ECONOMIC EVALUATION OF DISEASE MANAGEMENT IN CHINA: THE CASE OF HYPERTENSION

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Abstract

To combat the challenges of cardiovascular diseases (CVDs), the Chinese government launched a program in 2009 called the National Basic Public Health Service (NBPHS). This provides disease management services in primary healthcare facilities for hypertensive patients. Although a large amount of money has been invested since 2009, little is known about the benefits of such a large investment. Based on national datasets, this study conducted an economic evaluation of hypertension management in the NBPHS from 2009 to 2015.

A trend model was built based on data from 1991 to 2009, which was used to predict hypertension control rates for 2015. The direct impact of the NBPHS on hypertensives was generated by comparing the predicted hypertension control with that of the observed levels in 2015. This generated a figure of 9,532,719 hypertensives who were able to get their blood pressure (BP) under control incrementally during 2009-2015.

A hypothesized scenario in which the NBPHS had not been implemented was created to compare with the NBPHS scenario. Following the pathway of risk prediction studies on CVDs, a Markov model was developed to estimate the long-term health outcomes of the NBPHS by comparing the two scenarios from 2016 to 2045. It was estimated that at the end of the 30-year projection period, there would be 25,012, 296,258, and 744,493 hypertensive patients who would have avoided coronary heart disease, stroke and death, respectively, by being part of the NBPHS.

A standard model of economic evaluation was developed by estimating gross domestic product increases from labour force participation and productivity gained by averting morbidities and mortalities. Net present value (NPV) was used to estimate healthcare expenditure saved, and the economic and social benefit of morbidity and mortality averted. It was predicted that from 2016 to 2045, there would be an economic benefit of 169,857 million CNY in NPV, or 267,297 million CNY when including social benefit. Given that hypertension management accounts for 14.59% of the NBPHS funding: the benefit-cost ratio would be 6.0 at a discount rate of 3%, and if the social benefit is included, the benefit-cost ratio would be 15.4 at the same discount rate. The internal rate of return would be 14.6% if only the economic benefit is considered and

20.7% if the social benefit is included. This is a very high benefit investment compared to that identified in other studies.

This study contributes to academic knowledge by providing an economic framework of health interventions in primary healthcare settings in China. To some extent, it also fills a gap by addressing the economic evaluation of chronic disease interventions in China.

Student Declaration

"I, Yanchun Zhang, declare that the PhD thesis entitled *Economic evaluation of disease management in China: The case of hypertension* is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work".

Signature [redacted]

Date Dec. 7, 2020

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List of Acronyms

BP	Blood pressure
BMI	Body mass index
CBA	Cost-benefit analysis
CDPM	Cardiovascular Disease Policy Model-China model
CEA	Cost-effectiveness analysis
CHARLS	China Health and Retirement Longitudinal Study
CHD	Coronary heart disease
CHDP	Coronary Heart Disease Policy
CHNS	China Health and Nutrition Survey
CHOs	Community health organizations
CHS	China Hypertension Survey
CHSC	Community Health Service Centre
CNHDRC	China National Health Development Research Centre of NHFPC
CMA	Cost minimization analysis
CNY	Chinese Yuan (Ren Min Bi)
COI	Cost of illness
CUA	Cost-utility analysis
CVD	Cardiovascular disease
DALYs	Disability adjusted life years
DBP	Diastolic blood pressure
DM	Diabetes mellitus
EPHS	Equalization of Public Health Service to all in China
FHS	Framingham heart study
GDP	Gross domestic product
HDL	High density lipoprotein
HR	Hazard ratio
ICD	International classification of diseases
ICVD	Ischemic CVD
IHD	Ischemic heart disease
ILO	International Labour Organization
ISH	International Society of Hypertension
LDL	Low density lipoprotein
MI	Myocardial infarction
NBPHS	National Basic Public Health Service
NCDs	Non-communicable diseases
NHC	National Health Commission of China
NHFPC	National Health and Family Planning Commission of China
NPV	Net present value
OR	Odds ratio

PATC	Prevalence, awareness, treatment and control
PEN	Package of essential non-communicable disease interventions for primary care in low-resource settings
PRC	People's Republic of China
QALYs	Quality adjusted life years
RR	Relative risk
SBP	Systolic blood pressure
SME	Socialist market economy
TC	Total cholesterol
UN	United Nations
USD	US dollar
VISES	Victoria Institute of Strategic Economic Studies
VU	Victoria University
WB	World Bank
WBG	World Bank Group
WHO	World Health Organization
WTP	Willingness to pay

Chapter 1 Introduction

1.1 Background

Before China adopted a socialist market economy (SME) in the 1980s, its primary healthcare system had led the world in improving the life expectancy of its citizens. Unfortunately, this system encountered many problems, including the reduction of government investment in healthcare, decentralization of public health services and the weakening role of primary healthcare in public health (Bloom & Xingyuan, 1997; Tang et al., 2008). Meanwhile, with the rapid development of society, the prevalence of high risk behaviours, including unhealthy diets, physical inactivity and smoking, accelerated to an unprecedented degree (G. Yang et al., 2008). As a result, the leading cause of mortality in China shifted relatively quickly from infectious diseases and perinatal conditions to non-communicable diseases and injuries (G. Yang et al., 2008), also known as non-communicable diseases (NCDs). NCDs mainly include cardiovascular disease (CVD), heart attacks and stroke, chronic respiratory diseases (such as chronic obstructed pulmonary disease and asthma), diabetes and cancer (World Health Organization [WHO], 2015).

By 2010, there had been 1.7 million deaths in China resulting from stroke, 948,700 from ischemic heart disease (IHD) and 934,000 deaths attributed to chronic obstructive pulmonary disease (G. Yang et al., 2008; 2013). As estimated by the 2013 *Report of CVD* in China, 70% of strokes and 50% of myocardial infarctions, which are the main CVDs, were caused by high blood pressure (BP) (National Centre for CVDs, 2013). G. Yang et al. (2013) also reported that 24% of Chinese adults aged 15+ years were diagnosed with hypertension in 2012 (i.e. 270 million hypertensive patients). Another risk factor for patients with CVD was diabetes, which was prevalent among 11.6% of Chinese adults in 2010.

In recognition of the failure of the prevailing health system, and in order to curb the rapid increase of CVD, the Chinese Central Government introduced a new healthcare reform plan in 2009 (Central Committee of the Communist Party and State Council, 2009). This was designed to improve the primary healthcare system in both essential medical care and public health service provision. One important part of the reform was the program entitled the Equalization of Public Health Service (EPHS) to all, which was composed of the major public health service program and the basic public health service program. The basic public health service program, which is often referred to as the National Basic Public Health Service, is abbreviated to NBPHS in this study and is frequently referred to throughout this thesis. It is a defined package of basic healthcare services delivered by community health organizations (CHOs)[1] throughout the country (Yip W. et al., 2012). The NBPHS was designed in response to the increasing burden imposed by NCDs, and includes health education and disease management of hypertension and diabetes (Bank, 2011). In order to implement the policy, the government developed the criteria of service delivery for the NBPHS (The National Health Commission of China, 2018a). To finance the NBPHS, in 2009 it was stated that different levels of government would be required to provide an investment of 15 yuan (CNY) per capita each year. This amount has increased regularly by five CNY a year: from 20 CNY in 2011 to 40 CNY in 2015. Xiao, Long, Tang and Tang (2014) estimated that about 18% of the investment was spent on the disease management of patients with hypertension, which was the largest investment in hypertension in China's history. What had been gained in terms of social and economic benefit, and whether such a large investment is worthwhile to be continued in a long run, both rely on a comprehensive economic evaluation.

A number of studies in China have attempted to evaluate the NBPHS. For instance, in 2010, an *Annual Report of Essential Public Health Services Performance Evaluation* was published by the Centre for Project Supervision and Management, which is affiliated to the Ministry of Health (Centre for Project Supervision and Management, 2013). In 2014, the Community Health Association of China undertook the assessment of the national basic public health service programs (Community Health Association of China, 2015). A more recent study evaluated the accessibility and its determinants of essential public health service among adults with chronic diseases in China, and pointed out that the effectiveness of disease management needed to be improved (M. Tian et al., 2015). Yin et al. (2015) calculated the expected cost of a national essential public services package in Beijing by developing a workload-based model. They concluded that the present investment on NBPHS was not enough for what was needed.

[1] Community health organizations refer to community health service centres/stations in urban areas, and township hospitals and village clinics in rural areas.

Nevertheless, no research conducted has evaluated the economic and social benefits of this large investment. In other words, no economic evaluation has been conducted in a systematic manner. The research presented in this thesis has developed a framework for the economic evaluation of such interventions. It is designed to estimate the benefits and effectiveness of the investment in the NBPHS in terms of reduced costs, and increased productivity and financial benefits. The investment case for the program is estimated in the form of benefit-cost ratios.

1.2 Aims of the research

Based on three streams of national data for the years 2009 to 2015, this research first estimated the health outcomes of such a program for providing basic public health services in China in terms of more patients managed and better control of hypertension. Then the long-term health outcomes were calculated using appropriate techniques, linking these outcomes to hypertension. Accordingly, a framework for economic evaluation was developed to assess the economic and selected social benefits arising from the health outcomes in terms of increasing workforce participation, reducing health care costs and providing benefits to the community. Comparing the benefits with the costs, an investment case for the program was generated in terms of benefit-cost ratios or internal rates of return. Within this context, the specific aims of the research were:

1. To analyze the outcomes of the NBPHS in terms of managing more patients and improving the control rate of hypertension from 2009 to 2015.
2. To develop a Markov model to project long-term health outcomes from improved hypertension control from 2016 to 2045, in terms of CVDs avoided and deaths averted.
3. To use a cost-benefit analysis framework for disease management of hypertension by CHOs in China and estimate the investment case for the NBPHS expressed in terms of investment metrics (benefit-cost ratios and internal rates of return).
4. To provide policy recommendations for the Chinese government on further investment in chronic disease interventions through the primary healthcare system.

The reasons for selecting the period 2009 to 2015 are twofold: first, during this period, the NBPHS was a major invaluable policy measure undertaken at the national level for hypertension management in China (H. Wang, Gusmano, & Cao, 2011; Xiao et al., 2014; W. C.-M. Yip et al., 2012); second, hypertension management data was available for trend analysis, which is explained in Chapter 3.

1.3 Introduction to the NBPHS

The NBPHS has played a major part in equalizing access to basic public health services by both urban and rural residents. This was one of the four main goals of the new health reform plan issued in 2009 (World Bank Group; World Health Organization; Ministry of Finance; National Health, 2013). The NBPHS is delivered through the basic health care service system, based on a grass-roots health care service network. A set of NBPHS items were identified and defined, which included disease management of hypertension.

1.3.1 Primary healthcare system of China

As indicated above, the NBPHS is designed to be delivered through a grass-roots health care service network, namely the primary healthcare system of China. The quality of healthcare is dependent on the funding and resourcing of primary healthcare facilities.

The primary care system in China was founded on a three-tier health system, consisting of urban community health service facilities (centres or stations), township health centres, and village clinics and other primary care facilities (Hung, Shi, Wang, Nie, & Meng, 2013; World Bank Group; World Health Organization; Ministry of Finance; National Health, 2013). Each tier of the system is mandated to deliver essential healthcare services to the Chinese population, especially the aged and patients with chronic diseases (Xiao et al., 2014). It was widely researched that no healthcare system can function without quality healthcare professionals. Therefore, this study reviewed policies on human resourcing in primary health care facilities. In 2006, the functions and staffing standard of urban community health service facilities were defined by a related policy document (State Commission Office of Public Sectors Reform, 2006). In 2011, these functions and staffing standard of township hospitals were revised by the National Health and Family Planning Commission (State Commission Office of Public Sectors Reform, 2011).

Policy review shows that the NBPHS has been the biggest investment and the most major policy measure on hypertension management in primary health care in China. This study employed trend analysis and policy analysis to control the impact of differences in the timing across space.

To evaluate the impact of the NBPHS on hypertension, further analysis was conducted to link outcomes with the performance of the primary care facilities, especially in terms of health professionals and expertise. This is explained in Chapter 6.

1.3.2 The NBPHS program

The government funded the services of the NBPHS program and provided it to all residents for free through primary health care institutions (Xiao et al., 2014), regardless of their hukou (a record officially identifying the living area of the residents) (X. Li et al., 2017). The management of hypertension was one of the NBPHS items within the program.

The intention expressed by the *Opinion on the New Health Reform of China 2009*, was that urban and rural residents should be gradually provided with basic public health services, which consist of disease prevention and control, maternity and childcare, and health education, among other services. The average standard funding per capita for the NBPHS should be no less than 15 Yuan. It increased to 25 CNY in 2011, 30 CNY in 2013, 35 CNY in 2014 and 40 CNY in 2015 (Department of Primary Care, n.d.). According to the 2010 Chinese Census, the population of China was 1,332,810,869. Therefore, over 246.57 billion CNY (around 36.64 billion USD, at an exchange rate of 6.73 CNY per USD) was invested in this program. An estimation of how much was spent on hypertension is provided in Chapter 5 for the purpose of economic evaluation.

Although the specifications of basic public health services were revised three times, in 2011, 2013 and 2017 (The National Health Commission of China, 2018a), the specifications for hypertension management did not change much across the three revisions As the evaluation conducted in this research was based on data from 2009 to 2015, the 2013 version of the service delivery criteria was used to explain the NBPHS program and the content of hypertension control. The 2013 specification included 13 types of basic public health services with 43 specific service items with the numbers of types and items increasing from 2011 to 2017. This included the establishment of health records for urban and rural residents, health education, health management of elderly people aged 65+, health management of hypertension patients and so forth (The National Health and Family Planning Commission of China, 2013). All services referred to by these criteria were to be implemented mainly by township hospitals and community health service centres, which were required to shoulder part of the responsibility of service delivery.

1.3.3 Specifications for managing hypertension

According to the specifications of public health service delivery developed by the NHFPC, the target population for management of hypertension were adults aged 35+ years. Healthcare delivered through primary healthcare facilities mainly included hypertension screening and management (The National Health and Family Planning Commission of China, 2013). Primary health care facilities were to provide screening to people aged 35 years or above for hypertension, and if diagnosed, the patient would be taken into standard management as follows:

- For permanent residents aged 35+, measure their blood pressure on their first visit to primary health care facilities.
- For people with abnormal BP (SBP≥140 mmHg and/or DBP≥90 mmHg), remove the external factors raising up BP and re-measure the BP. If the BPs measured on different days remained abnormal, the patient would be diagnosed as hypertensive and put on the list of hypertension management under the NBPHS. If necessary, referral was to be made to hospitals for further diagnosis, with follow-up referral results in two weeks.
- For high risk populations, advice was to be provided on behavioral recommendations.

The specifications stated that regular (at least four times a year) follow-up and evaluations of hypertension should be delivered face-to-face. The services delivered included measuring BP and evaluating emergent conditions, ascertaining the date for the next follow-up, and providing advice on medication according to blood pressure (BP) levels. This was in line with the Chinese hypertension guidelines discussed by J.-G. Wang. (J.-G. Wang, 2015).

In addition, the government determined that community healthcare facilities should provide health examinations for hypertensive patients once a year. This would include measuring body temperature, pulse, breathing, blood pressure, height, weight, waistline, as well as undertaking skin, superficial lymph node, heart, lung and abdomen examinations, and making primary evaluations of oral cavity, vision and physical activity functions.

A performance evaluation indicator system was established by the Ministry of Health in China, comprising the following indicators:

(1) Hypertension health management rate = Number of hypertension patients managed / Number of hypertension patients within the community × 100%.
(2) Standard management rate of hypertension = Number of hypertension patients meeting a criterion / Number of hypertension patients managed × 100%.
(3) Control rate of hypertension = Number of patients with BP controlled in the latest follow-up / Number of patients managed × 100%.

The evaluation indicator system demonstrated that the goal of hypertension management was hypertension control, and this is used for evaluation of the NBPHS program in this thesis.

1.3.4 The NBPHS funding mechanism and hypertension control

To make an economic evaluation of hypertension management under the NBPHS, it is necessary to understand its funding mechanism and the broader Chinese healthcare financing system.

According to international standards, healthcare in China is financed through three channels: government, society (non-government social insurance, commercial health insurance, and donations) and out-of-pocket payments (Fu, Zhao, Zhang, Chai, & Goss, 2018). Government funds are transferred directly to healthcare facilities and generally used for employment, infrastructure, equipment purchasing and for subsidizing the delivery of public health services. Funds from health insurance and out-of-pocket payments go to medical care facilities upon individuals' healthcare seeking, and are used under a revenue and expenditure balance system according to government regulations (Ministry of Finance National Development and Reform Commission Ministry of Civil Affairs, Security, & Ministry of Health, 2009).

The NBPHS is funded by the government, which considers it a subsidy to primary healthcare facilities (Ministry of Finance, National Development and Reform Commission, Ministry of Civil Affairs, et al., 2009). People have access to NBPHS services free of charge (Yip et al., 2012). Given that the NBPHS represents a governmental investment into primary care facilities, performance evaluation has been conducted by the government county/district (Fang, n.d.). Following that, to make better use of funding and improve the performance of primary healthcare staff, the Ministry of Finance and Ministry of Health together released a policy on how to use the NBPHS funds for primary care facilities. These funds can be used for healthcare staff payments and consumable materials related to the NBPHS, but cannot be used for infrastructure, equipment, training and other infrastructure improvement (Ministry of Finance and Ministry of Health of China, 2010).

Theoretically, with the implementation of the NBPHS' disease management program, more patients would have access to services, and as a consequence, better treatment. This would then result in more hypertensive patients seeking medical care, and getting regular treatment and medication, thus leading to improved hypertension control. Such an investment, therefore, might increase healthcare expenditure from the patient side through health insurance and individual out-of-pocket payments. On the other hand, as a result of the program's hypertension management, treatment might be more efficient and effective, resulting in fewer negative consequences from hypertension, thus potentially saving on healthcare expenditure. The funding of the NBPHS is additional to revenues from general health care and it is free for people receiving the care. Figure 1.1 provides a visual representation of the relationships between management and the treatment-related care of hypertension.

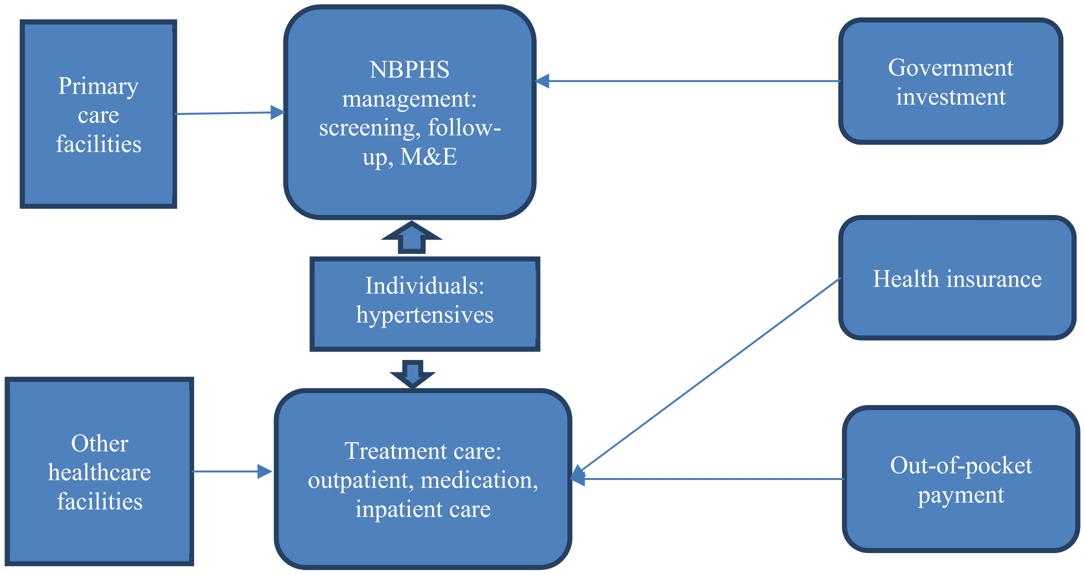

Figure 1.1 Funding mechanism for healthcare services of hypertension management in China

Note: M&E stands for monitoring and evaluation.

To determine whether the NBPHS increases or decreases healthcare expenditure, a cost of illness (CoI) method was employed (WHO, 2009). This is discussed further in Chapter 5.

1.4 Conceptual framework, methodologies and data sources

1.4.1 Framework and conceptual components of the research

Figure 1.2 is a diagrammatic representation of this research. The left-hand side of this figure shows the general terms of the research, and the right-hand side shows the economic evaluation indicators used.

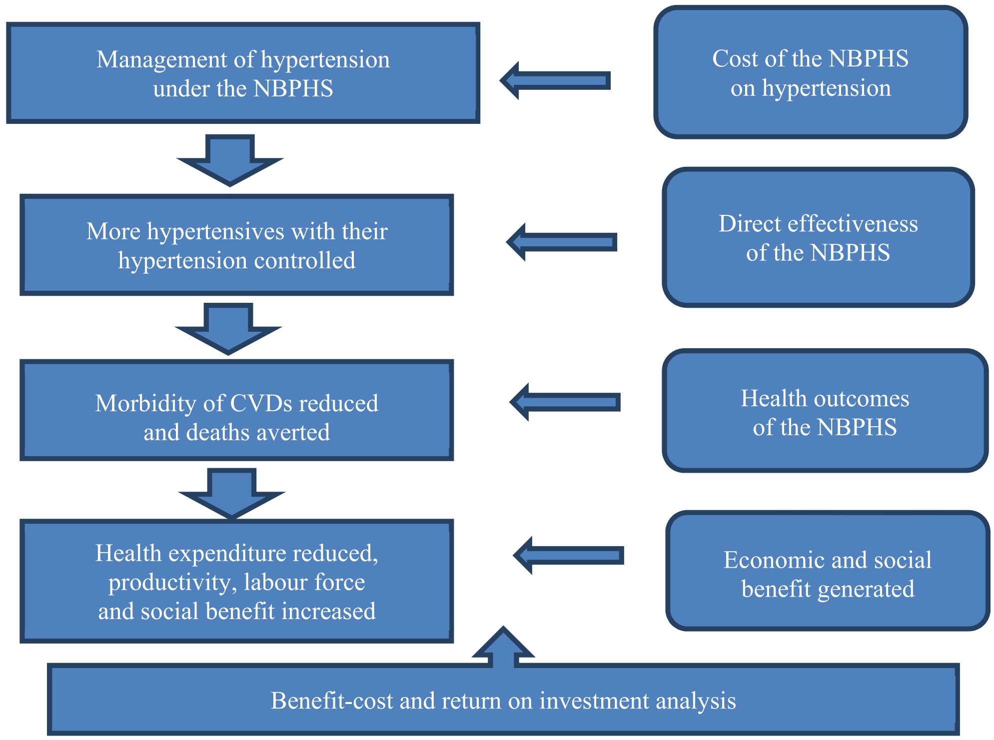

Figure 1.2 Framework of the study

As the NBPHS program was launched in 2009, this study used the data from that year to reflect the baseline status and the 2015 data to reflect the final status of the program, over a seven-year period. Based on the available data, this thesis comprises four main sections, as shown in Figure 1.2: the role of the NBPHS in terms of managing more people and providing better hypertension control; the long-term benefits arising from hypertension control; the benefits estimation and benefit-cost analysis of the program; and the findings and policy implications.

1.4.2 Components of the study

1.4.2.1 Using a time series model to identify the contribution of the NBPHS

A full literature review was conducted on prevalence, awareness, treatment and control (PATC) of hypertension in China from 1990 to the present. Representative data were identified to analyze the PATC of adults aged 35 years and above at the national level (Bundy & He, 2016; D. Li et al., 2015; Z. Wang et al., 2018). The Lagrange interpolation polynomial technique was employed to complete the missing data from 1991 to 2009 (Duan, 2015; Ren, Zhu, & Shao, 2005). Time series predicting analysis was performed with the expert modeler method and the predicted control rate of 2015 was calculated. The difference between the predicted and observed control rate of 2015 was considered to represent the incremental effectiveness of the NBPHS program. A literature review was performed to validate the estimate of trend analysis. In addition, age-specific analysis was made on the PATC of hypertension to analyze the mechanism of the NBPHS in hypertension management. Details are given in Chapter 3.

To conduct a comparative analysis, two scenarios were established in this study. The NBPHS scenario was represented by the incremental number of hypertensive patients under control. This is discussed in Chapter 3. The non-NBPHS scenario was identified as the number of hypertensive patients out of control.

1.4.2.2 Using a Markov model to project long-term health outcomes

According to the studies of Wu et al. (2006) and Zhang et al. (2005), the fatal or non-fatal outcomes of hypertension were mainly coronary heart disease (CHD) and stroke. Therefore, the significance of controlling hypertension was to prevent the trend of development of these related diseases. The long-term outcomes of the NBPHS program were estimated with a Markov model, as used in previous studies (Gu, D et al., 2015, 2008), in terms of adverse health episodes reduced and lives saved.

The direct health outcomes were identified as hypertension control, and long-term health outcomes were identified as morbidity averted and deaths reduced. These terms are explained as follows:

- "Hypertension control": the total number of hypertensives with their hypertension controlled from 2009 to 2015. This represents the direct impact on patients.
- "Morbidity reduced": morbidities of stroke and CHD reduced during the 30-year period are calculated, which are analyzed in Chapter 4.
- "Death averted": this was projected based on mortality from CVDs averted, to reflect long-term health outcomes. Again, this is explained in Chapter 4.

A sample of hypertensives from the China Health and Nutrition Survey (CHNS) 2009 was employed to simulate the two scenarios discussed above. It was discovered that between the two simulated groups, the major risk factor for CVD was the BP level, where blood pressure, diabetes, blood cholesterol, smoking, and body mass index (BMI) were considered. Comparisons were conducted on the difference of the two groups of age-gender specific risk factor distributions. Statistical analyzes were conducted using SPSS 22.0.[2]

A Markov model was established according to the CVD policy model-China (CDPM) (D. Gu et al., 2015; Moran et al., 2010), which had been well developed and calibrated. For the NBPHS scenario, the model parameters used to determine disease transitions were based on a recent published study (D. Gu et al., 2015). For the non-NBPHS scenario, the parameters were weighted by risk ratios of the two scenarios for each age-gender group based on BP and risk of CVD in the Chinese population (D. Gu et al., 2008).

In this study, a Markov model was used for the hypertensive population in China aged 35+ years, according to the CDPM (D. Gu et al., 2015a; Xie et al., 2018). The structure of the Markov model is illustrated in Chapter 4. The patient of either the hypertension-controlled or -uncontrolled group can shift to one of the six health states: hypertension only, acute heart disease, acute stroke, chronic CHD, chronic stroke, and death. It was assumed that there was no remission to a CVD-free state after an incident of CVD. Other health states or diseases were not considered. CHD and stroke were analyzed separately rather than in the form of CHD, stroke and the combination of both. A shift between any two health states was defined as the transition probability, which was derived from Gu et al.'s (2015) recent study. Each state and event had an annual probability of transition to a different CVD state. The hypertensive population was stratified by age in 10-year categories and gender.

The initial stroke or CHD event, which include cardiac arrest, myocardial infarction, and angina, and its sequelae for 28 days were described in the CDPM (D. Gu et al., 2015a; Xie et al., 2018). The cycle of the Markov model was one year. The 28-day case fatality was considered instant death from acute CHD or stroke. One-year case fatalities of CHD and stroke were calculated based on CHD and stroke mortality, and prior-prevalence of CHD and stroke, in line with Gu et al.'s (2015a) study. The non-CVD mortality equaled the difference between the all-cause death rate of the population (The

[2] SPSS is Statistical Package for the Social Sciences, a software package used for interactive, or batched, statistical analysis.

National Health and Family Planning Commission of China, 2014b) and the CHD mortality and stroke mortality.

In this study, the dynamic process of hypertension patients aged 35+ years follows that used in the CDPM (D. Gu et al., 2015; Xie et al., 2018) and is explained further in Chapter 4.

1.4.2.3 Estimation of economic and social benefits

This study estimated the economic and social impact of health benefits generated from hypertension control, and the reduced morbidity, mortality and other adverse health episodes. Economic and social benefits in monetary terms were modelled from the following aspects:

- Direct costs of illness avoided from hypertension control by the individuals and families concerned, including medical and other costs related to the illness, carer, cost on transport, and immediate loss of income.
- Benefits of higher gross domestic product (GDP) originated from improved health, including effects attributed to increased labour supply from morbidity and mortality averted, and productivity increased because fewer employees worked while ill.
- Social benefits were estimated in terms of the disease control impact to the community by estimating the value of a statistical life year in terms of per capita GDP beyond the economic benefit. According to recent studies, this equals 0.5 times the GDP per capita (Bertram et al., 2018; Stenberg et al., 2014).

A benefit-cost metric was employed for economic evaluation in this study from a societal perspective by estimating labour force and GDP increases from morbidity averted and lives saved. The benefits consist of both economic and social benefits.

The economic benefits from increased workforce participation for the working population was estimated with a maximum age of 65 years. Social benefit was considered equal to 0.5 GDP per capita estimated with a maximum age of 80 years.

Economic benefit: The economic modelling of mortality followed a cohort from 2016-2045 to determine rates of death and incidents. The economic impact from avoided mortality was calculated based on the labour force participation of every age-gender group and year category. The contribution to economic output was estimated by multiplying the number of people in each age-gender group by a productivity rate that varies with age and year. Each subsequent year, as they age, the age-specific participation rate was applied to that cohort to calculate the labour force for that cohort in that year. Account was also taken of average death rates by age. The labour force in any year was obtained by adding together all the cohorts up to that year. The participation rates used were grouped by age and gender categories of the International Labor Organization (ILO) (UN Department of Economic and Social Affairs, 2017). GDP per labour force was based on statistical data from 2017. The labour force by gender and age was accessed through the ILO (Bertram et al., 2018). Population and death rate data were extracted from the United Nations (UN) for 2017 (UN Department of Economic and Social Affairs, 2017). For each age-gender group, for the cohort of hypertensives whose lives were saved in a particular year, average ages were calculated based on the CHNS 2009 12 age-gender categories (male/female, 35-, 45-, 55-, 65-, 75- and 85+). The population structure was also taken from the UN population report (UN Department of Economic and Social Affairs, 2017). The persons are the sum of all persons of working age who were employed and those who were unemployed.

Social benefit: The social and economic components of the value of a life year saved were distinguished, as their effects may vary in different investment analyzes. In light of the discussion above, in this study we consider the total value of a life year under these two components as equal to 1.5 times GDP per capita, which was at the lower bound of the range employed in previous studies. This was made up of a social value equal to half of the sample GDP per capita, and hence common across countries, and the economic benefits of increased labour force participation calculated as national values. These assumptions varied in sensitivity analyzes.

Benefit estimation from morbidity averted: In this study, morbidities only include CHD and stroke, as they are the main health consequences identified in the model and in previous studies (WHO, 2010). The benefit estimation from morbidities averted was based on the numbers of deaths averted, according to the severity of diseases (Burstein et al., 2015).

Direct cost of illness (CoI) avoided: This was calculated for hypertension, CHD, and stroke, according to the method provided by the WHO guide (WHO, 2009). Direct costs measured the value of medical care used to prevent, diagnose, and treat a particular disease, also known as the total direct cost (Hodgson & Meiners, 1982). Expenses related to caring for a sick family member were not included, as this is difficult to measure.

1.4.2.4 Calculation of benefit-cost ratios and internal rate of return

To evaluate the benefits and costs of the NBPHS program, this study calculated the net social benefit, benefit-cost ratio and internal rate of return for such an investment.

1.4.3 Data source

Three streams of data from the Chinese government and published literature were used, as follows:

- The first stream of data was gathered from a literature review. As indicated earlier, a full literature review was conducted on hypertension PATC from 1990 to the present, through which representative data were extracted to analyze the PATC of adults aged 35 years and above at a national level.
- The second stream of data was from the CHNS conducted in 2009. A total of 9,552 participants were included in the analysis and 1,025 participants were hypertensives who had been diagnosed by health professionals. The measurements and definitions of hypertension, awareness, treatment and control are in line with previous studies (Guo et al., 2015a). Of the hypertensives, 1,017 were aged 35 years and above. Their data was adopted in this study and categorized into the hypertension-controlled group and the hypertension-uncontrolled group, where uncontrolled hypertension was defined as SBP/DBP≥140/90 mmHg.
- The third data source was a household interview survey conducted by the China National Health Development Research Centre in 2014, across 17 provinces in China. Sample households were selected under a multi-stage stratified clustering method, covered 20,777 households with 62,097 respondents in total. Among these, 9,607 hypertensives were identified (Qin et al., 2019). This survey was used for analyzing the CoI associated with hypertension, CHD and stroke in the hypertension-controlled group and hypertension-uncontrolled group.

- The fourth data source was the China Hypertension Survey (CHS) 2012-2015, which was conducted under a stratified multi-stage random sampling method. It obtained a nation-wide representative sample of 451,755 people aged over 18 years from mainland China during October 2012 to December 2015. The study results were published in 2018 (Z. Wang et al., 2018). The age-gender structure was weighted according to the 2010 Chinese Census population data.

Based on the above data and conceptual framework, a literature review was undertaken focused on all the research processes, and quantitative methods were adopted, including comparative analysis, trend analysis and modelling analysis.

1.4.4 Calculating the benefit, benefit-cost ratio and internal rate of return

Based on the costs and benefits data collected, a benefit-cost ratio and rate of return on investment were calculated. In the selection of discount rates, this research is mainly concerned with the maximization of the present value of health. An appropriate discount rate was employed based on the theoretical framework provided by Claxton (2011) with reference to the discount rates used, such as 0, 2%, 3%, and 5%. Sensitivity analysis was employed to justify the research results with estimations of different projected data.

Net present value (NPV) was employed to estimate both the economic and social benefits of the program generated from hypertension control. NPV is the difference between the present value of cash inflows and cash outflows during a defined period (Kenton, 2019). NPV is used in capital budgeting and investment planning for estimating the outcome of an investment (Kenton, 2019), which will be described in Chapter 5.

1.5 Structure of the thesis

The thesis is composed of six chapters. Chapter 1 provides an introduction to the thesis, presenting the background and rationale of the study, its research objectives, the general conceptual framework and the methodologies employed. Chapter 2 presents the literature review focused on hypertension, the relationship between hypertension and CVDs, the long-term health outcome estimations of healthcare, and the economic evaluation of hypertension management. This review also outlines the process used in selecting an appropriate methodology for this study. Chapter 3 examines the effectiveness of the NBPHS in terms of hypertension control by establishing a trend analysis model. Chapter 4 describes the performance of a health outcome estimation of the NBPHS from the perspective of CVDs avoided or postponed, or death averted. This chapter also outlines the development of a Markov model based on a CDPM. Chapter 5 clarifies the cost of hypertension management under the NBPHS. It also outlines the process of economic evaluation of the NBPHS based on the research findings presented in Chapter 4, applying an innovative cost-benefit framework. Chapter 6 presents a discussion of the policy implications of the research results, including the steps the Chinese government can take to address the findings. This final chapter also outlines the study's contributions to knowledge, its research significance, as well as its limitations (specifically in terms of the methodology used and data accessibility).

Chapter 2 Literature review: Hypertension and its consequences, health outcome quantification, and economic evaluations

2.1 Introduction

The NBPHS was launched nation-wide in China in 2009. Before 2009, patients with any diseases, including chronic conditions, tended to visit 'big hospitals'(W. C.-M. Yip et al., 2012). This limited the accessibility (M. Tian et al., 2015), availability and quality of healthcare for chronic disease (Centre for Health Statistics and Information of China, 2009). To combat the problem and strengthen primary health care delivery, a new health reform was launched (W. C.-M. Yip et al., 2012). The NBPHS was established in this context. Another objective in implementing the NBPHS was to facilitate tiered health care delivery for chronic disease interventions and guide patients into using primary healthcare (Ministry of Health of China, 2009; M. Tian et al., 2015). This study aims to evaluate the program in terms of quantity, quality, impact and economic outcomes, to see whether the above policy goals have been achieved.

As described in Chapter 1, hypertension management under the NBPHS involves a multi-intervention approach composed of hypertensive screening processes, evidence-based guidelines of practice, collaborative practice models, education for patient self-management, measurement and evaluations of process and outcome, and routine feedback (Perman G, Rossi E, Waisman GD, Agüero C, González CD, Pallordet CL, Figar S, González Bernaldo de Quirós F, Canning J, 2011). The NBPHS is designed to improve the health of patients and to save health care service costs related to avoidable complications, including emergency room visits and hospitalizations. This clearly denotes its economic significance (Georgetown University Health Policy Institute, 2004).

However, research on the economic benefits of prevention and public health programs has been limited, as traditional methods of economic evaluation are not always appropriate (Squires, Chilcott, Akehurst, Burr, & Kelly, 2016). In addition, hypertension is a risk factor for CVDs and is also related to other risk factors, such as age, gender, BMI, smoking, diabetes, and cholesterol (WHO/ISH, 2007). This makes it even more complex to conduct an economic evaluation of hypertension management.

To address this challenge, health economists have tried to provide a general framework for economic evaluations of healthcare programs. Tsiachristas, Cramm, Nieboer, and Rutten-van Mölken (2013) developed a general decision analysis model. This established five objectives of disease management programs, as follows: a) improvement of the process of care delivery; b) improvements in patient lifestyles and self-management behavior; c) improvements of biomedical, physiological and clinical health outcomes; d) gains of quality of life; and e) total health outcomes. Sculpher et al. (2004) emphasized that economic evaluations should use patient-level data and decision analytic modelling.

Economic evaluation requires that a money value be assigned to all or part of the disease management process and it should link investment with outcomes. Considering this, this review aimed to develop a research agenda for this study based on the following.

- First, as the target disease is hypertension, this study set out to review hypertension and its consequences.
- Secondly, the study sought to review changes in the process of care delivery for the management of hypertension under the NBPHS. A further step was to link the changes in care delivery with changes in patient lifestyles or self-management behavior, including awareness, treatment and control. This aligns with parts a) and b) of the Tsiachristas et al. (2013) study, discussed above.
- Thirdly, aiming at quantifying part c) of the Tsiachristas et al. (2013) study, this research sought to review how to estimate clinical health outcomes while taking into consideration other epidemiological factors using risk prediction models.
- Fourthly, this research sought to further quantify health outcomes from the Tsiachristas et al. (2013) study, and how to transform clinical outcomes into long-term health outcomes.
- Lastly, as the final health outcomes would be translated into economic terms, the study sought to review commonly used economic evaluation frameworks with the intention of selecting the most appropriate one for this study.

These components form the framework of the literature review presented in this chapter, as illustrated in Figure 2.1.

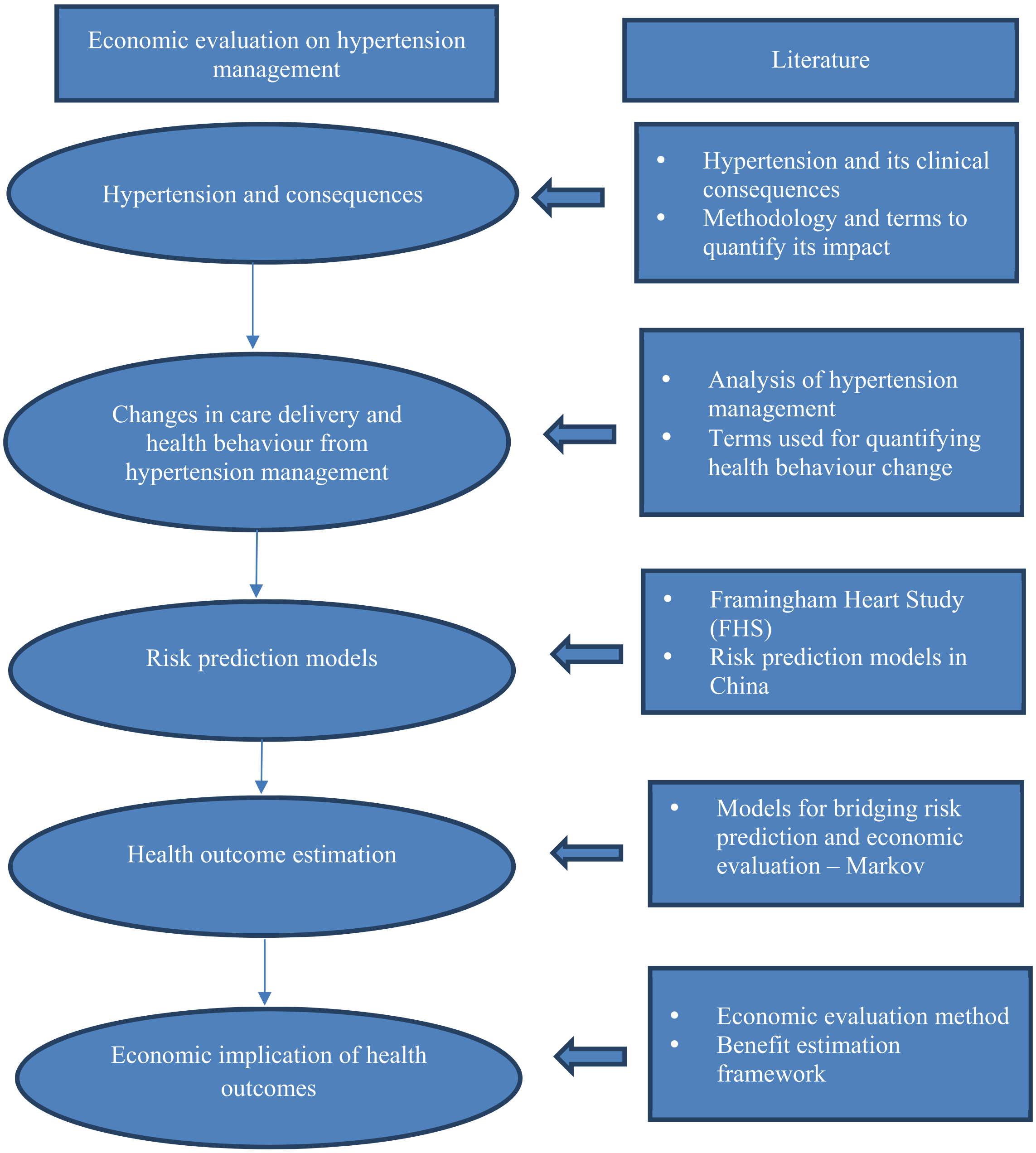

Figure 2.1 Structural components of the literature review

2.2 Hypertension and its consequences

2.2.1 Hypertension and CVD

Blood pressure (BP) is expressed by systolic pressure divided by diastolic pressure and is expressed by millimeters of mercury (mmHg) above the surrounding atmospheric pressure (Wikipedia, 2019). Hypertension (or high blood pressure) is usually defined as either systolic BP (SBP) equivalent to or over 140 mmHg, or diastolic BP (DBP) equal to or over 90 mmHg.

In population surveys, hypertension is measured directly by using a BP monitor or is self-reported typically when the person is asked if they have previously been diagnosed as hypertensives by a physician or are currently under medication for hypertension (Gao et al., 2013; Joffres et al., 2013). This definition is recommended by the WHO (2015) and the International Society of Hypertension (2019), and is widely used in the NBPHS (Gao et al., 2013; Jinwei Wang, Zhang, Wang, Liu, & Wang, 2014).

Treated hypertension is defined as currently taking anti-hypertensive medication among hypertensive patients. Controlled hypertension is considered as an average SBP of less than 140 mmHg and an average DBP of less than 90 mmHg over two (or three) measurements in people with hypertension (Hou, Meng, & Zhang, 2016a; Z. Wang et al., 2018).

Hypertension can lead to many adverse events for health. The Global Burden of Disease study in 2016 found that high BP was the most important risk factor globally for the burden of disease for women and the second most important (after smoking) for men (Gakidou et al., 2017), mainly because of its role in IHD and stroke.

2.2.2 Terms used in the study of hypertension and its consequences

This economic evaluation of the NBPHS draws upon a range of sources using several epidemiological terms. Definitions of some of these are presented below.

- Prevalence is the proportion of a population that has a condition at a specific time, but it is influenced by both the rate at which new cases are occurring and the duration of the disease (Le & Boen, 1995).

- Incidence is generated by dividing the number of new patients with a disease during a defined period (usually a year) by the number of the population considered, who do not suffer from the disease initially (Le & Boen, 1995).

Prevalence is a term for description of the extent of a disease in a population, while incidence is used to express the rate of developing new cases of disease. Also, prevalence is affected by the duration people live with a disease, something incidence usually does not consider (Le & Boen, 1995; Sara, 2011).

In describing the change of hypertension, prevalence is used to set up a context for the whole analysis and to estimate the number of hypertensive patients for estimates. Incidence is used to describe the new diseases attributable to hypertension, mainly CVDs, which are described later in this chapter.

Hypertension is an important cause of the mortality and morbidity resulting from CVD. CVD in China has a high case fatality (Bundy & He, 2016). The definitions of, and relationships between, these terms are explained as follows:

- Morbidity is another term for illness. Morbidities are not deaths. A person can have several co-morbidities simultaneously. Prevalence is used to measure the level of morbidity in a population.
- Mortality is a term for death. Mortality rate is a measure of the number of deaths in a population, divided by the size of the population, during a unit of time. The mortality rate is often described in units of deaths per 1,000 people annually. It is totally different from morbidity, and from the incidence rate (Samet, Wipfli, Platz, & Bhavsar, n.d.).
- Case fatality, also called case fatality rate or case fatality ratio, is the share of people who die from a particular disease compared to the total number of patients diagnosed with the disease in a defined period. The case fatality rate is often used for prognosis, and a comparatively high rate indicates a relatively poor outcome (Jeng et al., 1998).

These terms are used and explained further in the modelling undertaken for this study (see Chapter 4).

A number of epidemiological terms are commonly used to describe hypertension as a risk factor of CVD. These are as follows:

- Relative risk or ratio of risk (RR). For comparison of risks among groups, the ratio of risks, or the relative risk, is a statistic of choice. In epidemiology, RR is the ratio of the probability of an outcome in an exposed group to the probability of that in an unexposed group (Stare & Maucort-Boulch, 2016). It is computed as:

  RR = [A/(A + B)] ÷ [C/(C + D)] ＝ A(C + D)/C(A + B)

- The odds ratio (OR) is the ratio of the probability of an event occurring in a group and is a comparison of odds. It is calculated as follows:

  OR ＝ (A/B) ÷ (C/D) ＝ AD/BC

  where:

  A = the number of people who get a certain ill condition in the exposed group;
  B = the number of people who do not get the ill condition in the exposed group;
  C = the number of people who get a certain ill condition in the unexposed group; and
  D = the number of people who do not get the ill condition in the unexposed group.

  Therefore, A/(A+B) is the incidence in the exposed group, and (C/(C+D) is the incidence of the unexposed group. OR and RR measure the association between the exposure and the outcome.

  ORs can be used to compare the risk of CVDs in different hypertensive patient groups, for example, those with different BP levels.

- The hazard ratio (HR) is similar in concept to the RR and is used if the risk is not constant regarding time. Data collected at different times is employed and in the context of survival over time, it is often employed. For example, given an HR of 0.5, the RR of dying in one group is half the risk of dying in the other group (Stare & Maucort-Boulch, 2016). The HR is often estimated as the coefficients of Cox proportional hazard regression models, as hazard is connected to the survival function.

In summary, regarding hypertension and its complications: (a) prevalence can be used to describe both risk factors, including hypertension and complications, which are mainly CVDs; (b) incidence and morbidity are mainly used for CVDs as complications; (c) mortality and case fatality are used for the ending point of risk factors or complications; and (d) the HR is used to describe the strength of risk factors and their quantitative relationship with CVDs.

The following three terms are commonly used in analyzing health status changes for hypertension and many studies have been conducted on these topics.

- Awareness means being aware that you have hypertension. When derived from surveys, it is commonly defined by the answer "Yes" to the interview question "Have you ever been diagnosed by a physician or a health professional as a hypertensive (high blood pressure)?" (Kotchen, 2016)
- Treatment means undertaking some treatment for hypertension, such as a change in diet or physical activity and taking anti-hypertensive medication. In surveys, it is defined as self-reported use of anti-hypertensive medications.
- Control of hypertension means that the hypertension is at some defined level or lower, typically if the SBP/DBP is less than 140/90 mmHg (Guo et al., 2015; Lu et., 2017).

The prevalence of hypertension has been increasing in recent years in China (Bai et al., 2013; Gooding, McGinty, Richmond, Gillman, & Field, 2014; Guo et al., 2015a; C.-Y. Wu et al., 2015). The CHS 2012-2015 reported that 23.2% of the Chinese adult population, aged above 18 years, had hypertension and another 41.3% had pre-hypertension (Z. Wang, Chen, Zhang, et al. 2018). The survey on the Status of Nutrition and Health of the Chinese (Chen et al., 2017) revealed that prevalence of hypertension among adults aged ≥18 years old was 25.2% in 2012. However, the awareness, treatment and control rates are at a very low level (Gooding et al., 2014; Guo et al., 2015; Lu et al., 2017; J Wang et al., 2014).

By using the above terms, health behaviour changes can be quantified.

Recent studies have better explained the relationship between blood pressure, morbidity and mortality related to CVDs in China (Bundy & He, 2016). Increases in SBP were related to a greater risk of CVD compared to corresponding increases in DBP. As reported by D. Gu et al. (2008), compared to those with BP <110/75 mmHg, the relative risks of CVD incidence were 1.09, 1.25, 1.49, 2.15, 3.01, and 4.16 for those with systolic/diastolic BP of 110-119/75-79, 120-129/80-84, 130-139/85-89, 140-159/90-99, 160-179/100-109, and ≥180/110 mmHg. Therefore, the goal of hypertension management is to lower blood pressure, get hypertension controlled, and finally, reduce cardiovascular morbidity and mortality.

An economic evaluation of different measures in hypertension interventions could help determine the impact of each measure in reducing the burden of disease. Several efforts have been made to evaluate interventions on hypertension in China (D. Gu et al., 2015; Su et al., 2017). In 2015, the impact of anti-hypertensive drugs with a cost-effectiveness analysis was evaluated (D. Gu et al., 2015). This study concluded that expanded hypertension treatment from low-cost medication was borderline cost-effective. In 2018, Xie et al. conducted an economic evaluation on intensive hypertension management in China, concluding that it was more cost-effective than standard hypertension control (Xie et al., 2018). However, evidence of economic evaluation on hypertension is scarce (Tordrup & Bertollini, 2013; Tsiachristas et al., 2013).

2.3 The role of the NBPHS in the management and control of hypertension

Guidelines of hypertension management have clearly stated that lowering BP and controlling hypertension is the key to reduce CVDs (Bajorek et al., 2017; P. A. James et al., 2014; J.-G. Wang, 2015). The authors of these guidelines have also reviewed the evidence for treatments for lowering hypertension and set out recommendations for this, including improving lifestyle factors, comprising diet and physical activity, as well as anti-hypertensive medications. The implementation of these recommendations has increased the awareness of the role of hypertension in advanced economies, and has been important in improving hypertension control and reducing the death rate from CVD (P. A. James et al., 2014). Hypertension management under the NBPHS represents the implementation of these health intervention guidelines.

Detailed guidelines have been issued by the Ministry of Health on how the NBPHS should be implemented by CHOs (Ministry of Health, 2016). According to the specifications for hypertension management in the NBPHS program:

(1) Community health service facilities are obligated to conduct screening of hypertension; with all patients aged 35 years and above required to be screened by measuring their BP upon their first contact with general practitioners (GPs) or other doctors in primary care facilities. The results of the screening are conveyed to the patients, which may result in a major increase in the level of awareness of hypertension.

(2) If the patient is diagnosed as a hypertensive, primary care doctors are required to conduct regular visits (four times a year) to those patients. They record what medications are being taken, and give professional help if necessary, including supervision and advice on medication (J. Gu, Zhang, Wang, Zhang, & Chen, 2014).

(3) In cases of deterioration, GPs are obligated to refer patients to an appropriate hospital for further treatment. This facilitates timely treatment with appropriate care (J. Xu, Pan, Pong, Miao, & Qian, 2016).

(4) The NBPHS program provides better access to GPs (M. Tian et al., 2015). Before the introduction of the NBPHS program, Chinese patients tended to visit doctors in hospitals, where time available is limited for each patient. In addition, the in-hospital treatment mainly focuses on medication without considering non-pharmacological interventions (Tu et al., 2018).

Theoretically, hypertension management can be improved in terms of awareness, treatment and control. This has been confirmed in the evidence of several studies (Hou et al., 2016; M. Tian et al., 2015; Q. Zhang et al., 2014). Many studies on the rates of awareness, management and control of hypertension have been conducted in China in recent years based on large sample surveys. The most recent was conducted in 2017 (Lu et al., 2017), based on a survey of 1.7 million community-dwelling adults focused on an analysis of hypertension prevalence, awareness, treatment and control. Several other studies (Gao et al., 2013; Jinwei Wang et al., 2014; Z. Wang et al., 2018) were also based on cross-sectional surveys.

However, none of the abovementioned studies explored the dynamic progress of hypertension interventions. Two other studies did conduct dynamic trend analysis of hypertension prevalence, awareness, treatment and control. Both used the CHNS conducted in 2013 and 2015 (Guo et al., 2015a; Xi et al., 2012a). But, while these studies provided a good basis for the development of hypertension interventions, neither of them evaluated the effectiveness of the program. Without a random control trial study aimed at evaluating programs, it is very difficult to quantify the impact of awareness.

Based on data accessed through the literature review, this study analyzed the role of the NBPHS using trend analysis, with 2009 as a point of division. As stated in the above studies, awareness and treatment are structural indicators for hypertension, and control is the goal of hypertension interventions to prevent deterioration. Therefore, the focus of this study was on an analysis of hypertension control. Details of this analysis are presented in Chapter 3.

2.4 How to quantify the risk of CVD for hypertension

Research efforts to understand the role of hypertension as a risk factor can be dated back to the 1920s. Paullin, Bowcock and Wood (1927) reviewed 500 patients in the US and concluded that hypertension consequences could be categorized into seven groups, related to the heart, arteries, central nervous system, eyes, lungs, kidneys and other organs. They also demonstrated that cardiac hypertrophy is the first complication of hypertension, which was evident in 66.4% (332/500) of the patients reviewed. In 1964, Hamilton, Thompson, and Wisniewski conducted a study of the relationship between hypertension and stroke, and found that BP control could significantly reduce complications in males and stroke in females (Hamilton, Thompson, & Wisniewski, 1964).

A meta-analysis proved that for adults aged 40-69 years, each difference of 20 mmHg in the usual SBP (which is equivalent to 10 mmHg usual DBP) accounts for over a twofold difference in the stroke mortality, and with twice differences in case-fatalities from IHD and other vascular causes (S Lewington, Clarke, Qizilbash, & et al, 2002) . Randomized clinical trials have proved that lowering SBP by 10 mmHg, lowers the risk of stroke and IHD by about one-fourth (Turnbull, 2008). In China, evidence confirms that there is an obvious increase in the relative risk of CVD incidence as BP increases (D. Gu et al., 2008).

2.4.1 International studies on risk equations

Cox regression models are commonly used for risk estimation of CVDs, and the most well-known study is the Framingham Heart Study (FHS) in the US. This study began in 1948 (Framington Heart Study, 2020), with the main purpose of identifying the common factors or characteristics that contribute to CVD. The study involved a large group of participants who had not yet developed overt symptoms of CVD. The key outcome from the FHS was that the major risk factors of CVD were identified, which included hypertension, high blood cholesterol, diabetes, obesity, smoking, and physical inactivity. The study also provided evidence of the effects of related factors, including blood triglyceride and high-density lipoprotein (HDL) cholesterol levels, as well as age, gender, and psychosocial issues. The FHS is widely used and cited all over the world, generating over 1,200 articles in top medical journals in the past half century.

Different methodologies have been employed in estimation of parameters of risk factors (D'Agostino, Lee, Belanger, Cupples, & Anderson, 1990). The first methodology is logistic regression, which was used in Benjamin, Levy, Vaziri, D'Agostino and Belanger's (1994) study. They used gender-specific multiple logistic regression models to select independent risk factors for atrial fibrillation, with OR and RR used for risk factors. Other studies using this same approach are those of Singer, Nathan, Anderson, Wilson and Evans (1992) and Harris et al. (1998). The second method used is Cox regression, with HR used to express the relative risk of the factors analyzed (Preis et al., 2009), as this can better express the risk relationships by taking time into account.

In 2007, the World Health Organization and the International Society of Hypertension (WHO/ISH) generated a risk prediction chart for estimating the 10-year risk of fatal or non-fatal CVD by gender, age, SBP, smoking status, total blood cholesterol and diabetes mellitus (DM) for each WHO region (China belongs to the WHO West Pacific Region). The WHO/ISH risk prediction chart provided a visual and direct method for the public to acquaint themselves with CVD risks all over the world. This represents a world-wide application of FHS risk equations.

2.4.2 Risk prediction models developed in China

In terms of the consequences of CVD, early studies, especially for the western population, considered CHD to be the main complication. However, it is evident that CVDs should include not only CHD but also stroke, and strokes account for more deaths than CHD (Y. Wu et al., 2006; X. F. Zhang, Attia, D'Este, Yu, & Wu, 2005). Many longitudinal studies such as the FHS and MONICA (the MONICA is a project which aimed to evaluate trends of cardiovascular mortality and morbidity, and the relationship between these trends and changes in risk factor levels and/or medical care (Botig, Hobbs, Jamrozik, & et al, 1989)), among others, have been undertaken in a range of countries to quantify the importance of the various risk factors that contribute to IHD and stroke. Meta-analyzes and critical reviews of these and other studies have been undertaken by researchers (D'Agostino et al., 2008; Kuulasmaa et al., 2000). In recent years, models used for predicting risks have been further developed, with more factors taken into account and time used as a dynamic factor (D. Gu et al., 2015; X. Yang et al., 2016). Models used for risk prediction of CVDs in the Chinese population have also been developed. These are discussed as follows.

In 2005, Xiao-Fei Zhang et al. (2005) developed a risk prediction score of CVD based on a Chinese cohort. This used age, SBP, total cholesterol (TC), BMI and smoking as covariates and considered CHD, ischemic/hemorrhagic stroke as dependent variables. Their study concluded that the risk stratification rules derived from Caucasian cohorts overestimated the Oriental people's CHD risk. As a result, they derived a stratification rule for CHD, ischemic and hemorrhagic stroke for Chinese men.

In 2006, Yangfeng Wu et al. generated a gender-specific optimal 10-year risk prediction model for ischemic CVD (ICVD: including ischemic stroke and coronary events) in the Chinese population. They used Cox-proportional hazard regression, with data from the US-People's Republic of China (PRC) *Collaborative Study of Cardiovascular and Cardiopulmonary Epidemiology* (the USA-PRC Study) (Y. Wu et al., 2006). This demonstrated the relationship between ICVD and risk factors, composed of age, SBP, total cholesterol, BMI, current smoking status, and DM in both men and women.

In 2016, D. Gu et al. generated a 10-year risk prediction equation for atherosclerotic CVD (ASCVD) from four contemporary Chinese cohorts. In this study, they used the following risk factors: age, region, urban and rural, current smoking status, waist circumference, SBP, DBP, anti-hypertensive treatment within two weeks, total cholesterol, high density lipoprotein cholesterol (HDL-C), DM, and family history. They then predicted ASCVD for 10 years (X. Yang et al., 2016). This study was based on a large sample size and focused on all ASCVD, defined as non-fatal acute myocardial infarction or CHD death or fatal or non-fatal stroke.

The study by Yangfeng Wu et al. (2006) provided a simplified risk score system that could easily transform risk scores of ICVD into 10-year risk probabilities. The study by Dongfeng Gu et al. (2015) developed a risk prediction model for the Chinese general population and calibrated parameters in line with statistical data from China and the WHO. A similar application was performed in a 2016 study (X. Yang et al., 2016) for the Chinese population. The above studies provided a basis for long-term risk prediction tools.

Based on the 2015 study parameters, this study sought to develop a long-term health outcome estimation model with the CHNS data to perform risk predictions of CVDs. This is discussed further in Chapter 4.

2.5 Estimating health outcomes from hypertension control

Moran et al. (2010) reported that modest decreases in SBP could result in a significant impact on the progression of CVD in the Chinese population (D. Gu et al., 2015). Considering hypertension to be a main risk factor, the WHO/ISH formulated CVD risk prediction charts for implementation all around the world (International Society of Hypertension, 2007). Lowering SBP by 10 mmHg or the DBP by 5 mmHg reduced the risk of stroke by about 35% and that of IHD events by about 25% at the age of 65 (D. Gu et al., 2008; Lewington, 2003). An analysis of 354 randomized trials revealed that three anti-hypertension drugs at half of the standard dose were estimated to lower SBP by 20 mmHg or DBP by 11 mmHg, which would result in a 63% reduction in stroke risk or a 46% reduction in IHD risk (Law, Wald, Morris, & Jordan, 2003).

It was estimated that uncontrolled hypertension accounted for 750,000 CVD deaths a year. Given that the prevalence of hypertension could be reduced by 25%, 130,000 CVD deaths could be avert (Lewington, Lacey, & Clarke, 2016). In China, it was reported that anti-hypertensive intervention could avert the risk of stroke by 35% to

40%, the risk of myocardial infarction (MI) by 20% to 25%, and that of heart failure by over 50% (The Centre of National Cardovascular Disease of China, 2017).

While risk equations provided a good tool for linking hypertension as a risk factor to fatal and non-fatal CVDs, most risk predictions were based on a 10-year duration. The commonly used terminologies for hypertension were prevalence, incidence, case fatality, and mortality, which were generally quantified on a one-year basis or an even shorter time.

To estimate life-span analysis, a health outcome predictor based on a longer term should be generated. Therefore, many efforts have been focused on developing models to integrate risk equations and the long-term health outcomes of disease control in and out of China (Barton, Bryan, & Robinson, 2004). A systematic review by Unal et al. (Unal, Capewell, & Critchley, 2006) stated that by 2006, 42 CHD models had been developed and applied to CVD modelling, and six of these were considered major models widely used by researchers (Unal et al., 2006). In China, the CDPM model (Chan et al., 2012; Moran et al., 2008), impact model (Cheng et al., 2009), and Markov model (X. Zhang, 2015) have been studied to different extents. As described in Figure 2.3, CVDs, which are mainly composed of CHD and stroke, are caused by many risk factors, including age, gender, hypertension and other related factors. The relationship between risk factors and CVDs is described in HR. CVDs will increase the risk of death, of which probabilities are described in case fatality and morbidity.

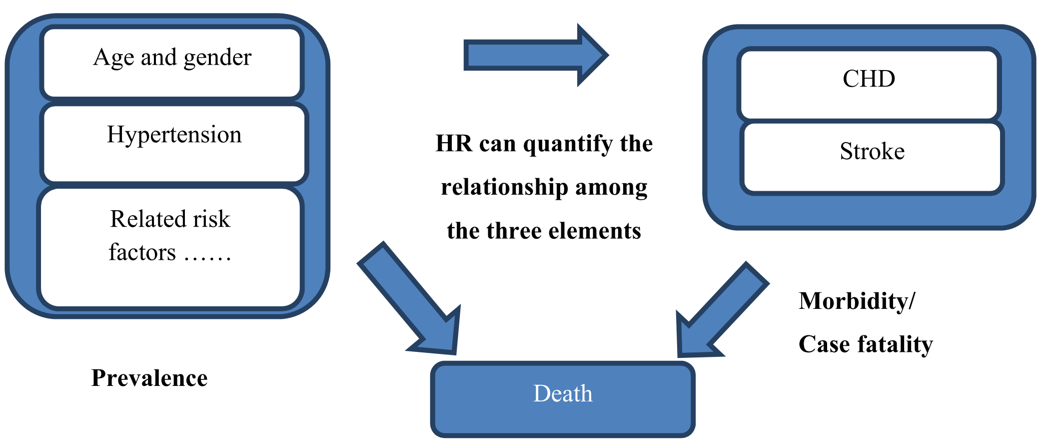

Figure 2.2 Relationships among hypertension, other risk factors and CVDs

2.5.1 Introduction to the CHDP model and its application in this study

Markov models are among the main approaches adopted when modelling economic evaluations in health care (Barton et al., 2004). In China, the CHDP (Coronary Heart Disease Policy) model, which is based on the Markov model, is widely used and has been well developed for risk prediction of CVDs (D. Gu et al., 2015).

The CHDP model is a state-transition, cell-based model that was developed in the 1980s. It consists of three sub-models (Weinstein et al., 1987): a demographical /epidemiological model; a bridge model; and a disease history model. The model can perform simulation of the effects of an intervention employing different case fatality rates and calculating the effects of long-term (up to 30 years) mortality, morbidity and costs. It has been applied in the US (Lightwood, Coxson, Bibbins-Domingo, Williams, & Goldman, 2009), Argentina (Konfino, Mekonnen, Coxson, Ferrante, & Bibbins-Domingo, 2013) and China (D. Gu et al., 2015; Moran et al., 2010).

This model is well developed and applied in China, and is known as the Cardiovascular Disease Policy Model – China model (CDPM). The methodology has been developed since 2008, and the latest study to apply it was conducted in 2015. The research progress in China is reviewed as follows.

In 2008, Moran et al. conducted a study on the relationship between population growth and aging, and coronary heart disease in China, developing the CHDP model for the Chinese population. In the study, China-specific CHD risk factors, incidence, case fatality, and prevalence data were integrated, and a Chinese-cohort-based model were generated, which was calibrated to age-specific Chinese mortality rates. It calculated disability-adjusted life years (DALYs) of CHD with a projected Chinese population aged 35-84 years. Moran et al.'s (2008) results predicated that during the period 2020-2029, there would be 7.8 million excess CHD events (a 69% increase from the 2000-2009 period) and 3.4 million CHD deaths (a 64% increase), together with a 67% annual burden growth of CHD death and disability on adults aged under 65 years.

In 2010, the same research team further developed the CHDP model (Moran et al., 2010). In this study, CVD was projected from 2010 to 2030, including both CHD and stroke, among people aged 35-84 years old. Moran et al. (2010) discovered that between 2010 and 2030, aging and population growth would contribute to an increase in CVD by more than half, and that unfavorable trends in BP, total cholesterol, diabetes and BMI would likely accelerate the epidemic.

In 2012, Chan et al. used the CHDP model to project the impact of urbanization on CVD over the period 2010 to 2030. They concluded that urbanization would increase CHD incidence by 73-81 per 100,000 and stroke incidence slightly.

In 2015, Gu et al. led another study, with the model focused on the cost-effectiveness of low-cost essential anti-hypertensive medicines for hypertension control in China (D. Gu et al., 2015). In this study, for the first time, the CHDP model was used for an economic evaluation of hypertension interventions in China and parameters were well calibrated. The authors estimated screening of hypertension, implementation of the essential medicine program, and administration of the hypertension management program. Costs of medication, disease-related expenditure, and quality-adjusted life years (QALYs) from prevention of CVD or lost from drug side effects were estimated for untreated adults who were to 35-84 years old during 2015-2025.

These applications of the CHDP model provide a good basis for better structuring the process of hypertension in the Chinese setting, using the latest epidemiological parameters for better estimation. Most importantly, the studies provide a method and guide for this study to transform 10-year risk predictions of CVDs into annual risk predictions. This makes it possible to predict long-term health outcomes.

2.5.2 The Markov model and scope of diseases for this study

This study sought to develop a Markov model based on the Gu DF's study (2015). The Markov model is a stochastic model for simulating randomly changing systems (Gagniuc, 2017). It is assumed that future states depend only on the current state, not on the events that occurred before them. The Markov model is a convenient way of simulating the prognosis of diseases with ongoing risk (Sonnenberg & Beck, 1993). The hypothesis of the model is that the patient is always in one of several defined states of health, named as Markov states. All events related are modelled as transitions from one state to another. In this study, the states for the Markov model consist of hypertension, CVDs, death attributable to CVDs and non-CVD death. The transition from one state to another can be generated from risk equations, as described in Chapter 1. Under each state, a utility can be assigned, where DALYs are commonly used (Hoang et al., 2016). The contribution of the utility to the overall process depends on the length of time spent in the state.

Epidemiological parameters for the transition of hypertension to CVDs is cited from Gu DF's study (2015), which have been adjusted and calibrated with other statistical data. Risk for those within the NBPHS program was considered the same as for the general population. And the non-NBPHS scenario was simulated using the 2009 CHNS. Then, following Gu et al.'s (2015) model, the Markov model was employed to estimate 30-year health outcomes.

The scope of diseases considered in this study follows the Gu et al. (2015) study, which reviewed the CVDs related to hypertension (Chan et al., 2012) as listed below:

- Coronary heart disease (CHDs): Myocardial infarction, angina and other ischemic heart disease, and a fixed proportion of 'ill-defined' CVD coded events.
- Stroke: Defined by ICD-9 codes 430-438 (excluding transient ischemic attack) or ICD-10 I60-I69. ICD is the international standard for reporting diseases and health conditions (World Health Organization; 2019). ICD-9, the International Classification of Diseases Ninth Revision, and ICD-10, the Tenth Revision coding systems, are used to identify specific patient cohorts and assess their clinical outcomes with risk adjustment in many cases (Myers, Leung, Shaheen, & Li, 2007).

Data of CHDs, stroke incidence and prevalence were from the China hypertension epidemiology follow-up study (Moran et al., 2010). The CHDP mortality projections were validated with age-specific and overall CHDs and stroke mortality numbers for the years 2000-2010, as studied by the WHO (D. Gu et al., 2015; Moran et al., 2010).

2.6 Economic evaluation of health programs

2.6.1 Some basics

According to Drummond et al. (Drummond, Sculpher, Karl, Stoddart, & Torrance, 1997), there are four types of health care program economic evaluations: cost-effectiveness analysis (CEA); cost-utility analysis (CUA); cost-benefit analysis (CBA); and cost-minimization analysis (CMA). Drummond, Sculpher, Torrance, O'Brien, and

Stoddart (2005) further developed the definitions of the above concepts for health programs, as follows:

- CMA: Deals with costs only, which stands for a partial form of economic evaluation.
- CEA: The outcomes of programs are described by the natural effects or physical units, which include “years of life gained” or “cases correctly diagnosed”.
- CUA: A broader form of CBA in which the outcome of programs is adjusted based on health state preference scores or utility weights, often expressed by QALYs gained or disability life years avoided. The most common measure of consequences in CUAs is QALY.
- CBA: A form of analysis which attempts to value the monetary consequences of programs. It is the broadest form of analysis, with the beneficial consequences of a program ascertained to justify the cost or not.

2.6.2 CBA and valuing the benefit in CBA

As emphasized by the WHO health economic evaluation agenda, the focus on the economic benefit of prevention and public health programs has been limited (Tordrup & Bertollini, 2013). This is also the case in China.

A systematic review of economic evidence on community hypertension interventions conducted in 2016 (D. Zhang, Wang, & Joo, 2017), indicated that only four studies were conducted from 1995 to late 2015 in China. Of these studies, two employed CEA (Bai et al., 2013; D. Gu et al., 2015), and the other two conducted CBA (Y. Huang & Ren, 2010; X. Wang et al., 2012). The 2010 study by Y. Huang and Ren involved an evaluation of a community-based stroke prevention program, in which benefit was defined as CoI saved. However, only stroke was considered, which is only one consequence of hypertension, as discussed earlier. In addition, future costs and benefits were not analyzed, and the methodology was not clearly explained for use in economic evaluation. The study conducted by X. Wang et al. (2012) only analyzed cost savings from hypertension management through a one-year follow-up study on 140 hypertensive patients in Beijing. In general, these two cost-benefit studies were not representative in terms of economic evidence for national hypertension management programs in China, and the methodologies used were not comprehensive enough as benchmarked in Drummond et al.'s interpretation of CBA (Drummond et al., 2005).

To improve the methods of economic evaluation in China, this study employed a CBA framework, with benefit defined as assigning money values to the outcomes of healthcare programs (Drummond, Sculpher, Claxton, Stoddart, & Torrance, 2015).

Every life saved is a benefit to the individual, as they enjoy additional years with better quality of life. The community also benefits through a reduction in treatment costs or a gain from that individual, who can contribute to social and economic affairs. There is an extensive range of studies on the value of a life year and the estimation of benefits from healthcare interventions. In the fourth edition of their study of methods for the economic evaluation of healthcare programs, Drummond et al. (2015) illustrated that willingness to pay (WTP) is commonly used for benefit estimation. It attempts to measure underlying consumer demand and value the non-marketed social goods, including healthcare programs. However, Drummond et al. (2015) also pointed out that each of the methods used, including WTP, has its strengths and weaknesses. The WTP method, although commonly used and well developed, has two major deficiencies: one is hypothetical and the other is that QALYs, once used for benefit estimation through WTP, may not include social benefit (Drummond et al., 2015). Several studies in the US have estimated that the value of a life year is equal to US$150,000 (Murphy & Topel, 2006), but other competing views and methods exist.

To solve the above deficiencies, Stenberg et al. (2014) developed an innovative metrics for calculating return to investment in women and children's health, which broadened the estimation of the benefits of health programs. In their study, health benefits were considered to be composed of economic benefit and social benefit. The economic benefits were estimated from increased workforce participation for the working age population based on labour force participation rates and productivity for each age-gender group. The social benefits from longer, healthy life expectancy were estimated by assigning a certain proportion of GDP per capita (Bertram et al., 2018; Stenberg et al., 2014). Compared to traditional frameworks of benefit estimation, where WTP was commonly used, this benefit estimation framework addressed the problem of bias in preference-based methodologies and provided a tangible and measurable tool for benefit estimation.

However, the framework has never been used specifically on NCDs in China. Therefore, based on Stenberg et al.'s framework (Bertram et al., 2018; Stenberg et al., 2014), this study applied the newly developed benefit estimations model to NCD interventions, specifically hypertension management in China.

2.6.3 International evidence on the economic evaluation of community-based hypertension interventions

Many studies of economic evaluations of hypertension interventions or management at the primary care level have been conducted. This study reviews several of these international studies.

In Bhutan, Dukpa et al. (2015) performed an economic evaluation of the WHO package of essential non-communicable (PEN) disease interventions in primary health care settings based on modeling (WHO, 2010). The models applied consisted of a decision tree and a Markov model. Final outcomes under the decision model were termed lifetime costs and DALYs averted under three scenarios: no screening; current PEN program; and universal screening. The Markov model for hypertension contained four health states: uncontrolled hypertension, controlled hypertension, stroke and death. The age range of the adult cohort was 40 years or older and the length of each cycle was one year. DALYs were calculated using WHO standard methods. Dukpa et al.'s (2015) study concluded that a screening program conducted by primary care facilities represented good value for money.

In Bangladesh, a CBA of the national hypertension treatment program was conducted from a societal perspective, and the results showed the return on investment of providing BP lowering drugs to 60% of hypertensives by 2021 and 2030 (Nugent, Brower, Cravioto, & Koehlmoos, 2017). The study concluded that if hypertension management is conducted proactively by government, this could result in a 12.7:1 annual return on investment by 2021 and an 8.6:1 annual return by 2030.

In Greece, Athanasakis, Kyriopoulos, Boubouchairopoulou, Stergiou, and Kyriopoulos (2015) conducted an economic evaluation of hypertension control in 2014 using a Markov model for CBA. This study concluded that interventions that promote BP control should be a health policy priority.

In the Netherlands, primary prevention of CVDs in mild hypertension was evaluated using a Markov model. This found that SBP reductions were cost-effective in both a 10-year and lifetime horizon (Stevanović et al., 2014).

The above studies provided a good basis and reference for the methodology and international scholarship presented in this thesis. Whether in developed or developing countries, intervention or screening measures at the primary care level were found to be cost-effective or good value for money. As indicated above, most economic studies adopted a Markov model. For example, the study in the Netherlands (Stevanović et al., 2014) built a Markov model that set five states of CVD progression: healthy with hypertension, acute non-fatal CVD, stable non-fatal CVD, CVD death, and non-CVD death. This is similar to the approach adopted by Gu et al. (2015) and provides an accurate reference for Markov modelling for hypertension control.

2.6.4 Study gap in China

In terms of the economic evaluation of disease management in China, the gap is threefold. First, nearly all the studies have focused on CEA or CUA, but neglect CBA. For example, in an evaluation of stroke intervention in China, CBA was not included (H. Tian, Guo, Song, & Wei, 2000; H. Tian, Song, & Dong, 2000). In the PhD thesis by Liang Xiao-Hua (2011), who was from the Chinese Academy of Medical Sciences and Peking Union Medical College, an economic evaluation of hypertension management in communities was conducted. However, she did not conduct a CBA either (Liang, 2011). Second, although several studies did undertake CBA on hypertension management in primary care settings, the methodology was not performed. For example, a study (R. Li, Wang, Yu, & et al, 2003) used the Monte Carlo model for a CBA of a diabetes screening program. However, in the study, only QALYs gained and treatment cost were considered, which was incomplete for the estimation. Another investigation, which was the analysis of curative effect and cost benefit of hypertension patients in a community management model, did not conduct sensitivity analysis (Tang, 2011). Thirdly, in the process of economic evaluations, the economic impact on individuals in society has not been considered (Mukhopadhyay & Thomassin, 2012).

In 2015, Gu et al. (2015) partially addressed the gap discussed above. However, there are at least two points that can be further developed. First, there is still no evidence on the return of investment for the NBPHS program, let alone for the disease management of hypertension. Second, although many reports have emphasized that measures taken at the primary care level would gain a high return for economic growth and social development (World Bank, 2011; WHO, 2016), Gu et al.'s (2015) study found that expanded hypertension treatment was only borderline cost-effective in China. From this perspective, this current study provides in-depth evidence for the cost-effectiveness of these measures.

2.7 Conclusion

This chapter has presented a review of studies on hypertension and its health consequences, how to quantify the impact of hypertension as a risk of CVD, the estimation of health outcomes based on risk equations, and economic evaluation methodologies for healthcare interventions. This study aims to estimate the health benefits arising from hypertension control, and the averted morbidity and mortality of diseases. Through a literature review, appropriate methodologies were identified for use in this study.

Comparative analysis and trend analysis are employed for estimation of the role of the NBPHS in management of hypertension from different data sources. Positive results provide the basis for further evaluation in terms of economic return and investment. This is described in Chapter 3.

Regarding risk equations and long-term health outcome modelling, this study developed a Markov model based on Gu et al.'s study (2015), which will be described further in Chapter 4.

As discussed, several healthcare economic evaluations of hypertension interventions have been conducted, such as studies in the Netherlands (Stevanović et al., 2014), Greece (Athanasakis et al., 2015), Bhutan (Dukpa et al., 2015), and Vietnam (Nguyen et al., 2016). This study drew on these international investigations by combining health outcome estimation processes with cost and benefit calculations to generate a Markov model framework. A CBA framework was also developed following previous studies (Bertram et al., 2018; Stenberg et al., 2014).

The economic and social benefits generated from NBPHS interventions on hypertension in monetary terms were modelled from the following aspects.

(1) Benefits in terms of higher GDP over a longer term, which includes effects of increased labour supply from death or illness averted, productivity increased from fewer workers working while ill, and investment effects associated with a healthier and more vibrant workforce.

(2) Social benefits were estimated in terms of the disease control impact to the community by estimation of the value of a statistical life year in terms of per capita GDP beyond the economic benefit (Stenberg et al., 2014). To compare the benefits with the costs of the program, the net social benefit, benefit-cost ratio and internal rate of return for such an investment were developed. The main process of economic evaluation is explained further in Chapter 5.

(3) Direct costs saved by the individuals and families, which include medical and associated costs on the illness, carer and transport, are also explained in Chapter 5.

Chapter 3 Role of the NBPHS on hypertension control

3.1 Introduction

Hypertension control is one of the main targets for reducing CVDs (Chen et al., 2017; He, Muntner, Chen, Roccella, Streiffer, & Whelton, 2002), and it is widely acknowledged that community-based interventions of hypertension are effective and cost-effective measures for hypertension control. As part of the EPHS program, disease management of hypertension was launched in China, but with no intervention-controlled pilot study (M. Tian et al., 2015). It was reported that by the end of 2017, the number of hypertensives managed by the NBPHS had reached 101 million (The National Health Commission of China, 2018b). However, baseline data was not available to evaluate hypertension management. According to government statistical data, the number of hypertensive patients had been increasing gradually from 2009 to 2013 (Community Health Association of China, 2016). In addition, involvement in the program was based on the willingness of patients who could participate in and drop out of the program at any time. This made it more difficult to calculate the participation rate of the program.

A systematic review of a framework for developing the structure of public health economic models pointed out that it is important to identify the impacts of public health interventions when conducting economic evaluations of public health programs (Squires et al., 2016). However, there are few studies that analyze the contribution of regular follow-up, medication, and non-pharmacological therapies in hypertension management (Z. Wang et al., 2014; Wong et al., 2012). Therefore, evaluation of the effectiveness of community-based programs is difficult in terms of linking program attendance to the health outcomes over time (D. Zhang et al., 2018).

On the other hand, it is even more difficult to quantify the incremental effectiveness of hypertension control in the NBPHS because of other confounding factors, such as social economic development. The reasons are twofold: (1) both the quality of primary healthcare and people's awareness of hypertension are under continued improvement as society and the economy develops; and (2) many other local or national level programs, which are difficult to detect and observe, may have been implemented at the same time as the NBPHS. To overcome these barriers in an economic evaluation of the

NBPHS program, time series trend analysis was employed to predict the hypertension control status of 2015 with data before 2009.

To estimate the effectiveness of hypertension management, relationships of PATC were explored. According to the specifications of hypertension management in the NBPHS program, community health service facilities were obligated to conduct screenings for patients with hypertension, provide treatment and referral, establish management information systems, stratify the risk factors, and implement regular follow-up and management (at least once every three months) (J. Gu et al., 2014). Therefore, theoretically, hypertension management would be improved in terms of awareness, treatment and control. This has been demonstrated in the findings of several studies (Hou et al., 2016a; M. Tian et al., 2015; Q. Zhang et al., 2014).

To achieve the study aims, it was necessary to find a time series dataset that would reflect the trend of hypertension PATC before and after 2009. Further estimation was made based on the time series prediction model.

There are five sections in this chapter. Section 3.2 presents the full literature review conducted to analyze data related to hypertension PATC from 1990 to the present. In Section 3.3, this data is further analyzed in terms of age-specific characteristics and trends. Section 3.4 focuses on the missing data in the period 1990 to 2009, which was addressed using a Lagrange interpolation polynomial method. A time series prediction model was also established using pre-2009 data. Then a predicted control rate of hypertension was estimated through the model. The difference between the predicted and observed control rate of hypertension in 2015 was seen as representing the effectiveness of the NBPHS. Section 3.5 presents a comparison between the evidence from the literature and the findings discussed in Section 3.4. The final two sections, Sections 3.6 and 3.7, provide a discussion and conclusions.

3.2 Literature review on hypertension PATC from 1990 to the present

3.2.1 Search strategy and selection criteria

Relevant studies on PATC of hypertension in China were searched via the search engine PubMed on 22 November 2018.

Key words included ((hypertension OR high blood pressure) AND (prevalence OR epidemiology OR awareness OR treatment OR control)) AND (China OR Chinese).

The following filters were used: full text; publication date from 2000/01/01 to 2018/12/31. From this initial search, 5,553 articles were identified. Another three articles were accessed from other sources (personal communication with scholars). In total, 5,556 articles were reviewed by title and abstract.

3.2.2 Inclusion criteria

Articles were included if the following criteria were met: (1) a national representative survey was used, with a multi-stage stratified random (or cluster) sampling method; (2) the age range of the target population was 18 years and above; (3) the survey population structure was weighted according to the national or international population; (4) BP was obtained during field surveys, measured by trained examiners at the time of survey, with an average of two or three measurements employed as the BP values; (5) the article was published in English or Chinese; and (6) hypertension was defined by SBP ≥ 140 mmHg or DBP ≥ 90 mmHg, and/or administration of anti-hypertensive drugs.

Awareness of hypertension was considered as the self-reporting of any previous diagnosis of hypertension by a healthcare professional among the hypertension population. Treatment of hypertension was considered as self-reported if medication for hypertension had been prescribed within two weeks of the survey. Control of hypertension was defined as hypertensive participants having the following readings: SBP <140 mmHg and DBP <90 mmHg. Studies in Hong Kong, Macao and Taiwan were not included.

Surveys undertaken in a population of specific ethnicity, occupation, or age-range were excluded, if that population could not be considered representative of all adults aged 18 and above across the national population. If articles were focused on the same theme and age range, the article with a higher impact factor was selected. Papers that were published as supplementary articles were excluded.

3.2.3 Articles extracted

Once the filtering and exclusion processes had been completed, 117 potential articles remained. These were further filtered by reviewing their abstracts, and 15 articles were selected for data extraction, with 15 more used for further analysis in relation to hypertension management effectiveness (discussed in Section 3.5). The filtering process is illustrated in Figure 3.1 and the selected articles are summarized in Table 3.1 below.

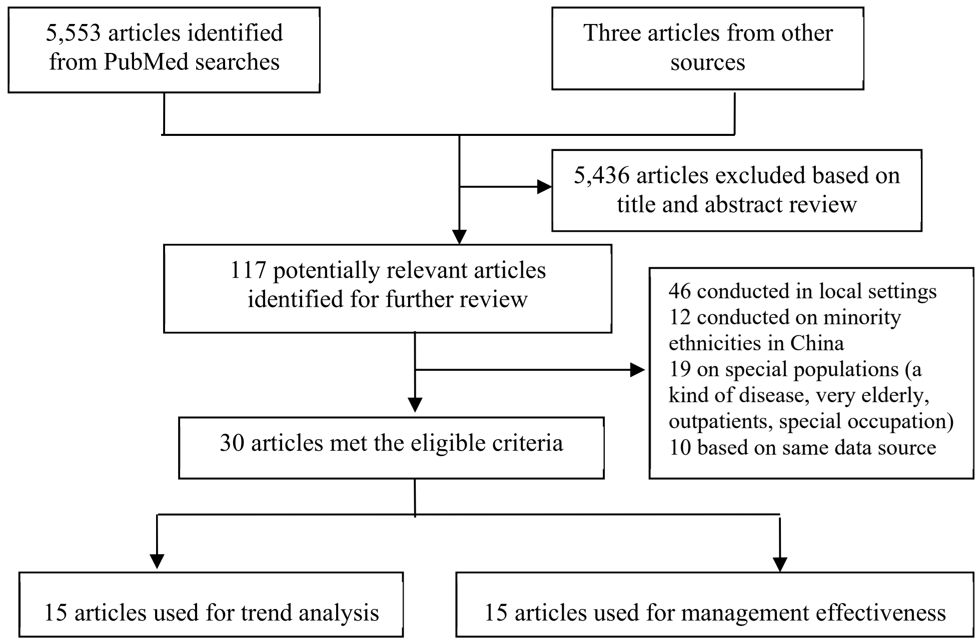

Figure 3.1 Selection of articles for further analysis

Table 3.1 Summary of articles on hypertension prevalence, awareness, treatment, and control in China, 1991-2018

No.	Title/Authors/Year of study/Publication	Year of survey	Survey design	Age range	Analysis methodology	Sample size
1	Trends in prevalence, awareness, treatment and control of hypertension in the middle-aged population of China, 1992-1998/ Zengwu Wang, Yangfeng Wu, Liancheng Zhao, et al./ Hypertension Research 2005; 27(10). (Wang et al., 2005)	1992-1994 and 1998	China Multi-Centre Study of Cardiovascular Epidemiology: Random cluster samples.	35-59	Comparative analysis between 1992 and 1998 of PATC	18,746 (1992-1994) 13,504 (1998)
2	Hypertension burden and control in mainland China: Analysis of nationwide data 2003-2012/ Dianjiang Li, Jun Lv, Fangchao Liu/ International Journal of Circulation 2015; 184(1), 637-644. (D. Li et al., 2015)	2003-2012	Review	18+	Systematic review	N/A
3	Hypertension in China: Data from the China National Nutrition and Health Survey 2002/ Yangfeng Wu, Rachel Huxley, Liming Li/ Circulation 2008; 118, 2679-2686. (Y. Wu et al., 2008)	2002	CNNHS (China National Nutrition and Health Survey)	18+	Comparative analysis	141,892
4	Prevalence, awareness, treatment, and control of hypertension in China/ Dongfeng Gu, Kristi Reynolds, Xigui Wu, Jing Chen, Xiufang Duan, Paul Muntner, Guanyong Huang, Robert F. Reynolds, Shaoyong Su, Paul K. Whelton, Jiang He, for the InterASIA Collaborative Group. (D. Gu et al., 2002)	2000-2001	InterASIA: 4-stage stratified sampling	35-74	Descriptive analysis (M, SD)	19,012
5	Trends in prevalence, awareness, treatment, and control of hypertension among Chinese adults 1991-2009/ Bo Xi, Yajun Liang, Kathleen Heather Reilly/ International Journal of Cardiology 2012; 158(2), 326-329. (Xi et al., 2012a)	1991-2009	CHNS	18+	Trend analysis	8,426-8,503
6	Hypertension prevalence, awareness, treatment, and control in 115 rural and urban communities involving 47,000 people from China/ Li, W., Gu, H., Teo, K. K., Bo, J., Wang, Y., Yang, J., … Yang, S./ Journal of Hypertension 2016; 34(1), 39-46. (W, Gu, Teo, & et al, 2016)	2005-2009	PURE (prospective, standardized collaborative study)	35-70	Generalized linear model	153,996
7	Prevalence of hypertension in China: A cross-sectional study/ Gao Y, Chen G, Tian H, Lin L, Lu J, et al./ PLoS ONE 2013; 8(6), e65938. (Gao et al., 2013)	2007-2008	Cross-sectional survey	20+	Analysis of prevalence of hypertension in China	46,239

8	Hypertension among older adults in low- and middle-income countries: Prevalence, awareness, and control/ Peter Lloyd-Sherlock, John Beard, Nadia Minicuci, et al./ International Journal of Epidemiology 2014; 43, 116-128. (Lloyd-Sherlock, Beard, Minicuci, et al., 2014)	2007-2010	SAGE	50+	Descriptive analysis (M, F)	13,348
9	Prevalence, awareness, treatment, and control of hypertension in China: Results from a national survey/ Jinwei Wang, Luxia Zhang, Fang Wang, et al./ American Journal of Hypertension 2014; 27(11), 1355-1361. (Jinwei Wang et al., 2014)	2009-2010	Multi-stage, stratified sampling	18+	Analysis of PACT of hypertension in China	50,171
10	Hypertension and related CVD burden in China/ Joshwa Bundy, He Jiang/ Annals of Global Health 2016; 82(2). (Bundy & He, 2016)	2010	China non-communicable disease surveillance 2010	18+	Literature review (China non-communicable disease surveillance 2010)	N/A
11	The dynamics of hypertension prevalence, awareness, treatment, control and associated factors in Chinese adults: Results from CHNS 1991-2011/ Jing Guo, Yin-Chao Zhu, Ya-Ping Chen, et al./ Journal of Hypertension, 2015; 33(8), 1688-1696. (Guo et al., 2015b)	2011	CHNS	18+	CHNS Longitudinal survey	8,658-12,474
12	China CVDs report 2015: A summary/ Wei-Wei Chen, Run-Lin Gao, Li-Sheng Liu, et al./ Journal of Geriatric Cardiology, 14(1), 1-10. (Chen et al., 2017)	2011	CHNS	18+	Literature review	N/A
13	Report on Chinese Residents' Chronic Diseases and Nutrition/ (Disease Prevention and Control Bureau of the Ministry of Health of China, 2016)	2012	China people's health publishing house/2016	18+	Descriptive analysis	
14	Status of hypertension in China: Results from the CHS 2012-2015/ Zengwu Wang, Zuo Chen, Linfeng Zhang/ Circulation 2018; 137(22), 2344-2356. (Z. Wang et al., 2018)	2012-2015	China Hypertension Survey	18+	T test and logistic regression	451,755
15	Burden of hypertension in China: A nationally representative survey of 174,621 adults/ Yichong Li, Ling Yang, Limin Wang/ International Journal of Cardiology 2017; 227, 516-523. (Y. Li et al., 2017)	2013-2014	China chronic disease and risk factors surveillance (CCDRFS) survey 2013-2014	18+	With consideration of the complex design, the mode adjusted means and prevalence were estimated and tested in design-based lineal regression and logistic regression	174,621

Hypertension PATC of adults aged 18 or above or 20 or above from 1991 to 2013 were analyzed. This therefore excluded articles 1, 4, 6, 8 in which the age range did not fit the study population.

The most consistent survey in China is the CHNS, which is a large-scale, national and successive cross-sectional survey. It was designed to identify how the health and nutritional status of the Chinese population has been affected by social and economic factors (B. Zhang, Zhai, Du, & Al, 2014). According to the guidelines of the NBPHS, adults aged 35 years or above are the main target population for hypertension screening and management. The CHNS dataset not only provides long-term data for further analysis, but also meets the requirement of extracting data related to hypertensives aged 35 years and above at the population level. Another two sources provided national level data that included this age range. These were the study conducted in 2016 (W. Li et al., 2016) and the China Hypertension Survey (2012-2015) (Z. Wang et al., 2018).

Therefore, this study applied both the published data of the CHNS 1991 to 2011 for further analysis and data selected from the full literature review. Data were weighted based on the 2010 Chinese Census.[3]

The full survey data from the CHNS 1991 to 2015 was used for this study. Based on the following criteria, records were excluded: age below 18 years or missing data for age, gender, SBP or DBP.

Finally, 75,526 records of 24,410 individuals were retained. From the 2015 CHNS database, there was a total of 11,525 cases aged 35+ years. Table 3.2 lists hypertension awareness, treatment, and control from 1991 to 2015, which are retrieved from 7 studies as shown in the last column. In each year, the survey was described in terms of survey year, sample size and age range. To analyze the relationship among awareness, treatment and control of hypertension, treatment/awareness and control/treatment (which were both proportions), are generated.

[3] Chinese Census data from 2000 and 2010 were accessed on 30 November 2018 from the National Bureau of Statistics of China. http://www.stats.gov.cn/tjsj/ndsj/.

Table 3.2 Relationships among awareness, treatment and control of hypertension

Survey year	Survey	Sample size	Age	Prevalence (%)	Awareness * (%)	Treatment * (%)	Control * (%)	Treat /Aware**	Control /Treat**	Reference or data source
1991	CHNS	8,436	18+	14.13	23.19	10.88	2.75	0.536	0.250	CHNS ***(1991-2011)
1993	CHNS	7,906	18+	15.23	18.46	9.45	2.71	0.543	0.257	
1997	CHNS	8,496	18+	17.51	13.87	8.13	1.70	0.738	0.177	
2000	CHNS	9,500	18+	17.42	21.28	12.58	3.09	0.697	0.243	
2004	CHNS	8,843	18+	19.90	23.47	16.18	4.72	0.772	0.277	
2006	CHNS	8,974	18+	18.58	28.39	19.00	5.10	0.742	0.237	
2009	CHNS	8,411	18+	21.92	26.46	20.53	6.12	0.874	0.268	
2011	CHNS	12,490	18+	19.85	36.11	26.52	9.31	0.734	0.351	
2002	CNNHS	141,892	18+	18	25	20	5	0.800	0.250	(Y. Wu et al, 2008)
2003-2012	SR	N/A	20+	26.7	44.6	35.2	11.2	0.789	0.318	(D. Li et al., 2015)
2009-2010	China National Survey of Chronic Kidney Disease	50,171	18+	29.6	42.6	34.1	9.3	0.800	0.273	(Jinwei Wang et al., 2014)
2010	China non-communicable disease surveillance	98,658	18+	33.7	33.3	23.9	3.9	0.718	0.163	(Xu Y, 2013)
2013-2014	China Chronic Disease and Risk Factors Surveillance	173,621	18+	27.8	31.9	26.4	9.15	0.828	0.347	(Y. Li et al., 2017)
2012-2015	China Hypertension Survey	451,755	18+	23.2	46.9	40.7	15.3	0.868	0.376	(Z. Wang et al., 2018)
2015	CHNS****	13980	18+	45.37	19.65	16.12	6.71	43.31	41.63	CHNS database, retrieved on May 26, 2019

Notes: * Awareness, treatment and control are presented as percentages of the hypertensive prevalent population.
** Treatment/awareness and control/treatment were both proportions.
***CHNS data were all age standardized on the 2000 or 2010 Chinese Census.
****The HTN prevalence in the age group 18-35 years was extremely high in the CNHS, which seems an exception in the sample population.
As the data set is newly released, it needs further confirmation. In the following section, only the sample aged 35+ years is employed, which is consistent with other studies.

As shown in Table 3.2 above, there was an increasing trend in the PATC of hypertension. From 1991 to 2015, hypertension prevalence increased from 14.13% to over 25%; awareness increased from 23.19% to 46.90%; treatment increased from

10.88% to 40.7%; and control, although kept at a low level, increased from 2.75% to 15.3%.

Further analysis was made to determine the relationships among awareness, treatment and control. This demonstrated that: (1) treatment/awareness ratios were higher than control/treated ratios. From 1991 to 2015, the highest control/treatment rate was no more than 0.4, while the lowest treatment/awareness ratio was more than 0.50; (2) after 1997, the treatment/awareness rate was higher than 0.70, which means that if a patient became aware they would be more likely to seek medical advice; and (3) control/treatment kept increasing, which reflects improved adherence on the part of patients, and in part also the role of other factors and players beyond the control of the health system.

From Table 3.2, it should be noted that the data of CHNS 2015 was not reliable. Firstly, in both the CHNS 2009 and CHNS 2011, the adults' hypertension prevalence was about 20%, while the CHNS 2015 showed 45.37%. Also, the awareness and treatment rate of hypertension in the 2015 survey result were both much lower than in the 2009 or 2011 survey results. Secondly, in the meantime in another survey, the CHS 2012-2015, of which the sample size was much larger than the CHNS 2015, the prevalence, awareness, treatment and control results were more consistent with the CHNS surveys during 1991-2011. Therefore, in the following section, data from the CHS 2012-2015 survey was used for the observed status of hypertension in China.

3.3 Age-specific analysis of PATC

Age is an important influencing factor for CVD (Y. Wu et al., 2006). This section analyzes the hypertension PATC trends among different age groups in the past 20 years.

The status of hypertension awareness, treatment and control is shown in Appendix Table A1. From 1991 to 2015, among the hypertensive patients aged 35+ years, awareness increased from 27.10% to 44.91%. Treatment increased from 14.44% to 38.42% and control from 2.87% to 14.72%. In 2015, 85.5% of patients who were aware of their hypertensive condition received anti-hypertensive treatment, with an increase of 32.2% from 1991 to 2015. Among patients who received treatment, the control rate increased from 19.9% in 1991 to 38.3% in 2015. Details are given in Table 3.3.

Table 3.3 Time series dataset for trend analysis of hypertension PATC of adults aged 35+ year in China, 1991-2015

	Prevalence (%)	Awareness[a] (%)	Treatment[a] (%)	Control[a] (%)	Treatment/ awareness (proportion)	Treatment/ control (proportion)
1991	22.18	27.10	14.44	2.87	0.533	0.199
1993	22.59	26.29	14.00	2.73	0.533	0.195
1997	26.10	18.78	12.12	2.95	0.645	0.243
2000	26.33	30.82	19.81	4.55	0.643	0.230
2004	27.46	33.33	23.95	6.95	0.719	0.290
2006	25.96	37.42	27.91	7.41	0.746	0.265
2007[b]	41.90	41.60	34.40	8.20	0.827	0.238
2009	30.47	37.85	29.54	8.61	0.780	0.291
2011	28.19	50.93	40.05	14.31	0.786	0.357
2015[c]	32.62	44.91	38.42	14.72	0.855	0.383

Notes: a. Awareness, treatment and control are listed as percentages of the hypertensive prevalent population.
b. 2007 data from hypertension prevalence, awareness, treatment, and control rates in 115 rural and urban communities involving 47,000 people from China (W. Li et al., 2016).
c. Data from the CHS 2012-2015 (Z. Wang et al., 2018).

Figures 3.2.1 to 3.2.4 describe hypertension prevalence, awareness, treatment and control trend from 1991 to 2013 for different age groups. The prevalence, awareness,

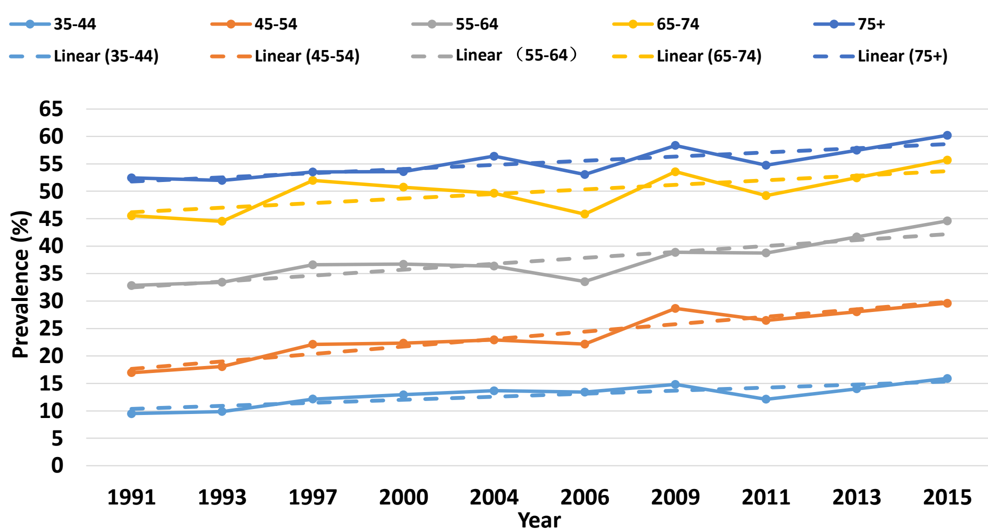

Figure 3.2.1 Hypertension prevalence among different age groups, 1991-2015

treatment and control of hypertension all showed an increasing trend from 1991 to 2015 in all age groups. It is observed that hypertension awareness, treatment and control are better in the older participants than their young counterparts. The highest prevalence was in the 75+ age group, and the highest awareness, treatment and control were all in the 65-74 age group.

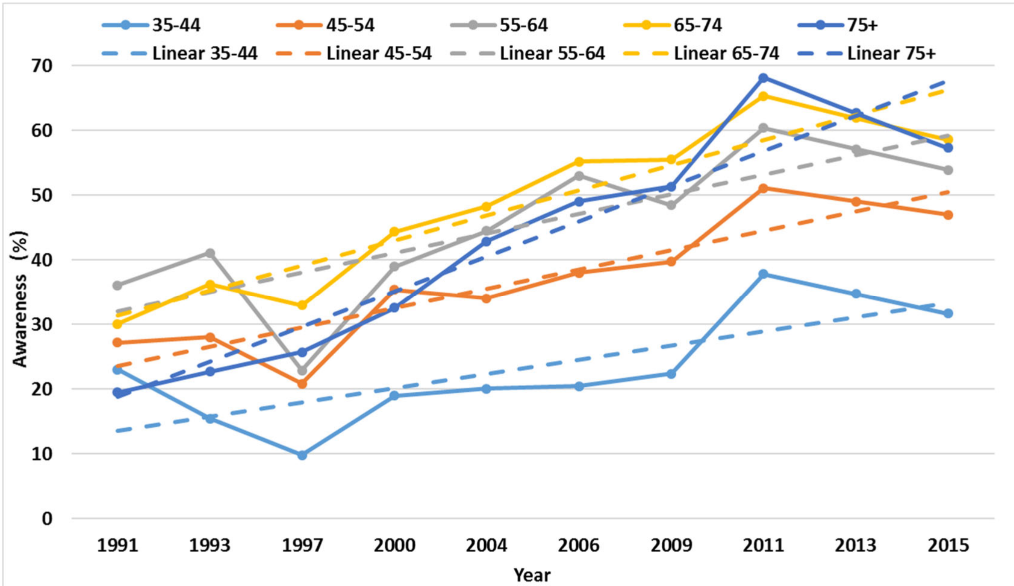

Figure 3.2.2 Awareness of hypertensives among different age groups, 1991-2015

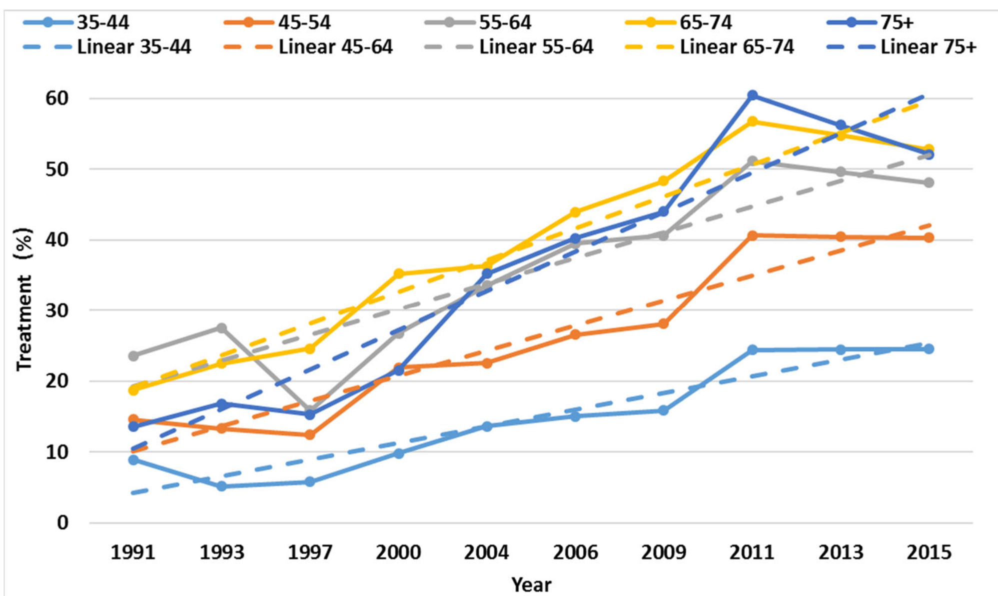

Figure 3.2.3 Treatment of hypertensives among different age groups, 1991-2015

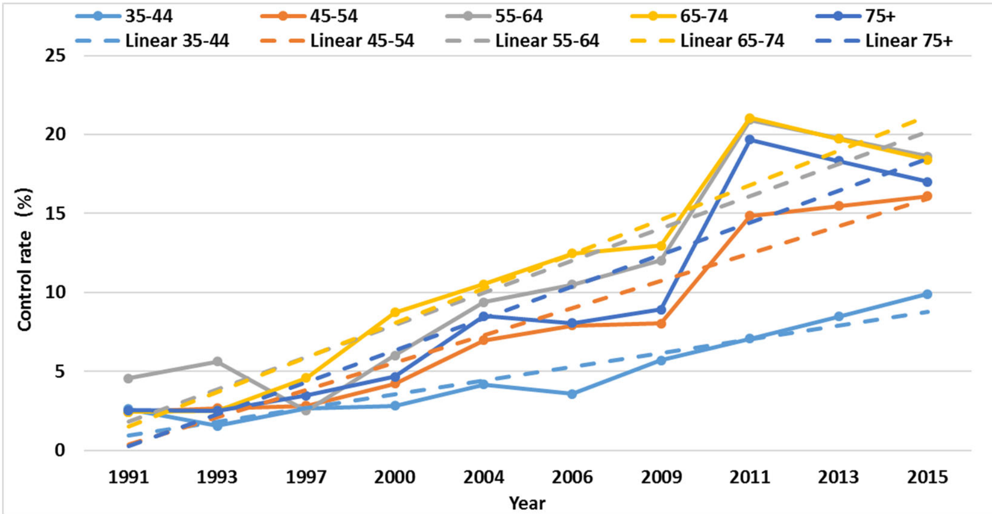

Figure 3.2.4 Control rate of hypertensives among different age groups, 1991-2015

As illustrated in the figures above: (1) there was a general increasing trend of hypertension PATC from 1991 to 2009 for all age groups; (2) hypertension prevalence increased with age, with the prevalence of hypertension among people aged less than 35 years below 10%, while for adults aged 35 years and above it was higher than 10% and increased sharply, peaking at the oldest age group; and (3) although prevalence peaked in the oldest group, awareness, treatment and control did not necessarily peak in the same way. For most time points analyzed, the highest awareness and treatment rates were seen in the 65-74 age group, and the highest control rates were seen in the 55-64 age group. An obvious decrease from the 65-74 age group to 75+ age group was observed. As shown in Figure 3.3, although the hypertension rate grew with age while the awareness, treatment, and the control rate decreased with age, the treatment control rate was higher in the younger group than in the elder group. These rates were 40.4%, 40.0%, 38.7%, 34.8% and 32.6%, for age groups 35-44, 45-54, 55-64, 65-74 and 75+, respectively.

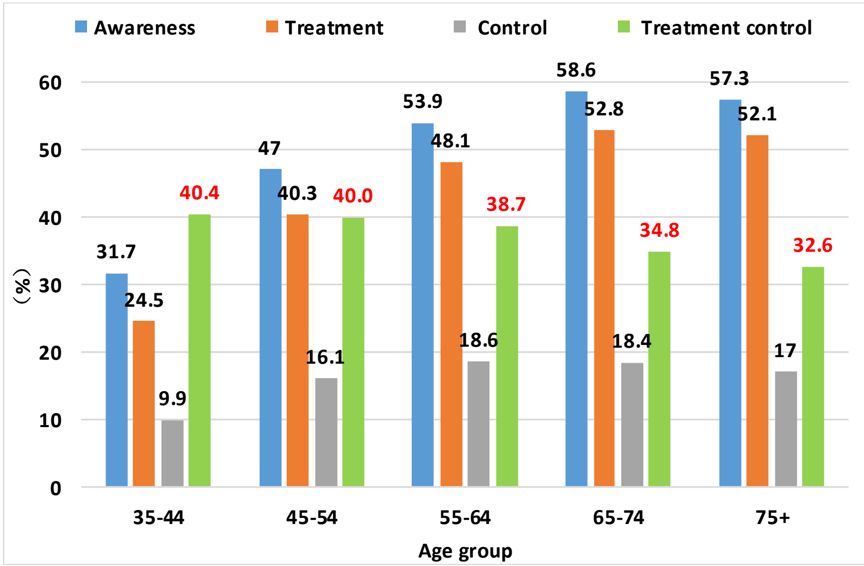

Figure 3.3 Hypertension awareness, treatment, control and treatment control of hypertensives aged 35+ years, 2012-2015.

Source: Z. Wang et al. (2018).

As shown in Table 3.3, from 1991 to 2015, the treatment/awareness ratio kept increasing. In 2015, this ratio was 0.855, which is much higher than the treatment/control ratio. This indicates that if the patient became aware of their hypertension, they would be more likely to seek medical advice, which is the most important step for getting hypertension under control (Bundy & He, 2016; D. Gu et al., 2015). According to the NBPHS guidelines, the first step in hypertension management is to measure BP during the patient's first visit to a primary healthcare physician. As shown in Table 3.3, the treatment/control ratio was much lower than the awareness/treatment ratio over the 1991 to 2015 period. Therefore, while it is difficult to quantify precisely, it can be inferred that a significant improvement had been reached in terms of awareness through the NBPHS program.

Treatment/awareness is used to reflect the willingness of hypertensives to receive treatment, while treatment/control reflects the effectiveness of treatment among hypertensives (Z. Wang et al., 2018). Treatment/awareness after 2009 did not change much compared with that before 2009, which was around 80%. Again, this means that if a person became aware of their hypertension, they would be likely to seek medical advice. The treatment/control rate after 2009was higher than that before 2009. Some of this improvement could be attributable to the NBPHS program since healthcare became more accessible and more available for hypertensive patients.

As the objective of hypertension management is to achieve properly controlled blood pressure and as the above analysis shows that the impact of awareness and treatment of hypertension can be transformed into hypertension control, the following section conducts further analysis on hypertension control.

3.4 Time series analysis of hypertension control

3.4.1 Data used

Trend analysis was performed using CHNS data from 1991 to 2009 (Guo et al., 2015a; Xi et al., 2012b). As the data were not continuous or in a time series form with the same intervals, data from other studies were inserted to generate a time series dataset. Hypertension PATC data for adults aged 35+ from 1991 to 2015 are shown in Table 3.3 and Figures 3.2.1-3.2.4.

The PATC rates before 2010 were age-standardized according to the 2010 Chinese Census data. An age-group analysis was performed, and is presented in the supplementary material (Appendix D).

3.4.2 Statistical analysis

Descriptive analysis on hypertension PATC was conducted to compare trends from scenarios of time and age.

Although the data extracted from the CHNS 1991 to 2011 and from the full literature review is comprehensive, data from 1991 to 2009 in one-year intervals is still not enough for time series analysis. Only 10 years of data were available for the estimation period, which represented a small sample. Therefore, a small sample time series analyzing method was employed based on two Chinese studies (Duan, 2015; Ren et al., 2005), in which R Language, Lagrange interpolation polynomial was employed to generate values for 1995 based on the data from 1991, 1993, 1997 and 2000, and values for 2002 were generated based on data from 1997, 2000, 2004 and 2006.[4]

[4] Ms. Wanwen Zhang from Nanjing University wrote the program for this thesis in R language for completing missing values through a Lagrange interpolation polynomial method.

Data of control rates for each year from 1991 to 2009 were completed using a Lagrange interpolation polynomial method (the R language program is listed in Appendix B).

Trend analysis was employed on the time series data from 1991 to 2009. With the trend formula generated, a predicted estimate for the year 2015 was generated. Regarding observational control rates of hypertension, estimates from the CHS 2012-2015 were used. By comparing the observed value with the predicted value of the number of patients under hypertension control, the difference was considered to represent the incremental effectiveness of the NBPHS program.

3.4.3 Results

3.4.3.1 Elementary trend analysis of PATC

In a study by Huiwen Li, Liu and Xi (2014), it was highlighted that in 2000-2001 (n=15,540), the control rate of hypertensive patients in China was 8.1%, while a similar study in 2005-2009 (n=18,915) showed that it was 8.2%. This means that the hypertension control rate was at a low level from 2000 to 2009, according to different studies. Figure 3.4 shows the trend of awareness, treatment and control of adults aged 35+ years from 1991 to 2013. An obvious jump can be seen from 2009 to 2011 in hypertension control rate, which provides a basis for further analysis of the role of the NBPHS.

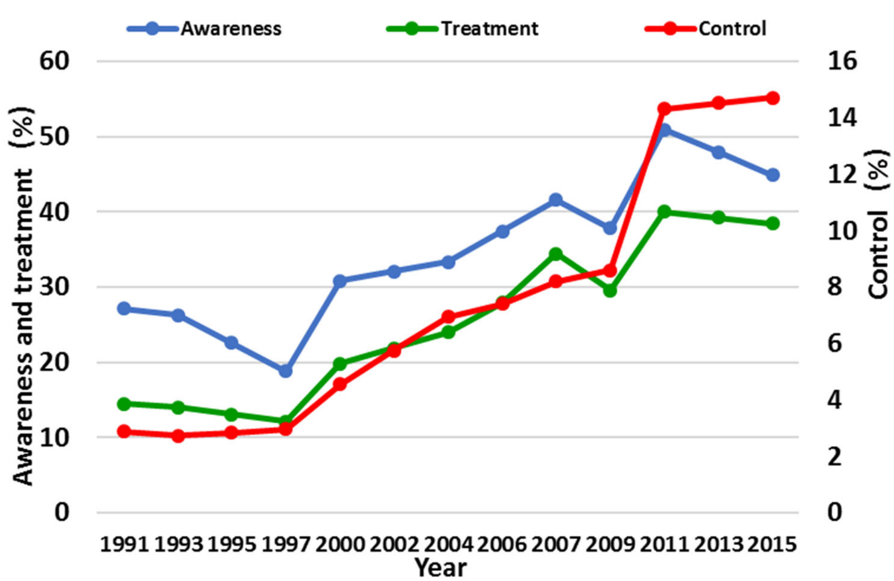

Figure 3.4 Trends of awareness, treatment and control among adults aged 35+, 1991-2015

3.4.3.2 Trend analysis of hypertension control and predictions of 2015

Using a Lagrange interpolation polynomial method, data of hypertension control from 1991 to 2009 were completed, as shown in Table 3.4.

Table 3.4 Completed data of hypertension control rates, 1991-2009

Year	Control rate (%)
1991	2.94
1992	2.92
1993	2.85
1994	2.78
1995	2.74
1996	2.78
1997	2.94
1998	3.37
1999	3.95
2000	4.60
2001	5.26
2002	5.90
2003	6.48
2004	6.95
2005	7.10
2006	7.41
2007	8.20
2008	8.26
2009	8.61

Given that the trend analysis is based on fewer than 20 data points, a small sample time series analysis was performed, where pre-treatment was performed on small sample data using the Lagrange Interpolation Polynomial method. With SPSS 22.0, time series predicting analysis was performed using an expert-modeler method in which the difference was used to realize time series stationarity to predict the control rate of 2015. According to the expert modeler, a Brown exponential smoothing model was selected for linear trend prediction, as shown in Table 3.5 and Figure 3.5.

The residual auto-correlation function (ACF) showed a random distribution with no outliers, which indicates good model fitness (see Appendix B in Supplementary material).

Table 3.5 Model statistics for the time series prediction of hypertension control rate

Model	Number of predictors	Model fit statistics		Ljung-Box Q (18)			Number of outliers
		Stationary R-squared	R-squared	Statistics	DF	Sig.	
Control-model_1	0	0.162	0.990	3.852	17	1.000	0

Table 3.6 is the forecasted control rate of hypertension from 2010 to 2015 based on the model established from 1991 to 2009. Both upper control limit and lower control limit are listed. It is predicted that in 2015, the control rate of hypertension would be 10.46% (95%CI: 7.33%, 13.59%) based on the trend from 1991 to 2009.

Table 3.6 Forecasted control rate of hypertension from the prediction model, 2010-2015

Model	2010	2011	2012	2013	2014	2015
Forecast	8.92	9.22	9.53	9.84	10.15	10.46
UCL*	9.40	10.13	10.93	11.80	12.73	13.71
LCL**	8.43	8.32	8.13	7.88	7.57	7.20

Notes: *UCL = Upper control limit.
**LCL = Lower control limit.

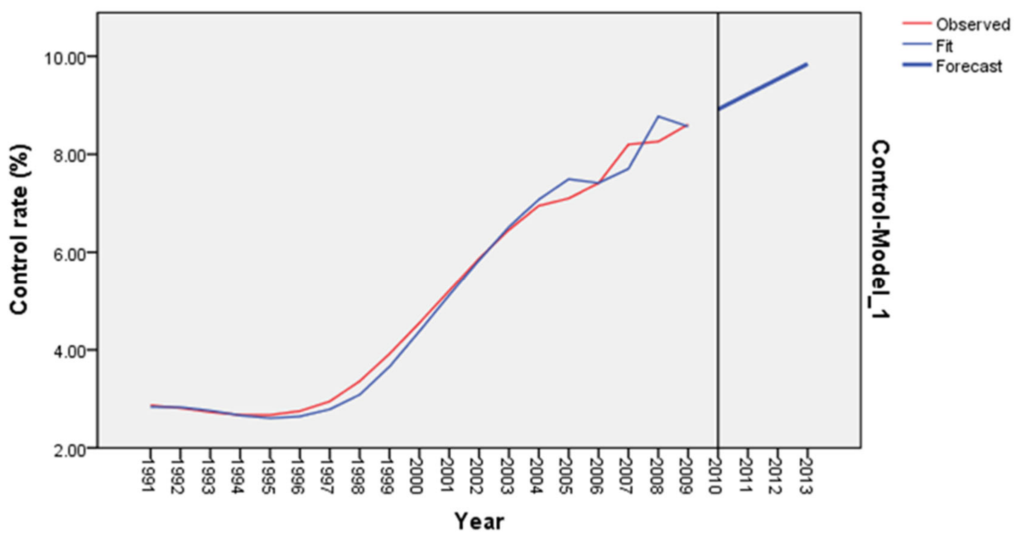

Figure 3.5 Time series trend of hypertension control rate, 1991-2009 and predicted analysis from 2010 to 2015

3.4.3.3 Estimation of the role of the NBPHS on hypertension control

This study aimed to use the difference between the predicted control rate and the observed control rate of hypertension to reflect the effectiveness of the NBPHS from

2009 to 2015. The number of adults aged 35+ years was 685,998,627, which was estimated based on the age-gender structure of the 2010 Chinese census data.

According to the CHS 2012-2015, the prevalence of hypertension among adults aged 35 or above was 32.62% in 2015 (Z. Wang et al., 2018), while the number of hypertensives aged 35+ in 2015 was 223,772,752. The predicted control rate of 2015 was 10.46% (95%CI:7.20%, 13.71%) and the observed control rate was 14.72%. The change of percentage points used as incremental effectiveness was 4.26 (95%CI:1.13, 7.39). Therefore, it was estimated that from 2009 to 2015, the NBPHS program increased the number of hypertensive patients under control by 9,532,719 (95%CI:2,528,632, 16,536,806).

Age-specific analysis was performed. The predicted control rates and the observed control rate of 2015 for each age group are listed in Appendix Table D3. With the same population data and method, it was estimated that from 2009 to 2015, the NBPHS program increased the number hypertensives under control by 8,009,449 (1,581,856, 13,065,018), which would be 0, 1,635,397, 1,564,164, 170,388 and 617,939 for males in age groups 35-44, 45-54, 55-64, 65-74 and 74+ respectively, and 0, 1,568,221, 1,523,002, 169,167 and 761,170 for females in each age group, respectively. Although the number of hypertensives under control estimated through age-specific analysis are significantly different from the all-age group analysis, the benefit-cost ratios generated from the two analyses are not significantly different from each other.

In addition, as the raw database of CHS 2012-2015 was not available, the hypertension prevalence and control rate of different genders were not available. Therefore, the prevalence and control rate of the two genders were considered to be the same; and, 75-84 and 85+ age group data were not accessible, so the two age groups were incorporated into people aged 75+, which made the results even less precise. Therefore, an all-age-group analysis was used in the thesis. (Details of the age-specific analysis are shown in Appendix D.)

To verify the estimate from trend analysis and CHS 2012-2015, further evidence was searched in the literature and a range of values of the effectiveness of hypertension control from the NBPHS were obtained from other researchers. Details are in Section 3.5.

3.4.3.4 Sensitivity analysis

To carry out a sensitivity analysis on the trend projection model, the author has done two things: firstly, calculate 95% CI around this model, see Table 3.6 (UCL and LCL); and secondly, compared this with another approach, where with data from 1991-2009, a linear regression model for trend analysis model was estimated (Fig. 3.6). It was found that the linear regression approach was slightly higher. Therefore, from the above analysis, it can be estimated that the predicted control rate of 2015 would be 10.66%.

The predicted hypertension control rate from the linear regression analysis (10.66%) was 0.2 percentage point higher than the coefficient regression model used in the thesis, which was 10.46% (95%CI:7.20%-13.71%). The change was minor and the result from the linear regression model lies in the 95% CI of the results from the coefficient regression model. Following that, under the linear regression analysis it was estimated that from 2009 to 2015, the NBPHS program increased the number of hypertensive patients under control by 9,085,173, compared with 9,532,719 generated from the coefficient regression model. The result still lies in the 95% CI (2,528,632, 16,536,806) of the analysis of the thesis.

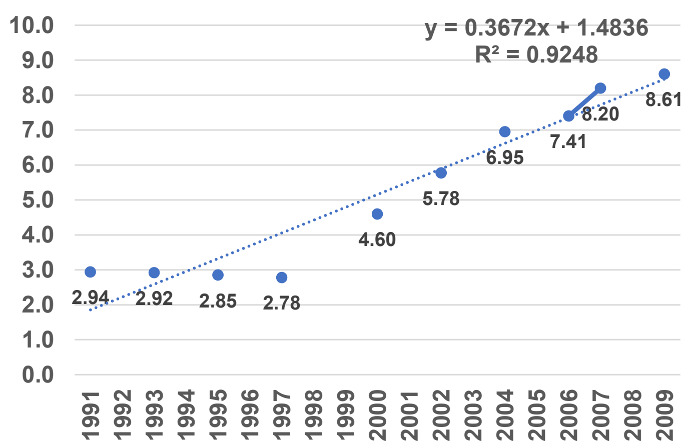

Figure 3.6 Original linear trend analysis on hypertension control rate 1991-2009 (%)

Linear trend model: $y = 0.3672x + 1.4836$, $R^2 = 0.9248$

3.5 Evidence from other sources on the role of the NBPHS

3.5.1 Statistical analysis of hypertension management

To quantify the effectiveness of hypertension control, it is essential to know how many hypertensive patients had participated in the NBPHS program. According to the statistical data of The Office of Health Reform of the State Council (OHRSC), the number of patients managed by CHOs from 2010 to 2013 increased from 14.8 million to 85.03 million, as shown in Figure 3.7. By the end of 2017, the number of hypertensive patients managed by the NBPHS program had reached 101,038,100, and the annual investment in the NBPHS had reached 55 CNY per capita. By 2018, a total financial commitment of 452.8 billion CNY had been invested into the NBPHS program, of which approximately 248.3 billion CNY came from the central government.

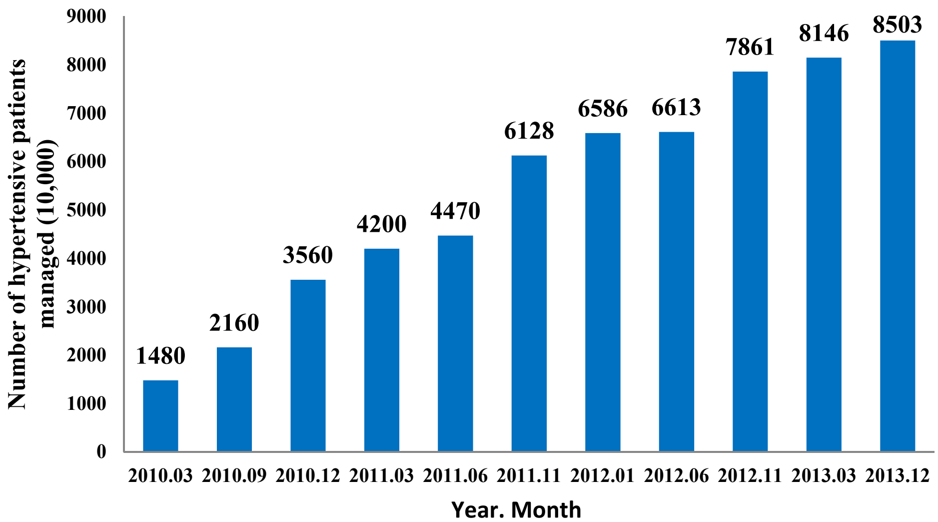

Figure 3.7 Number of hypertensive patients managed under the NBPHS, 2009-2013

Note: The lateral axis is of time, which expresses the year and month in each year, so, 2010.03 is March 2010.
Source: The Office of Health Reform of the State Council of China. Health reform monitoring report 2015, Retrieved April. 15, 2016 (The Office of Health Reform of the State Council of China, 2016).

Another estimate was made based on studies evaluating hypertension management at the community level after 1991 and these studies also evaluated the NBPHS. Government statistical data were used to determine the number of hypertensives managed by community health service facilities in China. If this number is multiplied by the control rate of hypertensives under community health service settings, the number of patients controlled can be generated. Based on this, further comparison can be made with estimates from the trend analysis.

As discussed earlier, the prevalence of hypertensives and awareness among hypertensive adults aged 35 or over equaled 32.62% and 44.91% respectively in 2015 (Z. Wang et al., 2018). It was estimated that the number of hypertensives aged 35+ in 2015 was 223,772,752, while 100,496,343 hypertensives became aware of hypertension. By the end of 2015, it was reported that about 88.35 million hypertensives were covered by the NBPHS program in China, which means that about 88% of hypertensives with awareness were under a certain level of management within the NBPHS program. Therefore, hypertensives with a level of awareness who were identified in the China Hypertension Survey (Z. Wang et al., 2018) can be used to represent the hypertensives under management within the NBPHS program in China.

3.5.2 Evidence from other literature on hypertension control within the NBPHS

Many attempts have been made to evaluate the effectiveness of hypertension management programs, in terms of lowering BP and improving hypertension control. To validate the results from trend analysis in this study, a literature review was conducted to analyze the quantitative effectiveness of hypertension management in terms of the number of patients under control.

In comparison to the method of trend analysis that employed hypertension PATC at the general population level, further evidence was based on a community health service setting or a specific evaluation of the NBPHS under the new health reform that began in 2009. Table 3.7 lists four studies with different survey datasets which attempted to analyze the impact of the NBPHS on hypertension management.

Linking data from the literature review with the analysis in Section 3.5.1, which reported that about 88.35 million hypertensives were covered by the NBPHS program in China, four estimates of the effectiveness of hypertension control from the NBPHS, which ranged from 6,979,650 to 16,212,225, were found as shown in the last row of Table 3.7.

Table 3.7 Control of hypertension under community health management in China

	Hypertension control in community health centres across China	**Impact of the national essential public health services policy on hypertension control in China**	**Hypertension PACT following China's healthcare reform**	**Essential public health services' accessibility and its determinants among adults with chronic diseases in China**
Year	2007-2010	2011, 2013	2008, 2012	2013
Setting	CHS			CHS
Sample size	249,830	4,958	1,961 and 1,836	1,367
Age range (y)	18-79	⩾45	⩾45	25-95
Design	Purposive sampling	China health and retirement longitudinal study (CHARLS)	CHARLS	Multi-stage stratified random sampling
Control (%)	27.0 (SE=0.7%)	Control rate improved by 7.9% (SE=2.9%)	21.7%-36.4%	33.65* (SE=1.28%)
Improvements by NBPHS **	Improved by 11.7 percentage points	Control rate improved by 7.9%	Improved by 15.3 percentage points	Improved by 18.35 percentage points
Estimated number of hypertension controlled as effectiveness of the NBPHS***	10,336,950	6,979,650	13,517,550	16,212,225

Notes: *The control rate of chronic disease denoted both hypertensive and diabetic patients, which did not display the two diseases separately.
**The CHS 2012-2015 led by Zengwu Wang et al. demonstrated that hypertension control of hypertensives aged 18+ was 15.3%, (Z. Wang et al., 2018). According to this benchmark, it was estimated that the effectiveness of the NBPHS was the difference between the control of hypertension of hypertensives managed in CHS settings minus that of the general population (15.3%).
***The Estimated number of hypertension controlled as effectiveness of the NBPHS was the Improvements by NBPHS (shown in previous row) multiplied by 88.35 million, which was the number of hypertensives covered by the NBPHS program in China.

3.5.2.1 An estimate using data before the implementation of the NBPHS

Two studies evaluated the community interventions that preceded the establishment of the NBPHS in 2009. The first was a 2008 follow-up evaluation of a guideline-oriented hypertension management program in Beijing. It focused on patients aged 50+ at high risk of stroke in primary healthcare settings and demonstrated that the rates of awareness, treatment and control of hypertension were 70.0%, 62.1% and 29.6%, respectively (Jiang et al., 2014). The study concluded that improvement of awareness and treatment in CHS settings would contribute to hypertension control.

A more representative study in China involving 1,000 community health service centres in urban areas across China, which included a total of 249,830 identified hypertensive patients, evaluated the association between drug use and BP control in community-based routine practice (see Table 3.7). It was reported that 37% of the patients covered by the CHCs were treated. Among the treated patients, 36.5% received monotherapy and 63.5% received combination therapy, of which hypertension control rates were 27.7% and 24.1%, respectively (Z. Wang et al., 2014). The general hypertension control rate could reach 27.0% under management of a community health service (Z. Wang et al., 2014). According to the studies by the same author group (Z. Wang et al., 2018) from 2012-2015, the hypertension control rate of the general hypertensive population aged 35+ was 14.72%. The difference between community management hypertensives and the hypertensives at the population level could be estimated as 12.28%. Taking the number of hypertensives covered by the NBPHS by the end of 2013 as the target population, or 85.03 million, the incremental number of hypertensives under control would be 10.44 million (85.03 million*12.28%).

3.5.2.2 An estimate with a before- and after-comparison

For evaluations of the NBPHS hypertension management at the national level in China, only two articles (in English) met the criteria set out in this investigator's search. Both articles used data from the China health and retirement longitudinal study (CHARLS) using before-after analysis, focusing on Zhejiang and Gansu Provinces. Donglan Zhang et al.'s (2018) study found that the coverage of the NBPHS program was associated with an increase of 7.9% in the hypertension control rate (SE = 2.9%) from 2011 to 2013 in Zhejiang and Gansu Provinces (D. Zhang et al., 2018). In Zhiyuan Hou et al.'s (2016) analysis, the proportion of patients with hypertension under effective control in Gansu and Zhejiang Provinces increased from 21.7% to 36.4% from 2008 to 2012, showing a difference of 14.7 percentage points at the national level (Hou et al., 2016). These two studies defined how to evaluate hypertension management under the NBPHS program according to the specifications and guidelines, which focused on hypertension awareness, treatment and control. They also provided more quantitative evaluation evidence on hypertension PATC, using improved methodologies compared with those used in local area studies. However, the target population of CHARLS, which consists of adults aged 45 years and above, is not consistent with that of the NBPHS. Therefore, CHARLS could not be used to fully evaluate the program. Although the above two studies provided evaluation evidence, neither reflected the NBPHS program comprehensively. In the first study (D. Zhang et al., 2018), the authors defined the patients who received a physical examination paid by the government as hypertension management, while the second study (Hou et al., 2016b) considered hypertension awareness, treatment and control as the contents of hypertension management.

The two analyzes at the national level provided an estimate of hypertension control reflected by a change in percentage points, from 7.9% to 14.7% in the interval of 2011-2013 and 2008-2012. With the targeted hypertensives of 85.03 million, the incremental effectiveness of the NBPHS in terms of the number of people under hypertension control was estimated to be between 6.72 million and 12.50 million.

3.5.2.3 An estimation using a specific evaluation result of the NBPHS

In 2015, Tian et al. further developed the evaluation of the NBPHS program on hypertension and diabetes management. They conducted a cross-sectional study of a national representative hypertensive and diabetic population managed by primary care facilities under the NBPHS, focusing on the accessibility and effectiveness of the NBPHS (M. Tian et al., 2015). This study revealed that patients with hypertension or diabetes were predominantly middle-aged or elderly, with a mean age of 65.26 years. Tian et al. (2015) defined hypertension management under the NBPHS program and effective management as regular follow-ups or check-ups. They concluded that the program provided effective disease management. Of all the participants, 33.65% had their BP or glucose controlled within the normal range for at least three months. Compared with other studies, Tian et al.'s (2015) was not conducted using a case-control or longitudinal design. However, it provided comprehensive information on the status of hypertension control. It also provided a comprehensive and specific evaluation of the NBPHS on hypertension and diabetes from the perspective of managed patients.

If the hypertension control rate was 33.65% and the control rate among general hypertensives was 14.72%, the difference would be 18.93%. With the targeted number of managed hypertensives at 85.03 million, the incremental effectiveness of the NBPHS in terms of hypertension control was estimated to be 16.10 million persons.

Other evaluations were mainly targeted at developed areas in China, which denoted a high control rate in community health service settings. This may not represent the national status. For example, a guideline-oriented primary healthcare hypertension management program in Beijing proved that the hypertension control rate increased from 40.0% to 70.7% in urban areas and increased from 27.9% to 72.9% in rural areas after a 12-month follow-up (X. Wang et al., 2012). This study involved four typical community health centres in Beijing, with 140 patients with hypertension recruited in each centre. Studies in developed regions demonstrated that patients covered by the NBPHS program range from 36.1% (in Xuhui, Shanghai) (J. Gu et al., 2014) to 83.2% (in Shanghai and Shenzhen) (Haitao Li et al., 2015). A study conducted in the Yulin Community Health Service Institution of Chengdu proved that after three years of hypertension management (33±25 months), the hypertension control rate increased from 32% to 85%.

The studies discussed in this section provided a range of estimates for the incremental effectiveness of hypertension control. These were based on evaluations of hypertension management in community health service settings and statistical data from the health administrative departments in China. Three estimates were generated from evaluations of hypertension management in community health service settings. By the end of 2015, the incremental number of hypertensive patients with BP under control had reached 10.44 million, 6.72 million to 12.50 million, and 16.10 million. Evidence from other sources showed that by the end of 2015, the influence of the NBPHS on hypertension control ranged from 6.72 million to 16.10 million people.

In Section 3.4, it was estimated that the number of hypertensive patients under control was 9,532,719 (95%CI:2,528,632, 16,536,806), which was consistent with other evidence.

3.6 Discussion

This chapter has provided an estimate of the incremental effectiveness of the NBPHS program in terms of hypertension control. Time series analysis showed that the number of hypertensive patients with BP under control increased by 9.53 million from 2009 to 2015, which was attributed to the implementation of the NBPHS. Evidence from other sources was searched to evaluate the incremental effectiveness of the NBPHS in terms of hypertension control. This was based on hypertension management under community health service settings and statistical data from the health administrative departments in China. According to literature analysis of other evidence, the estimated number of those with controlled hypertension ranged from 6.72 million to 16.10 million.

The estimate from the trend analysis lies within this range, which strengthened the confidence in the trend analysis.

In-depth analysis showed that awareness is the key influencing factor in hypertension control, encouraging patients to seek medical advice. The NBPHS has played a major role in improving hypertension awareness and, as a consequence, improving hypertension control.

It was discovered that awareness, treatment, and control rates increased with age. However, the treatment control rate was higher in the younger group than in the older group, at 40.4%, 40.0%, 38.7%, 34.8% and 32.6%, for age groups 35-44, 45-54, 55-64, 65-74 and 75+, respectively. This suggests that younger patients are not well managed under the current program. A small improvement in awareness, treatment and control of young patients may result in a big increase in hypertension control. More seriously, age-specific analysis shows that the NBPHS program did not play an effective role in hypertension control for the 35-44 age group (see Appendix D).

Although hypertension control has improved, it has been far from satisfactory (Bundy & He, 2016; D. Li et al., 2015). The treatment control rate, which ranged from 0.163 to 0.376, is much lower when compared with international levels (Bundy & He, 2016; D. Li et al., 2015). Although the Chinese guidelines on hypertension management[5] align with international hypertension guidelines (P. A. James et al., 2014), hypertensive patients managed under the program may not reduce their BP to a normal level. This may be partly attributable to the insufficient healthcare delivered by primary care facilities (Hesketh & Zhou, 2017; X. Li et al., 2017), based on the limited human resources of primary healthcare in China (Hou et al., 2016; D. Li et al., 2015). International comparisons highlight that there is still a big gap between China and developed countries in terms of hypertension awareness (Joffres et al., 2013).

Some studies revealed that China had marked deficiencies in the availability, cost, and prescription of anti-hypertensive drugs (Su et al., 2017). The low income levels and

[5] Ministry of Health, Treasury Department, State Administration of Traditional Chinese Medicine. Announcement on the NBPHS project in 2016. Accessed 17 May 2017 (in Chinese) from http://www.nhfpc.gov.cn/jws/s3577/201606/f29a4659c7f4455ca6f62f8d14eb4b02.shtml

high health insurance costs may compromise the effectiveness of the NBPHS program for hypertension control (Lu et al., 2017).

In addition, as China is a large country, accounting for one fifth of the world's population, the urban-rural gap and regional inequality are long-standing national problems (J. X. Wu & He, 2018). Evidence suggests that education, geographic regions, changes in health status, occupation and other factors were important factors of perceived equality and benefits from the healthcare system generally (Zhai et al., 2017). In terms of the development of primary care and hypertension management, the same problems exist (X. Tang, Yang，J., Li, & et al, 2013; Zhu, 2007). It was reported that only a small number of patients with hypertension in China were diagnosed, and far less patients among them achieved optimal control (X. Li et al., 2017). In this sense, the NBPHS still has a long way to go. More health system reform measures should be taken to improve the investment mechanism, human resource management, medication accessibility and availability, and balanced regional development.

This is not the only study to conduct trend analysis of hypertension PATC. On the contrary, many studies have conducted similar analyzes, such as those that employed the CHNS data (Guo et al., 2015a; Xi et al., 2012b). However, evidence on the trends before and after the new health reform, which was launched in 2009, has been scarce, so the analysis presented in this chapter is a first and fills some of the identified gaps.

China is a large country with obvious differences within the country and variations in terms of economic development, demographic status, climate, customs, and so forth. It may be argued that it is meaningless to generalize across the entire Chinese population. In response to this concern, it should be stated that the NBPHS program was implemented in 2009 all over China, with national specifications and guided standards related to government investment. In addition, the NBPHS program was a part of the EPHS (Equalization of Basic Public Health Service) in China, which reflects the concept of equalization in its very title. Finally, although this does not represent a tremendous investment per capita on public health, it is the largest basic public health service in the history of China. Therefore, it is necessary to evaluate the NBPHS at the national level, in terms of its contribution to hypertension awareness, treatment and control.

3.7 Limitations

The first limitation in this research is that the time series analysis data came from different sources and were not complete in an interval of one year. This may compromise the achievement of precise prediction. However, the employment of a full literature review and a Lagrange interpolation polynomial method improved confidence, where 95% confidence intervals have been provided for all estimates in this chapter and major results in Chapter 5. Secondly, as explained in the previous section, there is significant variation between regions in China, which makes it difficult to estimate the effectiveness of the NBPHS on hypertension control at the national level. This deficiency could only be solved through the collection of more consistent and complete data sources.

Although the CHNS database provided the most comprehensive and longitudinal information on hypertension PATC in China, it is not the largest representative study in China. Therefore, this study used data from the 2012-2015 Chinese Hypertension Survey (Z. Wang et al., 2018) for further analysis of the latest information on hypertension control in China. This may have caused data inconsistency. However, it was evident that data from the CHNS before 2009 were consistent with other studies. For example, the 1991 CHNS showed that the age-standardized hypertension PATC rates among adults aged 18+ were 14.13% (prevalence), 23.19% (awareness), 10.88% (treatment), and 2.75% (control), and those from the 1991 China Hypertension Survey of adults aged 15+ were 13.6%, 26.3%, 12.1%, and 2.8%, respectively. Another example was the similarity between the CHNS 2006 and 2009 and that of a national representative survey between 2005 and 2009, which analyzed hypertension PATC in 115 rural and urban communities involving 47,000 people from China (W. Li et al., 2016). After 2009, a significant difference can be seen between the CHNS and other national representative studies. The Chinese hypertension surveys conducted after 2009, indicated that the hypertension control rate reached 13.8% in 2012 and 16.8% roughly in 2015 (Z. Wang et al., 2018). The CHNS 2015 indicated that the control rate of hypertension among adults aged 35+ was 12.17%, while that of the CHNS 2011 was 14.31% and that of the 2015 Chinese Hypertension Survey was 14.72%. Therefore, this study employed the Chinese Hypertension Survey after 2009 as evidence for further analysis.

3.8 Conclusion

The NBPHS program has improved hypertension awareness, treatment and control. It was estimated that from 2009 to 2015, the NBPHS program increased the number of hypertensive patients under control by 9,532,719 (95%CI:2,528,632, 16,536,806). The NBPHS program also played a major role in improving hypertension awareness. This was most obvious among hypertensives aged 55 years or above. However, there is still a way to go in terms of improving hypertension awareness, treatment, and treatment control for primary care facilities, especially for younger hypertensives. Further policy measures should focus on early detection, treatment and control for young hypertensive patients. Functional community health service centres may play a major role in this focus. Hypertension treatment and control will also be improved by strengthening human resources, making health insurance more efficient, and medication more accessible.

Chapter 4 Health outcome estimation of the NBPHS: A Markov model

4.1 Introduction

Chapter 3 presented a discussion on the effectiveness of the NBPHS in terms of hypertension control and revealed the mechanism through which the NBPHS worked. This provided an estimate of 9,532,719 hypertensives having their BP properly controlled from 2009 to 2015 because of the NBPHS. This chapter analyzes the long-term health outcomes of hypertension control. A hypothesized scenario is set in which the NBPHS is not implemented and the 9,532,719 hypertensives do not get their BP properly controlled. This is known as the non-NBPHS scenario. The health consequences of hypertension in the two scenarios (NBPHS and non-NBPHS) are analyzed and compared. The difference represents the health outcomes of the NBPHS program.

As discussed in Chapter 2, CVDs are commonly referenced in the outcome assessment of hypertension intervention. However, if CVDs are considered the main consequence in assessments, it is important to consider other risk factors besides hypertension. This study used the CHNS 2009 data to extract information from a sample of hypertensives on other factors for the two scenarios (i.e. age, gender, BP, blood cholesterol, diabetes, BMI, and smoking). Based on a multi-factor analysis, risk levels in the development of CVDs were ascertained for the two scenarios. To compare the risk levels of the NBPHS scenario and the non-NBPHS scenario, published epidemiological and modelling studies of hypertension were drawn on (Chan et al., 2012; D. Gu et al., 2015; Moran et al., 2008) to generate the model parameters determining disease transitions. For the non-NBPHS scenario, the parameters of the NBPHS scenario were weighted by the relative rates generated.

A risk prediction and long-term health outcome model was developed by Gu et al. in 2015 based on a cost-effectiveness analysis of low-cost medicine for hypertension control (D. Gu et al., 2015). This model was applied and validated in a more recent economic evaluation of intensive hypertension control in China (Xie et al., 2018). Based on the above studies, a Markov model was developed to simulate the long-term development of hypertension and estimate related morbidities and mortalities. This is the focus of discussion in this chapter.

There are three further sections in this chapter: Section 4.2 provides a multi-factor analysis of CVD risk in the two scenarios based on the literature review and the CHNS 2009 data; Section 4.3 presents the Markov model and parameter estimations for the two groups; and Section 4.4 outlines the long-term estimations of CHD, stroke and deaths in a predicted 30-year period.

4.2 Analysis of CVD risks among hypertensives

4.2.1 Analysis of risk factors

As discussed in Chapter 2, age, gender, BP, BMI, total cholesterol, smoking and diabetes have been identified as independent variables for ICVDs, mainly focused on CHD and stroke (D. Gu et al., 2008; Y. Wu et al., 2006; X. Yang et al., 2016). However, the factors employed in different studies have not been the same. For example, Wu et al. (2006) used age, SBP, BMI, total cholesterol, smoking and diabetes to establish a Cox model for the evaluation of ICVDs. Yang et al. (2016) developed tools for the prediction of ASCVD in the Chinese population, using age, SBP, total cholesterol, HDL-C, waist circumference, smoking status, diabetes, urban-rural difference, and family history of ASCVD as risk factors. In 2007, the WHO/ISH developed a risk prediction chart for CVD applied to different WHO regions globally, with age, gender, SBP, total cholesterol, smoking status and diabetes mellitus as independent factors (WHO, 2010).

To simulate the relative rates of the two scenarios, a database with information on risk factors had to be employed. The only accessible qualified database was the CHNS 2009. The CHNS was a household-based study aiming to get information on key public health risk factors, demographic, social and economic factors, and health outcomes across ten rounds of surveys from 1989 to 2015. It employed a multi-stage, random cluster process for sampling (B. Zhang et al., 2014). Although the CHNS 2015 has been released recently, information about biomarkers, which is necessary for CVD risk analysis, was still not accessible.

In the CHNS conducted in 2009, a total of 9,552 participants were included in the analysis and 1,025 participants were hypertensives diagnosed by health professionals.

The measurements and definitions of hypertension, awareness, treatment and control were explicated elsewhere (Guo et al., 2015a). Of the hypertensives identified, data from 1,017 people aged 35 years and above were used for further analysis. The 1,017 hypertensives were categorized into either the hypertension-controlled group or the hypertension-uncontrolled group (uncontrolled hypertension was defined as SBP/DBP≥140/90 mmHg, otherwise controlled).

To conduct risk predictions of CVD, mean values of age, gender, SBP, DBP, BMI, and total cholesterol were extracted from the CHNS 2009 dataset of the 1,017 hypertensives. For each age-gender group, the smoking rate and prevalence of diabetes were calculated for the use of risk score equations. Diabetes was defined as a Hba1C value over 6.5 according to the WHO criteria (2011), receiving hypoglycemic treatment, or the answer "yes" to the question "Has a doctor ever told you that you are diabetic (U24a)". Smoking status was modified based on the response to question U27: "Do you still smoke cigarettes?"

First, descriptive analysis was conducted. G1 and G2 represented the hypertension-controlled group in the NBPHS scenario and the hypertension-uncontrolled group in the non-NBPHS scenario, respectively. They were compared in age-gender specific features for each risk factor. Mean values were compared for age, SPB, DBP, TC, HDL, and low-density lipoprotein cholesterol (LDL-C). A t-test was employed to identify whether differences were statistically significant ($P < 0.05$). Pearson's chi-square analysis was used to identify whether the difference between the two groups, considering the proportion of smoking and diabetes, was statistically significant ($P < 0.05$). Means and proportions of CVD risk factors were calculated for Chinese adults in 10-year age categories. Comparisons were conducted for the difference between the two groups of age-gender specific risk factor distributions. Statistical analyzes were conducted with SPSS 22.0. Figure 4.1 shows the decision tree of the process of the two scenarios established for comparison in this study. Starting from the first cell on the left, the upper two cells stand for the NBPHS scenario and the lower two cells stand for the non-NBPHS scenario.

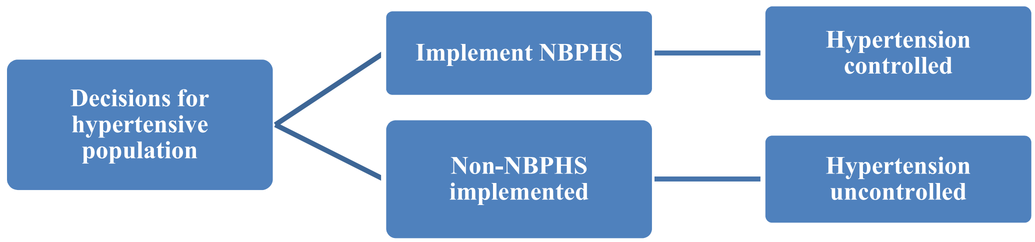

Figure 4.1 Decision tree for NBPHS and non-NBPHS implementation

4.2.2 Results of the risk factor analysis

Among the 1,017 analyzed participants aged 35+ years who were diagnosed as hypertensives, 44.05% were men and 55.05% women, and 68.53% were hypertension-uncontrolled and 31.47% hypertension-controlled. A significant difference was observed between the hypertension-controlled group and the uncontrolled group in SBP and DBP in all age-gender groups ($P < 0.05$). In the hypertension-controlled group, the mean SBP was around 127 mmHg for both males and females; while in the hypertension-uncontrolled group, the mean SBP ranged from 147 to 169 mmHg for both genders. There was no significant difference between the two groups for other factors, including mean age, TC, HDL-C, BMI, diabetes rate and smoking rate ($P >$ 0.05).

Based on the above analysis, out of the eight variables considered to be independent risk factors for CVDs, a difference was only found in BP, which provided a foundation for further analysis of risks among the two groups.

This author has written an article on the above analysis, published in 2018 in the journal *Chinese General Practice* (Y. Zhang, Liu, Pu, Qin, & Sweeny, 2018). Details can be seen in this article.

4.3 Method: A Markov model

The CDPM has been the best developed and most widely used model for CVD risk prediction among recent studies (D. Gu et al., 2015; Moran et al., 2010, 2008). Therefore, this study developed a Markov model for long-term projection based on the CDPM.

To assess the outcome of NBPHS implementation on hypertension management, the Markov model was used in the two scenarios over a predicted 30-year period. Results were reported for the whole hypertensive population simulated in a closed cohort under NBPHS management, as well as for different age and gender groups.

4.3.1 Markov model development

A Markov model is a state-transition model that is commonly used to evaluate the outcomes of anti-hypertensive treatments (Perman et al., 2011; Sesso et al., 2003). The CDPM was developed based on a Markov model. It was a state-transition, mathematical model for CHD and stroke prevalence, incidence, mortality, and costs in the adult Chinese population, with a cycle length of one year. Researchers have confirmed that the CDPM can be adapted to simulate a closed cohort (D. Gu et al., 2015; Moran et al., 2010).

In this study, the Markov model was used for the hypertensive population in China aged 35+ years following the CDPM (D. Gu et al., 2015; Xie et al., 2018). The structure of the Markov model is illustrated in Figure 4.2. In this thesis, CVD includes stroke and coronary heart disease, and therefore, one state is hidden in Figure 4.2.

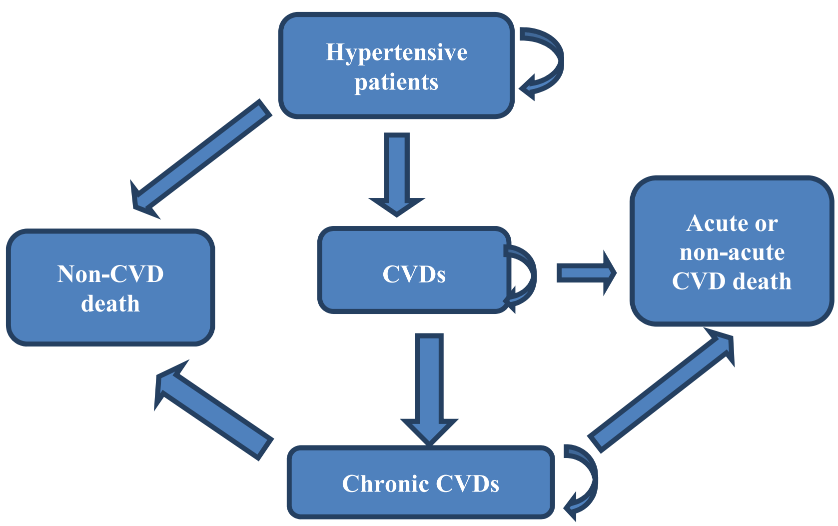

Figure 4.2 Markov model on the progression of CVD in hypertensive patients

The patients of either the hypertension-controlled or the uncontrolled group could shift to one of the six health states: hypertension only; acute heart disease; acute stroke; chronic CHD; chronic stroke; or death.

The initial stroke or CHD event and its sequelae for 28 days were described in the CDPM model (D. Gu et al., 2015; Xie et al., 2018).

The cycle of the Markov model was one-year. The 28-day case fatality was defined as instant death from acute CHD or stroke. One-year case fatalities of CHD and stroke were calculated based on CHD and stroke mortality, and prior-prevalence of CHD and stroke, aligned with Gu et al.'s study (2015).

The non-CVD mortality equaled the all-cause death rate of the population (The National Health and Family Planning Commission of China, 2014b) minus CHD mortality and stroke mortality.

Again, the definition of CHD and stroke under the CDPM aligned with Gu et al.'s (2015) study. It was assumed that there was no remission to a CVD-free state after a CVD incident. Other health states or diseases were not considered. CHD and stroke were analyzed separately, rather than in the form of CHD, stroke and their combination. A shift between any two health states was defined as a probable transition derived from Gu.et al.'s study (2015). Each state has an annual probability of shifting to a different CVD state. The hypertensive population was stratified by age in 10-year categories and gender.

In this study, the dynamic process of hypertension patients aged 35+ years follows that in the CDPM (D. Gu et al., 2015; Xie et al., 2018). Patients remained in the baseline state until a fatal or non-fatal CVD event or death from other non-CVD-related causes occurred. One year was used as the basic simulation cycle. From the stable CVD state, patients could get into a subsequent fatal or non-fatal CVD event or death from non-CVD causes. As shown in Figure 4.3 below, there are six health states: hypertension, CHD, CHD death, stroke, stroke death, and non-CVD death. The state of death is from three causes, which are CHD, stroke and non-CVD causes. Hypertension, CHD and stroke from the last cycle were all fed into the next cycle separately.

TreeAge Pro software 2019 R1.1 (TreeAge Software, Inc., Williamstown, MA, USA) was employed for the calculation of the Markov model. An example of the structure of the model is given in Figure 4.3.

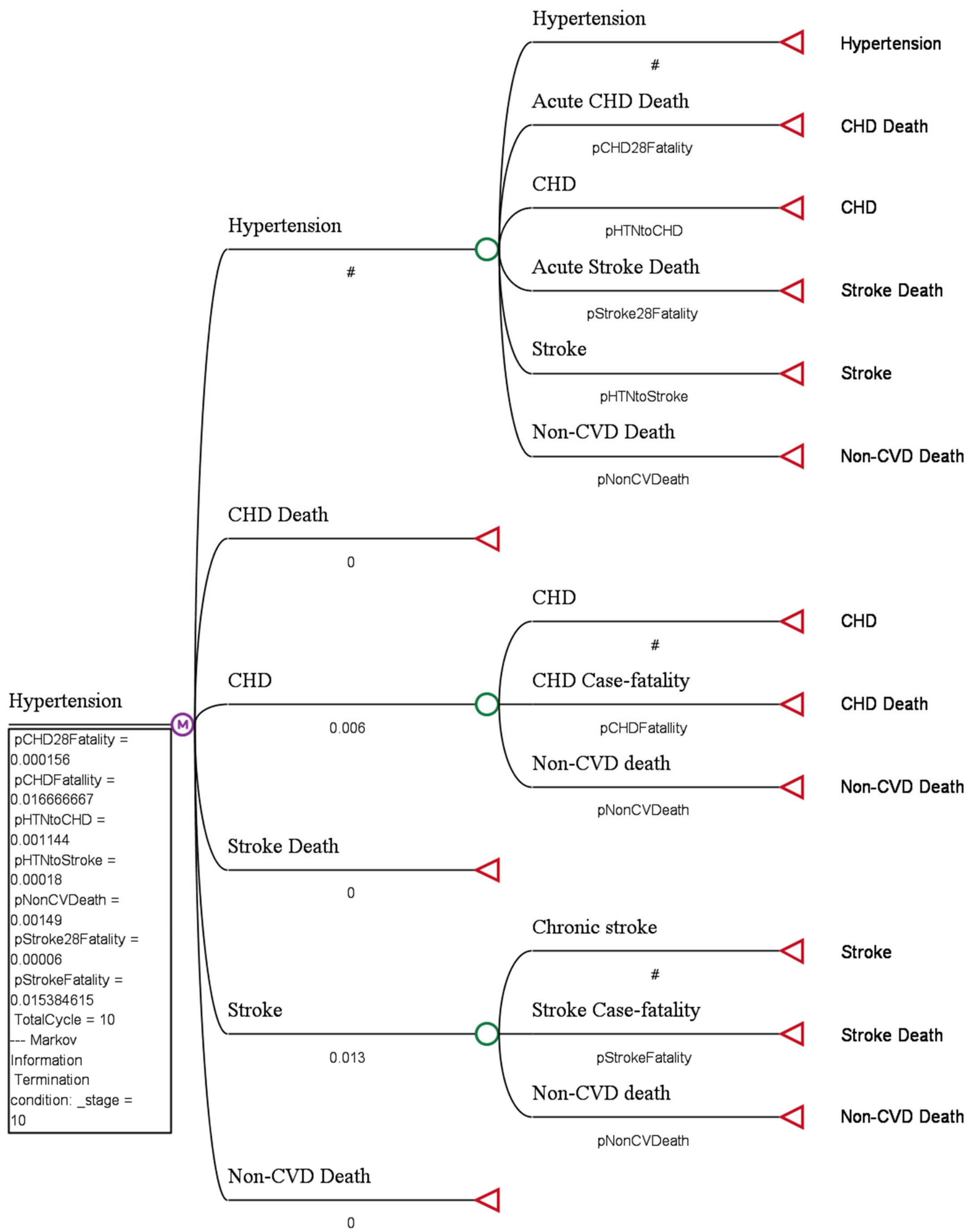

Figure 4.3 Markov model structure, taking the male G1 35-45 age group as an example

4.3.2 Target population

As discussed in Chapter 3, it was estimated that 9,532,719 hypertensive patients got their BP under control because of the NBPHS. Because there was no national representative survey available for such a population, this study employed the CHS

2012-2015 to represent the target population in terms of age-gender structure, prevalence and control of hypertension. The CHS was undertaken from October 2012 to December 2015 under a stratified multi-stage random sampling method, involving a nationally representative sample of 451,755 residents aged over 18 years from 31 provinces in China. The results of the survey were published in 2018 (Z. Wang et al., 2018). Age-gender structure was weighted according to data from the 2010 Chinese Census. The effectiveness of the NBPHS was quantified by the number of hypertensives under control. The age-gender structure of the controlled hypertensives in the CHS 2012-2015 was considered the same as that of the study population. Another reason for such a simulation is based on the analysis discussed in Chapter 3, which estimated that about 88% of hypertensives aged 35+ years with a level of awareness were under some form of management within the NBPHS program (see Table 4.1).

Table 4.1 Data used for age-standardizing the target population

Age group, years	Population (%) [a]	Crude prevalence [b]	Crude control rate [b]**
Men			
35-44	10.2	17.8	9.9
45-54	13.1	30.0	16.1
55-64	14.0	43.5	18.6
65-74	8.9	53.8	18.4
75-84	4.5	56.8	17.0
85+*	0.7	56.8	17.0
Women			
35-44	5.9	10.8	9.9
45-54	11.6	27.8	16.1
55-64	14.2	45.0	18.6
65-74	9.8	58.0	18.4
75-84	5.7	62.7	17.0
85+*	1.3	62.7	17.0

Notes: * Crude prevalence and control rates of people aged 85+ were not specifically described in the China Hypertension Survey and this study considers it the same as that of the 75+ age group.
** The age-sex specific control rates were not described in the China Hypertension Survey and this study considers the control rates of the two sexes were the same.
Source: a. 2010 Chinese Census data, China National Bureau of Statistics.
b. China Hypertension Survey (Z. Wang et al., 2018).

Based on the data extracted from the CHS and the 2010 Chinese Census, further assumptions were made: 1) the 9,532,719 hypertensives controlled by the NBPHS had the same age-gender structure as those involved in the CHS 2012-2015 (Z. Wang et al., 2018); 2) in the non-NBPHS scenario, the 9,532,719 hypertensives without hypertension control also had the same age-gender structure as those involved in the CHS; and 3) as the hypertension prevalence of the age group aged 85+ years was not available through the CHS 2012-2015 (Z. Wang et al., 2018), the hypertension prevalence and control of this group was assumed to be the same as that of the group aged 75-84.

To calculate the number of hypertensives in each age-gender group: first, the hypertension prevalence and control rate (taken from the CHS 2012-2015) in each age-gender group was weighted by the population in each age-gender group, according to the 2010 Chinese Census; second, the proportion of each age-gender group was multiplied by 9,532,719. The results are shown in Table 4.2.

Table 4.2 Weighted structure and number of target hypertensives aged 35+ years

Age group, years	Proportion (%)	Number of hypertensives
Men		
35-44	6.11	582,276
45-54	12.71	1,211,554
55-64	16.04	1,529,342
65-74	10.29	981,285
75-84	4.64	442,566
85+	0.79	75,476
Women		
35-44	3.55	338,476
45-54	11.29	1,076,590
55-64	16.16	1,540,445
65-74	11.02	1,050,308
75-84	5.96	568,066
85+	1.43	136,336
Total	100.00	9,532,719

4.3.3 Parameters for estimating long-term health outcomes

For the hypertension-controlled group and the non-controlled group, middle-term and long-term health outcomes were represented by CVDs avoided and deaths averted, which assumed that the 9,532,719 hypertensives were categorized into a closed cohort under the two scenarios.

It was assumed that in the NBPHS scenario (G1), in which the 9,532,719 hypertensives got their BP controlled, the model parameters that determine disease shifts were the same as those of the general population extracted from previous studies (D. Gu et al., 2015). In the non-NBPHS scenario (G2), in which the 9,532,719 hypertensives did not get their BP controlled, the model parameters that determine disease shifts were weighted by the annual risk ratios of the two groups for each age-gender group.

As discussed earlier, the only risk factor for fatal and non-fatal CVDs was the BP level for the two groups. Parameters for G2 were weighted by the relative risks of G2 to G1 in terms of the SBP level, based on BP and the risk of CVD in the Chinese population (D. Gu et al., 2008). The SBP levels of the two groups, as evident in the CHNS 2009 data, have been described in Section 1 of this chapter, which also described risk factors of CVDs. The relative risks of CHD and stroke were calculated from the SBP levels (D. Gu et al., 2008). The risk ratio of G1 to G2 was also calculated, as shown in Table 4.3. By comparing the relative rates of G2 and G1, the risk ratios of each age-gender group were generated, also shown in Table 4.3.

Table 4.3 SBP level and relative risks of developing CHD and stroke, G1 and G2

Age /gender	SBP (mmHg)*		Multivariate-adjusted RR as indicated by Gu et al. (2008)					
			CHD			Stroke		
	G1	G2	G1	G2	G2 to G1 ratio	G1	G2	G2 to G1 ratio
Men								
35-44	127	147	1.23	2.03	**1.65**	1.76	3.62	**2.06**
45-54	127	149	1.23	2.03	**1.65**	1.76	3.62	**2.06**
55-64	129	152	1.23	2.03	**1.65**	1.76	3.62	**2.06**
65-74	127	157	1.23	2.03	**1.65**	1.76	3.62	**2.06**
75-84	126	160	1.23	2.84	**2.31**	1.76	5.83	**3.31**
85+	127	157	1.23	2.03	**1.65**	1.76	3.62	**2.06**
Women								
35-44	131	155	1.17	1.63	**1.39**	1.98	3.32	**1.68**
45-54	125	152	1.16	1.63	**1.41**	1.59	3.32	**2.09**
55-64	127	156	1.16	1.63	**1.41**	1.59	3.32	**2.09**
65-74	131	156	1.17	1.63	**1.39**	1.98	3.32	**1.68**
75-84	126	164	1.16	2.00	**1.72**	1.59	4.96	**3.12**
85+	138	164	1.17	2.00	**1.71**	1.98	4.96	**2.51**

Note: *The SBP level for each age-gender group was taken from the 2009 CHNS.

The parameters for the Markov model are as follows:

- The age-gender structure of the hypertensive population is as described in Section 4.3.2.
- Prior myocardial infarction (MI), prior stroke, incidence of CHD and stroke, 28-days case fatality and mortality of CHD, and stroke were all adopted from recent epidemiological and modeling studies (Chan et al., 2012; D. Gu et al., 2015), in which they were well calibrated. It was assumed that prior MI or stroke in the study population was the same as that in the general population.

- Non-CVD mortality was calculated based on 2013 statistics of urban/rural age-gender disease specific mortality (China National Health and Family Planning Commission, 2014) and the population structure was based on the 2010 Chinese Census. As the age-gender structure of urban and rural populations was not available, it was assumed that there was no significant difference between those populations. This study adjusted 2013 urban-rural specific mortalities and generated age-gender specific all-cause mortality rates (The National Health and Family Planning Commission of China, 2014a). The non-CVD mortality rates adjusted by age-gender are listed in Appendix Table B3.

- Mortality rates for CHD and stroke were taken from Chan et al. (2012) for hypertensives younger than 85 years. Mortality rates were calculated by dividing the number of deaths by the population at risk during a defined time period, usually one year (Harrington, 2017). The CHD mortality and stroke mortality rates for adults aged 85+ were calculated based on urban and rural age-gender disease specific mortality from the 2014 *Chinese Health Statistic Yearbook* and the age-gender structures were adjusted according to the data from the 2010 Chinese Census.

- The 28-day case fatality rate was used to represent deaths caused by acute CVDs based on Chan et al.'s (2012) study in each cycle (one year). The case fatality rate, or the case fatality ratio, is the proportion of deaths of a defined disease as in all individuals diagnosed with the disease over a specific period of time. The case fatality rate was generated by dividing the number of deaths, because of the analyzed disease, over a certain period (one year), by the number of patients with the disease during that time.

- The case fatality rate of CHD or stroke was generated from CHD or stroke mortality and the prevalence of prior MI or prior stroke (used as the general prevalence of CHD or stroke). This was calculated by dividing the CHD or stroke mortality rate by prevalence of prior myocardial infarction or stroke.

For details, see Table 4.4 and Appendix Table B4.

Table 4.4 Parameters and data sources

Parameters	Source
Age-gender specific proportion of hypertensives	The 2010 Chinese Census & Z. Wang et al. (2018)
CHDs	
Prior CHD	(D. Gu et al., 2015)
Incidence of CHD for G1	(D. Gu et al., 2015)
Incidence of CHD for G2	Recalculation
28-days case fatality	(D. Gu et al., 2015)
CHD mortality	(D. Gu et al., 2015)
CHD case fatality (yearly)	Calculated
Stroke	
Prior stroke	(D. Gu et al., 2015)
Incidence of stroke for G1	(D. Gu et al., 2015a)
Incidence of stroke for G2	Recalculation
28-days case fatality	(D. Gu et al., 2015a)
Stroke mortality	(D. Gu et al., 2015a)
Stroke case fatality (yearly)	Calculated
Non-CVD mortality	China Health Statistical Yearbook, 2014

All the parameters were in 10-year age categories and the Markov process was run in one-year cycles. Parameters were changed into the next 10-year age groups after running for 10 cycles. Results of hypertension, CHDs, stroke, deaths due to CHD or stroke and non-CVDs death running from the first 10 cycles were fed into the next 10-year age-gender group. Details are provided in Appendix Table B4.

The model started with four states: hypertension only, with prior MI, with prior stroke, and death (0 at the start point). Cumulative incidences of CHD, stroke, instant (28-day) case fatalities, deaths due to chronic CVDs, and deaths due to non-CVD causes in each age-gender group of the target population were estimated under the two scenarios.

In the Markov model, shifts among CVDs, adverse events, and death over the 30-year period were evident. For the age group 75-84, only 10- and 20-year shifts were reported, and for the age group 85+, only 10-year shifts were reported because of the lack of data on life expectancy. In each cycle, the number of CHDs, strokes and deaths were aggregated with the previous cycle over time.

4.3.4 Sensitivity analysis

The CHNS 2009 showed that the difference between G1 and G2 (hypertension control or not) was mainly caused by blood pressure. Although 2015 CHNS didn't have bio-marker data, it did have blood pressure data. And in the CHNS 2015, the measurement of blood pressure and the definition of hypertension was exactly the same as that of

CHNS 2009. Therefore, a sensitivity analysis was carried out with the use of 2009 data, and SBP levels of G1 and G2 were analyzed with data from the CHNS 2015, with results shown in Table 4.5.1 and Table 4.5.2. The differences between the CHNS 2009 and 2015 in both the hypertension controlled and uncontrolled groups across all age-groups are quite small, except for 35-45 of women (5.47%) in G1 and 85+ of women in G2 (5.62%). The difference of SBP across all age groups between 2009 and 2015 as a percentage of 2009 was 0.63% for the hypertension controlled group, and 0.60% for hypertension uncontrolled group, as shown in Table 4.4.1 and Table 4.4.2.

Table 4.5.1 SBP of hypertension controlled group of CHNS 2009 and 2015 (G1)

Age /gender	**2009**				**2015**			Difference of SBP between 2009 and 2015 as of 2009 (%)
	N	Mean Blood pressure (mmHg)	Standard Deviation		N	Mean Blood pressure (mmHg)	Standard Deviation	
Men								
35-44	10	127.13	5.675		13	129.18	10.14	1.61
45-54	28	127.33	11.195		48	124.62	7.487	-2.13
55-64	35	128.65	10.841		97	127.67	9.02	-0.76
65-74	42	127.44	9.605		117	127.3	8.405	-0.11
75-84	16	126.5	9.022		40	128.25	6.65	1.38
85+	2	127	5.185		2	130.67	6.6	2.89
Women								
35-44	7	131.1	9.863		10	123.93	9.815	-5.47
45-54	43	125.04	9.543		57	126.66	9.751	1.30
55-64	51	126.69	11.169		123	125.52	9.539	-0.92
65-74	63	130.68	8.343		103	126.52	8.472	-3.18
75-84	22	125.52	13.155		41	129.59	7.676	3.24
85+	1	136.67	N/A		4	133.83	4.29	-2.08
Total	320	127.68	10.101		655	126.88	8.743	-0.63

Note: *The SBP level for each age-gender group was taken from the CHNS 2009 and 2015.

Table 4.5.2 SBP of hypertension controlled group of CHNS 2009 and 2015 (G2)

Age /gender	**2009**				**2015**			**Difference in SBP between 2009 and 2015 as of 2009 (%)**
	N	**Mean Blood pressure (mmHg)**	**Standard Deviation**		**N**	**Mean Blood pressure (mmHg)**	**Standard Deviation**	
Men								
35-44	14	147.24	14.556		26	148.53	14.882	0.88
45-54	55	148.63	13.642		106	148.94	15.154	0.21
55-64	74	152.15	18.032		199	152.27	14.904	0.08
65-74	78	156.64	14.886		193	154.94	16.721	-1.09
75-84	38	159.94	19.435		64	154.22	14.54	-3.58
85+	3	156.67	6.11		13	157.79	11.375	0.71
Women								
35-44	11	155.45	28.772		26	150.54	15.361	-3.16
45-54	48	151.88	14.52		111	155.88	16.421	2.63

55-64	97	156.08	14.913		208	153.96	14.788	-1.36
65-74	99	155.8	15.144		234	158.13	17.357	1.50
75-84	56	164.35	23.929		109	157.25	17.1	-4.32
85+	4	163.08	5.865		13	153.92	14.859	-5.62
Total	577	155.43	17.273		130 2	154.5	16.104	-0.60

Note: *The SBP level for each age-gender group was taken from the CHNS 2009 and 2015.

4.4 Long-term health outcome estimations

4.4.1 Long-term trends in CVD development and deaths in the two groups

In each projected year, the number of patients developing CHDs, strokes, or dying due to CVDs, and non-CVD deaths in the total were generated in the Markov process.

Figure 4.4 provides a graphic representation of the trends in total deaths over the projected 30-year period for G1 and G2, taking the 35-44 age group of male and female hypertensives as an example. This indicates that at the end of the projection period, the number of deaths due to CVDs in the G2 scenario was higher than in the G1 scenario.

Trends in deaths over the projected 30-year period for all other age-gender groups are presented in Appendix B: Supplementary materials.

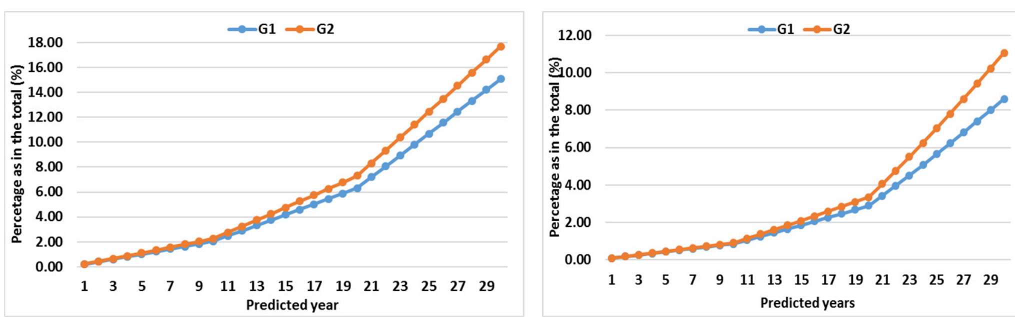

Figure 4.4 Percentages of deaths in G1 (blue) and G2 (orange), for 35-44-year-old males (left-hand side) and females (right-hand side)

4.4.2 Estimates of CVDs and deaths averted

At the end of the 10th projection year in the G1 scenario, compared with G2, 43,386, 314,004, and 289,644 hypertensive patients would have avoided CHD, stroke and death, respectively. At the end of the 20th projection year, 45,035, 400,313, and 558,625 hypertensive patients would have avoided CHD, stroke and death, respectively. At the end of the 30th projection year, 25,012, 296,258, and 744,493 hypertensive patients would have avoided CHD, stroke and death, respectively. Details of these results are provided in Tables 4.6, 4.7, and 4.8. In Table 4.8, there are some negative figures which are generated mainly from older age groups of both genders in the 30-year horizon analysis (age groups of 65-74 and 75-84 years). This is because in the non-NBPHS group, more patients die from CVD than those in the NBPHS group, which makes less CVD survivors compared with those, especially for stroke.

Table 4.6 Running results for a 10-year horizon

Age/ gender	G1			G2			Number of patients avoiding CVD and death		
	CHD	Stroke	Death	CHD	Stroke	Death	CHD	Stroke	Death
Men									
35-44	8,850	7,325	11,961	12,685	8,295	13,241	3,835	970	1,279
45-54	20,764	43,028	55,518	27,332	55,544	62,625	6,568	12,516	7,107
55-64	52,845	171,455	160,667	62,566	235,985	181,610	9,720	64,529	20,943
65-74	39,085	134,254	250,126	47,710	182,196	281,718	8,625	47,943	31,591
75-84	10,657	27,684	262,932	13,782	44,502	330,665	3,124	16,818	67,733
85+	196	708	63,276	214	1,017	67,247	18	310	3,971
Women									
35-44	1,822	3,301	2,901	2,010	3,713	3,061	187	413	160
45-54	15,382	37,287	24,892	16,788	53,124	29,098	1,406	15,838	4,205
55-64	52,731	151,827	104,128	57,084	231,981	130,512	4,353	80,154	26,384
65-74	36,524	142,037	188,712	40,111	187,380	215,570	3,587	45,343	26,858
75-84	16,363	39,042	288,907	18,303	67,216	376,364	1,941	28,174	87,457
85+	529	1,628	105,549	550	2,626	117,503	21	998	11,954
Total							43,386	314,004	289,644

Table 4.7 Running results for a 20-year horizon

Age/ gender	G1			G2			Number of patients avoiding CVD and death		
	CHD	Stroke	Death	CHD	Stroke	Death	CHD	Stroke	Death
Male									
35-44	11,288	11,640	36,786	17,081	18,271	42,491	5,794	6,632	5,705
45-54	27,984	87,416	165,285	39,953	147,164	191,465	11,969	59,748	26,180
55-64	49,619	176,237	501,353	63,760	270,605	575,794	14,141	94,368	74,441
65-74	16,748	49,410	689,698	19,449	76,986	812,824	2,701	27,576	123,127
75-84	464	1,683	413,651	193	1,152	434,930	-271	-531	21,278
85+	196	708	63,276	214	1,017	67,247	18	310	3,971
Female									
35-44	2,675	7,595	9,779	3,278	12,979	11,345	603	5,384	1,566
45-54	21,910	86,113	89,760	25,939	153,118	115,012	4,028	67,005	25,252
55-64	47,061	199,008	362,939	52,755	295,357	438,796	5,694	96,349	75,857
65-74	22,513	66,566	633,132	23,385	109,438	779,062	873	42,872	145,930
75-84	1,058	3,309	506,396	523	2,912	549,760	-535	-397	43,364
85+	529	1,628	105,549	550	2,626	117,503	21	998	11,954
Total							45,035	400,313	558,625

Table 4.8 Running results for a 30-year horizon

Age/ gender	G1			G2			Number of patients with avoiding CVD and death		
	CHD	Stroke	Death	CHD	Stroke	Death	CHD	Stroke	Death
Male									
35-44	14,331	34,814	87,775	21,795	63,359	102,978	7,464	28,545	15,203
45-54	33,031	113,086	412,957	45,871	191,467	482,630	12,840	78,381	69,673
55-64	23,572	67,940	1,113,669	25,708	107,119	1,301,559	2,136	39,179	187,891
65-74	740	2,721	935,116	259	1,666	970,908	-481	-1,055	35,792
75-84	464	1,683	413,651	193	1,152	434,930	-271	-531	21,278
85+	196	708	63,276	214	1,017	67,247	18	310	3,971
Female									
35-44	5,111	24,123	29,135	6,516	45,658	37,457	1,405	21,535	8,323
45-54	24,115	128,254	259,680	28,452	200,737	321,327	4,337	72,483	61,647
55-64	30,398	91,952	970,678	29,347	149,716	1,189,612	-1051	57,764	218,934
65-74	1,552	4,928	959,805	682	3,973	1,026,267	-870	-955	66,463
75-84	1,058	3,309	506,396	523	2,912	549,760	-535	-397	43,364
85+	529	1,628	105,549	550	2,626	117,503	21	998	11,954
Total							25,012	296,258	744,493

4.5 Discussion and conclusion

Based on the above analysis, obvious decreases in CVDs and deaths due to CVDs were found in 10-, 20- and 30-year horizon projections due to the implementation of the NBPHS. The G2 scenario (non-NBPHS implementation) had a much higher incidence of CVDs and deaths compared with that of G1. This indicates that the NBPHS was effective in preventing CVDs and averting deaths.

The assumption in the analysis was that there was no significant difference between the hypertension-controlled population under the NBPHS scenario and those in the general population, and between the hypertension uncontrolled population under the non-NBPHS scenario and those in the general population. According to the analysis of the CHNS 2009, BP levels increased with age, which is the same as other findings (Y. Li et al., 2017; Z. Wang et al., 2018). It was discovered that the major determinant of CVD risk was BP level in the two simulated groups.

This is the first study to analyze hypertension management from this perspective. As discussed in Chapter 3, several studies have attempted to evaluate hypertension management under the NBPHS in terms of improved hypertension control rates and decreased BP levels (Hou, Meng, & Zhang, 2016; Tian et al., 2015; D. Zhang et al., 2018). However, evidence on the middle- and long-term impact of hypertension management is scarce. This study has, to an extent, filled this gap.

This study has several strengths. First, a population survey was employed to reflect the real status of risk factors for a hypertensive population. By employing data from the CHNS 2009, the risk factors for hypertension-controlled and uncontrolled populations were compared, including age, gender, BP, total cholesterol, BMI, smoking, and diabetes. To make the analysis more representative, the CHS 2012-2015 was used for the age-gender structure analysis of the hypertensive population. As explained in Chapter 3, based on the CHS 2012-2015 (Z. Wang et al., 2018), the number of hypertensives aged 35+ in 2015 was 223,772,752, while 100,496,343 hypertensives became aware of their condition. According to statistical data from the health reform report (The Office of Health Reform of the State Council of China, 2016), by then end of 2015, about 88.35 million hypertensives were covered by the NBPHS program in China. This means that about 88% of hypertensives with awareness of their condition, were under a certain level of management in the NBPHS program. Therefore, the hypertensives with awareness in the China Hypertension Survey (Z. Wang et al., 2018) can be used to represent the hypertensives under management in the NBPHS program in China. Secondly, by employing a Markov model (D. Gu et al., 2015; Moran et al., 2008), combined with a risk prediction model (D. Gu et al., 2008), a long-term projection was made. This fills a gap in economic evaluation research on hypertension management in China. As hypertension is a "chronic disease", effectiveness should be expressed from a middle- or long-term perspective. This will help policymakers in their long-term decision-making. Thirdly, the analysis provided a clear structure of all simulated states in the projected 30-year period. This provides a basis for all kinds of economic evaluations, including CEA, CUA and CBA, as cost, effectiveness, utility and benefit data can be assigned to each state in each year (Hoang et al., 2016; Standfield, Comans, & Scuffham, 2014).

People may challenge the assumption that in the non-NBPHS scenario, none of the 9,532,719 patients got their BP under control. However, this is a possibility. As discussed in Chapter 3, China still has quite low rates of awareness, treatment, and control in relation to hypertension; and the improvement of awareness, treatment and control has been far from satisfactory. From 1991 to 2015, the control rate of hypertension among adults in China was still lower than 20%, which means that in that

25-year period more than 150 million hypertensives did not have their hypertension properly under control.

It has been suggested that treating all hypertensives in China could prevent about 800,000 CVD events each year (D. Gu et al., 2015). This study takes this estimation further through longer-term projections and by taking both CVDs and deaths averted into account. Although progress has been achieved, there is still a way to go. The latest data shows that no more than 15% of hypertensives aged 35+ years have their hypertension under control (Z. Wang et al., 2018). If all hypertensives had their BP controlled, the number of deaths averted would be many times the current estimates.

This chapter has provided a bridge between Chapter 3 and Chapter 5, linking direct health outcomes with economic outcomes, respectively. The methods used were twofold: a CVD risk estimation model based on Gu et al.'s (2015, 2008) studies; and a Markov model used for long-term health impact estimation, commonly used in the economic evaluation of healthcare programs (Athanasakis et al., 2015; Xie et al., 2018). Internationally, economic evaluations of hypertension management in primary care settings have been well conducted, such as studies in Argentina (Perman et al., 2011), the Netherlands (Stevanović et al., 2014), Vietnam (Nguyen et al., 2016), and the UK (Peñaloza-Ramos, Jowett, Sutton, McManus, & Barton, 2018). In China, the evidence in this area is scarce. Again, this study helps fill that gap.

The limitation of this study lies mainly in the data used for analyzing the risk factors of fatal and non-fatal CVDs, which were extracted from the CHNS 2009. If more recent data were available, an up-to-date analysis could be performed.

In conclusion, in a 30-year horizon, the implementation of the NBPHS reduced the incidence of CHD, stroke and deaths by 25,012, 296,258, and 744,493, respectively. The Markov model results provided the patient numbers for hypertension, CHD, stroke, and deaths in each simulated year. These were applied to an economic evaluation, discussed in the following chapter.

Chapter 5 Benefit, cost and return on investment of the NBPHS on hypertension control: An innovative framework

5.1 Introduction

Based on the results discussed in Chapters 3 and 4, this chapter presents an economic evaluation of the investment in hypertension management under the NBPHS, focused on a return on investment based on a benefit-cost analysis.

The return on investment framework on health interventions was developed by the Victoria Institute of Strategic Economic Studies (VISES) of Victoria University (VU) and has been peer-reviewed and validated in a number of different studies. The model was initially developed for maternal and child health (Stenberg et al., 2014), and adolescent health (Sheehan et al., 2017; Sweeny, Friedman, Sheehan, Fridman, & Shi, 2019). Importantly, it has been used in the evaluation of interventions for NCDs, namely CVD (Bertram et al., 2018) and mental health (Chisholm et al., 2016). These studies covered a number of countries and all included China in the analysis. More recently, the framework has been used in individual countries, such as India and Burundi.

All these studies included health outcome models and economic models. The health outcomes were modelled using the One Health Tool (OHT). This is a Markov-based model, which uses an integrated approach to evaluate costs and health benefits (Bertram et al., 2018; Chisholm et al., 2016; Stenberg et al., 2014). For this study, a Markov model was developed, as presented in Chapter 4. The economic model developed by VISES at Victoria University was then adapted (Bertram et al., 2018; Chisholm et al., 2016; Stenberg et al., 2014), using demographic and labour force data for China from the UN and the ILO, based on Chinese published data.

An important concern in economic evaluation is to determine the perspective of analysis, which can be individual, societal, enterprise or insurance (G. Liu, Hu, & Wu, 2011; Luhnen, Prediger, Neugebauer, & Mathes, 2017). The NBPHS was implemented at the national level and aimed to provide quality-equalized and quantity-equalized services to all people across China, to benefit individuals, families, organizations and even the whole society. Therefore, this study adopted a social perspective, in line with similar international studies (Nugent et al., 2017). When considering the NBPHS as an incremental investment in supporting the hypertensive population, the benefits of the program should include the cost saved by reducing CHD and stroke, improved health of the labour force and consequent increases in productivity, and social benefits, which can be converted into monetary terms (Dehmer et al., 2016; Nugent et al., 2017).

5.2 Conceptual framework

As discussed in Chapter 2, there are four types of economic evaluations of healthcare programs (CMA, CUA, CEA and CBA). CBA is considered the broadest form of analysis, because it could ascertain whether the beneficial outcomes of a program justify the cost (Drummond et al., 2005). Benefits are defined by assigning monetary values to the outcomes of healthcare programs (Drummond et al., 2015).

The conceptual framework of this study is summarized in Figure 5.1. It mainly consists of two parts. The first part (pink background) involves the specification of the direct and indirect improvements in health outcomes generated, and the time frame of those improvements, which were discussed in Chapter 4. The second part of the framework (blue background) represents the calculation of the economic and social benefits derived from improved health outcomes.

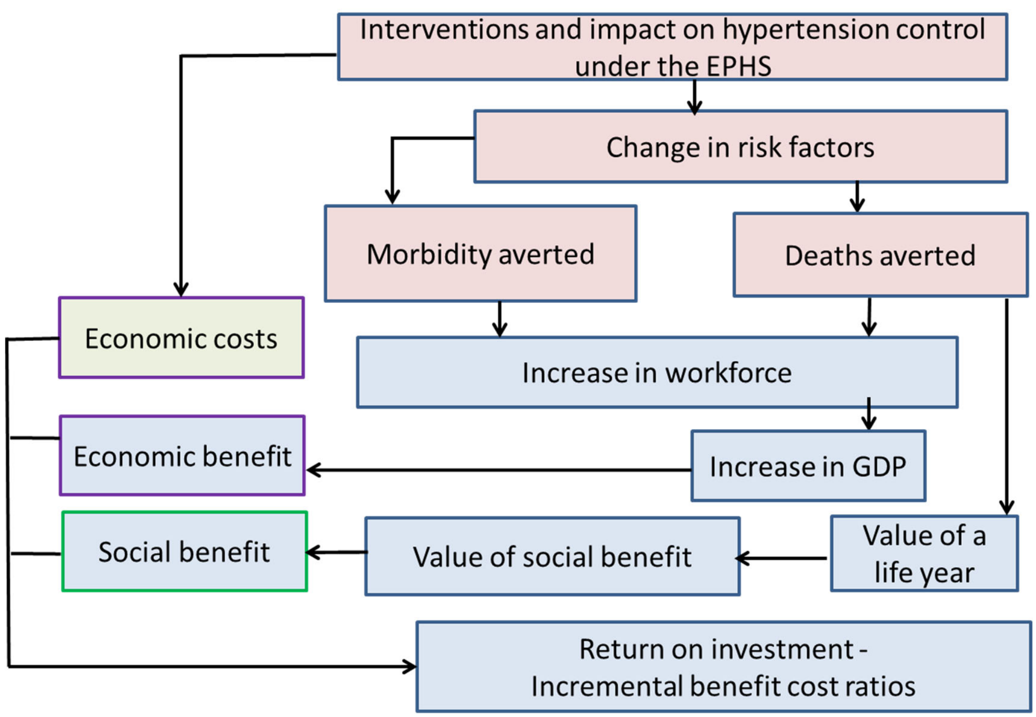

Figure 5.1 The VISES framework for return on investment of health interventions

Within the framework, the economic costs are defined as the cost of hypertension management in the NBPHS. However, as discussed in Chapter 1, with the implementation of the NBPHS, patients would become more aware of the need for treatment and receive better treatment. This might result in greater consumption of healthcare services from the patient side, thus increasing the cost of treatment. On the other hand, as discussed in Chapter 4, control of hypertension would result in a decrease in CHD and stroke, which would save healthcare expenditure. To estimate the long-term benefit, healthcare expenditure, which was considered part of the cost of the intervention, was calculated in both hypertension-controlled and uncontrolled scenarios. To do this, the cost of illness (CoI) framework developed by the WHO was employed (WHO, 2009) with data from the China National Health Development Research Centre's household survey conducted over 17 provinces in China (Qin et al., 2019).

5.2.1 Interventions, costs and benefits

5.2.1.1 Interventions and costs

It has been clearly defined that the intervention referred to in this study is the hypertension management component of the NBPHS in China across a specific time frame (2009 to 2015). Hypertension management includes the screening of adults aged 35+ upon their first visit to a GP in community health servicefacilities, regular follow-ups with monitoring and evaluation, advice on hypertension control, and referral to hospitals in case of hypertension deterioration.

The direct health outcome of this initiative would be hypertension control, which was defined as the number of hypertensives with BP being properly controlled (SBP/DBP≤140/90 mmHg) (J.-G. Wang, 2015) compared with the non-NBPHS scenario. The number was estimated to be 9,532,719 from 2009 to 2015, as detailed in Chapter 3.

As for long-term health outcomes, a Markov model was developed following the CDPM employed by Gu et al. (2015) in terms of CVDs and deaths (see Chapter 4). The differences in the number of deaths and cardiovascular events between the two scenarios was considered to signify the impact of the NBPHS health promotion investment.

5.2.1.2 Modelling the benefits of improved health outcomes

Premature death of members of the labour force would have an impact on future contributions to GDP. People who continued to live with disease would suffer from disability caused by that disease and may discontinue working as part of the labour force or may continue working with somewhat impaired productivity. Consequently, a reduction in the incidence of CVD would likely result in greater workforce participation and increased productivity. Better health in older age groups would also potentially lead to increased participation by older workers, a phenomenon evident in many developed countries (Stenberg et al., 2014). Estimating these impacts on the labour force and productivity, which can be transformed into GDP, was therefore an important task of the model. To do this, this study followed an innovative study which used the VISES economic model for benefit estimation (Bertram et al., 2018), while taking into account the *China guidelines for pharmacoeconomic evaluations* (Liu et al., 2011).

The defined period for the model projection was set as 2016 to 2045 and benefits were generated from both mortality and morbidity averted. The economic impacts of avoided mortality were calculated based on the labour force participation of each age, gender, and year category. The contribution to economic outcomes of the NBPHS program was calculated by multiplying the number of people in each age-gender group by a productivity rate that varied according to age and year. Each subsequent year of the age-specific participation rate was applied to that cohort to calculate the labour force for that cohort in that year. Average death rates by age were also calculated. The labour force in any year was obtained by adding together all the cohorts up to that year. The participation rates used were for those currently in that age group.

Labour force participation rates by gender and age, and the population and death rates were accessed from the ILOSTAT database (ILO 2019). Data for GDP was sourced from the World Bank Development Indicators (World Bank 2019). Death rates were obtained from the UN World Population Prospects forecasts (UN 2017).

In each age-gender group, the average ages of the hypertensives whose lives were saved in a particular year were calculated based on the CHNS 2009 in 12 age-gender categories (male/female, 35-, 45-, 55-, 65-, 75- and 85+). The persons in this study represented the sum of all persons of working age, employed or unemployed. According to the ILO (2017), for the age group aged 65+ years, the labour force participation rates of males and females were 27.6% and 15.2%, respectively in 2016. Therefore, in the economic benefit estimation of this study, the maximum age of those in the labour force was assumed to be 70 years. GDP per person in the labour force was calculated by dividing total GDP by the total labour force.

Considering social benefits, it was assumed that the social and economic components of the value of a life year saved were distinguished. This approach has been used frequently in previous studies (Bertram et al., 2018; Chisholm et al., 2016; Stenberg et al., 2014). Similarly, the maximum age for social benefit estimation was 80 years, in line with the parameters used in these studies.

5.2.1.3 Benefits estimation from morbidity averted

In this study, morbidities only included CHD and stroke. Estimates of benefits from morbidity averted CHD and stroke were provided based on severity and their distribution. The chronic states of CHD and stroke was considered as morbidity, and the acute state was incorporated in mortality. As described in the latest Global Burden of Disease (GBD) study on morbidity (S. L. James et al., 2018), there are four levels of severity of angina pectoris: asymptomatic, mild, moderate, and severe. Mild angina is described as having chest pains during strenuous physical activity, moderate angina refers to chest pains during moderate physical activity, and severe angina occurs during minimal physical activity. The last of these levels was considered to be severe enough to prevent the person from working and was treated as equivalent to death for the purposes of analysis. The other two severity levels were considered equal to complete health and were not included in the benefit estimation for morbidity averted. A similar approach was taken in analyzing stroke morbidity. Chronic stroke has five severity levels: mild, moderate, moderate plus cognition problems, severe, and severe plus cognition problems (S. L. James et al., 2018). The latter three severity levels all resulted in some difficulty in mobility (e.g. using the hands and dressing, being confined to bed or a wheelchair), or cognitive abilities (e.g. speaking, thinking and remembering things), and dependence levels (e.g. needing to be fed, toileted, and/or dressed). The mild and moderate levels were excluded, and were considered equal to complete health.

Based on severity distributions (Burstein et al., 2015), the number of patients with CHD or stroke in each year with the above severity levels were generated for each age-gender group in the two scenarios. The benefit estimation was determined to be the difference in these numbers between the non-NBPHS scenario and the NBPHS scenario. Details are provided in Table 5.1.

Table 5.1 Severity levels and distribution used for CHD and stroke in the analysis

CHD			Stroke		
Severity level	**Distribution (proportion)**	**Disability weight**	**Severity level**	**Distribution (proportion)**	**Disability weight**
Asymptomatic angina	30.40	0.000	Mild	18.60	0.00
Mild angina	24.00	0.033	Moderate	42.80	0.02
Moderate angina	12.60	0.080	Moderate plus cognition problems	22.70	0.07
Severe angina	33.00	0.167	Severe	11.70	0.32
			Severe plus cognition problems	1.60	0.55

5.2.1.4 Net present value (NPV)

Net present value (NPV) was employed to estimate both the economic and social benefits of the program designed for hypertension control. NPV is the difference between the present value of cash inflows and that of cash outflows over a period. NPV is mainly employed in capital budgeting and investment planning to analyze the outcome of an investment (Kenton, 2019). It is calculated as follows:

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t}$$

where:

Rt = net cash inflow-outflows during a single period;

ti = discount rate or return that could be earned in alternative investments; and

t = number of timer periods, which is a year in this study.

A return on investment framework was used to compare the benefit generated from the intervention with the cost of the NBPHS on hypertension management under a certain discount rate over the projected period. Parameters for estimations are listed in Table 5.2.

Table 5.2 Parameters input for health outcomes and cost benefit analysis

Category	Unit	Value	Source and publication year
Incremental cost	Billion CNY		
Lower estimate		24.66	**Expert consultation**
Middle estimate		35.97	Jq et al., 2015; Zhao, Chen, & Zhou (2015)
Upper estimate		44.38	Xiao et al. (2014)
Incremental effectiveness in hypertension control (number of patients)		9,532,719	**Trend analysis discussed in Chapter 3**
GDP per capita 2017	CNY	58681	World Bank (2017)
Discount rate	%	0,2,3,5	G. Liu et al. (2011)
Productivity growth rate from 2013 to 2017	/	/	World Bank (2017)
Population and death rate	/	/	UN Department of Economic and Social Affairs, Population Division (2017)

5.2.2 Target population structure and assumptions

The target population was the 9,532,719 hypertensives in the NBPHS scenario and the hypothesized non-NBPHS scenario in 2016. It was assumed that the two scenarios had the same age-gender structure and distribution as the national hypertensive population (Z. Wang et al., 2018). This model projected the population by age and gender for China in a 30-year period from 2015 to 2045, based on the population data of China from the UN statistics. The labour force comprises all persons of working age who furnish the supply of labour for the production of goods and services during a specified time-reference period. It refers to the sum of all persons of working age who are employed and those who are unemployed. The series is part of the ILO estimates and is harmonized to account for differences in national data and scope of coverage, collection and tabulation methodologies, as well as for other country-specific factors. Data for 1990-2015 are estimates, while 2016-2030 data are projections. The dataset was updated as of July 2017 (UN Department of Economic and Social Affairs, Population Division, 2017). Number of annual deaths of the male and female population by five-year age group, region, sub-region and country for the years 2015-2050 (thousands of annual deaths) were from the UN as well.

It was also considered likely that the increasing incidence of chronic disease in an economy or several economies would have dynamic effects on growth (Mukhopadhyay & Thomassin, 2012). However, such an effect was very difficult to estimate and therefore the migration and dynamic growth effects were not included.

5.2.3 Sensitivity analysis

To address uncertainty around mean incremental costs and benefits, a univariate sensitivity analysis was performed, with only one variable analyzed every time while controlling for other variables at their mean or base-case value. Whenever possible, the analysis was conducted using the upper and lower bounds of previous estimates, including costs and health outcomes. Moreover, the following range of discount rates of costs and socio-economic benefits were applied: 0, 2%, 3% and 5%.

5.2.4 Analysis of cost of illness (CoI)

As explained earlier, there was the potential for healthcare expenditure to increase under the NBPHS scenario because of the cost of medications used for hypertension control. To address this concern, this study analyzed the direct CoI.

Based on data availability, the direct CoI saved was calculated in reference to reduced CHDs and stroke, using the CoI methodology recommended by the WHO (Changik, 2014). Direct CoI is calculated in person-years multiplied by average direct cost of each patient in each illness, taking the probability of seeking medical care into account. Calculation was based on the survey conducted by the China National Health Development Research Centre (CNHDRC) in the 2014 household health service interview survey.

CHD includes angina pectoris, myocardial infarction and other IHD, and stroke includes cerebrovascular disease as in the survey design of the CNHDRC. The direct CoI was estimated annually and composed of direct medical expenditure and direct non-medical expenditure, which were sub-categorized into inpatient related expenditure and outpatient expenditure. This was calculated based on each disease, with the probability of seeking healthcare taken into account in each population with the disease analyzed (i.e. hypertension, CHD and stroke in this study) (Qin et al, 2014). The non-inpatient healthcare expenditure was calculated from two weeks of expenditure multiplied by 26 (as there are 52 weeks in a year), while the inpatient related expenditure was calculated from annual expenditure as designed by the data source survey.

The CoIs of CHD and stroke in the hypertension-controlled group are considered the same as that in the hypertension-uncontrolled group. The annual CoI was generated by adding the two expenditure figures together. The formula used is as follows:

Direct medical expenditure = [hypertensive population × outpatient visit rate of a fortnight × average outpatient expenditure per person time × 26 + hypertensive population × self-treatment rate of a fortnight × average self-treatment expenditure per person time × 26 + hypertensive population × admission rate of inpatient care × average inpatient expenditure of each admission]

Direct non-medical expenditure = [hypertensive population × outpatient visit rate of a fortnight × average outpatient related cost per person time × 26 + hypertensive population × admission rate of inpatient care × average non-medical expenditure of each admission]

Definitions of each term used in the above formulas are provided in Table 5.3.

Table 5.3 Definitions of terms used in the CoI calculation

Terms used	Definitions and calculating methods
Outpatient visit rate of a fortnight	The number of patients who received outpatient care during the past fortnight before the survey as a share of the total number of hypertensives.
Average outpatient expenditure per person time	Generated by dividing the total expenditure of outpatient medical care of hypertensives by the number of hypertensives.
Self-treatment rate of a fortnight	The number of patients who conducted self-treatment during the past fortnight before the survey as a share of the total number of hypertensives. This mainly denotes expenditure on drug purchasing from a pharmacy, nutritional treatment by family members, and so forth.
Average self-treatment expenditure per person time	Generated by dividing the total expenditure of self-treatment of hypertensives by the number of hypertensives.
Average outpatient related cost per person time	The total outpatient related cost divided by the number of patients who received outpatient care during the past fortnight. This denotes expenditure on transportation, nutrition, taking care of patients, and so forth.
Admission rate of inpatient care	The number of patients who received inpatient care during the past year before the survey as a share of the total number of hypertensives.
Average inpatient expenditure of each admission	Calculated by dividing the total expenditure of inpatients by the number of patients for each disease.
Average non-medical expenditure of each admission	Calculated by dividing the total inpatient related non-medical care cost divided by the number of patients who received inpatient care during the past year. This denotes expenditure on transportation, nutrition, taking care of the patients, and so forth.

The above methodology was developed by the WHO (2009), and has been widely used and validated. In 2014, this researcher co-authored an article using the same methodology with a similar dataset (Qin et al., 2014), which included an analysis of the CoI of hypertension, CHD and stroke, providing a good basis for this current study. The article analyzed the prevalence of NCDs and the economic burden on patients in eight typical cities in China. The survey, employed in this thesis, included 9,677 hypertensives and patients who sought healthcare in the past year and who were further analyzed, including 9,166 hypertensives, 1,047 patients with CHD, and 736 patients with stroke (Qin et al., 2019).

5.3 Results of intervention cost, benefits and return on investment

5.3.1 Investment into hypertension management under the NBPHS

The NBPHS program, as discussed in Chapter 2, was established to provide free basic public health services, including hypertension management, to the entire population of China (M. Tian et al., 2015). Initially, funding for the program was provided by the government on the basis of 15 CNY per capita each year (2009, 2010). This was increased to 25 CNY in 2011, 30 CNY in 2013, 35 CNY in 2014 and 40 CNY in 2015 (Department of Primary Care, n.d.). According to the 2010 Chinese Census, the population of China was 1,332,810,869. Therefore, it was estimated that over 246.57 billion CNY (around 36.64 billion USD at an exchange rate of 6.73 CNY per USD) was invested in this program.

The 2009 to 2015 investment from the NBPHS on hypertension control was considered to be the cost identified in the economic evaluation framework in this study. Although the total investment of the NBPHS was easy to estimate, the investment on different categories varied. The results varied from study to study, considering how much had been invested into hypertension management during the estimated period. In 2014, for example, a study by the World Bank estimated that about 18% of the investment was spent on the hypertension management of the patients, representing around 44.38 billion CNY in total (or 6.59 billion USD) (Xiao et al., 2014). A study on the fund allocation measurement of basic public health service in communities (Zhao et al., 2015), which was based on workload, estimated that 20.4% of the NBPHS fund was allocated to chronic diseases management, including both hypertension and diabetes. However, this study did not indicate how much had been allocated to hypertension only (Zhao et al., 2015). Another study in Shenzhen, conducted by the same research team as the study above (Jinquan et al., 2015), provided further details of cost on hypertension and diabetes. This indicated that the cost of hypertension was 2.51 times that of diabetes. As the study from the World Bank (Xiao et al., 2014) denoted that proportions of the total budget for the management of patients with hypertension only and diabetes only were 18% and 7%, respectively, it can be inferred that the cost of hypertension was 2.57 times that of diabetes. The studies conducted by Zhao et al. (2015) and that by Xiao et al. (2014) revealed the same results on the ratio of hypertension to diabetes, although their estimations on the cost of hypertension as proportions of the NBPHS fund were different. Taking the 2015 studies as the criteria for funds allocated to hypertension management, these indicated that hypertension and diabetes management took a 20.4% share of the total funding and the cost of hypertension was 2.51 times that of diabetes. The proportion of the total budget of the NBPHS for hypertension management was 14.59%. Multiplying the total funding by 14.59%, we get to know that 35.97 billion CNY (5.34 billion USD) was invested in hypertension management from 2009 to 2015.

However, in February 2019, a focus group discussion was conducted with Chinese experts, coming to an agreement that only about 10-12% of the NBPHS fund was used for the management of hypertension in China. Therefore, another lower estimate of 10% was employed in this study for estimation, which was equivalent to 24.66 billion CNY.

To sum up, three estimates were employed for further analysis based on the literature and expert panel discussion: 24.66 billion CNY, 35.97 billion CNY and 44.38 billion CNY.

5.3.2 Mortality and morbidity averted

To conduct the benefit estimation, deaths and morbidity averted were assigned a monetary value. The difference between deaths in the non-NBPHS group and those in the NBPHS group can be considered as deaths averted because of the implementation of the program. In the NBPHS scenario, the deaths in the 10-, 20-, and 30-year scenarios were 1,519,570, 3,577,605, and 5,857,687, respectively; while the counterparts in the non-NBPHS scenario were 1,809,214, 4,136,230, and 6,602,179, respectively. It was estimated that the number of deaths averted was 289,644, 558,625, and 744,493 at a 10-, 20- and 30-year prediction horizon, respectively (see Table 5.4 below). The number of deaths in each predicted year was also listed in the Markov results, where the year and ages of the dead were also displayed. Details of these deaths are provided in Appendix Tables C3.1 and C3.2.

Table 5.4 Deaths in the two groups and deaths averted in projected years

	NBPHS scenario	Non-NBPHS scenario	Death averted (lives saved)
10-year horizon	1,519,570	1,809,214	289,644
20-year horizon	3,577,605	4,136,230	558,625
30-year horizon	5,857,687	6,602,179	744,493

In terms of morbidity averted, this study took CHD and stroke into account. The difference between morbidities in the non-NBPHS group and those in the NBPHS group can be considered as morbidity averted because of the implementation of the program. The numbers of hypertensives with CHD at the 10-, 20- and 30-year horizons were 65,093, 83,165, and 69,293, respectively, while those of stroke were 386,888, 590,021, and 562,666, respectively (see Table 5.5).

Table 5.5 Numbers of hypertensives with CHD and stroke in the two groups projected

	CHD	Stroke
	Number of hypertensives	
10-year horizon	65,093	386,888
20-year horizon	83,165	590,021
30-year horizon	69,293	562,666

The number of people with CHD or stroke in the predicted year was also listed in the Markov results, where the year and ages were also displayed, and weighted by GDP or productivity to generate economic and social benefits. Details are provided in Appendix Tables C4.1-C4.4.

The economic benefit arising from the deaths and morbidity averted was calculated using a return on investment model developed by VISES. This model uses average productivity per worker to estimate the economic output produced. The growth path for this productivity is assumed to increase at a rate based on historical trends in China but approaches that of high income countries over time. The social benefit can be generated by multiplying the number of patients in each age and gender group in each year by 0.5 of GDP per capita in the specified year.

5.3.3 Return on investment and benefit-cost ratio

Using a standard model of economic evaluation, total economic and social benefits were calculated by aggregating all the above data in each year. GDP increases due to death and morbidity averted were calculated at the discount rates of 0, 2%, 3% and 5%. The projected economic benefits in NPVs would be 330,523 (87,674, 573,372), 210,745 (55,902, 365,588), 169,857 (45,056, 294,658) and 112,310 (29,791, 194,829) CNY for each discount rate. With social benefit included, the total benefit would be 605,047 (160,494, 1,049,600), 347,956 (92,298, 603,614), 267,297 (70,903, 463,691), and 161,698 (42,892, 280,504) million CNY. Benefit-cost ratios and internal rate of return were calculated with different estimates of the cost of hypertension management under the NBPHS. Given that hypertension management accounts for 14.59% of the NBPHS funding: the benefit-cost ratios would be 8.9 (2.36, 15.44), 6.6 (1.75, 11.45), 6.0 (1.59, 10.41), and 4.9 (1.30, 8.50), at the discount rates of 0, 2%, 3% and 5%; and if the social benefit is included, the benefit-cost ratios would be 25.1 (6.66, 43.54), 17.6 (4.67, 30.53), 15.4 (4.08, 26.72), and 11.9 (3.16, 20.64), at the discount rates of 0, 2%, 3% and 5%. The internal rate of return would be 14.6% (3.87%, 25.33%) if considering only the economic benefit, and 20.7% (6.45%, 42.15%) if social benefit is included. Details are provided in Tables 5.6 and 5.7.

Age-specific analyses were performed, which showed that the benefit-cost ratios and internal rate of return would be less than the all-age-group analysis. With age-specific analysis based on the CHS 2012-2015 data, at a discount rate of 3% and given that 14.59% of the NBPHS funding was spent on hypertension management, the BCR would be 5.9. With social benefit included, the BCR would be 15.1. The internal rate of return would be 14.7% and 20.4%. Details are in Appendix D.

Table 5.6 Cost and return on investment at different discount rates (million CNY)

Discount rate	0% (95%CI)	2%(95%CI)	3%(95%CI)	5%(95%CI)
GDP – deaths averted, NPV	330,523 (87,674, 573,372)	210,745 (55,902, 365,588)	169,857 (45,056, 294,658)	112,310 (29,791, 194,829)
Social benefit, NPV	605,047 (160,494, 1,049,600)	347,956 (92,298, 603,614)	267,297 (70903, 463691)	161,698 (42,892, 280,504)
Cost				
10% of the NBPHS funding	25,526	21,727	19,499	15,837
14.59% of the NBPHS funding	39,540	33,654	30,204	24,532
18% of the NBPHS funding	44,383	37,720	33,801	27,388

Table 5.7 Benefit-cost ratios at different discount rates and internal rate of return

Benefit-cost ratios	0% (95%CI)	2% (95%CI)	3% (95%CI)	5% (95%CI)	Internal rate of return (%)
18% of the NBPHS funding as cost					
GDP – deaths averted/cost	7.2 (1.91, 12.49)	5.4 (1.43, 9.37)	4.8 (1.27, 8.33)	3.9 (1.03, 6.77)	12.9 (3.42, 22.38)
GDP – deaths averted plus social benefit/cost	20.4 (5.41, 35.39)	14.3 (3.79, 24.81)	12.5 (3.32, 21.68)	9.6 (2.55, 16.65)	18.8 (4.99, 32.61)
14.59% of the NBPHS funding as cost					
GDP – deaths averted/cost	8.9 (2.36, 15.44)	6.6 (1.75, 11.45)	6.0 (1.59, 10.41)	4.9 (1.30, 8.50)	14.6 (3.87, 25.33)
GDP – deaths averted plus social benefit/cost	25.1 (6.66, 43.54)	17.6 (4.67, 30.53)	15.4 (4.08, 26.72)	11.9 (3.16, 20.64)	20.7 (5.49, 35.91)
10% of the NBPHS funding as cost					
GDP – deaths averted/cost	12.9 (3.42, 22.38)	9.7 (2.57,16.83)	8.7 (2.31,15.09)	7.1 (1.88,12.32)	17.9 (4.75, 31.05)
GDP – deaths averted plus social benefit/cost	36.7 (9.73, 63.67)	25.7 (6.82, 44.58)	22.4 (5.94, 38.86)	17.3 (4.59, 30.01)	24.3 (6.45, 42.15)

5.3.4 CoI analysis

The CoI of hypertension, CHD and stroke were calculated using the CoI framework. Among the 9,166 hypertensives, 1,047 patients with CHD, and 736 patients with stroke, the number of patients under two-week healthcare and inpatient care were extracted. The results were used for weighting expenditure in the hypertensive population. Details are provided in Table 5.8.

Table 5.8 Expenditure of hypertensives who sought healthcare in the year prior to the CNHDRC survey 2014

	Hypertension controlled	Hypertension uncontrolled	CHD	Stroke
Number of patients	7,054	2,112	1047	736
Two-week healthcare expenditure (CNY)	392,167	87,945	118,981	113,839
Annual inpatient care expenditure (CNY)	1,856,960	680,683	4,457,273	6,338,632

Based on total direct CoI of hypertension, CHD and stroke, and the number of patients for each disease in the hypertension-controlled and uncontrolled groups, the annual CoI of the three diseases was generated. The CoI of hypertension in the hypertension-controlled group was more than that of the hypertension-uncontrolled group. It is hypothesized that the CoI of CHD and stroke in the two groups are the same. The results are presented in Table 5.9 below.

Table 5.9 Annual direct CoI of hypertension, CHD and stroke, based on the CNHDRC survey 2014 (CNY)

	Annual direct CoI
Hypertension	
Blood pressure controlled	1,708.72
Blood pressure uncontrolled	1,404.95
CHD	7,211.82
Stroke	12,633.76

Through the Markov model, the probabilities of each illness (hypertension only, hypertension with CHD, and hypertension with stroke) were projected for the 30-year period from 2016. Aggregated person-years were generated from the above results, as shown in Table 5.10. This denotes that in each age-gender group, there were many more CHD and stroke patients in the non-NBPHS scenario than in the NBPHS scenario.

Table 5.10 Aggregated person-years for each illness at the end of the 30-year predicted period

	NBPHS (hypertension-controlled)			Non-NBPHS (hypertension-uncontrolled)		
	Hypertension	CHD	Stroke	Hypertension	CHD	Stroke
Male						
35-44	15,774,791	385,036	494,318	15,236,919	563,014	763,971
45-54	28,925,971	1,042,323	2,618,662	26,704,540	1,402,874	4,050,810
55-64	26,811,417	2,324,601	6,108,210	22,235,813	2,855,632	8,843,384
65-74	11,093,710	1,542,623	3,806,906	8,217,278	1,862,944	5,172,743
75-84*	2,829,335	526,010	975,734	1,633,406	674,884	1,385,107
85+**	267,002	34,976	69,733	220,257	41,678	85,155
Female						
35-44	9,528,274	89,048	294,487	9,265,155	106,115	497,553
45-54	27,035,525	712,319	2,560,542	25,036,257	810,456	4,103,754
55-64	30,016,795	2,139,024	6,489,494	25,131,870	2,354,465	9,785,280
65-74	14,108,563	1,623,837	4,397,236	10,797,864	1,771,355	6,136,027
75-84*	4,322,289	775,930	1,325,807	2,677,173	875,451	2,001,330
85+*	569,880	71,819	127,464	442,573	85,147	174,885

Note: * The prediction duration of the age group 75-84 and 85+ is 20 years and 10 years, respectively, because of parameter availability and average life expectancy in the Chinese population.

Total direct CoI in the projected 30 years of the two groups was calculated through weighting the total person-years by CoI of hypertension, CHD and stroke. The results showed that the total direct cost of hypertension, CHD and stroke for the hypertension-controlled group in the projected 10, 20, and 30 years was 262,141.37, 521,912.78, and 738,025.82 million CNY, respectively, and for the hypertension-uncontrolled group was 272,198.41, 576,172.47, and 847,288.39 million CNY, respectively, without consideration of the discount rate. There was a difference of 111,416.33 million CNY between the cost of hypertension in the uncontrolled group and the controlled group. Given that the investment for hypertension was 35.97 billion CNY (14.90% of the total NBPHS investment), the CoI saved from hypertension was calculated as 3.10 times the investment. As CoI was only used as a reference for analysis, whose results were not used in the main analysis, 95% CI were not calculated. Details are provided in Table 5.11.

Table 5.11 CoI of the two groups over the projected years (million CNY)

	NBPHS scenario	Non-NBPHS scenario	COI averted
10-year horizon	262,141.37	272,198.41	10,057.04
20-year horizon	521,912.78	576,172.47	56,412.80
30-year horizon	738,025.82	847,288.39	111,416.33

5.4 Discussion

The potential health and economic benefits of hypertension management are very high. It was calculated that such an intervention as the NBPHS had the potential to avert 744,000 deaths in China over a 30-year period. In addition to the health benefits, investment in implementing these interventions would generate broader benefits to the economy. At the discount rate of 0, 2%, 3% and 5%, the projected economic benefits in NPVs would be 330,523, 210,745, 169,857 and 112,310 million CNY, respectively, and with social benefit included, the total benefit would be 605,047, 347,956, 267,297, and 161,698 million CNY, respectively. Benefit-cost ratios and internal rate of return were calculated with different estimates of the cost of hypertension management under the NBPHS. Given that hypertension management accounts for 14.59% of the NBPHS funding: the benefit-cost ratio would be 6.0 at a discount rate of 3%, and if the social benefit is included, the benefit-cost ratio would be 15.4 at the same discount rate. The internal rate of return is 14.6% if considering only the economic benefit and 20.7% if social benefit is included. These results are higher than those in a recent study conducted on investing in NCDs, which suggested an average ratio of 5.6 for economic returns and 10.9 if social returns are included (Bertram et al., 2018). This means that hypertension management delivered by a primary care system under the NBPHS represents a very high return on investment.

To address the concern that such an investment may increase the cost of hypertensive treatment, the total direct cost of hypertension, CHD and stroke were analyzed. The results show that 111,416.33 million CNY would be saved in the projected period, with no discount rate considered. Given that the investment for hypertension is 35.97 billion CNY (14.90% of the total NBPHS investment), the CoI saved from hypertension management is 3.10 times the investment.

The results also show that the social benefit is greater than the economic benefit. The reasons are twofold: the health outcomes generated from the younger groups are less efficient than those from the older groups, as discussed in Chapter 3. As indicated by the economic evaluation model, the labour force participation and productivity rates of young people are much higher than for their older counterparts. If further measures can be taken on young hypertensives, more young lives will be protected and much greater economic benefits will be generated.

This chapter has discussed the development of an integrated economic evaluation framework for hypertension based on previous studies. Using epidemiological parameters that have been well validated and calibrated (D. Gu et al., 2015, 2008), a health outcome model based on a Markov process was developed in terms of CVD mortality and morbidity. Following the studies of VISES (Bertram et al., 2018; Chisholm et al., 2016; Sheehan et al., 2017; Stenberg et al., 2014; Sweeny et al., 2019), a social and benefit estimation framework was developed and applied in this study. In this sense, this study contributes to the knowledge of economic evaluation on hypertension management through primary care in China.

The model was based on previous studies that conducted benefit analyzes with similar frameworks on mental health (Chisholm et al., 2016), CVDs (Bertram et al., 2018), maternal and child health (Stenberg et al., 2014), and adolescents (Sheehan et al., 2017; Sweeny et al., 2019). This study developed a framework for hypertension interventions in the Chinese primary healthcare settings, which may be used for rolling out other healthcare programs in China or in other developing countries.

This study conducted a conservative analysis. It may have underestimated the benefits from the following three aspects:

(1) In the Markov model, CHD and stroke as consequences of hypertension are considered here, which may underestimate the benefit. It is known that kidney diseases can also

result from hypertension (P. A. James et al., 2014). However, because the epidemiological parameters were not accessible, kidney diseases were not considered.

(2) The cut-off age for economic benefit estimation was set at the age of 70, which was based on the labour force participation rate and previous frameworks (Bertram et al., 2018; Stenberg et al., 2014). However, a recent study from the World Bank argued that people do not become economically inactive just because they reach a certain age. Older people can be part of the labour force as household participants, volunteers, and in mobilizing other community activities (Flochel, Ikeda, Moroz, & Umapathi, 2015). With the growth in number and proportion of older people globally, more and more measures are needed to explore and release the productivity of the elderly (Murrugarra, 2011).

(3) The social value of a life year is considered to be 0.5 GDP per capita, which is also quite conservative. Previous reviews have provided a broad range for the value of a life year, which is 2-4 times GDP per capita (Stenberg et al., 2014). Following the published studies on NCDs, by distinguishing between the social and economic components, the social benefit of each life year was assigned a value of 0.5 GDP per capita to people aged 70-80 years (Bertram et al., 2018). However, as China is aging rapidly, healthy life expectancy will be prolonged (S. L. James et al., 2018), with a lot more people living healthy lives beyond the age of 80 years. This means more social benefit will be generated.

Limitations: This estimate of the costs and benefits of increased investment in hypertension management is elementary, and estimates would change with different assumptions. However, both the economic and individual health benefits were predicted to be more than five times the costs by 2045. So, the economic and social returns on investment studied here would be very high, and this would be unlikely to change with reasonable variations in assumptions.

5.5 Conclusion

This study has indicated that the potential health and the economic benefits of hypertension management under the NBPHS are very high. The benefit-cost ratio would be 6.0, given that the cost of hypertension management accounts for 14.59% of the NBPHS investment; and with social benefit included, the benefit-cost ratio would be 15.3, at a discount rate of 3%. An economic evaluation framework for hypertension management has been developed and can be applied to other chronic diseases in primary healthcare settings in or out of China. If further investment is made on younger hypertensives, much more will be gained in terms of labour force participation and productivity improvements.

Chapter 6 Discussion and conclusion

6.1 Summary of the thesis

In this thesis, the impact of the NBPHS on hypertensives from 2009 to 2015 in China has been estimated, in terms of hypertension control, morbidity and mortality averted, and economic and social benefits generated.

6.1.1 Hypertension control from the NBPHS

According to the 2009 *Opinion on deepening health system reform in China* (Communist Party of China Central Committee, 2009), the NBPHS represented the largest investment in hypertension management from 2009 to 2015 (WHO, 2016; Xiao et al., 2014; Yip et al., 2012). Considering the NBPHS as an incremental investment into a primary care system on hypertension control, this study sought to quantify the number of hypertensives who were able to get their blood pressure under control because of the program. To this end, a small-sample time series model of hypertension control rates from 1991 to 2009 was established to analyze the trend of hypertension control before 2009.

To access national representative data before 2009, a full literature review was conducted, and the CHNS data were used as the main source, supplemented by data from the reviewed publications. Control rate data for each year from 1991 to 2009 were completed using a Lagrange interpolation polynomial method (discussed in Chapter 3). Using a time series prediction model based on the data from 1991 to 2009, the predicted control rate for 2015 was calculated as 10.46% (95%CI: 7.33%-13.59%). Using data from the CHS 2012-2015 as observed information, the incremental effectiveness from the trend analysis was 4.26% compared with the observed control rate (14.72%) of hypertension in 2015. Based on population data extracted from the 2010 Chinese Census, it was estimated that 9,532,719 hypertensives had their BP properly controlled (under 140/90 mmHg).

In addition, age-specific trend analyzes of hypertension awareness, treatment and control were undertaken based on data from 1991 to 2015. It was found that the highest awareness and treatment rates were in the 65-74 age group, and the highest control rates were observed among the 55-64 age group. This indicated that people aged over 55 years were under the best hypertension management and younger patients were in an unsatisfactory management status. Further analysis demonstrated that poor awareness was responsible for unsatisfactory management among the young hypertensives.

Although there were some uncertainties, this analysis provided a method of estimation of the effectiveness of a large interventional program for hypertension in China. The unsatisfactory management status of young hypertensives provides a guide to policy priorities in the next stages of the NBPHS.

6.1.2 Estimation of the long-term health outcomes from the NBPHS

Based on the incremental number of hypertension patients under control, two scenarios were established for evaluating long-term health outcomes. In the NBPHS scenario, the 9,532,719 hypertension patients had their BP properly controlled, while in the non-NBPHS scenario, the 9,532,719 hypertension patients did not have their BP properly controlled.

Multi-factor risk analysis of developing CVDs was undertaken with a sample of hypertensives from the 2009 CHNS to simulate the two scenario groups (Guo et al., 2015a; Xi et al., 2012b). It was discovered that the most significant risk factor for CVDs was blood pressure level, where blood pressure, diabetes, blood cholesterol, smoking, and BMI were considered.

To make long-term projections, a Markov model was established following the CDPM, which had been well developed and calibrated. For the NBPHS scenario, the model parameters determining the disease transitions were extracted from a recent published study (D. Gu et al., 2015); as for the non-NBPHS scenario, the parameters were weighted by risk ratios of the two scenarios for each age-gender group according to BP and risk of CVD in China (D. Gu et al., 2015; Moran et al., 2008).

The expected numbers of deaths under the NBPHS scenario with hypertension management were calculated by age and gender and used to compare with the hypothesized scenario (the non-NBPHS). The non-NBPHS scenario had a much higher incidence of CVDs and deaths compared with that of the NBPHS scenario. At the end of the 30th projection year, 25,012, 296,258, and 744,493 hypertensive patients would be protected from CHD, stroke and death, respectively. In addition, the Markov model provided estimates of the number of hypertensives, CHD, stroke, CVD-related deaths, and non-CVD deaths each year during the projected period.

6.1.3 Cost, benefit and return on investment analysis of the NBPHS

From 2009 to 2015, over 246.57 billion CNY (around 36.64 billion USD, at an exchange rate of 6.73 CNY per USD) was invested in the NBPHS. It was estimated that about 10% to 18% (three estimates were employed for further calculation, which were 10%, 14.59% and 18%) (How et al, 2016; Jq et al., 2015; Xiao et al., 2014; Zhao et al., 2015) of the fund was used for the management of hypertension. These estimates – 24.66 billion, 35.97 billion and 44.38 billion CNY, which were 0%, 14.59% and 18% of the fund, respectively – were used for a range of further analyzes on the cost of the NBPHS on hypertension management from 2009 to 2015.

A benefit-cost metric was employed for economic evaluation in this study from a societal perspective. Based on the VISES innovative framework of economic evaluation on health interventions (Bertram et al., 2018; Stenberg et al., 2014), economic and social benefits were estimated based on labour force participation and GDP increases resulting from deaths prevented and morbidity averted. The economic benefits were estimated based on increased workforce participation of the working age population. The estimation was made on hypertensives with a maximum age of 70 years. Social benefit was considered equal to 0.5 GDP per capita, where estimation was made on hypertensives with a maximum age of 80 years.

At the discount rates of 0, 2%, 3% and 5%, the projected economic benefits in NPVs would be 330,523, 210,745, 169,857 and 112,310 million CNY, respectively, and with social benefit included, the total benefit would be 605,047, 347,956, 267,297, and 161,698 million CNY, respectively. Benefit-cost ratios and internal rate of return were calculated with different estimates of the cost of hypertension management under the NBPHS. Given that hypertension management accounts for 14.59% of the NBPHS funding, the benefit-cost ratio would be 6.0, at a discount rate of 3%; and if the social benefit is included, the benefit-cost ratio would be 15.4 at the same discount rate. The internal rate of return would be 14.6% if only considering economic benefit and 20.7% if social benefit is included. This is higher than the result of a recent study conducted on investing in NCDs, which demonstrated that the average ratio would be 5.6 for economic returns and 10.9 if social returns are included (Bertram et al., 2018). This means that hypertension management delivered by the primary care system under the NBPHS represents a very high return on investment.

To check whether such an investment may increase the cost of treatment of hypertensives, the total direct cost of hypertension, CHD and stroke based on previous studies (Qin et al., 2014; WHO, 2009) and available datasets (Qin et al., 2019) was analyzed. The results show that 92,841.07 million CNY will be saved in the projected period with no discount rate considered. Given that the investment for hypertension is 35.97 billion CNY (14.90% of the total NBPHS investment), the CoI saved from hypertension would be 2.58 times the investment.

6.2 Contribution to knowledge and policy implications

The economic evaluation framework of hypertension management under the NBPHS presented in this study highlights some important findings that have implications for policy-makers in China.

6.2.1 A good return on investment for hypertension management under the NBPHS

This study provided an overall effectiveness estimation of the NBPHS focused on hypertension control at the national level. It demonstrated that interventions through the NBPHS on hypertensives can result in improvement in awareness, treatment and control, substantial reductions in mortality and morbidity, and an increase in benefits.

Compared with the non-NBPHS scenario, it was estimated that with the implementation of the NBPHS, from 2009 to 2015, 9,532,719 hypertension patients had their BP properly controlled. Based on this, it is estimated that 744,493 deaths would be prevented in the period 2016 to 2045 in China. It was estimated that a one-dollar input could generate a 6.0 to 15.2 dollar output when comparing the investment with economic and social benefits, using NPV with a discount rate of 3.0%. Another study, from which economic metrics were also drawn for this study, reported that the benefit-cost ratio of the maternal and child health program in China was 3.8 (Stenberg et al., 2014). This program was implemented in 2005-2006, aimed at elevating the number of births through hospital delivery and reducing maternal mortality. The Stenberg (2014) study further confirms the research conclusions of other studies, including the findings of the CHS 2012-2015 (Z. Wang et al., 2018), which concluded that the improvement in hypertension levels may be partially attributed to healthcare reform and community-based standardized BP management programs launched by the government.

The high benefit-cost ratio in this evaluation of the NBPHS indicates that for chronic disease interventions, it was a good decision to invest in the primary care system in China. It is significant that the management of chronic disease could combat the CVD challenge. These findings might also encourage further financial investment from the government.

6.2.2 A way to go to achieve policy goals

The latest statistical data showed that by the end of 2017, the number of hypertensives under the control of NBPHS primary care facilities had reached 101.04 million. The CHS 2012-2015 revealed that the number of hypertensives aged 35+ in 2015 was 246,479,307. This means that about 41% of all hypertensives aged 35+ and 88% of hypertensives with some level of awareness were under the management of the NBPHS program. However, more than half of hypertensives, unaware of the onset of hypertension and its related conditions, were still not covered by the program.

A number of studies have been conducted on the PATC of hypertension at regional and national levels. For example, Dianjiang Li et al. (2015) conducted a systematic review of hypertension burden and control in mainland China through an analysis of nationwide data from 2003 to 2012. They reported that 48 studies before 2012 provided prevalence data, while 30 studies provided awareness, treatment and control data. D. Li et al. (2015) also found that among hypertensive patients aged 20 to 79 years, the awareness, treatment and control rates were 44.6%, 35.2% and 11.2%, respectively.

The most recent and largest-sample study, with results published in *The Lancet* in October 2017, reported that the awareness, treatment and control rates of hypertensive adults aged 35-75, were 36.0%, 22.9% and 5.7%, respectively (Lu et al., 2017). Although a convenience sampling strategy was employed, which may compromise the representativeness of the sample, the results reflected the unsatisfactory status of hypertension management in China. Results from the CHS 2012-2015 indicated that hypertension PATC rates among adults aged 18 years or above, were 23.2%, 46.9%, 40.7% and 15.3%, respectively (Z. Wang et al., 2018). Although the awareness, treatment and control rates improved after 2009, there were still gaps compared with international levels (Bundy & He, 2016; D. Li et al., 2015). Global comparisons also indicated that the effectiveness of hypertension management in China was far from satisfactory. Although the hypertension management care package was designed to improve awareness, treatment and control rates, these rates were still at a relatively low level nationally (Y. Li et al., 2017; Lu et al., 2017; Shen et al., 2018; Z. Wang et al., 2018). This presents some policy implications, which are explained as follows.

First of all, further investment should be made into hypertension management in the primary care system through the NBPHS. Such a conclusion is drawn from the evidence of the benefit-cost analysis. In addition, a previous study by the author and supervisor concluded that the management of hypertension played a role in hypertension control that was independent of medication compliance (Qin et al., 2019).

Secondly, it is necessary to take measures to strengthen the primary healthcare system in China, such as in the capacity building of human resources and information systems (K. Huang, Song, He, & Feng, 2016). Although all enablers are important, several factors should be further prioritized, and root causes of unsatisfactory hypertension management need further clarification. The root cause can be summarized as a “weak primary care system”, and factors include insufficient investment, lack of high quality workers, and the low capacity of healthcare delivery (Hou et al., 2016b; Lu et al., 2017; Xiao et al., 2014).

Lack of high quality workers in the primary care system has been discussed frequently (Hou et al., 2016b; Xiao et al., 2014). According to the author’s experience, the root causes of the lack of high quality workforce are twofold. The first is that the policy design for the implementation of the NBPHS was irrational. The NBPHS was implemented in primary care settings in 2009 in a nation-wide manner. Among all the service items, some were implemented even before 2009, such as vaccination and infectious disease reports, and some were additional, such as the management of hypertension and diabetes, and the health management of aged people. However, the number of health staff in primary care facilities, known as “bianzhi”, was determined based on services before 2009. “Bianzhi” was the number of staff determined for public institutions according to their function in China (G. Xu, 2010). For example, the staffing standard policy for community health service facilities was released in 2006. This defined the healthcare delivery function and gave CHS facilities a staffing standard of 7-8 health staff members for every 10,000 citizens (State Commission Office of Public Sectors Reform, 2006). In rural areas, the staffing standard was revised in 2011 to one health staff member per 1,000 citizens and required a recheck of staffing standards every five years (State Commission Office of Public Sectors Reform, 2011). Although in rural areas the staffing standard was adequate for China as it was released after 2009, it was far more difficult to enroll health professionals (Xiao et al., 2014). It is also more difficult to incentivize staff in primary facilities as the salary is lower than in other health facilities in China, plus a sound performance-oriented management system has not yet been established (Qin, Zhang, Lin, Zhang, & Zhang, 2016). Therefore, it is difficult to attract new medical and public health graduates, and retain qualified professionals in these facilities (Xiao et al., 2014).

For chronic disease management, a sound information system is also needed to collect accurate data for performance evaluations. However, if one is put in place, the primary care facilities in China do not have the technological capabilities to manage evaluations. In an article published in *Chinese Health Economics* in 2017 (Y. Zhang, Qin, Zhang, & Lin, 2017), the importance of improving information systems for primary healthcare practice in China is explained, using the UK Quality and Outcome Framework as an international example.

Some researchers have argued that drug accessibility and availability has also influenced the unsatisfactory disease management status of hypertension, indicating that although low-cost generic anti-hypertensive medications are available, the current treatment approaches are still ineffective (Hesketh & Zhou, 2017; Z. Wang et al., 2014).

Two recent studies analyzed trends in hypertension awareness, treatment and control in 12 high-income countries (Zhou et al., 2019) and the state of hypertension care in 44 low- and middle-income countries (Geldsetzer et al., 2019). These studies revealed that high-income countries had a much better performance on hypertension management than low-income countries, and the analysis of hypertension management performance of low-income countries concluded that higher GDP per capita is an important contributor to hypertension control. However, among the low- and middle-income countries, some had good performance on hypertension control, such as countries in Latin America and the Caribbean (Geldsetzer et al., 2019). China is among the low- and middle-income countries. It is worthwhile for China to learn from similar countries to improve performance on hypertension management.

Another concern is that China has obvious regional differences. Several studies have evaluated the NBPHS program on hypertension control in China across different regions, such as Beijing (X. Wang et al., 2012), Shanghai and Shenzhen (Haitao Li et al., 2015), and Gansu and Zhejiang (Hou et al., 2016). These studies revealed that the impact of the NBPHS varied from region to region. For in-depth analysis, the author conducted a regional analysis at the national level using the household interview survey data (discussed in Chapter 5) (Qin et al., 2019). In this analysis, regression analysis is used to estimate the impact of management provided under the NBPHS on hypertension control, adjusting for the effects of other determinants. From this analysis, a high interaction between hypertension management and geographical region was detected. Further analysis demonstrated that the primary healthcare information management system is the main factor accounting for the difference across regions, which has been highlighted above.

6.2.3 Hypertension management of younger patients should be strengthened

This study also found, in line with previous studies (Hou et al., 2016; Y. Li et al., 2017), that older hypertensives were managing their hypertension better than their younger counterparts, for whom the status of disease management was poor.

This study linked all studies on prevalence, awareness, treatment and control together through trend analysis and provided evidence by analyzing the relationship between prevalence, awareness, treatment and control, especially in age-gender specific characteristics. The positive focus on the aged was also the result of the design of the project (Yip et al., 2012). One of the reasons for this was that among the NBPHS items, several others were focused on older people's health management, including health record files, and health education programs. These records provided overlapping effectiveness data on hypertension control. However, in-depth analysis revealed that the treatment control rate of younger patients was a little better than that of the aged patients. For example, the treatment control rates of the 35-44, 45-54, 55-64, 65-74 and 75+ age group were 40.4%, 40.0%, 38.7%, 34.8% and 32.6%, respectively. This denoted that among the young hypertensives, poor awareness was responsible for unsatisfactory management.

As discussed in Chapter 5, the social benefit generated is more than the economic benefit. One of the reasons for this is that the health outcomes generated from younger groups are less efficient than those of the aged group. As indicated in the economic evaluation model, the labour force participation and productivity rates of young people are much higher than those of their older counterparts, and for the aged group, benefit is mainly generated from a social perspective. If further measures can be taken on young hypertensives, more young lives will be protected from premature death and more economic benefits will be generated.

6.2.4 Evidence-based policy making can be strengthened

This study provides a framework of policy tools for a return on investment framework in evaluating healthcare programs at both national and regional levels. Such an approach can be applied to other areas and systems. The Chinese government established an investment mechanism in the NBPHS, which steadily increased by 5 CNY per capita each year. It is now necessary to ascertain whether such an increase was enough for further policy measures. In addition, a dynamic adjustment mechanism should be established in the NBPHS service package for service items in the program, such as hypertension management. To these ends, the effectiveness analysis framework and economic evaluation framework of this study can be applied from financial or social perspectives.

6.3 Strength and limitations

6.3.1 An integrated evaluation of health outcomes is established

First, this research increased our knowledge of the feasibility and desirability of applying a comprehensive framework to evaluating chronic disease management programs in community health organizations (CHOs) in China. The dynamic process of hypertension management evaluation can be simulated based on the data of prevalence, awareness, treatment and disease control, including complications of CVDs.

The small-sample time series model established in this study has provided a perspective from which to analyze the impact of the NBPHS on hypertension control. This excluded the impact of socio-economic confounding. To identify the impact of interventions, most of the time, case-control or intervention-control design was needed (Husereau et al., 2013; G. Liu et al., 2011). This study made it possible to evaluate a healthcare program in a data-limited environment.

By developing an epidemiological framework and a Markov model, a longer-term projection model for health outcomes of CVDs was established. By employing the CHNS 2009, the analysis considered other factors of CVD risks, including bio-marker information. Through relationship analysis of the CHS 2012-2015 (Z. Wang et al., 2018) data and hypertension management statistical data from the National Health Commission, this study analyzed hypertensives according to age-gender structures. This strengthened the representativeness of the study. To the knowledge of the author, this is the first study to evaluate the NBPHS program in China at the national level in an integrated manner.

6.3.2 An innovative model of economic evaluation is developed

Economic evaluations of hypertension management and interventions have been developed in many countries. In Vietnam, a screening program for managing identified hypertension to prevent CVDs was evaluated from an economic perspective with a cost-effectiveness framework (Nguyen et al., 2016). In Greece, the economic benefits of hypertension control was quantified, concluding that cardiovascular events prevention by controlling blood pressure could avert morbidity, thereby leading to great cost savings (Athanasakis et al., 2015). However, such evidence was much less developed in China. It also overcame the contingent deficiency of benefit estimation in traditional economic evaluation frameworks (Drummond et al., 2015).

An integrated economic evaluation framework on hypertension was developed based on previous studies. In China, Gu et al. (2015, 2008) provided calibrated epidemiological parameters for the estimations of health outcomes in terms of CVD mortality and morbidity. Based on the VISES economic approach (Bertram et al., 2018; Stenberg et al., 2014), a social and benefit estimation framework was developed and applied to this research. As reviewed in Chapter 2, the most recent and integrated studies for economic evaluation on hypertension were both from medical treatment perspectives (D. Gu et al., 2015; Xie et al., 2018). In this sense, this study added knowledge to economic evaluation on disease management of hypertension in primary care settings in China.

The benefits of the hypertension management program as identified in this research include, not only the cost of disease interventions avoided and human capital gained, but also an individual's impact in society, in terms of social value, which equals to 0.5 GDP per capita for each life year (Bertram et al., 2018; Stenberg et al., 2014).

6.3.3 Strengths of the study

Although many models and estimations were undertaken in this study with a level of hypothesizing, accuracy was improved by adopting a multi-factor analysis model for CVD risk estimation with the latest epidemiological data (Gu et al. 2008, 2015) and employing national representative data. This allowed for the generation of scenario modelling, based on evidence-based global epidemiological protocols. This analysis aligns with previous and ongoing modelling efforts (Drummond et al., 2015; D. Gu et al., 2015; Stenberg et al., 2014), and made full use of the data currently available in China, as highlighted in the methods section. Moreover, the analysis made a start to identify and estimate the economic benefits from averted morbidity, instead of only reduced mortality for NCDs in China. This is applicable to other interventions, such as diabetes, mental health problems and even cancers.

A series of data were extracted and used to improve the accuracy of the analysis. A full literature review was used to extract data on hypertension PATC from 1991 to 2018, providing a good basis for time series analysis. The CHNS 2009 database, which provided bio-marker data of hypertensives in China, was employed to analyze CVD risks in hypertension-controlled and uncontrolled scenarios. Well-calibrated parameters of CVD risks from a recent study by Gu et al. (2015), who were among the pioneers leading CVD studies in China, were employed for long-term health outcome estimation under a Markov model. The CHS 2012-2015 and the 2010 Chinese Census were used to improve the representativeness of the analysis in terms of age-gender structure.

6.3.4 Limitations

6.3.4.1 Data availability

In this study, a clear pathway for estimation of direct and long-term health outcomes, and economic impact was established. Although data from different sources were accessed, there was still a limitation in terms of the precision of calculations. Like most economic modelling, a hypothesis was applied when no data was accessible. Although a full literature review was employed for extracting data from the past 30 years, the CHNS data was used as the main source. Experts at a meeting conducted in February 2019 pointed out that the data may not be as representative as that of the China Hypertension Survey, considering survey point selection and sample size.

Another limitation in terms of data is that for multi-factor CVD risk analysis, this study adopted the 2009 data as a compromise. Although the CHNS 2015 was released before the submission of the thesis, it did not provide the 2015 bio-marker data. If 2015 data could be accessed, the accuracy of the analysis would be further improved. A further limitation, as discussed in Chapter 4, is that the parameters of CVD risk estimation for people aged 75+ year were not available.

6.3.4.2 The hypothesis in the modelling may underestimate the benefits

In the Markov modelling process, CVD was put in a Markov chain, 28-day-fatal CVD was only considered to happen once in the whole process of estimation, which may underestimate the benefits generated. In addition, to estimate the health consequences of hypertension, only CVDs were considered. Other health consequences, such as kidney disease (P. A. James et al., 2014; Penaloza-Ramos et al., 2015), were not considered. This may be another cause for underestimation of benefits.

In addition, there is still a debate in social benefit estimation about how much should be assigned on a life year as social benefit. In this study, the value of 0.5 GDP per capita is conservative and may have underestimated the benefits generated (Stenberg et al., 2014).

6.4 Conclusions and policy recommendations

First, the results generated are significant for further studies and policy making. This research calculated the amount of money to be saved from the interventions by the NBPHS, providing evidence for the investment in chronic diseases at the primary care level in monetary terms. This research built on Stenberg et al.'s study (2014), which showed very high returns for such interventions (4.8 for economic benefit and 8.7 for total benefits at a discount rate of 3% for the period to 2035) in women and children's health. In comparison, the NBPHS program had a higher return to investment ratio, creating an enormous impact in this field in terms of research, policy making and implementation.

This study enriches the scarce economic evaluation evidence on hypertension management in China. Sensitivity analysis was performed by varying estimates of cost and discount rates. This is applicable to other items of the NBPHS program, and of its value to other health interventions, such as cancer screening and early interventions in China.

Second**,** this study indicated the great benefit of hypertension interventions in primary healthcare settings in China and the necessity for further investment in the management of hypertension. This research has provided the Ministry of Health with a framework from this perspective, as well as an indication of how much more is needed to better implement the program. The findings of this research enhance our understanding of the reasons for prioritizing such investments to reduce the burden of NCDs in China.

Policy recommendations to the government are summarized in three points.

(1) To further implement the NBPHS program in terms of increased investment and strengthening the primary healthcare system through its human resources systems.

(2) To strengthen information management systems and improve the performance evaluation of primary healthcare facilities (Y. Zhang et al., 2017). Information technologies should be applied to chronic disease management to improve their performance and work efficiencies (WHO, 2016).

(3) Young hypertensives and people at high risk should be prioritized in the next stage of the NBPHS. Most young patients are part of the workforce and assume that they are in good health.

There has been a call for developing functional community healthcare facilities in China that mainly provide healthcare services to employees of companies or work units. So far, however, these facilities have had poor results (X. Liu et al., 2013; F. Wang et al., 2012). Other young patients are part of the migrant population, which denotes that healthcare services should be strengthened for this population group (Zhu, 2007).

6.5 How further progress can be made

When considering the benefit estimation framework, societal gains will be generated not only in the health sector, but also in economic growth and social empowerment. Some of these benefits were difficult to calculate. To enhance the understanding of the potential societal gains of investment in NCDs, subsequent analysis is recommended to explore the impact of reducing NCDs regionally based on previous work.

Regarding further study in China, the following investigations would be beneficial: (1) case studies on specific regions can be undertaken based on the framework established at the national level; (2) a cohort study on chronic diseases in primary care settings could be conducted, providing accurate information on blood pressure, diabetes, smoking status and other risk factors for CVDs; and (3) the economic analysis approach used in this study could be applied to other items of the NBPHS, such as diabetes management, serious mental disease management, and other health programs in China.

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Appendices

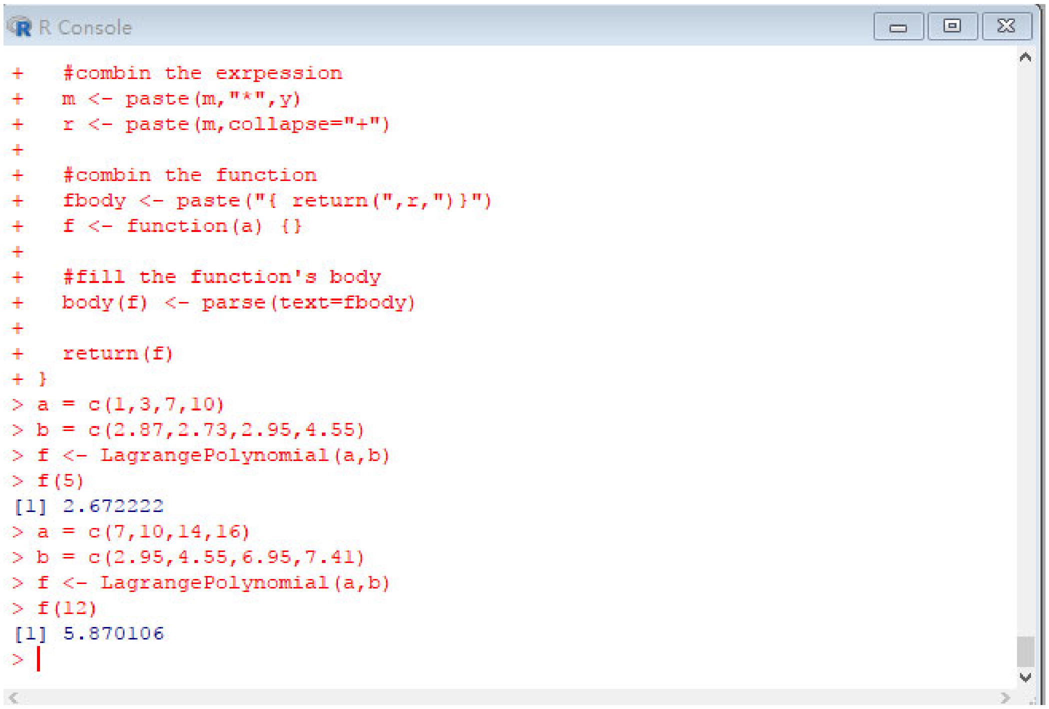
Appendix A Supplementary material for Chapter 3

Table A1 Hypertension PATC of different age groups in China, 1991-2015

	1991	1993	1997	2000	2004	2006	2009	2011	2015
Prevalence									
18-24	2.44	4.21	4.70	3.65	4.50	3.71	3.80	2.37	4.00
25-34	3.74	5.92	6.59	6.35	6.94	5.80	7.84	5.95	6.10
35-44	9.50	9.87	12.14	12.93	13.67	13.41	14.82	12.11	15.90
45-54	16.95	18.06	22.12	22.33	22.92	22.16	28.66	26.48	29.60
55-64	32.84	33.43	36.61	36.71	36.36	33.55	38.88	38.76	44.60
65-74	45.56	44.53	51.97	50.74	49.64	45.83	53.56	49.20	55.70
75+	52.44	51.97	53.53	53.58	56.39	53.05	58.35	54.74	60.20
Awareness*									
18-24	8.82	7.84	6.12	3.03	0.00	11.11	0.00	7.14	5.70
25-34	22.97	7.92	7.87	11.40	9.47	11.94	9.72	9.64	14.70
35-44	23.04	15.46	9.78	18.95	20.08	20.43	22.36	37.81	31.70
45-54	27.18	28.00	20.85	35.37	34.02	38.02	39.78	51.07	47.00
55-64	36.08	41.12	22.86	38.97	44.47	53.02	48.50	60.41	53.90
65-74	30.08	36.25	32.97	44.39	48.25	55.18	55.52	65.32	58.60
75+	19.49	22.69	25.69	32.56	42.91	49.04	51.38	68.15	57.30
Treatment*									
18-24	0.00	3.92	2.04	0.00	0.00	0.00	0.00	0.00	3.40
25-34	9.46	2.97	3.15	4.39	3.16	4.48	6.94	2.41	8.40
35-44	8.90	5.15	5.78	9.82	13.64	15.05	15.85	24.38	24.50
45-54	14.56	13.33	12.39	21.89	22.54	26.59	28.10	40.64	40.30
55-64	23.58	27.51	15.83	26.77	33.58	39.50	40.63	51.12	48.10
65-74	18.70	22.50	24.59	35.20	36.29	43.97	48.34	56.75	52.80
75+	13.56	16.81	15.28	21.51	35.22	40.23	44.00	60.42	52.10
Control*									
18-24	0.00	3.92	0.00	0.00	0.00	0.00	0.00	0.00	0.60
25-34	4.05	1.98	0.00	1.75	1.05	1.49	2.78	0.00	3.30
35-44	2.62	1.55	2.67	2.81	4.17	3.58	5.69	7.07	9.90
45-54	2.43	2.67	2.82	4.21	6.97	7.91	8.03	14.84	16.10
55-64	4.55	5.62	2.51	6.00	9.38	10.50	12.02	20.91	18.60
65-74	2.44	2.50	4.59	8.74	10.52	12.47	12.96	21.04	18.40
75+	2.54	2.52	3.47	4.65	8.50	8.05	8.92	19.67	17.00

Note: *The rate of awareness, treatment and control were of the prevalent hypertensives.

Source: 1991-2011 data from the CHNS, and 2015 data from Z. Wang et al. (2018).



```
R Console
+   #combin the exrpession
+   m <- paste(m,"*",y)
+   r <- paste(m,collapse="+")
+
+   #combin the function
+   fbody <- paste("{ return(",r,")}")
+   f <- function(a) {}
+
+   #fill the function's body
+   body(f) <- parse(text=fbody)
+
+   return(f)
+ }
> a = c(1,3,7,10)
> b = c(2.87,2.73,2.95,4.55)
> f <- LagrangePolynomial(a,b)
> f(5)
[1] 2.672222
> a = c(7,10,14,16)
> b = c(2.95,4.55,6.95,7.41)
> f <- LagrangePolynomial(a,b)
> f(12)
[1] 5.870106
>
```

Figure A1 Screen shot of R Console to realize Lagrange interpolation polynomial

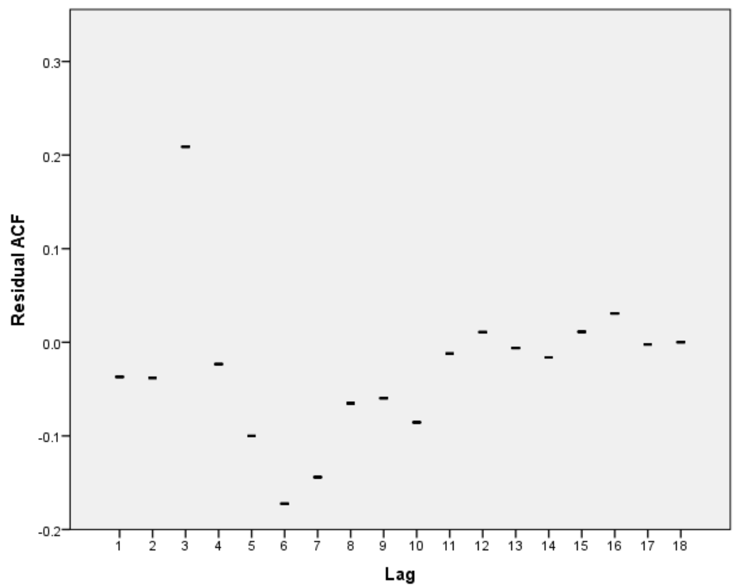


Figure A2 Residual ACF of the time series model for hypertension control, 1991-2009

Table A2 Summary of articles on hypertension prevalence, awareness, treatment, and control in China, 1991-2018

Authors	Study period	Region	Sampling	Study setting (U=urban; R=rural)	Age range	Sample size	SBP/DBP lowered (mmHg)	Control rate	Control rate improved	Duration of follow-up
Jiang et al., 2014	2008	Beijing	Cluster	U	≥50	9,397	N/A	45.8% with regular therapy	N/A	N/A
Liang, Chen, Liu, He, & Li, 2014	2009	Chongqing	Cluster	U	≥18	6,681	3.5 (3.2-3.7)/2.9 (2.7-3.2)	N/A	N/A	1 year
Z. Wang et al., 2014	2007-2010	National	Stratified cluster	U	18-79	249,830	N/A	25.5%	37%. monotherapy 27.7% combination 24.1%	N/A
Haitao Li et al., 2015	2010-2011	Shanghai & Shenzhen	Multi-stage random sampling	U	≥18	3,196	N/A	83.2% 76.3%	N/A	2 years
J. Gu et al., 2014	2011	Xuhui, Shanghai	Cluster	U	≥35	3,328		36.1		
Q. Zhang et al., 2014	2011	Yulin CHSC (Chengdu)	Cluster	U	≥35	3,191	147 ± 17 vs. 133 ± 8 83 ± 11 vs. 75 ± 6	32% vs. 85%	53%	33±25 Months
Hou et al., 2016	2008, 2012	National Zhejiang & Gansu	CHARLS	U&R	≥45	1,961 1,836	N/A	21.7% 36.4%	14.7	N/A
D. Zhang et al., 2018	2011, 2013	National	CHARLS	U&R	≥45	4,958	N/A	27.3% 35.5%	7.9%	N/A
M. Tian et al., 2015	2013	National	Multi-stage stratified random sampling	U&R	≥35	2,173	N/A	33.65%	N/A	N/A

X. Wang et al., 2013	2013	Beijing	Case-control	U&R	≥18	436	N/A	42.1% vs. 34.3% urban /30.7% vs. 10.0% rural 70.7% vs. 40.0% urban and 72.9% vs. 27.9% in rural	7.8-U* 20.7-R* 30.7-U* 45-R*	3 months 1 year

Note: *U = urban area and R = rural area.

Appendix B Supplementary material for Chapter 4

Table B1 Characteristics and age-group specific risk factors, comparison of hypertensive population grouping by hypertension control or not, male

Age group	Group	N	Age (mean±SD)	SBP (mm Hg) (mean±SD)	DBP (mm Hg) (mean±SD)	TC (mmol/L) (mean±SD)	HDL-C (mmol/L) (mean±SD)	BMI (kg/m^2) (mean±SD)	Diabetes 〔n(%)〕	Smoking 〔n(%)〕
35～44	G1	10	41.86±1.66	127±6	83±4	4.97±0.71	1.24±0.32	24.9±1.85	2/10 (20.0)	8/10
	G2	22	41.09±2.48	147±15	101±10	5.18±1.10	1.16±0.44	27.3±3.12	4（18.2）	11（50.0）
T (Chi-squared) value			0.895	4.13	5.49	0.55	-0.55	2.11	0.015	2.57
P			0.378	＜0.01	＜0.01	0.59	0.59	0.04	0.903	0.14
45～54	G1	28	49.24±3.41	127±11	84±6	4.84±0.96	1.14 (1.02-1.40)*	25.7±3.82	6（21.4）	18（64.3）
	G2	66	50.29±2.97	149±14	100±11	5.21±0.98	1.25(1.06-1.51)*	26.1±3.25	13（19.7）	37（56.1）
T (Chi-squared) value			-1.501	7.12	7.23	1.68	-1.62*（Z value）	0.54	0.037	0.55
P			0.137	＜0.01	＜0.01	0.10	0.11* (P value)	0.59	0.848	0.50
55～64	G1	35	60.03±3.01	129±11	83±6	5.12±0.91	1.24±0.31	25.0±2.66	9（25.7）	15（42.9）
	G2	91	60.24±2.92	152±18	97±13	4.97±0.85	1.27±0.37	24.7±3.11	17（18.7）	44（48.4）
T (Chi-squared) value			-0.369	7.12	6.40	-0.88	0.54	-0.46	0.763	0.31
P			0.713	＜0.01	＜0.01	0.38	0.59	0.65	0.382	0.69
65～74	G1	42	69.23±3.03	127±10	80±7	4.61±0.85	1.28±0.34	23.4±3.55	6（14.3）	20（47.6）
	G2	91	69.13±2.78	157±15	91±11	5.10±0.94	1.31±0.38	23.4±3.76	20（22.0）	32（35.2）
T (Chi-squared) value			0.196	11.48	5.87	2.35	0.43	3.25	1.081	1.87
P			0.845	＜0.01	＜0.01	0.02	0.67	0.00	0.298	0.19
75～84	G1	16	78.57±2.63	126±9	77±9	4.61±0.89	1.30±0.34	23.3±3.47	3（18.8）	6（37.5）
	G2	42	78.89±2.49	160±19	92±11	5.00±0.79	1.31±0.39	23.4±3.77	10（23.8）	12（28.6）

T (Chi-squared) value			-0.429	6.56	4.80	1.63	0.08	0.09	0.171	0.43
P			0.669	＜0.01	＜0.01	0.11	0.94	0.93	0.680	0.54
85+	G1	2	87.65±1.48	127.00±5.19	65.83±6.84	4.85±2.22	1.36±0.58	20.97±0.40	0	0
	G2	3	89.17±3.20	156.67±6.11	89.78±8.39	4.70±1.03	1.55±0.23	23.77±3.63	0	0
T (Chi-squared) value			-0.604	U test**	U test	U test	U test	U test	N/A	N/A
P			0.589	0.400	0.400	0.800	1.000	0.400	N/A	N/A

Notes: Test of difference: For age, blood pressure, TC, and HDL-C independent sample T test was performed; for diabetes and smoking rate, Pearson's $\chi 2$ analysis was performed.

*Non-normal distribution, non-parametric test was adopted, range interquartile were listed in the brackets.

**U test means Mann-Whitney U test.

Table B2 Characteristics and age-group specific risk factors, comparison of hypertensive population grouping by hypertension control or not, female

Age group	Group	N	Age (mean±SD)	SBP (mm Hg) (mean±SD)	DBP (mm Hg) (mean±SD)	TC (mmol/L) (mean±SD)	HDL-C (mmol/L) (mean±SD)	BMI (kg/m^2) (mean±SD)	Diabetes〔n(%)〕	Smoking〔n(%)〕
35～44	G1	7	42.49±2.02	131±10	86±4	5.14±1.26	1.31±0.25	24.5±3.36	1（14.3）	0
	G2	22	40.54±2.82	155±29	102±11	4.65±0.85	1.30±0.23	26.1±4.41	2（9.1）	〔1（4.5）〕
T (Chi-squared) value			1.683	2.14	3.51	-1.19	-0.11	0.90	0.155	0.33
P			0.104	0.05	0.003	0.25	0.91	0.38	0.694	1.00
45～54	G1	43	50.92±2.82	125±10	82±6	5.30±1.23	1.53 (1.24-1.76)*	24.9±3.37	10（23.3）	0
	G2	59	51.03±2.87	152±15	97±11	5.22±1.12	1.34 (1.12-1.52)*	26.6±3.74	9（15.3）	7（11.9）
T (Chi-squared) value			-0.188	10.29	7.94	-0.35	-2.58*（Z value）	2.45	1.051	5.48
P			0.852	0.000	0.000	0.73	0.01*（P value）	0.02	0.305	0.02
55～64	G1	51	60.27±2.86	127±11	81±6	5.24±0.99	1.40±0.51	25.3±3.03	11（21.6）	1（2.0）
	G2	128	60.23±2.72	156±15	96±8	5.48±0.97	1.33±0.31	25.7±3.46	32（25.0）	11（8.6）
T (Chi-squared) value			0.074	12.36	11.93	1.52	-1.10	0.66	0.235	2.57
P			0.941	0.000	0.000	0.13	0.27	0.51	0.628	0.18
65～74	G1	63	70.04±2.94	131±8	79±8	5.24±0.99	1.38±0.37	25.2±3.41	22（34.9）	〔1（1.6）〕
	G2	109	70.31±2.89	156±15	90±11	5.27±1.02	1.44±0.30	24.7±4.25	29（26.6）	〔11（10.1）〕
T (Chi-squared) value			-0.578	12.05	6.93	0.18	1.10	-0.90	1.323	4.45
P			0.546	0.000	0.000	0.86	0.27	0.37	0.250	0.06
75～84	G1	22	78.30±2.26	126±13	79±9	4.87±0.88	1.40±0.35	24.3±4.52	7（31.8）	0

	G2	60	79.24±2.75	164±24	87±11	5.51±0.88	1.46±0.35	23.5±4.32	15（25.0）	（5（8.3））
T (Chi-squared) value			-1.431	7.72	3.30	2.94	0.72	-0.76	0.381	1.95
P			0.156	0.000	0.003	0.004	0.48	0.45	0.537	0.32
85+	G1	1	86.50	137.67	75.00	4.04	1.78	19.33	0	0
	G2	4	85.80±0.81	164.08±5.87	87.33±6.37	4.68±1.31	1.38±0.30	23.91±3.39	0	0.25
T (Chi-squared) value			0.771	U test**	U test	U test	U test	U test		
P			0.497	0.200	0.200	1.000	0.800	0.800		

Notes: Test of difference: For age, blood pressure, TC, and HDL-C independent sample T test was performed; for diabetes and smoking rate, Pearson’s $\chi 2$ analysis was performed.

*Non-normal distribution, non-parametric test was adopted, range interquartile were listed in the brackets.

**U test means Mann-Whitney U test.

Table B3 Age-gender urban-rural population mortality rate and structure

Age/gender	Mortality rate (1/100,000)		Proportion in the whole population (%)	
	Urban	Rural	Urban	Rural
Male				
35-	116.12	166.82	2.72	4.08
40-	220.52	268.42	2.61	4.64
45-	274.92	349.22	2.25	3.93
50-	531.18	627.51	1.65	3.05
55-	755.40	830.51	1.49	3.37
60-	1,227.23	1,368.67	1.01	2.53
65-	1,984.41	2,305.59	0.67	1.79
70-	3,169.18	3,725.56	0.57	1.38
75-	5,167.37	6,138.59	0.41	0.94
80-	9,052.67	10,598.65	0.21	0.49
85-	18,323.58	19,594.67	0.11	0.23
Female				
35-	48.04	67.15	2.56	3.92
40-	96.84	109.39	2.43	4.56
45-	118.50	149.91	2.07	3.91
50-	234.83	293.95	1.57	2.92
55-	324.37	393.48	1.50	3.25
60-	606.47	721.00	1.03	2.39
65-	1,064.47	1,296.45	0.71	1.71
70-	1,882.75	2,290.84	0.61	1.36
75-	3,509.27	3,945.77	0.44	1.07
80-	6,721.27	7,423.16	0.24	0.66
85-	15,318.04	15,928.79	0.15	0.42

Source: China Health and Family Planning Yearbook 2014, China Statistical Bureau 2014.

Table B4 Parameter values for projection in a Markov model of the two groups

Age /gender	Age-gender structure of hypertensive population (%)	CHD					Stroke					Non-CVD mortality /100,000
		Prior CHD (%)*	Incidence of CHD of G1 /100,000	Incidence of CHD of G2 /100,000	28-days case fatality (proportion)	CHD case fatality (proportion)	Prior stroke (%)*	Incidence of stroke of G1 /100,000	Incidence of stroke of G2 /100,000	28-days case fatality (proportion)	Stroke case fatality (proportion)	
Male												
35-44	9.36	0.6	130	215	0.12	0.02	1.3	24	49	0.25	0.02	149
45-54	7.13	1.2	135	223	0.21	0.03	3.2	145	298	0.18	0.02	305
55-64	5.23	3.4	220	363	0.29	0.03	8.8	670	1,378	0.12	0.02	696
65-74	2.71	4.7	500	825	0.33	0.05	14.2	1,250	2,571	0.20	0.04	1,741
75-84	1.28	6.0	2,010	4,641	0.48	0.18	15.0	2,510	8,314	0.45	0.11	4,142
85+*	0.21	6.0	2,010	3,317	0.48	0.65	15.0	2,510	5,163	0.45	0.28	10,806
Female												
35-44	8.92	0.4	19	26	0.18	0.00	0.9	23	39	0.18	0.01	67
45-54	6.8	1.3	49	69	0.23	0.02	2.4	180	376	0.14	0.01	141
55-64	5.13	3.1	141	198	0.27	0.01	6.0	800	1,670	0.15	0.02	333
65-74	2.75	4.0	310	432	0.43	0.04	10.0	1,500	2,515	0.20	0.04	946
75-84	1.48	6.0	1,900	3,276	0.51	0.17	12.0	2,500	7,799	0.45	0.11	2,670
85+*	0.34	6.0	1,900	3,248	0.51	0.55	12.0	2,500	6,263	0.45	0.30	8,335

Notes: *The parameters not available for the age group of 85+ were substituted by that of the age group of 75-84, which includes 28-days case fatality of CHD, CHD Mortality, 28-days case fatality of stroke and stroke mortality. CHD mortality and stroke mortality of adults aged 85+ were calculated based on urban-rural age-gender disease-specific mortality from the 2013 Chinese Health Statistic Yearbook and the age-gender structure of the 2010 Chinese Census data.

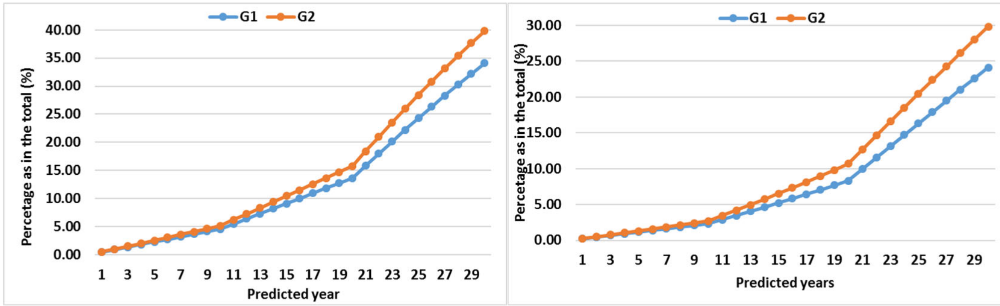


Figure B1 Percentages of deaths in G1 (blue) and G2 (orange), 45-54-year age group, male (left-hand side) and female (right-hand side)

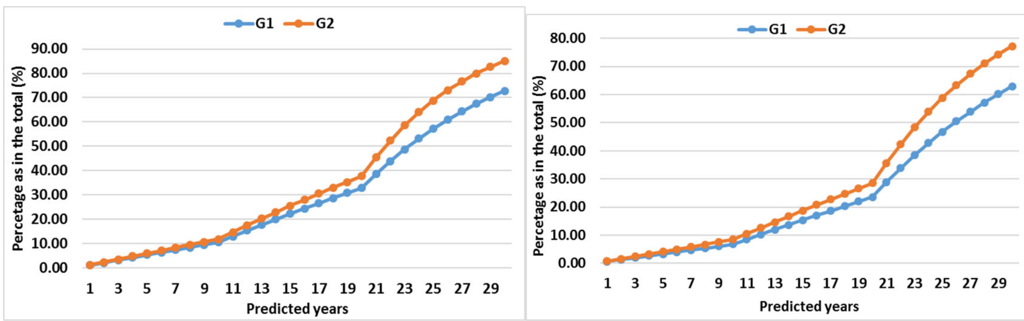


Figure B2 Percentages of deaths in G1 (blue) and G2 (orange), 55-64-year age group, male (left-hand side) and female (right-hand side)

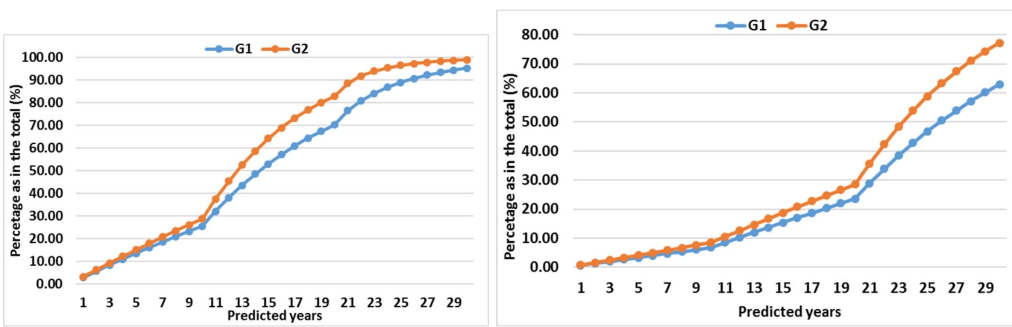


Figure B3 Percentages of deaths in G1 (blue) and G2 (orange), 65-74-year age group, male (left-hand side) and female (right-hand side)

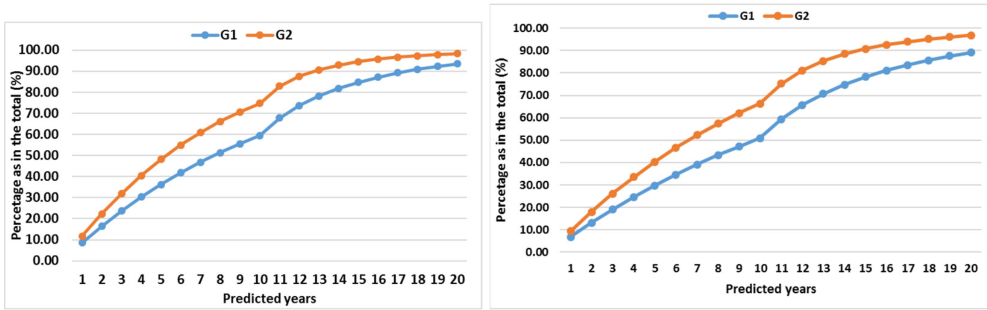


Figure B4 Percentages of deaths in G1 (blue) and G2 (orange), 75-84-year age group, male (left-hand side) and female (right-hand side)

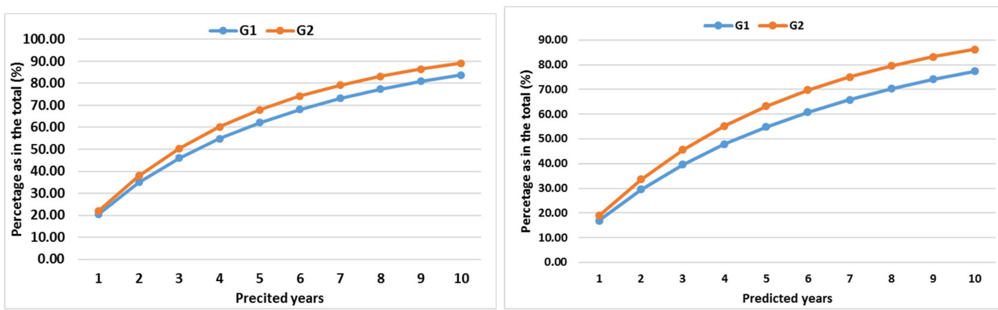


Figure B5 Percentages of deaths in G1 (blue) and G2 (orange), 84+-year age group, male (left-hand side) and female (right-hand side)

Appendix C Supplementary material for Chapter 5

In Table C1, HTN means simple hypertension; CHD means hypertension with co-morbidity of CHD; stroke means hypertension with stroke.

Table C1 Accumulative probabilities of each illness at the end of predicted 30 years for each group (person-years)

Age/gender	With NBPHS (HTN controlled)			Without NBPHS (HTN uncontrolled)		
	HTN	CHD	Stroke	HTN	CHD	Stroke
Male						
35-44	38,995,672	27,995	1,383,296	37,275,289	57,935	2,354,312
45-54	78,488,850	70,185	5,150,234	73,006,122	153,108	8,442,201
55-64	62,237,009	74,190	9,025,025	57,005,290	152,649	11,803,038
65-74	23,815,907	33,350	4,940,132	21,392,395	69,469	6,020,998
75-84*	2,854,003	5,164	604,500	2,568,392	10,365	705,204
85+*	19,126	44	4,028	18,115	79	4,401
Female						
35-44	28,232,339	9,984	605,057	27,124,297	33,404	1,297,875
45-54	69,464,945	61,294	3,769,957	62,434,246	161,475	8,068,701
55-64	75,686,346	122,564	10,214,433	61,836,177	283,756	17,756,172
65-74	27,049,344	64,610	6,100,186	20,073,023	135,737	9,370,996
75-84*	4,193,453	11,759	937,886	2,942,426	28,158	1,402,902
85+*	29,168	87	5,621	23,291	240	7,896

Notes: *The prediction duration of the age group 75-84 and 85+ is 20 years and 10 years, respectively, because of parameter availability and average life expectancy of the population in China.

Table C2 Mean age of each age group of hypertensives estimated based on CHNS 2015

Age/gender	N	Mean	SD
Male			
35-44	39	41.10	2.761
45-54	154	50.06	2.705
55-64	296	60.10	2.715
65-74	310	69.06	2.824
75-84*	104	78.23	2.735
85+*	15	87.33	2.127
Female			
35-44	36	41.06	2.540
45-54	168	50.61	2.606
55-64	331	60.34	2.674
65-74	337	68.89	2.720
75-84*	150	78.68	2.781
85+*	17	87.53	21.25

Notes: *The prediction duration of the age group 75-84 and 85+ is 20 years and 10 years, respectively, because of parameter availability and average life expectancy of the population in China.

Table C3.1 Deaths of difference in the NBPHS and non-NBPHS groups in projected years, male

Year	35-44 age group		45-54 age group		55-64 age group		65-74 age group		75-84 age group		85+ age group	
	Age	Number	Age	Number	Age	Number	Age	Number	Age	Number	Age	Number
2016	42	94	51	533	61	1,698	70	2,956	79	13,547	88	1,086
2017	43	102	52	578	62	1,810	71	3,085	80	12,203	89	1,220
2018	44	110	53	620	63	1,913	72	3,176	81	10,603	90	977
2019	45	118	54	661	64	2,006	73	3,233	82	8,911	91	675
2020	46	125	55	700	65	2,090	74	3,260	83	7,237	92	403
2021	47	132	56	737	66	2,166	75	3,260	84	5,650	93	180
2022	48	139	57	772	67	2,233	76	3,237	85	4,193	94	9
2023	49	146	58	805	68	2,292	77	3,194	86	2,888	95	-116
2024	50	153	59	836	69	2,344	78	3,133	87	1,743	96	-203
2025	51	159	60	866	70	2,390	79	3,058	88	758	97	-259
2026	52	379	61	1,663	71	5,921	80	22,089	89	-1,378		
2027	53	395	62	1,735	72	5,865	81	18,769	90	-5,064		
2028	54	411	63	1,800	73	5,775	82	15,453	91	-6,099		
2029	55	425	64	1,858	74	5,656	83	12,289	92	-6,184		
2030	56	439	65	1,909	75	5,512	84	9,368	93	-5,880		
2031	57	452	66	1,954	76	5,346	85	6,738	94	-5,410		
2032	58	464	67	1,993	77	5,163	86	4,420	95	-4,882		
2033	59	476	68	2,027	78	4,966	87	2,415	96	-4,349		
2034	60	487	69	2,055	79	4,756	88	710	97	-3,840		
2035	61	497	70	2,078	80	4,538	89	-715	98	-3,368		
2036	62	851	71	4,963	81	30,424	90	-5,625				
2037	63	881	72	4,874	82	25,215	91	-10,257				
2038	64	908	73	4,762	83	20,212	92	-11,421				
2039	65	931	74	4,630	84	15,569	93	-11,260				
2040	66	952	75	4,482	85	11,373	94	-10,541				
2041	67	970	76	4,320	86	7,661	95	-9,594				
2042	68	985	77	4,146	87	4,438	96	-8,583				
2043	69	997	78	3,963	88	1,690	97	-7,590				
2044	70	1,008	79	3,774	89	-616	98	-6,658				
2045	71	1,016	80	3,579	90	-2515	99	-5,807				

Notes: *The minus numbers are treated as 0 in calculations.

Table C3.2 Deaths of difference in the NBPHS and non-NBPHS groups in projected years, female

Year	35-44 age group		45-54 age group		55-64 age group		65-74 age group		75-84 age group		85+ age group	
	Age	Number	Age	Number	Age	Number	Age	Number	Age	Number	Age	Number
2016	42	14	52	332	61	2,043	70	2,307	80	14,376	89	2,662
2017	43	14	53	353	62	2,205	71	2,451	81	13,441	90	2,942
2018	44	15	54	374	63	2,355	72	2,569	82	12,233	91	2,551
2019	45	15	55	394	64	2,493	73	2,663	83	10,871	92	1,956
2020	46	16	56	413	65	2,621	74	2,736	84	9,445	93	1,352
2021	47	16	57	432	66	2,738	75	2,788	85	8,017	94	814
2022	48	17	58	450	67	2,845	76	2,823	86	6,634	95	367
2023	49	17	59	468	68	2,943	77	2,841	87	5,326	96	14
2024	50	18	60	486	69	3,031	78	2,844	88	4,111	97	-254
2025	51	18	61	503	70	3,111	79	2,834	89	3,002	98	-450
2026	52	113	62	1,744	71	5,313	80	22,187	90	2,262		
2027	53	120	63	1,843	72	5,274	81	19,909	91	-2,111		
2028	54	126	64	1,935	73	5,216	82	17,477	92	-4,417		
2029	55	132	65	2,020	74	5,141	83	15,013	93	-5,572		
2030	56	138	66	2,097	75	5,051	84	12,603	94	-6,059		
2031	57	144	67	2,167	76	4,946	85	10,306	95	-6,148		
2032	58	150	68	2,230	77	4,831	86	8,161	96	-6,002		
2033	59	155	69	2,288	78	4,704	87	6,192	97	-5,719		
2034	60	161	70	2,339	79	4,569	88	4,409	98	-5,361		
2035	61	166	71	2,384	80	4,427	89	2,816	99	-4,966		
2036	62	562	72	4,017	81	29,393	90	454				
2037	63	594	73	3,958	82	25,698	91	-5,405				
2038	64	623	74	3,887	83	21,988	92	-8,446				
2039	65	649	75	3,807	84	18,383	93	-9,869				
2040	66	673	76	3,717	85	14,964	94	-10,342				
2041	67	695	77	3,620	86	11,784	95	-10,257				
2042	68	715	78	3,516	87	8,874	96	-9,850				
2043	69	733	79	3,407	88	6,246	97	-9,266				
2044	70	749	80	3,292	89	3,904	98	-8,595				
2045	71	763	81	3,174	90	1,842	99	-7,893				

Table C4.1 The difference in the numbers of hypertensives of CHD in the two groups projected, male

Year	35-44 age group		45-54 age group		55-64 age group		65-74 age group		75-84 age group		85+ age group	
	Age	Number	Age	Number	Age	Number	Age	Number	Age	Number	Age	Number
2016	42	428	51	799	61	1,370	70	1,735	79	4,783	88	405
2017	43	854	52	1,586	62	2,677	71	3,302	80	8,189	89	648
2018	44	1,276	53	2,361	63	3,925	72	4,714	81	10,510	90	777
2019	45	1,695	54	3,123	64	5,114	73	5,981	82	11,981	91	825
2020	46	2,111	55	3,874	65	6,247	74	7,114	83	12,795	92	820
2021	47	2,523	56	4,613	66	7,326	75	8,121	84	13,105	93	781
2022	48	2,933	57	5,341	67	8,353	76	9,013	85	13,035	94	721
2023	49	3,340	58	6,056	68	9,328	77	9,798	86	12,685	95	650
2024	50	3,743	59	6,761	69	10,255	78	10,483	87	12,132	96	575
2025	51	4,144	60	7,454	70	11,134	79	11,077	88	11,440	97	501
2026	52	4,501	61	8,442	71	12,882	80	15,999	89	9,207		
2027	53	4,853	62	9,381	72	14,430	81	19,231	90	7,350		
2028	54	5,199	63	10,274	73	15,794	82	21,148	91	5,814		
2029	55	5,540	64	11,123	74	16,988	83	22,055	92	4,550		
2030	56	5,875	65	11,928	75	18,024	84	22,194	93	3,515		
2031	57	6,204	66	12,692	76	18,914	85	21,762	94	2,672		
2032	58	6,528	67	13,415	77	19,669	86	20,915	95	1,991		
2033	59	6,847	68	14,100	78	20,301	87	19,777	96	1,444		
2034	60	7,161	69	14,746	79	20,818	88	18,445	97	1,009		
2035	61	7,469	70	15,357	80	21,230	89	16,995	98	665		
2036	62	7,896	71	16,540	81	26,675	90	13,384				
2037	63	8,301	72	17,572	82	30,006	91	10,425				
2038	64	8,684	73	18,464	83	31,707	92	8,014				
2039	65	9,047	74	19,227	84	32,170	93	6,059				
2040	66	9,390	75	19,870	85	31,706	94	4,485				
2041	67	9,713	76	20,404	86	30,566	95	3,227				
2042	68	10,018	77	20,836	87	28,946	96	2,228				
2043	69	10,305	78	21,176	88	27,004	97	1,443				
2044	70	10,574	79	21,430	89	24,861	98	832				
2045	71	10,826	80	21,605	90	22,612	99	364				

Table C4.2 The difference in the numbers of hypertensives of CHD in the two groups projected, female

Year	35-44 age group		45-54 age group		55-64 age group		65-74 age group		75-84 age group		85+ age group	
	Age	Number	Age	Number	Age	Number	Age	Number	Age	Number	Age	Number
2016	42	17	52	156	61	588	70	623	80	3,140	89	739
2017	43	33	53	309	62	1,148	71	1,197	81	5,442	90	1,207
2018	44	50	54	461	63	1,680	72	1,724	82	7,058	91	1,475
2019	45	67	55	610	64	2,185	73	2,208	83	8,114	92	1,599
2020	46	83	56	758	65	2,664	74	2,649	84	8,718	93	1,620
2021	47	100	57	903	66	3,117	75	3,052	85	8,960	94	1,571
2022	48	116	58	1,047	67	3,547	76	3,417	86	8,914	95	1,476
2023	49	132	59	1,189	68	3,952	77	3,747	87	8,644	96	1,353
2024	50	149	60	1,329	69	4,335	78	4,045	88	8,203	97	1,215
2025	51	165	61	1,467	70	4,695	79	4,311	89	7,634	98	1,072
2026	52	214	62	1,850	71	5,220	80	7,539	90	6,354		
2027	53	262	63	2,213	72	5,692	81	9,757	91	5,186		
2028	54	310	64	2,557	73	6,114	82	11,156	92	4,138		
2029	55	357	65	2,884	74	6,489	83	11,894	93	3,210		
2030	56	403	66	3,192	75	6,819	84	12,107	94	2,399		
2031	57	449	67	3,483	76	7,109	85	11,905	95	1,698		
2032	58	494	68	3,757	77	7,359	86	11,383	96	1,101		
2033	59	539	69	4,015	78	7,573	87	10,618	97	597		
2034	60	583	70	4,258	79	7,752	88	9,674	98	178		
2035	61	626	71	4,485	80	7,900	89	8,605	99	-166		
2036	62	746	72	4,805	81	11,029	90	6,754				
2037	63	861	73	5,089	82	12,993	91	5,114				
2038	64	969	74	5,339	83	14,021	92	3,680				
2039	65	1,071	75	5,559	84	14,304	93	2,445				
2040	66	1,168	76	5,748	85	14,001	94	1,393				
2041	67	1,259	77	5,910	86	13,247	95	510				
2042	68	1,345	78	6,046	87	12,152	96	-221				
2043	69	1,426	79	6,158	88	10,808	97	-816				
2044	70	1,502	80	6,247	89	9,290	98	-1,291				
2045	71	1,573	81	6,315	90	7,660	99	-1,662				

Table C4.3 The difference in the numbers of hypertensives of stroke in the two groups projected, male

Year	35-44 age group		45-54 age group		55-64 age group		65-74 age group		75-84 age group		85+ age group	
	Age	Number	Age	Number	Age	Number	Age	Number	Age	Number	Age	Number
2016	42	109	51	1,448	61	8,365	70	8,412	79	11,160	88	870
2017	43	216	52	2,875	62	16,389	71	16,072	80	19,352	89	1,408
2018	44	323	53	4,282	63	24,080	72	23,031	81	25,181	90	1,709
2019	45	430	54	5,669	64	31,451	73	29,335	82	29,138	91	1,842
2020	46	535	55	7,035	65	38,510	74	35,030	83	31,626	92	1,860
2021	47	640	56	8,382	66	45,268	75	40,157	84	32,968	93	1,802
2022	48	744	57	9,710	67	51,733	76	44,756	85	33,427	94	1,695
2023	49	848	58	11,018	68	57,916	77	48,864	86	33,214	95	1,561
2024	50	950	59	12,307	69	63,824	78	52,514	87	32,500	96	1,413
2025	51	1,052	60	13,577	70	69,467	79	55,740	88	31,420	97	1,262
2026	52	1,726	61	19,949	71	78,047	80	66,254	89	26,258		
2027	53	2,391	62	26,055	72	85,725	81	73,147	90	21,879		
2028	54	3,045	63	31,901	73	92,565	82	77,203	91	18,177		
2029	55	3,691	64	37,497	74	98,626	83	79,054	92	15,055		
2030	56	4,327	65	42,850	75	103,964	84	79,213	93	12,430		
2031	57	4,953	66	47,969	76	108,630	85	78,093	94	10,230		
2032	58	5,571	67	52,860	77	112,675	86	76,025	95	8,391		
2033	59	6,179	68	57,530	78	116,144	87	73,273	96	6,858		
2034	60	6,779	69	61,987	79	119,080	88	70,048	97	5,583		
2035	61	7,369	70	66,238	80	121,524	89	66,515	98	4,527		
2036	62	10,343	71	72,578	81	131,652	90	55,427				
2037	63	13,191	72	78,220	82	137,307	91	46,092				
2038	64	15,917	73	83,215	83	139,494	92	38,249				
2039	65	18,526	74	87,608	84	139,027	93	31,673				
2040	66	21,020	75	91,443	85	136,559	94	26,170				
2041	67	23,405	76	94,761	86	132,617	95	21,573				
2042	68	25,682	77	97,601	87	127,620	96	17,741				
2043	69	27,856	78	99,998	88	121,901	97	14,554				
2044	70	29,930	79	101,987	89	115,722	98	11,907				
2045	71	31,907	80	103,598	90	109,290	99	9,714				

Table C4.4 The difference in the numbers of hypertensives of stroke in the two groups projected, female

Year	35-44 age group		45-54 age group		55-64 age group		65-74 age group		75-84 age group		85+ age group	
	Age	Number	Age	Number	Age	Number	Age	Number	Age	Number	Age	Number
2016	42	43	52	1,742	61	10,362	70	7,335	80	13,574	89	2,314
2017	43	87	53	3,467	62	20,359	71	14,163	81	24,308	90	3,861
2018	44	130	54	5,175	63	30,002	72	20,513	82	32,661	91	4,829
2019	45	173	55	6,868	64	39,299	73	26,407	83	39,026	92	5,368
2020	46	216	56	8,543	65	48,260	74	31,870	84	43,735	93	5,591
2021	47	259	57	10,203	66	56,895	75	36,924	85	47,073	94	5,588
2022	48	302	58	11,847	67	65,211	76	41,592	86	49,279	95	5,427
2023	49	344	59	13,474	68	73,218	77	45,893	87	50,556	96	5,160
2024	50	387	60	15,086	69	80,924	78	49,846	88	51,078	97	4,827
2025	51	430	61	16,682	70	88,338	79	53,472	89	50,989	98	4,457
2026	52	982	62	23,693	71	94,939	80	67,971	90	45,492		
2027	53	1528	63	30,452	72	100,983	81	78,969	91	40,389		
2028	54	2070	64	36,967	73	106,500	82	87,054	92	35,700		
2029	55	2606	65	43,243	74	111,518	83	92,723	93	31,427		
2030	56	3137	66	49,287	75	116,065	84	96,399	94	27,563		
2031	57	3663	67	55,106	76	120,167	85	98,441	95	24,089		
2032	58	4184	68	60,706	77	123,849	86	99,152	96	20,983		
2033	59	4699	69	66,092	78	127,136	87	98,787	97	18,219		
2034	60	5210	70	71,271	79	130,049	88	97,563	98	15,772		
2035	61	5716	71	76,248	80	132,611	89	95,661	99	13,612		
2036	62	7938	72	80,438	81	146,777	90	84,513				
2037	63	10081	73	84,250	82	156,836	91	74,418				
2038	64	12146	74	87,705	83	163,499	92	65,329				
2039	65	14135	75	90,824	84	167,371	93	57,187				
2040	66	16051	76	93,625	85	168,964	94	49,925				
2041	67	17895	77	96,125	86	168,709	95	43,475				
2042	68	19669	78	98,343	87	166,971	96	37,766				
2043	69	21376	79	100,295	88	164,057	97	32,729				
2044	70	23016	80	101,995	89	160,225	98	28,299				
2045	71	24593	81	103,460	90	155,690	99	24,415				

Appendix D Age-specific analysis on hypertension control and re-analysis of return on investment and benefit-cost ratio

1. Trend analysis of hypertension control, 1991-2009

Using a Lagrange interpolation polynomial method, age-specific data of hypertension control from 1991 to 2009 were completed, as shown in Table D1.

Table D1 Completed data of hypertension control rates, by age group, 1991-2009

Year	Control rate (%)				
	35-44	45-54	55-64	65-74	75+
1991	2.62	2.43	4.55	2.44	2.54
1992	1.86	2.60	5.58	2.41	2.48
1993	1.55	2.67	5.62	2.50	2.52
1994	1.59	2.68	5.00	2.74	2.65
1995	1.87	2.67	4.06	3.14	2.86
1996	2.26	2.70	3.12	3.75	3.14
1997	2.67	2.82	2.51	4.59	3.47
1998	2.71	3.19	3.41	5.96	3.77
1999	2.75	3.66	4.63	7.39	4.15
2000	2.81	4.21	6.00	8.74	4.65
2001	3.22	4.90	6.98	9.29	5.74
2002	3.65	5.61	7.88	9.67	6.87
2003	4.00	6.32	8.68	10.03	7.85
2004	4.17	6.97	9.38	10.52	9.38
2005	3.81	7.50	7.78	11.55	8.30
2006	3.58	7.91	10.50	12.47	8.50
2007	3.68	8.15	10.55	13.13	7.93
2008	4.32	8.21	11.01	13.34	8.16
2009	5.69	8.03	12.02	12.96	8.92

Given that the trend analysis is based on fewer than 20 data points, small sample time series analysis was performed, where pre-treatment was performed on small sample data using the Lagrange Interpolation Polynomial method. With SPSS 22.0, time series predicting analysis was performed using an expert-modeler method in which the difference was used to realize time series stationarity. According to the expert modeler and modelling figures, ARIMA models (2,0,1 for ages 35-44 and 65-74; 1,0,1 for other age groups) were selected for linear trend prediction, as shown in Table D2.

The residual auto-correlation function (ACF) showed a random distribution with no outliers, which indicates good model fitness (see Appendix B: Supplementary material).

Table D2 Model statistics for the time series prediction of hypertension control rate for people aged, by age group

Control-model_1	Number of predictors	Model fit statistics		Ljung-Box Q (18)			Number of outliers
		Stationary R-squared	R-squared	Statistics	DF	Sig.	
35-44	1	0.736	0.955	3.410	3	0.333	0
45-54	1	0.984	0.984	39.293	16	0.001	0
55-64	1	0.882	0.882	11.618	16	0.770	0
65-74	1	0.995	0.995	26.241	15	0.036	0
75+	1	0.949	0.949	18.986	16	0.269	0

Table D3 is the forecasted control rate of hypertension from 2010 to 2015 based on the model established from 1991 to 2009. Both upper control limit and lower control limit are listed. It is predicted that in 2015, the control rate for people aged 35-44 of hypertension would be 11.64% (95%CI: 8.34%, 14.93%), 10.39% (95%CI: 8.99%, 11.79%) for those aged 45-54, 13.79% (95%CI: 10.28%, 17.29%) for those aged 55-64, 17.60% (95%CI: 15.57%, 19.64%) for those aged 65-74, and 12.04% (95%CI: 10.11%, 13.96%) for those aged 75 and over, based on the trend from 1991 to 2009. Details are shown in Table D3 and Figures D1-D5.

Table D3 Forecasted control rate of hypertension from the prediction model, 2010-2015

Age group	Model	2010	2011	2012	2013	2014	2015
35-44	Forecast	7.34	8.82	9.88	10.54	11.03	11.64
	UCL*	6.85	7.58	7.84	7.86	7.94	8.34
	LCL**	7.83	10.06	11.91	13.21	14.11	14.93
45-54	Forecast	8.11	8.58	9.04	9.50	9.95	10.39
	UCL*	7.71	7.75	7.98	8.29	8.63	8.99
	LCL**	8.51	9.41	10.10	10.71	11.27	11.79
55-64	Forecast	12.25	12.47	12.74	13.06	13.41	13.79
	UCL*	9.98	9.52	9.50	9.67	9.95	10.28
	LCL**	14.52	15.41	15.99	16.45	16.88	17.29
65-74	Forecast	12.74	13.01	13.79	14.96	16.31	17.60
	UCL*	12.14	11.77	12.06	12.99	14.28	15.57
	LCL**	13.33	14.25	15.52	16.94	18.34	19.64
75+	Forecast	9.56	10.12	10.63	11.11	11.58	12.04
	UCL*	8.26	8.41	8.79	9.22	9.66	10.11
	LCL**	10.87	11.82	12.47	13.01	13.50	13.96

Notes: *UCL = Upper control limit.
**LCL = Lower control limit.

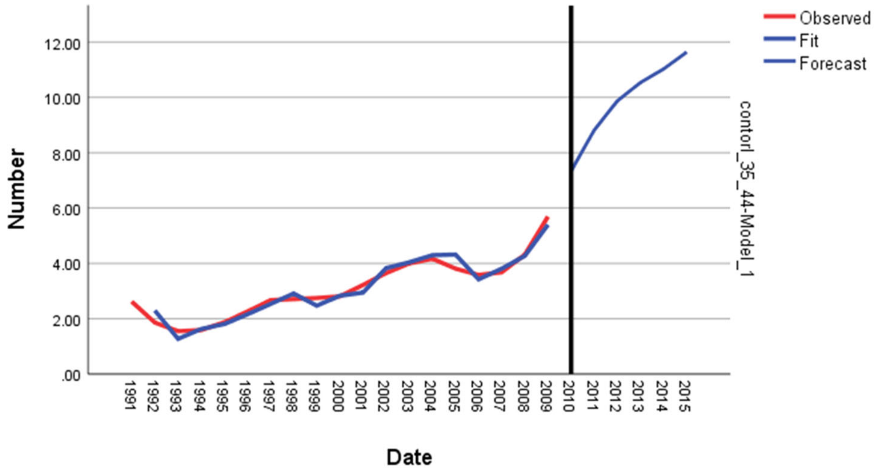


Figure D1 Time series trend of hypertension control rate for people aged 35-44, 1991-2009 and predicted analysis from 2010 to 2015

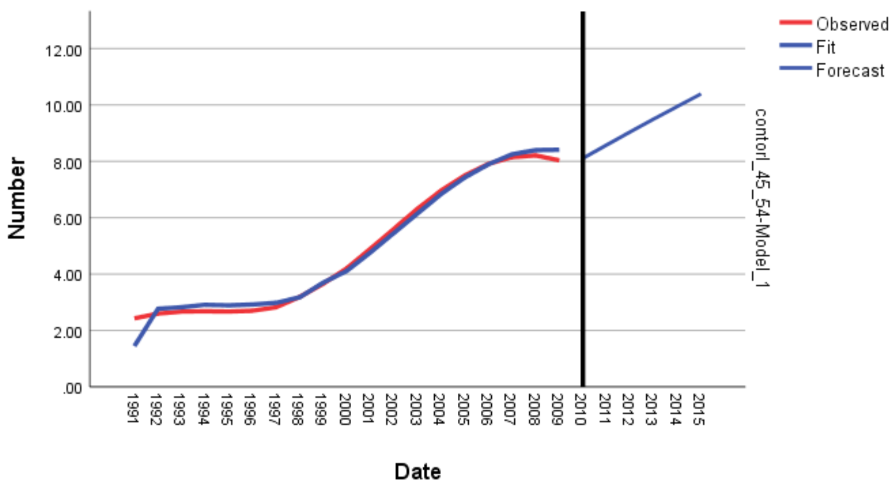


Figure D2 Time series trend of hypertension control rate for people aged 45-54, 1991-2009 and predicted analysis from 2010 to 2015

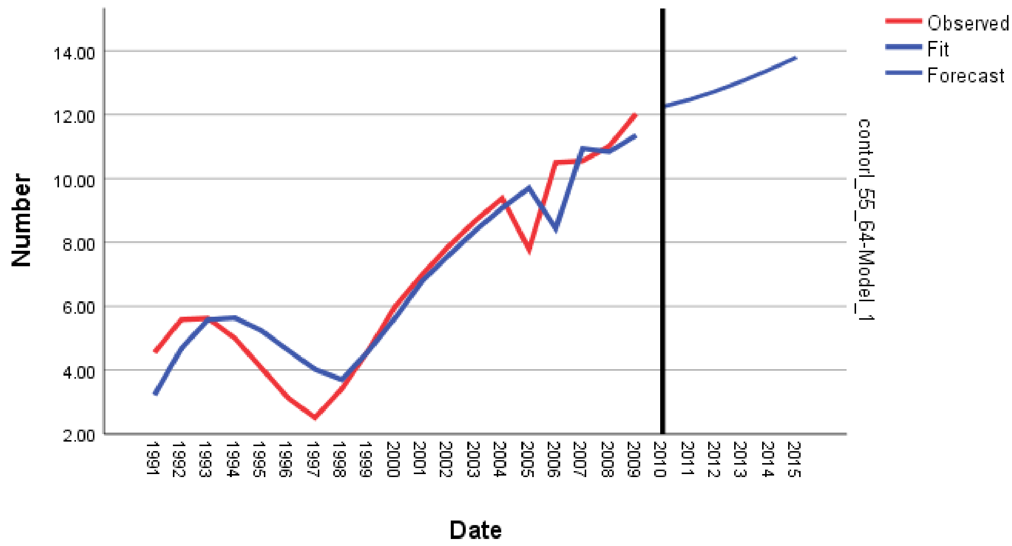


Figure D3 Time series trend of hypertension control rate for people aged 55-64, 1991-2009 and predicted analysis from 2010 to 2015

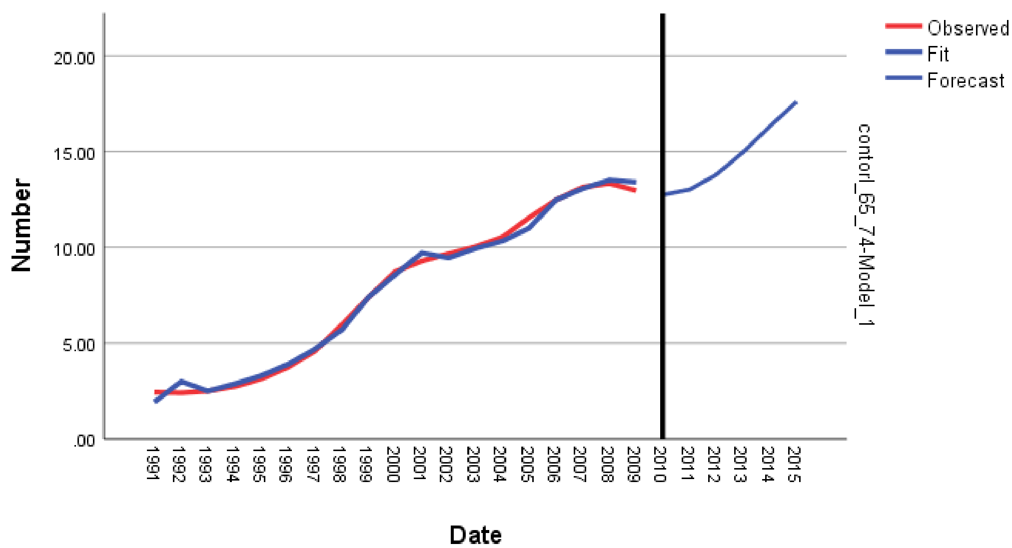


Figure D4 Time series trend of hypertension control rate for people aged 65-74, 1991-2009 and predicted analysis from 2010 to 2015

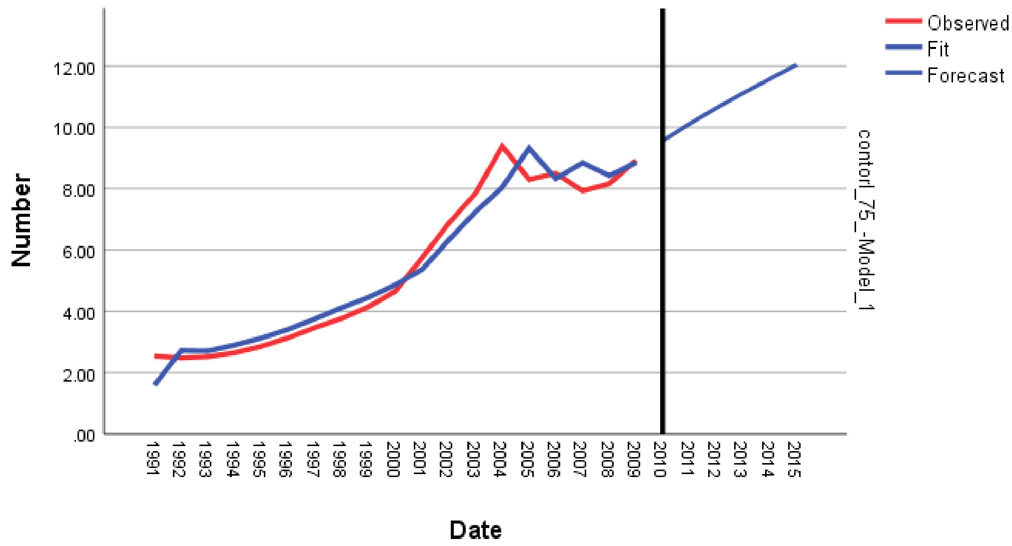


Figure D5 Time series trend of hypertension control rate for people aged 75 and over, 1991-2009 and predicted analysis from 2010 to 2015

2. Estimation of hypertension control from the NBPHS

According to the China Hypertension Survey 2012-2015, the prevalence of hypertension among adults aged 35 or above was 32.62% in 2015 (Z. Wang et al., 2018). The predicted control rates and the observed control rate of 2015 for each age group were listed in Table D3. With the same population data and method, it was estimated that from 2009 to 2015, the NBPHS program increased the number hypertensives under control by 0, 1,635,397, 1,564,164, 170,388 and 617,939 for males in age groups 35-44, 45-54, 55-64, 65-74 and 75+, respectively. The numbers would be 0, 1,568,221, 1,523,002, 169,167 and 761,170 for females in each age group, respectively. The total number of hypertensives under blood pressure control increased by the NBPHS would be 8,009,449 (1,581,856, 13,065,018). Details are shown in Table D4.

Table D4 Estimation of the number of hypertensives under control through the NBPHS (CHS 2012-2015)

Age/ gender	Number of population	Prevalence (%)	Observed control rate (%)	Predicted control rate (%)	Number of hypertension controlled through NBPHS (95%CI)
Males					
35-44	127,459,929	15.90	9.90	11.64	0* (-1,019,386, 316,152)
45-54	96,759,903	29.60	16.10	10.39	1,635,397 (1,234,424, 2,036,370)
55-64	72,912,562	44.60	18.60	13.79	1,564,164 (425,999, 2,705,581)
65-74	38,237,979	55.70	18.40	17.6	170,388 (-264,102, 602,749)
75+	20,695,107	60.20	17.00	12.04	617,939 (378,737, 858,388)
Females					
35-44	122,114,836	15.90	9.90	5.1	0** (-976,638, 302,894)
45-54	92,785,346	29.60	16.10	10.39	1568221 (1,183,718, 1,953,723)
55-64	70,993,810	44.60	18.60	13.79	1,523,002 (414,788, 2,634,382)
65-74	37,963,871	55.70	18.40	17.6	169,167 (-262,209, 598,428)
75+	25,491,986	60.20	17.00	12.04	761,170 (466,524, 1,057,351)
Total	705,415,330	N/A	N/A	N/A	**8,009,449 (1,581,856, 13,065,018)**

Notes: N/A is not applicable. *Actual value is -352631, to make it fit to reality, negative values were changed to 0. ** Actual value is -337,843, to make it fit to reality, negative values were changed to 0.

3. Age-specific analysis of estimates of CVDs and deaths averted

At the end of the 10th projection year in the G1 scenario, compared with G2, 34,198, 262,071, and 284,796 hypertensive patients would have avoided CHD, stroke and death, respectively. At the end of the 20th projection year, 41,632, 380,448, and 355,955 hypertensive patients would have avoided CHD, stroke and death, respectively. At the end of the 30th projection year, 23,476, 306,955 and 697,204 hypertensive patients would have avoided CHD, stroke and death, respectively. Details of these results are provided in Tables D5, D6, and D7. In Table D7, there are some negative figures which are generated mainly from older age groups of both genders in the 30-year horizon analysis (age groups of 65-74 and 75-84 years). This is because in the non-NBPHS group, more patients die from CVD than those in the NBPHS group, which makes less CVD survivors compared with those in the non-NBPHS group, especially for stroke. This section further explains analisis of Chapter 4.

Table D5 Running results for a 10-year horizon

Age/ gender	G1			G2			Number of patients avoiding CVD and death		
	CHD	Stroke	Death	CHD	Stroke	Death	CHD	Stroke	Death
Male									
35-44	0	0	0	0	0	0	0	0	0
45-54	28,028	58,081	74,940	36,894	74,975	84,533	8,866	16,895	9,593
55-64	54,048	175,359	164,325	63,991	241,358	185,745	9,942	65,999	21,420
65-74	6,787	23,312	43,431	8,284	31,636	48,917	1,498	8,325	5,486
75-84	14,880	38,654	367,123	19,243	62,137	461,696	4,363	23,482	94,573
85+	0	0	0	0	0	0	0	0	0
Female									
35-44	0	0	0	0	0	0	0	0	0
45-54	22,406	54,314	36,259	24,454	77,383	42,386	2,048	23,069	6,127
55-64	52,134	150,108	102,949	56,438	229,354	129,034	4,304	79,246	26,085
65-74	5,883	22,877	30,395	6,460	30,180	34,721	578	7,303	4,326
75-84	21,925	52,314	387,116	24,525	90,065	504,302	2,599	37,751	117,186
85+	0	0	0	0	0	0	0	0	0
Total	206,091	575,018	1,206,538	240,289	837,089	1,491,334	34,198	262,071	284,796

Table D6 Running results for a 20-year horizon

Age/ gender	G1			G2			Number of patients avoiding CVD and death		
	CHD	Stroke	Death	CHD	Stroke	Death	CHD	Stroke	Death
Males									
35-44	0	0	0	0	0	0	0	0	0
45-54	37,774	117,997	223,107	53,930	198,647	258,446	16,156	80,650	35,339
55-64	50,749	180,250	512,768	65,212	276,766	588,904	14,463	96,517	76,136
65-74	2,908	8,579	119,758	3,377	13,368	141,137	469	4,788	21,379
75-84	648	2,350	577,566	269	1,608	607,277	-378	-741	29,711
85+	0	0	0	0	0	0	0	0	0
Female									
35-44	0	0	0	0	0	0	0	0	0
45-54	31,915	125,437	130,749	37,784	223,040	167,533	5,869	97,603	36,783
55-64	46,528	196,755	358,829	52,158	292,013	433,827	5,630	95,258	74,998
65-74	3,626	10,721	101,975	3,766	17,627	125,479	140	6,905	23,504
75-84	1,418	4,434	678,536	701	3,902	736,641	-717	-532	58,105
85+	0	0	0	0	0	0	0	0	0
Total	175,566	646,523	2,703,289	217,197	1,026,971	3,059,245	41,632	380,448	355,955

Table D7 Running results for a 30-year horizon

Age/ gender	G1			G2			Number of patients with avoiding CVD and death		
	CHD	Stroke	Death	CHD	Stroke	Death	CHD	Stroke	Death
Male									
35-44	0	0	0	0	0	0	0	0	0
45-54	44,586	152,647	557,423	61,918	258,449	651,470	1,7332	105,801	94,047
55-64	24,109	69,487	1,139,026	26,293	109,558	1,331,195	2,185	40,071	192,168
65-74	128	472	162,371	45	289	168,586	-84	-183	6,215
75-84	648	2,350	577,566	269	1,608	607,277	-378	-741	29,711
85+	0	0	0	0	0	0	0	0	0
Female									
35-44	0	0	0	0	0	0	0	0	0
45-54	35,127	186,822	378,264	41,445	292,405	468,063	6,318	105,583	89,798
55-64	30,054	90,911	959,687	29,015	148,021	1,176,142	-1,039	57,110	216,455
65-74	250	794	154,590	110	640	165,295	-140	-154	10,705
75-84	1,418	4,434	678,536	701	3,902	736,641	-717	-532	58,105
85+	0	0	0	0	0	0	0	0	0
Total	136,320	507,917	4,607,465	159,796	814,872	5,304,669	23,476	306,955	697,204

4. Re-analysis of the return on investment and benefit-cost ratio (BCR)

Originally, analysis for all age groups based on the CHS 2012-2015 data was performed. At a discount rate of 3% and given that 14.59% of the NBPHS funding were spent on hypertension management, the BCR would be 6.0. With social benefit included, the BCR would be 15.4. The internal rate of return would be 14.6% and 20.7%.

With age-specific analysis based on the CHS 2012-2015 data, at a discount rate of 3% and given that 14.59% of the NBPHS funding were spent on hypertension management, the BCR would be 5.9. With social benefit included, the BCR would be 15.1. The internal rate of return would be 14.7% and 20.4%. Details are shown in Tables D8 and D9.

Table D8 Cost and return on investment at different discount rates (million CNY)

Discount rate	0% (95%CI)	2% (95%CI)	3% (95%CI)	5% (95%CI)
GDP – deaths averted, NPV	321,976 (63,590, 525,207)	206,498 (40,783, 336,840)	166,880 (32,959, 272,215)	110,882 (21,899, 180,871)
Social benefit, NPV	597,498 (118,005, 974,639)	343,187 (67,779, 559,807)	263,261 (51,994, 429,432)	158,597 (31,323, 258,704)
Cost				
10% of the NBPHS funding	25,526	21,727	19,499	15,837
14.59% of the NBPHS funding	37,243	31,699	28,449	23,107
18% of the NBPHS funding	45,947	39,108	35,099	28,507

Table D9 Benefit-cost ratios at different discount rates and internal rate of return

Benefit-cost ratios	0% (95%CI)	2% (95%CI)	3% (95%CI)	5% (95%CI)	Internal rate of return (%) (95%CI)
18% of the NBPHS funding as cost					
GDP – deaths averted/cost	7.0 (1.38, 11.42)	5.3 (1.05, 8.65)	4.8 (0.95, 7.83)	3.9 (0.77, 6.36)	12.9 (2.5, 21.0)
GDP – deaths averted plus social benefit/cost	20.0 (3.95, 32.62)	14.1 (2.78, 23.00)	12.3 (2.43, 20.06)	9.5 (1.88,15.50)	18.6 (3.7, 30.3)
14.59% of the NBPHS funding as cost					
GDP – deaths averted/cost	8.6 (1.70, 14.03)	6.5 (1.28, 10.60)	5.9 (1.17, 9.62)	4.8 (0.95, 7.83)	14.7 (2.9, 24.0)
GDP – deaths averted plus social benefit/cost	24.7 (4.88, 40.29)	17.3 (3.42, 28.22)	15.1 (2.98, 24.63)	11.7 (2.31,19.09)	20.4 (4.0, 33.3)
10% of the NBPHS funding as cost					
GDP – deaths averted/cost	12.6 (2.49, 20.55)	9.5 (1.88, 15.50)	8.6 (1.70, 14.03)	7.0 (1.38, 11.42)	18.0 (3.6, 29.4)
GDP – deaths averted plus social benefit/cost	36.0 (7.11, 58.72)	25.3 (5.00, 41.27)	22.1 (4.36, 36.05)	17.0 (3.36, 27.73)	24.0 (4.7, 39.1)