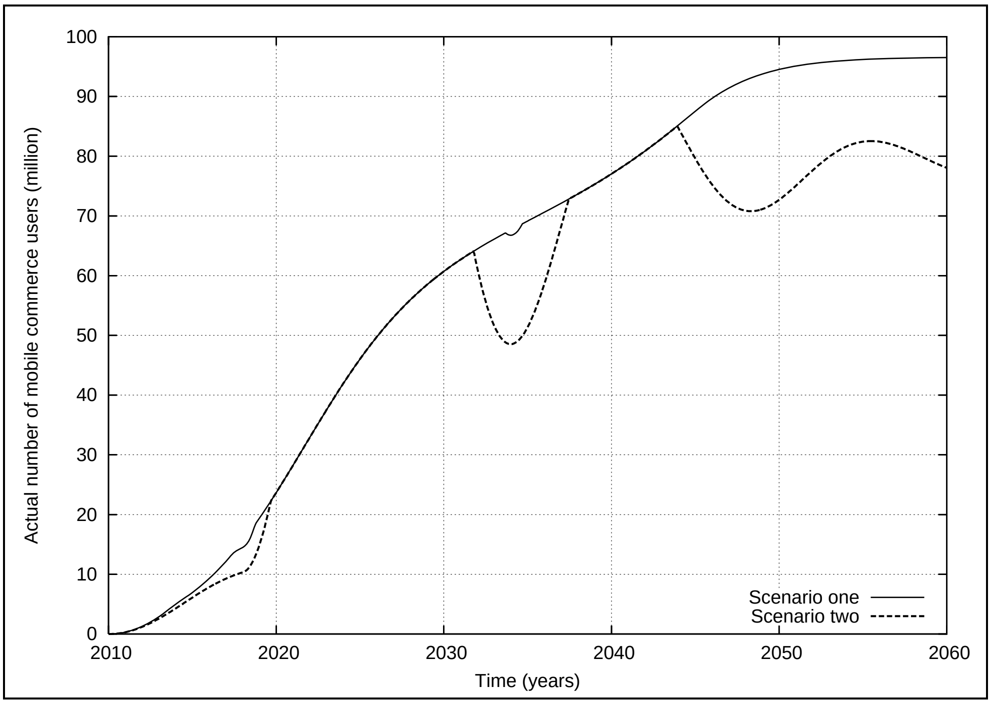


Figure 6.18: Influence of hidden barrier on mobile commerce diffusion

### 6.5.4 Two complex scenarios of MCT provision

This section examines the mobile commerce diffusion under two complex scenarios of MCT provision. Two scenarios i.e. undersupply and oversupply scenarios are simulated and analyzed and compared to the base case scenario described in chapter 5.

#### 6.5.4.1 Simulation of MCT provision under an undersupply scenario

An undersupply scenario occurs when a protectionism policy is used in practice and limited capacity can be built by the Chinese companies. Suppose that the actual market openness only reaches a value of 40% from the initial value of 20% ten years after the implementation of mobile commerce. In terms of the domestic MCT manufacturing capacity, the Chinese companies cannot manufacture the needed demand from a huge market. Suppose that, under the base scenario of mobile commerce diffusion, the Chinese companies can build an initial capacity of 3 million MCTs per year within the first 20 years and then take another 20 years to increase this to a full capacity of 30 million units. The Chinese companies spend great efforts in increasing their capacities and have no time for the research and marketing of MCTs. In order to temporarily relieve the pressure of high demands from the market, they design and produce durable MCT products instead. Table 6.4 lists the values used for the parameters that simulate the undersupply scenario.

Table 6.4: Values set for parameters in simulating undersupply and oversupply scenarios

| Parameters | Undersupply scenario | Oversupply scenario |
|---|---|---|
| $IMO_t$ | 20% | 20% |
| $MMO_t$ | 40% | 60% |
| $MT_t$ | 10 | 8 |
| $MCTLC_t$ | 5 | 5 |
| $IDMC_t$ | 3,000,000 | 9,000,000 |
| $FDMC_t$ | 30,000,000 | 70,000,000 |
| $IT_t$ | 20 | 8 |
| $ICT_t$ | 20 | 8 |

Three elements in the mobile commerce market are simulated for observation: the MCTs needed, the MCTs supplied and the actual number of mobile commerce users. Figure 6.19 illustrates the market dynamics during the simulation period. Since MCT provision falls under a conservative strategy, the actual number of mobile commerce users is constrained by the limited amount of MCT provision. The actual number of mobile commerce users is the same as the number of MCTs supplied. In Figure 6.19, the curves for the actual number of mobile commerce users and the provided MCTs overlap. Simulation finds that under the undersupply scenario, the accumulated number of actual mobile commerce users that should have increased because of the shortage of MCTs has reached about eight hundred million. In other words, about eight hundred million more MCTs should have been supplied.

In comparison with the base scenario of mobile commerce diffusion (same as the curve of MCT demand in Figure 6.19), the actual number of mobile commerce users shows a slow diffusion in the first 20 years, then increases very quickly in the next 20 years, and then stabilises after several oscillations.

The curve of the annual increase in the number of actual mobile commerce users experiences significant fluctuations in comparison with the annual increase in the number of total mobile

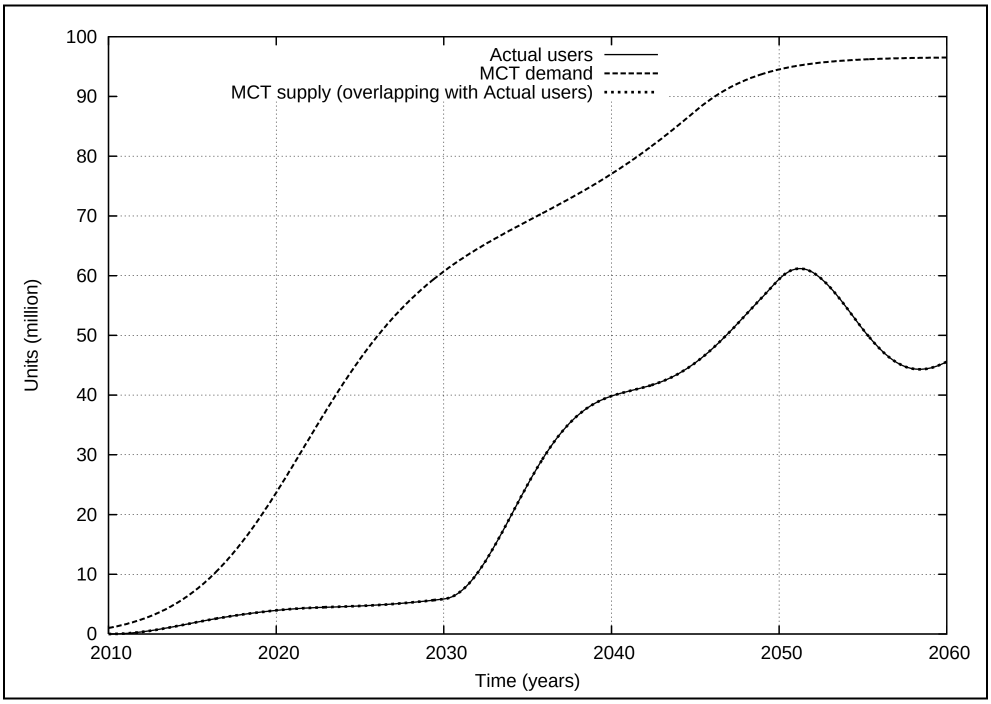


Figure 6.19: Market dynamics under an undersupply scenario

commerce users in the base scenario. Figure 6.20 illustrates the change in behaviour during the simulation period. The uncertainty in MCT provision greatly increases the dynamics of the annual increase in the number of mobile commerce users. The negative values denote the contraction of the mobile commerce market.

The undersupply scenario is characterised by the limited production capacity of the Chinese companies, the low level of market opening to the outside, the long MCT life cycle, the high demands from mobile commerce users and the constrained mobile commerce diffusion. The MCT industry obtains unconstrained progress at the cost of a compressed mobile commerce diffusion.

#### 6.5.4.2 Simulation of MCT provision under an oversupply scenario

An oversupply scenario occurs when a liberal policy is adopted in practice and a surplus capacity exists in China. China opens its MCT market to the outside world in order to learn new technologies and management practices and attracts more investment. It strictly abides by its promise as negotiated upon entry into the WTO. The market openness will reach 60% from an initial 20% eight years after the implementation of mobile commerce. International cooperation

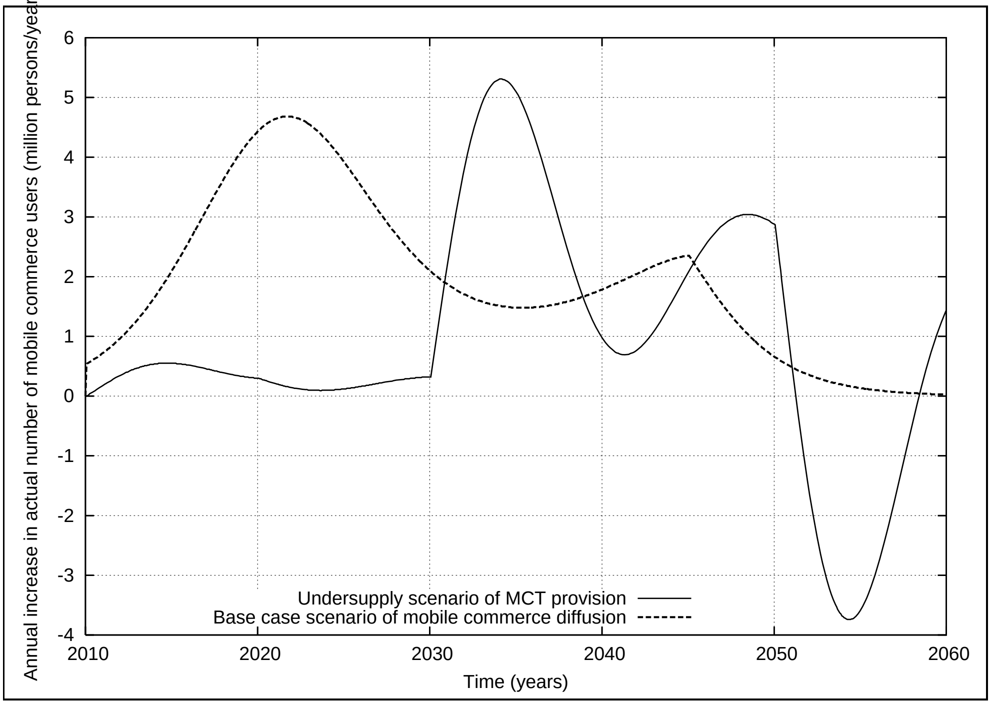


Figure 6.20: Annual increase in actual number of users under an undersupply scenario

improves the capacity of MCT manufacturing by Chinese companies. The Chinese companies can easily form an initial capacity of 9 million units per year within the first eight years and take another eight years to increase this to a full capacity of 70 million units. Long-life, expensive, multi-function MCT terminals are produced and marketed. Table 6.4 lists the values used for the parameters that simulate the oversupply scenario.

Figure 6.21 illustrates the evolution of the actual number of mobile commerce users, and the demand and supply of MCTs during the simulation period. Since the MCT provision falls under a liberal strategy, the actual number of mobile commerce users will be in full swing with no constraint from MCT supply. The actual number of mobile commerce users under an oversupply MCT provision scenario is the same as the base case scenario of mobile commerce diffusion. In Figure 6.21, the curves for the actual number of mobile commerce users and the needed MCTs overlap. Simulation under an oversupply scenario finds that the accumulated number of MCTs to be supplied has reached more than three hundred million units. In other words, about three hundred million less MCTs should have been supplied.

In comparison with the base case scenario of mobile commerce diffusion, the diffusion of the actual number of mobile commerce users and the increase in the number of actual mobile com-

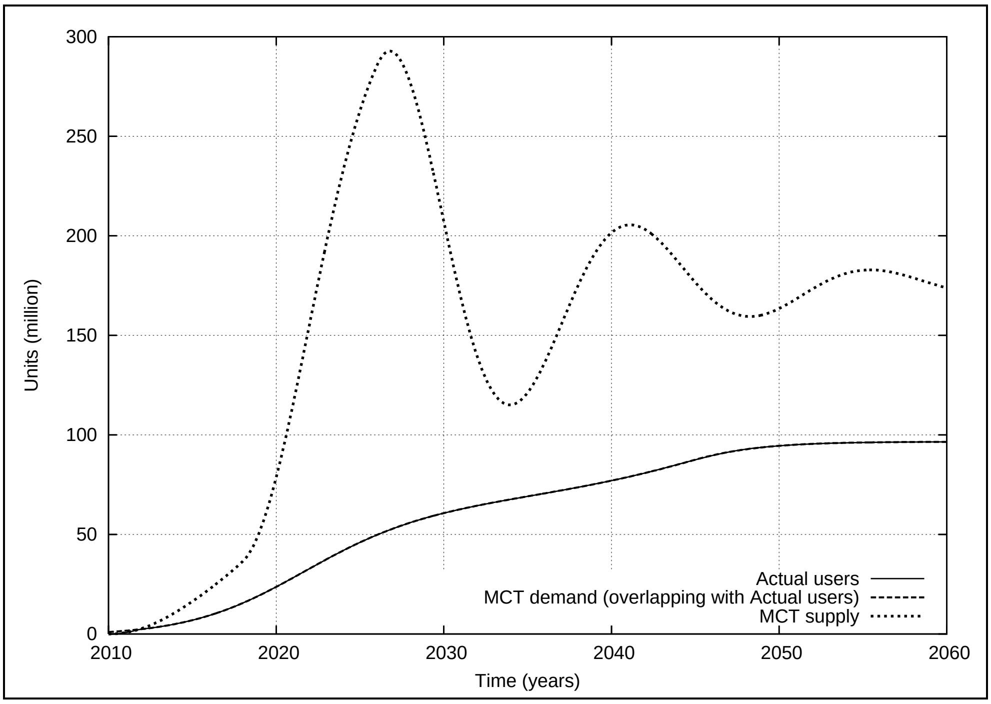


Figure 6.21: Market dynamics under an oversupply scenario

merce users have the same behaviour as in the base case scenario of mobile commerce diffusion as shown in Figure 6.22.

An oversupply scenario is characterised by a surplus capacity from Chinese companies, quicker and higher market opening to the outside world, a long MCT life cycle, limited demands from mobile commerce users and full mobile commerce diffusion. The full mobile commerce diffusion is at the cost of a constant oversupply of MCTs in the market.

## 6.6 Strategy development

The behaviour of mobile commerce diffusion under a scenario may not be what is expected. How to manipulate the achievements displayed and overcome the risks incurred in a scenario is useful in practice. This section demonstrates how to develop effective strategies to mitigate the side effects from the undersupply and oversupply scenarios should these occur in real life.

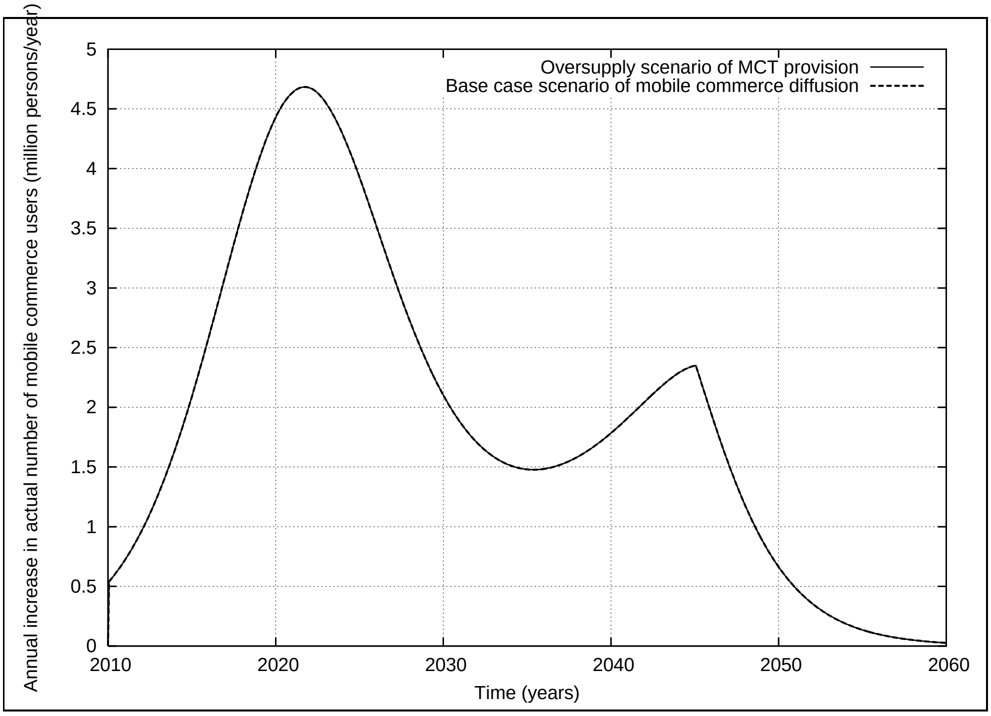


Figure 6.22: Annual increase in actual number of users under an oversupply scenario

### 6.6.1 Strategies for controlling an undersupply scenario

An undersupply scenario displays two obvious negative aspects: a high variation in the supply of MCTs and a constrained diffusion of mobile commerce due to limited supply of MCTs.

The scenario analysis in the previous sections found that adopting a shorter MCT life cycle will reduce the variation in MCT provision, and also adjusting the market openness and the elements in an MCT strategic plan can change the amount of MCT provision in the market. Based on these relationships, three strategies are designed and listed in Table 6.5.

In strategy one, the MCT life cycle is set to two years. The market openness is used to adjust the MCT provision. Simulation finds that when the market openness is increased from an initial value of 20% to a final value of 70% within three years, MCT provision is increased and meets market demands. This strategy can be adopted when the domestic MCT manufacturing capacity cannot be improved within a certain period of time. Adopting this strategy means that foreign companies will have more share of the market and can obtain bargaining power in controlling the market. This may incur possible trade blocks from foreign business allies.

Table 6.5: Parameter values used in forming suitable strategies for an undersupply scenario

| Parameters | Original | Strategy one | Strategy two | Strategy three |
|---|---|---|---|---|
| $IMO_t$ | 20% | 20% | 20% | 20% |
| $MMO_t$ | 40% | 70% | 40% | 49% |
| $MT_t$ | 10 | 3 | 10 | 5 |
| $MCTLC_t$ | 5 | 2 | 2 | 2 |
| $IDMC_t$ | 3,000,000 | 3,000,000 | 5,500,000 | 5,000,000 |
| $FDMC_t$ | 30,000,000 | 30,000,000 | 65,000,000 | 50,000,000 |
| $IT_t$ | 20 | 20 | 10 | 10 |
| $ICT_t$ | 20 | 20 | 25 | 25 |

Similarly to strategy one, the MCT life cycle is set to two years in strategy two. The aim of domestic MCT strategic planning is to amend MCT provision. Experiments find that MCT provision is improved to meet the market requirements under the following conditions: using ten years to improve the initial capacity from an original value of 3 million to 5.5 million units, and using twenty-five years to increase the final capacity from an original value of 30 million to 65 million units. This strategy can be adopted when the domestic companies have extra manufacturing capacities. This strategy protects the market share and allows more business expansion for domestic companies. It may incur disagreements or protest from foreign companies.

The MCT life cycle is also set to two years in strategy three. Both market openness and domestic MCT strategic planning are used to change the state of MCT provision in the market. As listed in the righthand column of Table 6.5, in order to improve MCT provision, market openness will be lifted from an initial value of 20% to 49% within five years and, at the same time, the initial and final capacities are respectively increased from an original value of 3 million to 5 million units in ten years, and from an original value of 30 million to 50 million units in twenty-five years. This strategy releases the pressure of large-scale capacity formation from the domestic companies and is an optimal option when undersupply conditions exist in real life.

### 6.6.2 Strategies for controlling an oversupply scenario

An oversupply scenario also demonstrates two obvious side effects: the oscillation of MCT provision and the constant surplus of MCTs in the market. Similarly to strategy development in the undersupply scenario, three strategies are designed to overcome the side effects as listed in Table 6.6.

Table 6.6: Parameter values used in forming suitable strategies for an oversupply scenario

| Parameters | Original | Strategy one | Strategy two | Strategy three |
|---|---|---|---|---|
| $IMO_t$ | 20% | 20% | 20% | 20% |
| $MMO_t$ | 60% | 30% | 60% | 49% |
| $MT_t$ | 8 | 10 | 8 | 10 |
| $MCTLC_t$ | 5 | 2 | 2 | 2 |
| $IDMC_t$ | 9,000,000 | 9,000,000 | 8,000,000 | 8,500,000 |
| $FDMC_t$ | 70,000,000 | 70,000,000 | 38,000,000 | 50,000,000 |
| $IT_t$ | 8 | 8 | 10 | 8 |
| $ICT_t$ | 8 | 8 | 25 | 25 |

In strategy one, the aim is to reduce the fraction of the capacity of foreign MCT producers. In order to reduce their MCT provision, the maximum market openness is adjusted from the original value of 49% to 30% and the monopoly time prolonged from the original 8 years to 10 years. Under this strategy, the domestic MCT strategy is unchanged. This strategy may raise resistance from foreign partners.

In strategy two, the idea is mainly to reduce the fraction of the capacity of domestic MCT manufacturers. In order to reduce MCT provision, the initial capacity is reduced from the original 9 million units to 8 million units per year, the introduction time will be prolonged from the original 8 years to 10 years, the final capacity will be greatly reduced from the original 70 million units to 38 million units per year and the increase time raised from 8 to 25 years. Under this strategy, the domestic MCT industry will have to cut its capacity.

In strategy three, both the market openness and the domestic MCT production capacity will be adjusted. On the one hand, the maximum market openness is reduced from the original value of 60% to 49% and monopoly time increased from the original value of 8 to 10 years. On the other hand, the initial capacity is slightly reduced from the original 9 million units per year to 8.5 million per year, the introduction time prolonged from the original 8 years to 10 years, the final capacity decreased from the original 70 million units to 50 million units per year and the increase time increased from 8 to 25 years. This strategy may easily reach the consensus among different market participants. This is the optimal choice when an oversupply scenario is expected to occur.

## 6.7 Summary

This chapter has demonstrated how to use the models developed in the previous chapters for modelling MCT provision. Scenarios were imagined for MCT provision, mobile commerce diffusion examined under these scenarios and strategies developed to mitigate the possible negative aspects arising from these scenarios.

Sensitivity analysis found the main factors that exert significant influence on mobile commerce diffusion to include: the way to plan the domestic MCT industry; the length of the MCT life cycle and MCT market opening.

Further experiments found mobile commerce diffusion to be in full swing under a liberal MCT strategy, but would be constrained under both a conservative and the mixed strategies. This constraint can be removed by adjusting the designed capacities and the times taken to reach these capacities. The greater the length of the MCT life cycle, the greater the oscillation it will create in MCT provision, which will similarly impact on the mobile commerce diffusion when the negative and mixed strategies are adopted. In practice, manufacturers can design MCTs with a life time of two years and marketers can market these MCTs with a two-year service package so that they are biennially recycled. With an increase in market openness, MCT provision will increase and vice versa. Under the conservative and mixed strategies, the increase of market openness will increase the number of mobile commerce users, but this increase in mobile commerce users will stop when market openness reaches a certain value.

The undersupply MCT provision scenario will cause a possible shortage of MCTs in the market and thus constrain mobile commerce diffusion. The oversupply MCT provision scenario will create a possible surplus of MCTs in the market. Three strategies have been designed to manipulate the situations arising from these two scenarios.

# Chapter 7

# CONCLUSION AND FUTURE RESEARCH

## 7.1 Introduction

A set of System Dynamics simulation models was developed to simulate and establish the relationship among population evolution, mobile commerce diffusion and MCT provision in China using the available information. These models were used for identifying sensitive factors, scenario design, simulation and analysis and strategy development. The results demonstrate that SD simulation modelling is a viable and promising alternative for understanding mobile commerce diffusion trends and for examining diffusion behaviour. This chapter presents a summary of the research work and the results obtained. The contributions and limitations of this study are highlighted. The chapter concludes with suggestions for future research.

## 7.2 Summary of the research work

This research has developed models to illustrate the process of population evolution, mobile commerce diffusion and MCT provision. These models were used for establishing experiments that contribute to the fulfilment of the objectives of this research, which are the identification of sensitive factors, scenario design, simulation and analysis and strategy development. The research work is summarised in Table 7.1 and in the following paragraphs.

A summary of the three submodels of SD simulation modelling in chapters 4, 5 and 6 is as follows. For each SD submodel, the influential factors are identified from a literature survey.

Table 7.1: Summary of research work

| Activity | Sub activity |
|---|---|
| SD simulation modelling | Factor identification<br>Causal loop diagram<br>Stock flow diagram<br>Calibration and validation Strategy development |
| Experimentation | Sensitivity analysis<br>Determination of sensitive factors<br>Scenario design, simulation and analysis<br>Strategy development |

The causal loop diagrams and stock and flow diagrams of the subsystems are drawn. The SD simulation model is obtained through theoretical, mathematical and logical formalisation and is validated through historical behaviour reproduction using available data.

A summary of scenario design, simulation and analysis and strategy development performed in chapters 4, 5 and 6 is as follows. Sensitivity analysis was used to identify the key influential factors, which were used for designing reasonable scenarios and for providing countermeasures in strategy formulation. In addition, some important business implications from sensitivity analysis were identified. In scenario design, active factors were classified. Typical scenarios were designed by combining the factors or restructuring the developed model for experimentation. The behaviours from these scenarios were simulated, their characteristics analysed and findings were drawn. Some scenarios may generate desirable behaviours. Therefore strategies were developed in order to influence such possible negative consequences so that the behaviours can be positively adjusted.

Chapters 4 to 6 contain the research on the SD simulation modelling undertaken in this thesis. In Chapter 4, an SD simulation model of population evolution was developed and validated. The population dynamics was illustrated and the influential factors analysed. Four urbanisation development scenarios, five family planning scenarios, four life quality scenarios and two complex population scenarios were designed and experimented with, and alternative family planning strategies were provided for four urbanisation scenarios.

In Chapter 5, an SD simulation model of mobile commerce diffusion was developed and validated. Sensitivity analysis was conducted and the key influential factors were analysed. The dynamics of mobile commerce diffusion was illustrated and the business implications were presented. Chapter 5 also illustrated the behaviours of mobile commerce diffusion under four scenarios from urbanisation development and two complex scenarios of mobile commerce development. One strategy was developed to mitigate the negative aspects from the carry away scenario of mobile commerce diffusion.

In Chapter 6, a simulation model of MCT provision was developed and simulated. Factors such as how to develop Chinese domestic MCT strategic planning, the MCT life cycle and the way to open the MCT market were identified as sensitive. The influence of the three MCT strategic plans, MCT life cycle and market openness were also examined. The behaviours of mobile commerce diffusion under two extreme scenarios of MCT provision were also experimented upon. Three strategies were designed and simulated to overcome the shortcomings that exist in the undersupply and oversupply scenarios.

## 7.3 Summary of the results

The research uses the SD technique to develop a set of SD submodels in forming a complete simulation model of mobile commerce diffusion and experiments were designed for exploring the dynamics involved. A systemic approach was thus used to examine the new area of mobile commerce. The following findings were obtained in the process of SD simulation modelling, calibration and validation, sensitivity analysis, scenario design, simulation and analysis and strategy development.

The population submodel illustrates demographic dynamics, which propagates to the submodel of mobile commerce diffusion in the next stage. The population model can also act as an independent platform for examining demographic change in China. Its reliability was demonstrated in reproducing the historical population and simulating the UN forecast. Although national policy makers may never be expected to use demographic change as a leverage point to control market behaviours, strategists can still experiment with how the demographic structure forms the market base and how demographic changes influence the changes of market structure. Factors within the categories of family planning, urbanisation and life quality will significantly influence population development. Urbanisation development under different scenarios will drive Chinese population development trends in different directions. Planners can choose family planning as a leverage point to mitigate the effects of the instability of urbanisation and life quality, and hence lead the population in the right direction. To understand the dynamics of population development, it is important to adopt the right kind of family planning and urbanisation policies and speculate on the population's life quality in China both currently and in the future. These were examined in chapter 4.

The mobile commerce diffusion submodel provides a platform for exploring the dynamics of mobile commerce diffusion. It shows how demographic changes and market forces will form the future basis of mobile commerce diffusion. The mobile commerce submodel illustrates the sensitivity and inertia of the factors involved. Implementation time will significantly influence the formation of the rural mobile commerce market. The later mobile commerce is implemented, the quicker the rural market will develop. This influence will only take effect within a certain time span. Beyond that period, this influence will become weak. The existence of a floating population will also be an obvious advantage when opening the rural market. The higher the level of electronic commerce penetrated, the more mobile commerce users there will be. The quicker and the greater the network renovation, the greater the number of mobile commerce users. The contact rate and the acceptance behaviour of people will also influence mobile commerce diffusion. However, discard rates and propaganda will not notably influence mobile commerce diffusion in the long run. urbanisation, family planning and life quality from the population model are also active in influencing mobile commerce diffusion. Mobile commerce diffusion demonstrates different behaviours under the four urbanisation scenarios described in chapter 5. The carry away scenario will generate explosive market expansion. The cautious scenario will produce excellent mobile commerce behaviour in terms of market planning. Strategists can adopt a delayed network strategy to mitigate the negative aspects of the explosive market expansion from the carry away scenario, and use the values of parameters involved in the cautious scenario to cultivate the emerging Chinese market in advance so that this scenario can be realised in practice.

The modelling and simulation of MCT provision provides an effective technique for establishing the relationship between the different scenarios of MCT provision and mobile commerce diffusion, especially the relationship among the strategic planning of the Chinese MCT industry, the MCT life cycle, market openness and mobile commerce diffusion. For each scenario of mobile commerce diffusion, an optimal MCT strategy can be formulated. An alternative MCT strategic planning can also fall under the liberal, conservative or mixed area scenario. When in the mixed or conservative area, the MCT industry will become a bottleneck for mobile commerce development. The strategy that can be used to break the bottleneck is to increase MCT capacities, shorten the time needed to build those capacities and increase market openness.

In addition to the influence from MCT strategic planning, the MCT life cycle considerably influences MCT provision, which will further propagate mobile commerce diffusion when the MCT strategic planning is in the conservative or mixed areas. The more the MCT life cycle varies, the bigger the turbulence it creates. The best strategy for determining the MCT life cycle is to set the MCT life cycle at around two years.

Market openness also exerts influence on mobile commerce diffusion. The influence is especially significant if the variation of market openness draws the MCT strategic planning into the conservative and mixed areas. With an increase of market openness, the number of mobile commerce users will increase. However, when the market openness reaches a certain value, this increase will stop. If planners use the hidden barrier strategy to disadvantage foreign competitors they must carefully examine the consequences of their MCT strategic planning; otherwise this practice will bring great instability to both the MCT strategic planning and mobile commerce diffusion.

Undersupply scenarios generate variations in MCT provision and constrain mobile commerce diffusion. Oversupply scenarios also bring oscillation in MCT provision and cause a constant surplus of MCTs in the market. Setting the MCT life cycle at two years will greatly reduce the oscillation in MCT provision under these two scenarios. Increasing market openness, or increasing capacities and shortening the times taken to build the capacity, or both of these, will alleviate the constraints on mobile commerce diffusion under the undersupply scenario. Reducing market openness, or decreasing capacities and prolonging the times taken to build capacity, or combining these together, will overcome the possible surpluses of MCT provision under the oversupply scenario without influencing mobile commerce development.

In general, this study developed three simulation models for the understanding of population dynamics, mobile commerce diffusion and MCT provision under different scenarios in China. It established the linkages among influential factors, and demonstrated how designing scenarios and strategies can generate more efficient and effective mobile commerce implementation in China. This thesis also demonstrated the implementation of SD modelling as applied to simulating population development, mobile commerce diffusion and MCT provision in an interrelated dynamic system. The findings from this study form basic insights into the way mobile commerce will appear and diffuse. More importantly, this research uses China as a case for exploring the applicability of this type of modelling for simulating mobile commerce diffusion.

During the process of SD simulation modelling, the variables, causal loop diagrams, stock and flow diagrams, equations, and sensitive factors from the population development model, mobile commerce diffusion model and MCT provision model were all outlined in Chapters 4 to 6. The processes entailed in scenario design, simulation analysis and strategy development were also demonstrated in detail in chapters 4 to 6. Some scenarios, strategies and their consequences experimented in Chapters 4 to 6 for this research are also summarized in Table 7.2.

## 7.4 Contributions of the research

There are three contributions of this study.

Firstly, this study develops an effective SD model that is applicable for understanding mobile commerce diffusion and three useful submodels for examining population development, mobile commerce diffusion and MCT provision in China. This model provides an alternative method for international strategists and planners to examine the dynamics of mobile commerce diffusion as well as population change and MCT industry strategies under different scenarios, and therefore helps to form basic insights into their future trends. The results demonstrate that SD simulation modelling is a viable, competitive and promising alternative in understanding the complexity of dynamic systems such as mobile commerce diffusion. Simulation is effective in identifying influential factors, scenario design and analysis and strategy development.

Secondly, this study applies SD simulation modelling in order to explore population dynamics, mobile commerce diffusion and MCT provision in China. It enlarges the application of SD simulation modelling into new areas. It represents an early attempt at applying SD simulation

Table 7.2: List of scenarios, strategies and consequences

| Scenario | Strategy | Consequence |
|---|---|---|
| Modelling and simulating population dynamics in Chapter 4 | | |
| As-usual-urbanisation | In 2021, urban fertility can be increased from 1.2 to 1.6 and rural fertility decreased from 3.6 to 2.0 | Keep total population unchanged |
| Early-urbanisation-stop | In 2017, urban fertility can be increased from 1.2 to 1.5 and rural fertility decreased from 3.6 to 2.2 | Keep total population unchanged |
| Early-urbanisation-explosion | In 2007, urban fertility can be increased from 1.2 to 1.5 and rural fertility increased from 3.6 to 4.0 | Keep total population unchanged |
| Late-urbanisation-explosion | In 2013, urban fertility can be increased from 1.2 to 1.4 and rural fertility decreased from 3.6 to 2.8 | Keep total population unchanged |
| Modelling and simulating mobile commerce diffusion in Chapter 5 | | |
| Carry-away | Delayed network renovation | Cool down the hottest market<br>Reduce the increase in annual users and<br>Prolong the time to reach that value |
| Modelling and simulating MCT provision in Chapter 6 | | |
| Undersupply | *Strategy one*: improve MCT provision by increasing the maximum market openness and shortening the monopoly time<br>*Strategy two*: increase MCT provision from domestic producers by reducing the time to reach the capacities and improving the initial/final capacities<br>*Strategy three*: combine strategies one and two by increasing the market openness and the domestic MCT production capacity | Foreign companies occupy more market and obtain strong bargaining power, which incurs possible trade blocks<br>Protects the domestic market share; allows more domestic business expansion; incurs resistance from foreign partners<br>Easily reaches the consensus; releases the pressure of large-scale capacity formation in the beginning |
| Oversupply | *Strategy one*: reduce the capacity of foreign MCT producers by lowering the maximum market openness and prolonging the monopoly time<br>*Strategy two*: reduce MCT provision from domestic producers by prolonging the time to reach the capacities and reducing the initial/final capacities<br>*Strategy three*: combine strategies one and two by reducing the market openness and the domestic MCT production capacity | Domestic MCT manufacturers are under protection and it raises resistance from foreign partners<br>Foreign MCT producers are protected and it raises resistance from domestic partners<br>Easily reach the consensus among market participants |

modelling to the research area of mobile commerce.

Lastly, the study adds to the modelling and simulation literature using an SD simulation approach to modelling and simulating mobile commerce diffusion and population dynamics. It represents an early attempt at applying modelling and simulation to business and demographic fields. The usefulness and effectiveness of the approach was also demonstrated throughout this research.

## 7.5 Limitations of the research

A number of limitations of this study need to be recognised.

It is necessary to reiterate that the results of the experiments are based on information related to China and for a particular time period. Therefore they may not be representative for other countries, or other time periods.

Since high-level mobile commerce services are not in operation in China yet, it is impossible to validate the diffusion model of high-end mobile commerce services using historical behaviour reproduction as was done for validating the population model using Chinese historical population data and validating the mobile commerce model using the volume of mobile phone subscribers. The model developed should constantly be tested in the future as China implements high-end mobile commerce services, and as the data becomes available.

The output of the model only provides an understanding at a strategic level and does not have predictive accuracy in terms of the quantity of mobile commerce users and population level at an operational level. Although SD modelling is capable of justifying its prediction, it is conditional on other methods being used in accurately collecting data in calibration.

Although any imaginary scenario can be designed and simulated, better scenarios can be designed when more people participate in the process, and experiments with scenarios will have more practical implications. This is a practical issue of this research to be solved in the future if the model is used for commercialisation purposes.

## 7.6 Suggestion for future research

There are a few areas worth exploring further as a continuation of the research presented in this study.

Firstly, investigations of evolutionary computing and intelligent research methods in calibrating the parameters and testing the reliability of the model are worthwhile. These include the application of evolutionary computing technologies and contemporary intelligent methods for acquiring more relevant knowledge in the processes of SD modelling, scenario design and analysis and strategy development.

Secondly, the model developed can be readily applied to test its applicability in exploring mobile commerce diffusion and population development in other regions. A challenge will be to test the SD simulation model of mobile commerce diffusion across different countries. The use of data collected from other countries can provide rigorous validation of the generalisation ability of the model.

Thirdly, the model developed can be used for exploring the diffusion behaviour of an individual mobile commerce service or mobile commerce diffusion in a small-scale market. A challenge will be to test the SD simulation model of the diffusion of a particular mobile commerce service or diffusion within a limited market. The use of a data collection from a particular service or within a smaller market could provide rigorous validation of the generalisation ability of the model.

Fourthly, exploring the usefulness of other research methods in predicting population development, mobile commerce diffusion and MCT provision is worthwhile. The SD modelling, scenario design and analysis and strategy development used in this study are preliminary. The development of derivatives from an SD approach or other research methods may better forecast mobile commerce diffusion and population dynamics, leading to more accurate predictions.

Fifthly, exploring the usefulness of hidden factors other than those identified in this research in explaining the influence on population dynamics, mobile commerce diffusion and MCT provision is worthwhile. The factors identified in this study are preliminary. Other potential factors may also affect the diffusion, leading to more accurate explanations.

Sixthly, applications of the System Dynamics approach can be extended to solve other similar issues within social science and management. The essence of the SD modelling, scenario design, simulation and analysis and strategy formulation can be readily applied to other areas of innovation diffusion of ICT applications.

Lastly but not least, establishment of a global or national SD simulation model (virtual globe), of which population dynamics, mobile commerce diffusion, and MCT provision may be molecule, is worthwhile with the deepening of the multidimensional globalization and the availability of the powerful processing capacity of contemporary mainframe computer. Under this virtual globe, the applicability of the models developed in this study may be thoroughly examined and improved.

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# Appendix A

# Population and its composition in China

1. Data in this table includes the values of year-end.
2. Data in this table exclude the population of Hong Kong SAR, Macao SAR and Taiwan Province.
3. Data before 1982 were taken from the annual reports of the Ministry of Public Security.
4. Data from 1982-1989 were adjusted on the basis of the 1990 national population census.
5. Data from 1990-2000 were adjusted on the basis of the estimated 2000 national population census.
6. Data from 2001-2003 have been estimated on the basis of the annual national sample surveys on population changes.
7. Total population and population by sex include the military personnel of the Chinese People's Liberation Army, the military personnel are classified as urban population in the item of population by residence.

Table A.1: Population and its composition in China

| Year | Total person (x10000) | Male person (x10000) | Male percent (%) | Female person (x10000) | Female percent (%) | Urban person (x10000) | Urban percent (%) | Rural person (x10000) | Rural percent (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1978 | 96,259 | 49,567 | 51.49 | 46,692 | 48.51 | 17,245 | 17.92 | 79,014 | 82.08 |
| 1980 | 98,705 | 50,785 | 51.45 | 47,920 | 48.55 | 19,140 | 19.39 | 79,565 | 80.61 |
| 1985 | 105,851 | 54,725 | 51.70 | 51,126 | 48.30 | 25,094 | 23.71 | 80,757 | 76.29 |
| 1989 | 112,704 | 58,099 | 51.55 | 54,605 | 48.45 | 29,540 | 26.21 | 83,164 | 73.79 |
| 1990 | 114,333 | 58,904 | 51.52 | 55,429 | 48.48 | 30,195 | 26.41 | 84,138 | 73.59 |
| 1991 | 115,823 | 59,466 | 51.34 | 56,357 | 48.66 | 31,203 | 26.94 | 84,620 | 73.06 |
| 1992 | 117,171 | 59,811 | 51.05 | 57,360 | 48.95 | 32,175 | 27.46 | 84,996 | 72.54 |
| 1993 | 118,517 | 60,472 | 51.02 | 58,045 | 48.98 | 33,173 | 27.99 | 85,344 | 72.01 |
| 1994 | 119,850 | 61,246 | 51.10 | 58,604 | 48.90 | 34,169 | 28.51 | 85,681 | 71.49 |
| 1995 | 121,121 | 61,808 | 51.03 | 59,313 | 48.97 | 35,174 | 29.04 | 85,947 | 70.96 |
| 1996 | 122,389 | 62,200 | 50.82 | 60,189 | 49.18 | 37,304 | 30.48 | 85,085 | 69.52 |
| 1997 | 123,626 | 63,131 | 51.07 | 60,495 | 48.93 | 39,449 | 31.91 | 84,177 | 68.09 |
| 1998 | 124,761 | 63,940 | 51.25 | 60,821 | 48.75 | 41,608 | 33.35 | 83,153 | 66.65 |
| 1999 | 125,786 | 64,692 | 51.43 | 61,094 | 48.57 | 43,748 | 34.78 | 82,038 | 65.22 |
| 2000 | 126,743 | 65,437 | 51.63 | 61,306 | 48.37 | 45,906 | 36.22 | 80,837 | 63.78 |
| 2001 | 127,627 | 65,672 | 51.46 | 61,955 | 48.54 | 48,064 | 37.66 | 79,563 | 62.34 |
| 2002 | 128,453 | 66,115 | 51.47 | 62,338 | 48.53 | 50,212 | 39.09 | 78,241 | 60.91 |
| 2003 | 129,227 | 66,556 | 51.50 | 62,671 | 48.50 | 52,376 | 40.53 | 76,851 | 59.47 |

# Appendix B

# Population by age and sex

Table B.1: Population by age and sex (1 October 1995) (to be continued)

Figures in this table are from the sampling survey on 1 October 1995.
The sample proportion is 1.04%.
Sex ratio is calculated based on the assumption 'female=100'.

| Age | Total (Person) | Male (Person) | Female (Person) | Sex Ratio | Age | Total (Person) | Male (Person) | Female (Person) | Sex Ratio |
|---|---|---|---|---|---|---|---|---|---|
| Total | 12,366,952 | 6,294,901 | 6,072,051 | 103.67 | 50 | 113,515 | 57,803 | 55,712 | 103.75 |
| 0-4 | 901,256 | 488,560 | 412,696 | 118.38 | 51 | 106,693 | 54,827 | 51,866 | 105.71 |
| 0 | 172,308 | 92,746 | 79,562 | 116.57 | 52 | 100,909 | 51,884 | 49,025 | 105.83 |
| 1 | 149,659 | 81,965 | 67,694 | 121.08 | 53 | 99,102 | 50,875 | 48,227 | 105.49 |
| 2 | 176,120 | 96,520 | 79,600 | 121.26 | 54 | 103,904 | 54,039 | 49,865 | 108.37 |
| 3 | 188,911 | 102,719 | 86,192 | 119.17 | 55-59 | 475,776 | 246,614 | 229,162 | 107.62 |
| 4 | 214,258 | 114,610 | 99,648 | 115.01 | 55 | 98,846 | 51,318 | 47,528 | 107.97 |
| 5-9 | 1,320,225 | 692,121 | 628,104 | 110.19 | 56 | 88,569 | 45,525 | 43044 | 105.76 |
| 5 | 269,053 | 142,744 | 126,309 | 113.01 | 57 | 98,604 | 51,519 | 47,085 | 109.42 |
| 6 | 269,091 | 140,809 | 128,282 | 109.77 | 58 | 95,288 | 49,669 | 45,619 | 108.88 |
| 7 | 258,517 | 135,324 | 123,193 | 109.85 | 59 | 94,469 | 48,583 | 45,886 | 105.88 |
| 8 | 280,753 | 146,619 | 134,134 | 109.31 | 60-64 | 429,181 | 219,026 | 210,155 | 104.22 |
| 9 | 242,811 | 126,625 | 116,186 | 108.98 | 60 | 95,184 | 48,132 | 47,052 | 102.3 |

Table B.2: Population by age and sex (1 October 1995)(to be continued)

| Age | Total (Person) | Male (Person) | Female (Person) | Sex Ratio | Age | Total (Person) | Male (Person) | Female (Person) | Sex Ratio |
|---|---|---|---|---|---|---|---|---|---|
| 10-14 | 1,084,741 | 563,047 | 521,694 | 107.93 | 61 | 86,962 | 44,366 | 42596 | 104.16 |
| 10 | 224,016 | 116,222 | 107,794 | 107.82 | 62 | 92,130 | 47,541 | 44,589 | 106.62 |
| 11 | 203,234 | 105,485 | 97,749 | 107.91 | 63 | 80,342 | 40,630 | 39,712 | 102.31 |
| 12 | 211,852 | 110,184 | 101,668 | 108.38 | 64 | 74,563 | 38,357 | 36,206 | 105.94 |
| 13 | 241,613 | 125,444 | 116,169 | 107.98 | 65-69 | 337,823 | 168,389 | 169,434 | 99.38 |
| 14 | 204,026 | 105,712 | 98,314 | 107.52 | 65 | 81,579 | 41,245 | 40,334 | 102.26 |
| 15-19 | 912,734 | 469,837 | 442,897 | 106.08 | 66 | 67,872 | 33,904 | 33,968 | 99.81 |
| 15 | 188,956 | 97,944 | 91,012 | 107.62 | 67 | 70,571 | 35,288 | 35,283 | 100.01 |
| 16 | 202,060 | 104,670 | 97,390 | 107.48 | 68 | 61,532 | 30,456 | 31,076 | 98 |
| 17 | 178,302 | 91,601 | 86,701 | 105.65 | 69 | 56,269 | 27,496 | 28,773 | 95.56 |
| 18 | 166,616 | 85,230 | 81,386 | 104.72 | 70-74 | 242,721 | 114,915 | 127,806 | 89.91 |
| 19 | 176,800 | 90,392 | 86,408 | 104.61 | 70 | 59,869 | 28,897 | 30,972 | 93.3 |
| 20-24 | 1,080,610 | 535,303 | 545,307 | 98.17 | 71 | 52,078 | 24,987 | 27,091 | 92.23 |
| 20 | 182,449 | 90,781 | 91,668 | 99.03 | 72 | 46,391 | 21,975 | 24,416 | 90 |
| 21 | 198,485 | 97,569 | 100,916 | 96.68 | 73 | 43,787 | 20,463 | 23,324 | 87.73 |
| 22 | 217,540 | 106,959 | 110,581 | 96.72 | 74 | 40,596 | 18,593 | 22,003 | 84.5 |
| 23 | 229,840 | 114,046 | 115,794 | 98.49 | 75-79 | 142,224 | 61,986 | 80,238 | 77.25 |
| 24 | 252,296 | 125,948 | 126,348 | 99.68 | 75 | 36,751 | 16,313 | 20,438 | 79.82 |
| 25-29 | 1,257,801 | 626,178 | 631,623 | 99.14 | 76 | 31,131 | 14,096 | 17,035 | 82.75 |
| 25 | 262,479 | 129,739 | 132,740 | 97.74 | 77 | 27,608 | 11,948 | 15,660 | 76.3 |
| 26 | 254,907 | 126,726 | 128,181 | 98.86 | 78 | 25,304 | 10,773 | 14,531 | 74.14 |
| 27 | 266,519 | 132,914 | 133,605 | 99.48 | 79 | 21,430 | 8,856 | 12,574 | 70.43 |
| 28 | 222,316 | 110,868 | 111,448 | 99.48 | 80-84 | 72,345 | 28,302 | 44,043 | 64.26 |
| 29 | 251580 | 125931 | 125649 | 100.22 | 80 | 20209 | 8187 | 12022 | 68.1 |
| 30-34 | 1,090,887 | 546,709 | 544,178 | 100.47 | 81 | 17,039 | 6,843 | 10,196 | 67.11 |
| 30 | 250,244 | 125,367 | 124,877 | 100.39 | 82 | 14,059 | 5,432 | 8,627 | 62.97 |
| 31 | 241,765 | 120,752 | 121,013 | 99.78 | 83 | 11,226 | 4,188 | 7,038 | 59.51 |
| 32 | 285,183 | 143,824 | 141,359 | 101.74 | 84 | 9,812 | 3,652 | 6,160 | 59.29 |
| 33 | 196,715 | 98,795 | 97,920 | 100.89 | 85-89 | 25,506 | 8,258 | 17,248 | 47.88 |
| 34 | 116,980 | 57,971 | 59,009 | 98.24 | 85 | 7,726 | 2,622 | 5,104 | 51.37 |

Table B.3: Population by age and sex (1 October 1995)(continued)

| Age | Total (Person) | Male (Person) | Female (Person) | Sex Ratio | Age | Total (Person) | Male (Person) | Female (Person) | Sex Ratio |
|---|---|---|---|---|---|---|---|---|---|
| 35-39 | 859,345 | 439,150 | 420,195 | 104.51 | 86 | 6,404 | 2,137 | 4,267 | 50.08 |
| 35 | 150,701 | 76,385 | 74,316 | 102.78 | 87 | 4,856 | 1,517 | 3,339 | 45.43 |
| 36 | 139,968 | 71,603 | 68,365 | 104.74 | 88 | 3,579 | 1,095 | 2,484 | 44.08 |
| 37 | 181,141 | 93,240 | 87,901 | 106.07 | 89 | 2,941 | 887 | 2,054 | 43.18 |
| 38 | 203,826 | 104,505 | 99,321 | 105.22 | 90-95 | 6,458 | 1,682 | 4,776 | 35.22 |
| 39 | 183,709 | 93,417 | 90,292 | 103.46 | 90 | 2,281 | 596 | 1,685 | 35.37 |
| 40-44 | 916,950 | 465,029 | 451,921 | 102.9 | 91 | 1,507 | 420 | 1,087 | 38.64 |
| 40 | 202,816 | 103,563 | 99,253 | 104.34 | 92 | 1,182 | 310 | 872 | 35.55 |
| 41 | 194,547 | 98,671 | 95,876 | 102.92 | 93 | 890 | 211 | 679 | 31.08 |
| 42 | 181,798 | 92,057 | 89,741 | 102.58 | 94 | 598 | 145 | 453 | 32.01 |
| 43 | 181,502 | 91,846 | 89,656 | 102.44 | 95-99 | 941 | 182 | 759 | 23.98 |
| 44 | 156,287 | 78,892 | 77,395 | 101.93 | 95 | 424 | 86 | 338 | 25.44 |
| 45-49 | 685,194 | 350,151 | 335,043 | 104.51 | 96 | 185 | 44 | 141 | 31.21 |
| 45 | 155,341 | 79,490 | 75,851 | 104.8 | 97 | 174 | 19 | 155 | 12.26 |
| 46 | 148,735 | 76,573 | 72,162 | 106.11 | 98 | 109 | 25 | 84 | 29.76 |
| 47 | 130,893 | 66,963 | 63,930 | 104.74 | 99 | 49 | 8 | 41 | 19.51 |
| 48 | 130,855 | 66,982 | 63,873 | 104.87 | 100+ | 111 | 34 | 77 | 44.16 |
| 49 | 119,370 | 60,143 | 59,227 | 101.55 | | | | | |
| 50-54 | 524,123 | 269,428 | 254,695 | 105.78 | | | | | |

# Appendix C

# The number of mobile phone subscribers in China from 1991 to 2005

Table C.1: The number of mobile phone subscribers in China (1991-2005)

| Year | Total numbers (ten thousands) | Year | Total numbers (ten thousands) |
|---|---|---|---|
| 1991 | 4.7544 | 1999 | 4330.0000 |
| 1992 | 17.6943 | 2000 | 8453.0000 |
| 1993 | 63.8268 | 2001 | 14481.2000 |
| 1994 | 156.8000 | 2002 | 20661.6000 |
| 1995 | 362.9000 | 2003 | 26869.3000 |
| 1996 | 685.3000 | 2004 | 33482.4000 |
| 1997 | 1323.3000 | 2005 | 39342.8000 |
| 1998 | 2386.0000 | 2006 | - |

1. Data in this table includes the values of year-end.
2. Data in this table exclude the number of Hong Kong SAR, Macao SAR and Taiwan Province.
3. Source: all the data from the database available at URL: http://www.mii.gov.cn/mii/hyzw/tjxx.html

# Appendix D

# Simulation results of sensitivity analysis for chapter 5

Table D.1: Results of sensitivity tests (absolute values) (to be continued)

| | $UU_e$ | $RU_e$ | $UUI_m$ | $UUIT_m$ | $RUI_m$ | $RUIT_m$ | $UP_m$ | $UP_e$ |
|---|---|---|---|---|---|---|---|---|
| Base case | 62.10 | 34.42 | 4.46 | 11.56 | 2.31 | 35.06 | 94.30 | 64.30 |
| $IT_t$ | 66.81 | 33.05 | 4.92 | 11.63 | 2.37 | 32.06 | 94.50 | 66.90 |
| $IUU_t$ | 62.10 | 34.42 | 4.48 | 11.31 | 2.29 | 35.06 | 94.40 | 64.30 |
| $IRU_t$ | 62.10 | 34.42 | 4.46 | 11.56 | 2.27 | 35.06 | 93.9 | 64.30 |
| $FPF_t$ | 62.10 | 34.45 | 4.46 | 11.56 | 2.13 | 34.38 | 94.00 | 64.30 |
| $UEF_t$ | 74.52 | 34.44 | 5.59 | 11.94 | 2.15 | 34.75 | 94.9 | 68.4 |
| $REF_t$ | 62.10 | 41.27 | 4.70 | 11.75 | 2.97 | 35.06 | 94.00 | 60.10 |
| $UD_t$ | 62.10 | 34.42 | 4.46 | 11.56 | 2.31 | 35.06 | 94.30 | 64.30 |
| $RD_t$ | 62.10 | 34.42 | 4.46 | 11.56 | 2.31 | 35.06 | 94.30 | 64.30 |
| $UPE_t$ | 62.10 | 34.42 | 4.52 | 11.06 | 2.28 | 35.06 | 94.50 | 64.30 |
| $RPE_t$ | 62.10 | 34.42 | 4.46 | 11.56 | 2.27 | 35.06 | 94.10 | 64.30 |

Table D.2: Results of sensitivity tests (absolute values)(continued)

| | $UU_e$ | $RU_e$ | $UUI_m$ | $UUIT_m$ | $RUI_m$ | $RUIT_m$ | $UP_m$ | $UP_e$ |
|---|---|---|---|---|---|---|---|---|
| Base case | 62.10 | 34.42 | 4.46 | 11.56 | 2.31 | 35.06 | 94.30 | 64.30 |
| $UCR_t$ | 62.10 | 34.42 | 5.48 | 9.81 | 2.20 | 35.06 | 95.20 | 64.30 |
| $RCR_t$ | 62.10 | 34.42 | 4.46 | 11.56 | 2.19 | 33.69 | 94.00 | 64.30 |
| $RUCR_t$ | 62.10 | 34.44 | 4.46 | 11.56 | 2.14 | 34.69 | 94.00 | 64.30 |
| $UAF_t$ | 62.10 | 34.43 | 5.48 | 9.81 | 2.20 | 35.06 | 95.20 | 64.30 |
| $RAF_t$ | 62.10 | 34.46 | 4.46 | 11.56 | 2.22 | 34.25 | 94.10 | 64.30 |
| $RUAF_t$ | 62.10 | 34.46 | 4.46 | 11.56 | 2.11 | 34.06 | 93.90 | 64.30 |
| $UNC_t$ | 62.10 | 34.44 | 5.48 | 9.81 | 2.04 | 34.38 | 95.00 | 64.30 |
| $RNC_t$ | 62.10 | 34.48 | 4.46 | 11.56 | 2.07 | 33.00 | 93.70 | 64.30 |
| Variables from population model | | | | | | | | |
| $UI_t$ | 63.99 | 34.26 | 4.09 | 12.06 | 5.39 | 30.50 | 93.80 | 65.10 |
| $UF_t$ | 62.90 | 34.44 | 4.39 | 11.63 | 2.46 | 35.13 | 94.30 | 64.60 |
| $UAWB(t,i)$ | 62.65 | 34.44 | 4.76 | 11.50 | 2.37 | 35.31 | 94.40 | 64.50 |
| $RF_t$ | 62.20 | 35.56 | 4.43 | 11.56 | 2.33 | 37.19 | 94.40 | 63.60 |
| $RAWB(t,i)$ | 62.15 | 34.66 | 4.46 | 11.56 | 2.28 | 36.44 | 94.40 | 64.20 |
| $ULE_t$ | 63.80 | 34.42 | 4.50 | 11.63 | 2.48 | 34.94 | 94.40 | 65.00 |
| $RLE_t$ | 62.37 | 35.69 | 4.45 | 11.56 | 2.30 | 36.63 | 94.30 | 63.60 |

Table D.3: Results of sensitivity tests (change in percentage)

| | $UU_e$ | $RU_e$ | $UUI_m$ | $UUIT_m$ | $RUI_m$ | $RUIT_m$ | $UP_m$ | $UP_e$ |
|---|---|---|---|---|---|---|---|---|
| $IT_t$ | 7.58 | -3.98 | 10.31 | 0.61 | 2.60 | -8.56 | 0.21 | 4.04 |
| $IUU_t$ | 0.00 | 0.00 | 0.45 | -2.16 | -0.87 | 0.00 | 0.11 | 0.00 |
| $IRU_t$ | 0.00 | 0.00 | 0.00 | 0.00 | -1.73 | 0.00 | -0.42 | 0.00 |
| $FPF_t$ | 0.00 | 0.09 | 0.00 | 0.00 | -7.79 | -1.94 | -0.32 | 0.00 |
| $UEF_t$ | 20.00 | 0.06 | 25.34 | 3.29 | -6.93 | -0.88 | 0.64 | 6.38 |
| $REF_t$ | 0.00 | 19.90 | 5.38 | 1.64 | 28.57 | 0.00 | -0.32 | -6.53 |
| $UD_t$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $RD_t$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $UPE_t$ | 0.00 | 0.00 | 1.35 | -4.33 | -1.30 | 0.00 | 0.21 | 0.00 |
| $RPE_t$ | 0.00 | 0.00 | 1.35 | 0.00 | -1.73 | 0.00 | -0.21 | 0.00 |
| $UCR_t$ | 0.00 | 0.00 | 22.87 | -15.14 | -4.76 | 0.00 | 0.95 | 0.00 |
| $RCR_t$ | 0.00 | 0.00 | 0.00 | 0.00 | -5.19 | -3.91 | -0.32 | 0.00 |
| $RUCR_t$ | 0.00 | 0.06 | 0.00 | 0.00 | -7.36 | -1.06 | -0.32 | 0.00 |
| $UAF_t$ | 0.00 | 0.03 | 22.87 | -15.14 | -4.76 | 0.00 | 0.95 | 0.00 |
| $RAF_t$ | 0.00 | 0.12 | 0.00 | 0.00 | -3.90 | -2.31 | -0.21 | 0.00 |
| $RUAF_t$ | 0.00 | 0.12 | 0.00 | 0.00 | -4.33 | -2.85 | -0.42 | 0.00 |
| $UNC_t$ | 0.00 | 0.06 | 22.87 | -15.14 | -11.69 | -1.94 | 0.74 | 0.00 |
| $RNC_t$ | 0.00 | 0.17 | 0.00 | 0.00 | -10.39 | -5.88 | -0.64 | 0.00 |
| Variables from population model | | | | | | | | |
| $UI_t$ | 3.04 | -0.46 | -8.30 | 4.33 | 133.33 | -13.01 | -0.53 | 1.24 |
| $UF_t$ | 1.29 | 0.06 | -1.57 | 0.61 | 6.49 | 0.20 | 0.00 | 0.47 |
| $UAWB(t,i)$ | 0.89 | 0.06 | 6.73 | -0.52 | 2.60 | 0.71 | 0.11 | 0.31 |
| $RF_t$ | 0.16 | 3.31 | -0.67 | 0.00 | 0.87 | 6.08 | 0.11 | -1.09 |
| $RAWB(t,i)$ | 0.08 | 0.70 | 0.00 | 0.00 | -1.30 | 3.94 | 0.11 | -0.16 |
| $ULE_t$ | 2.74 | 0.00 | 0.90 | 0.61 | 7.36 | -0.34 | 0.11 | 1.09 |
| $RLE_t$ | 0.43 | 3.69 | -0.22 | 0.61 | -0.43 | 4.48 | 0.00 | -1.09 |

# Appendix E

# Powersim equations for population dynamics model in chapter 4

init Rural_Population = Rural_Initial_Population
flow Rural_Population = -dt*(Rural_Decrease)
+dt*Rural_Increase
-dt*Migration
doc Rural_Population = Rural population is the sum of
rural initial population and the integration of the difference of
rural population increase, rural population decrease and migration.
init Urban_Population = Urban_Initial_Population
flow Urban_Population = +dt*Urban_Increase
+dt*Migration
-dt*Urban_Decrease
aux Migration = IF(TIME¡=Urbanization_Change_Time,
Historical_Urbanization_Rate*(Urban_Population+Rural_Population),
Urbanization_Rate*(Urban_Population+Rural_Population))
aux Rural_Decrease = Rural_Population*
(Rural_Death_Rate+Rural_Mortality) aux Rural_Increase = IF(TIME¡=8,
(Fertile_Women22+Fertile_Women25+0.6*Fertile_Women28)*
(1-Urbanization), IF(TIME¡Family_Planning_Change_Time,
(Fertile_Women22+Fertile_Women25+Fertile_Women28+
Fertile_Women31*0.6)*(1-Urbanization),
(Fertile_Women22+Fertile_Women25+

Fertile_Women28+Fertile_Women31*0.6)*(1-Urbanization)))
doc Rural_Increase = Total births are determined
by population and the fractional birth rate.
aux Urban_Decrease = Urban_Population*
(Urban_Death_Rate+Urban_Mortality)
aux Urban_Increase = IF(TIME¡=8,
(Fertile_Women25+Fertile_Women28+0.2*Fertile_Women31)*
Urbanization, IF(TIME¡Family_Planning_Change_Time,
(Fertile_Women28+0.2*Fertile_Women31)*Urbanization,
(Fertile_Women28+0.2*Fertile_Women31)*Urbanization))
doc Urban_Increase = Total births are
determined by population and the fractional birth rate.
aux Fertile_Women22 =
GRAPH(TIME,0,1,[10091600,9166800,8640800,8138600,8670100,
9739000,9101200,9831400,11616900,10166800,9774900,10779400,
11618600,13413400,12319300,12828200,12630900,9964800,
8619200,7960000,6769400,7956200,5529100,5045800,4583400,
4320400,4069300,4335100,4869500,4550500,4915700,5808500,
5083400,4887500,5389700,5809300,6706700,6159700,6414100,
6315500,4982400,4309600,3980000,3384700,3978100,2764550,
2522900,2291700,2160200,2034650,2167550,2434750,2275250,
2457850,2904250,2541700,2443750,2694850,2904650,3353350,
3079850,3207050,3157750,2491200,2154800,1990000,1692350,
1989050”Min:0;Max:20000000”])
doc Fertile_Women22 = This data set is the time series of women at the age of 22,
which is from population data base.
aux Fertile_Women25 =
GRAPH(TIME,0,1,[12634800,11579400,11058100,10091600,9166800,
8640800,8138600,8670100,9739000,9101200,9831400,11616900,
10166800,9774900,10779400,11618600,13413400,12319300,12828200,
12630900,9964800,8619200,7960000,6769400,7956200,6317400,
5789700,5529100,5045800,4583400,4320400,4069300,4335100,
4869500,4550500,4915700,5808500,5083400,4887500,5389700,
5809300,6706700,6159700,6414100,6315500,4982400,4309600,

3980000,3384700,3978100,3158700,2894850,2764550,2522900,
2291700,2160200,2034650,2167550,2434750,2275250,2457850,
2904250,2541700,2443750,2694850,2904650,3353350,3079850,
3207050,3157750,2491200,2154800,1990000,1692350,
1989050"Min:0;Max:20000000"])
doc Fertile_Women25 = This data set is the time series of women at the age of 25, which is from population data base.
aux Fertile_Women28 =
GRAPH(TIME,0,1,[13360500,12818100,13274000,12634800,
11579400,11058100,10091600,9166800,8640800,8138600,
8670100,9739000,9101200,9831400,11616900,10166800,
9774900,10779400,11618600,13413400,12319300,12828200,
12630900,9964800,8619200,7960000,6769400,7956200,
6630300,6409100,6637000,6317400,5789700,5529100,5045800,
4583400,4320400,4069300,4335100,4869500,4550500,4915700,
5808500,5083400,4887500,5389700,5809300,6706700,6159700,
6414100,6315500,4982400,4309600,3980000,3384700,3978100,
3315150,3204550,3318500,3158700,2894850,2764550,2522900,
2291700,2160200,2034650,2167550,2434750,2275250,2457850,
2904250,2541700,2443750,2694850,2904650,3353350,3079850,
3207050,3157750,2491200,2154800,1990000,1692350,
1989050"Min:0;Max:20000000"])
doc Fertile_Women28 = This data set is the time series of women at the age of 28, which is from population data base.
aux Fertile_Women31 =
GRAPH(TIME,0,1,[12487700,12564900,11144800,13360500,
12818100,13274000,12634800,11579400,11058100,10091600,
9166800,8640800,8138600,8670100,9739000,9101200,9831400,
11616900,10166800,9774900,10779400,11618600,13413400,
12319300,12828200,12630900,9964800,8619200,7960000,6769400,
7956200,6243900,6282500,5572400,6630300,6409100,6637000,
6317400,5789700,5529100,5045800,4583400,4320400,4069300,
4335100,4869500,4550500,4915700,5808500,5083400,4887500,
5389700,5809300,6706700,6159700,6414100,6315500,4982400,

4309600,3980000,3384700,3978100,3121950,3141250,2786200,
3315150,3204550,3318500,3158700,2894850,2764550,2522900,
2291700,2160200,2034650,2167550,2434750,2275250,2457850,
2904250,2541700,2443750,2694850,2904650,3353350,3079850,
3207050,3157750,2491200,2154800,1990000,1692350,
1989050”Min:0;Max:20000000”])
doc Fertile_Women31 = This data set is the time series of women at the age of 31, which is from population data base.
aux Interim_Urbanization =
Initial_Urbanization+Historical_Urbanization_Rate*
Urbanization_Change_Time
aux Rural_Death_Rate = 1/Rural_Life_Expectancy
aux Rural_Population_Change_Speed = DERIVN(Rural_Population)
aux Rural_Proportion = Rural_Population/Total_Population
aux Total_Population = Rural_Population+Urban_Population
aux Total_Population_Change_Speed = DERIVN(Total_Population)
aux Urban_Death_Rate = 1/Urban_Life_Expectancy
aux Urban_Population_Change_Speed = DERIVN(Urban_Population)
aux Urban_Proportion = Urban_Population/Total_Population
aux Urbanization = IF(TIME¡Urbanization_Change_Time,
Initial_Urbanization+RAMP(Historical_Urbanization_Rate, 0),
Interim_Urbanization+RAMP(Urbanization_Rate, Urbanization_Change_Time))
aux Urbanization_Rate = IF(TIME¡Urbanization_Change_Time,
0.014352, 0.014352)
const Family_Planning_Change_Time = 8
const Historical_Urbanization_Rate = 0.014352
const Initial_Urbanization = 0.2854
const Rural_Initial_Population = 859470000
const Rural_Life_Expectancy = 68
doc Rural_Life_Expectancy = Average Lifetime of the population
const Rural_Mortality = 0.0002
const Urban_Initial_Population = 351740000
const Urban_Life_Expectancy = 71
doc Urban_Life_Expectancy = Average Lifetime of the population

const Urban_Mortality = 0.0001
const Urbanization_Change_Time = 8

# Appendix F

# Powersim equations for mobile commerce diffusion model in chapter 5

init Rural_Potential_Users = Rural_Population
Rural_Electronic_Commerce_Fraction-Rural_Users
flow Rural_Potential_Users = +dt*Rural_Discard
-dt*Rural_Adoption
doc Rural_Potential_Users = The number of potential rural mobile commerce users
is determined by the total rural population size and the current number of active
urban and rural mobile commerce users.
init Rural_Users = Initial_Rural_Users
flow Rural_Users = -dt*Rural_Discard
+dt*Rural_Adoption
doc Rural_Users = The number of active rural mobile commerce users in the system.
init Urban_Potential_Users = Urban_Population
Urban_Electronic_Commerce_Fraction-Urban_Users
flow Urban_Potential_Users = +dt*Urban_Discard
-dt*Urban_Adoption
doc Urban_Potential_Users = The number of potential urban mobile commerce users
is determined by the total urban population size and the current number
of active urban mobile commerce users.
init Urban_Users = Initial_Urban_Users
flow Urban_Users = +dt*Urban_Adoption
-dt*Urban_Discard

doc Urban_Users = The number of active urban mobile commerce users in the system.
aux Rural_Adoption = Rural_Adoption_From_Propaganda+Rural_Adoption_From_WOM
aux Rural_Discard = Rural_Users*Rural_Discard_Fraction
doc Rural_Discard = This is the annual dicarded number of mobile commerce users
aux Urban_Adoption = Urban_Adoption_From_Propaganda+Urban_Adoption_From_WOM
aux Urban_Discard = Urban_Users*Urban_Discard_Fraction
doc Urban_Discard = This is the annual discarded number of mobile commerce users.
aux Rural_Adoption_From_Propaganda = Rural_Potential_Users
Rural_Propaganda_Effectiveness
doc Rural_Adoption_From_Propaganda = Adoption can result from propaganda
according to the effectiveness of the propaganda effort with the pool
of potential rural users.
aux Rural_Adoption_From_WOM =
((Rural_Users*Rural_Potential_Users*Rural_Network_Coverage
(1-Floating_Population_Fraction)*Rural_Adoption_Fraction
Rural_Contact_Rate)+(Rural_Users*Rural_Potential_Users
Rural_Network_Coverage*Floating_Population_Fraction
Rural_Urban_Adoption_Fraction*Rural_Contact_Rate)
+(Urban_Users*Rural_Potential_Users*Rural_Network_Coverage
Urban_Network_Coverage*Floating_Population_Fraction
Rural_Urban_Adoption_Fraction*Rural_Urban_Contact_Rate))
/(Rural_Population*Rural_Electronic_Commerce_Fraction)
doc Rural_Adoption_From_WOM = Adoption by word of mouth is
driven by the contact rate between potential rural users
and active urban and rural users and the fraction of times
these interactions will result in adoption.
The word of mouth effect is small if the number of active rural users
relative to the total rural population size is small.
aux Rural_Population =
GRAPH(TIME,0,1,[689827298,680740666,671918715,661742163,650662262,
639418645,625821780,612222191,597369829,580292055,562954588,544546030,
524878622,505400511,485444701,465075086,445142741,425132834,405009549,
384960501,365154665,345551587,326440047,307143318,288013763,269166581,
250244040,231530819,212959904,194418099,176090926,157813798,139686416,

121771119,104002050,86416342"Min:0;Max:1200000000"])
doc Rural_Population = This data set is from population model.
aux Rural_User_Increase = DERIVN(Rural_Users)
aux Rural_User_Proportion = Rural_Users/Total_Users
aux Total_User_Increase = DERIVN(Total_Users)
aux Total_Users = Rural_Users+Urban_Users
aux Urban_Adoption_From_Propaganda = Urban_Potential_Users
Urban_Propaganda_Effectiveness
doc Urban_Adoption_From_Propaganda = Adoption can result
from propaganda according to the effectiveness of the propaganda
effort with the pool of potential urban users.
aux Urban_Adoption_From_WOM =
Urban_Users*Urban_Potential_Users*Urban_Network_Coverage
Urban_Adoption_Fraction*Urban_Contact_Rate/(Urban_Population
Urban_Electronic_Commerce_Fraction)
doc Urban_Adoption_From_WOM = Adoption by word of mouth is driven
by the contact rate between potential urban users and active
urban users and the fraction of times these interactions will result
in adoption. The word of mouth effect is small if the number of active
urban users relative to the total urban population size is small.
aux Urban_Population =
GRAPH(TIME,0,1,[621074098,636624518,652041873,668115884,684595369,
702079722,719043368,736354852,753664127,769255355,783949319,
798101664,811164901,824767571,837262991,849341952,861480427,
873083080,884110038,894690447,904780280,914287818,923397918,
932075690,940722419,949596187,957963057,966411019,975438565,
983613565,991447372,999613261,1007969152,1017052695,1025537994,
1034046259"Min:0;Max:1500000000"])
doc Urban_Population = This data set is from population model.
aux Urban_Proportion = Urban_Users/Total_Users
aux Urban_User_Increase = DERIVN(Urban_Users)
const Floating_Population_Fraction = 1/5
doc Floating_Population_Fraction = A fraction of rural
population temporarily making living in urban cities.

const Initial_Rural_Users = 500000
doc Initial_Rural_Users = assumed
const Initial_Urban_Users = 500000
doc Initial_Urban_Users = assumed
const Rural_Adoption_Fraction = 0.01
const Rural_Contact_Rate = 30
doc Rural_Contact_Rate = The rate at which active rural users
come into contact with potential rural users.
const Rural_Discard_Fraction = 0.1
doc Rural_Discard_Fraction = Assume it will have
a 10% discard fraction in rural areas.
const Rural_Electronic_Commerce_Fraction = 0.05
doc Rural_Electronic_Commerce_Fraction = This is assumed value.
Its sensitivity will be examined later.
const Rural_Network_Coverage = 0.1
const Rural_Propaganda_Effectiveness = 0.01
doc Rural_Propaganda_Effectiveness = Propaganda results in adoption
in rural areas according the effectiveness of the propaganda.
const Rural_Urban_Adoption_Fraction = 0.02
const Rural_Urban_Contact_Rate = 40
doc Rural_Urban_Contact_Rate = The rate at which part of
active rural users come into contact with potential urban users.
const Urban_Adoption_Fraction = 0.03
const Urban_Contact_Rate = 60
doc Urban_Contact_Rate = The rate at which active urban users
come into contact with potential urban users.
const Urban_Discard_Fraction = 0.05
doc Urban_Discard_Fraction = Assume it will have
a 5% discard fraction in urban areas.
const Urban_Electronic_Commerce_Fraction = 0.1
doc Urban_Electronic_Commerce_Fraction = This is assumed value.
Its sensitivity will be examined later.
const Urban_Network_Coverage = 0.2
const Urban_Propaganda_Effectiveness = 0.011

doc Urban_Propaganda_Effectiveness = Propaganda results in adoption in urban areas according the effectiveness of the propaganda.

# Appendix G

# Powersim equations for MCT provision model in chapter 6

init Provided_Mobile_Commerce_Terminal
= Initial_Provided_Mobile_Commerce_Terminal
flow Provided_Mobile_Commerce_Terminal =
-dt*Obsolescence
+dt*Provision
doc Provided_Mobile_Commerce_Terminal = the total number
of mobile commerce terminals provided in the system.
aux Obsolescence = DELAYINF(Provided_Mobile_Commerce_Terminal,
Mobile_Commerce_Terminal_Life_Cycle)
doc Obsolescence = the rate at which mobile commerce terminals
will become obsolescent.
aux Provision = Domestic_Manufacturing_Capacity/(1-Market_Openness)
doc Provision = the rate at which mobile commerce terminals will be
produced and provided to hands of mobile commerce users.
aux Actual_Mobile_Commerce_User_Increase =
DERIVN(Actual_Mobile_Commerce_Users)
doc Actual_Mobile_Commerce_User_Increase =
the annual increase in the number of actual mobile commerce users.
aux Actual_Mobile_Commerce_Users =
IF(Total_Users¿=Provided_Mobile_Commerce_Terminal,
Provided_Mobile_Commerce_Terminal, Total_Users)

doc Actual_Mobile_Commerce_Users = the number of users who want to
use mobile commerce and have actually got their mobile commerce terminals.
aux Difference = Actual_Mobile_Commerce_Users-Total_Users
doc Difference = The number of shortfall between total mobile commerce users
and the amount of mobile commerce terminals provided in the system.
aux Domestic_Manufacturing_Capacity = IF(TIME¡=Intro_Time,
RAMP(Initial_Capacity/Intro_Time, 0), IF(TIME¡Intro_Time+Increase_Time,
Initial_Capacity+RAMP((Final_Capacity-Initial_Capacity)/Increase_Time,
Intro_Time), Final_Capacity))
doc Domestic_Manufacturing_Capacity = the annual volume of mobile commerce
terminals formed from domestic manufacturing sector.
aux Market_Openness = IF(TIME¡=Monopoly_Time,
Initial_Market_Openness+RAMP((Max_Market_Openness-Initial_Market_Openness)
/Monopoly_Time, 0), Max_Market_Openness)
doc Market_Openness = the process that illustrate the opening development
of MCT market to foreign competitors in the system.
aux Mobile_Commerce_Terminal_Life_Cycle = NORMAL(3, 1)
doc Mobile_Commerce_Terminal_Life_Cycle = the random lifetime
in which a fashion of mobile terminal will be replaced.
aux Total_Users = GRAPH(TIME,1,0.1,[0,0,0,0,0,0,0,0,0,0,0"Min:0;Max:300000000"])
doc Total_Users = The total number of mobile commerce users who want to
get their mobile commerce terminals and whereas become actual mobile commerce users.
This is a data set automatically generated from mobile commerce diffusion model.
const Final_Capacity = 73000000
doc Final_Capacity = the final number of mobile commerce terminals that
can be produced and provided to the hands of mobile commerce users.
const Increase_Time = 10
doc Increase_Time = the period in which the mobile commerce capacity
will have a fast growth from initial capacity to final capacity.
const Initial_Capacity = 12000000
doc Initial_Capacity = the initial number of mobile commerce terminals
that can be produced and provided to the hands of mobile commerce users.
const Initial_Market_Openness = 0.2
doc Initial_Market_Openness = the initial proportion of market

that are open to the foreign participants.
const Initial_Provided_Mobile_Commerce_Terminal = 0
doc Initial_Provided_Mobile_Commerce_Terminal =
the initial total number of mobile commerce terminals in the system.
const Intro_Time = 3 doc Intro_Time = the time during which the mobile commerce terminals will be introduced and reach the initial capacity in the system.
const Max_Market_Openness = 0.49
doc Max_Market_Openness = the maximum proportion of market
that can be open to the foreign companies.
const Monopoly_Time = 3
doc Monopoly_Time = the time during which a country will
promise to open its controlled market to an specified proportion.