LEVELS AND TRENDS IN CHILD MORTALITY IN CHINA BETWEEN 1950 AND 2017 AND THE CONTRIBUTION OF THE HEALTH WORKFORCE TO MORTALITY DECLINE

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Abstract

Background: China has achieved spectacular success in reducing child mortality since 1949. The health workforce is thought to have been important in this progress, but a thorough understanding of how the health workforce contributes to lowering child mortality is lacking. This PhD aims to examine the declines in child mortality in China over the past seven decades and to understand how the health workforce contributes to that progress.

Methods: I did a systematic review to understand the profile and density of the maternal and child health workforce in China since 1949, and a scoping review to evaluate national trends in and determinants of child mortality between 1949 and 2019. I analysed longitudinal data between 1950 and 2017 to examine the speed of decline in child mortality and to investigate the strength of association between doctor density and child mortality in 1950-1964, 1965-1980, and 2000-2016.

Results: In 1950, child mortality was very high in all provinces - one out of five infants died in the first year of life and three out of ten children died before reaching age five. Both infant mortality and child mortality aged 1-4 declined by more than 90% across all provinces between 1950 and 2017. The most rapid decline in child mortality occurred between 1950 and 1955. Increased density of doctors, though not highly educated compared to international standards, contributed to lowering child mortality in China during 1950-1964, independent of economic growth. But in 1965-1980 doctor density was positively associated with child mortality after adjusting for socio-economic, environmental and health system determinants of child mortality. The association disappeared in 2000-2016.

Conclusion: The rapidly decreased child mortality in the early period can give other countries - particularly the poor countries confidence that progress is possible through efforts to scale up the production of health workers. Improving doctor density alone is unlikely to achieve further progress in reducing child mortality in China.

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Abbreviations

CI	Confidence Interval
CMR1-4	Child Mortality Rate aged 1-4
FP	Fractional Polynomial
GBD	Global Burden of Disease
HRH	Human Resources for Health
ICD	International Classification of Diseases
IHME	Institute for Health Metrics and Evaluation
IMR	Infant Mortality Rate
ISCO	International Standard Classification of Occupations
LMIC	Low- and Middle-Income Countries
MCH	Maternal and Child Health
MCHARS	Maternal and Child Health Annual Report System
MCHSS	Maternal and Child Health Surveillance System
MDG	Millennium Development Goal
NMR	Neonatal Mortality Rate
OR	Odds Ratio
PCA	Principal Component Analysis
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-analyses
SD	Standard Deviation
SDG	Sustainable Development Goal
SDI	Socio-demographic index
U5MR	Under-5 Mortality Rate
UN	United Nations
UNICEF	United Nations Children’s Fund
WHO	World Health Organization

Chapter 1. Introduction

The thesis aims to examine the declines in child mortality in China and to understand how the health workforce contributes to that progress in order to show the achievements and lessons of the past, and to share lessons with other countries with high child mortality.

China has made substantial progress in reducing child mortality over the past decades, meeting the Millennium Development Goal (MDG) 4 ahead of schedule. Given the vast size of the country, the achievements were particularly impressive. The successes in child health are attributable to contributors both within and outside health systems. As a pivotal contributor, the health workforce remains neglected. Chapter 1 provides an introduction on the global burden of child mortality, China’s success in reducing child mortality and the rationale for the focus of the thesis on child mortality and the health workforce.

This introductory chapter is based on a broad reading of the literature on the topic and searching for specific information regarding global estimation of child mortality, goals and targets regarding child mortality reductions.

1.1 Global burden of child mortality

The MDG4 was set with a target to reduce the under-5 mortality rate (U5MR) by two-thirds between 1990 and 2015. The world has witnessed substantial progress in reducing the U5MR from 93 deaths per 1,000 live births in 1990 to 38 in 2019. However, an assessment of global statistics in 2016 suggests that most of the 75 poorest so-called Countdown countries failed to achieve the MDG4 for child mortality reductions[1]. The global burden of child mortality remains unacceptably high. It has been estimated that around 5.2 million children under age 5 died primarily of preventable or treatable causes in 2019. Infants accounted for 3.9 million of these deaths and children aged 1-4 accounted for 1.3 million deaths[2].

Most child deaths occur during infancy, especially the first 28 days after birth due to preterm births, congenital abnormalities and birth complications[3]. Among the neonatal deaths each year, two-thirds die in the first week, and two-thirds of these in the first 24 hours[4]. An analysis of results from 44 demographic and health surveys in 2003 showed that in countries with very high U5MR (>200 deaths per live births), one fifth of all child deaths occurred in neonates, while in countries with the U5MR lower than 35 per 1,000 live births more than half of child deaths were in neonates [5].

Progress in child mortality diverges across age groups[6]. Global progress in neonatal mortality declines has been slower than that for older children, resulting in a bigger share of neonatal deaths among under-5 deaths[1, 7]. During the MDG era, the majority of countries (106 out of 193 countries) had accelerated declines in child mortality, which was related to the decline in post-neonatal mortality[8]. In almost all countries where the U5MR declined, the share of infant mortality rate (IMR) has increased relative to the child mortality rate aged 1-4 (CMR1-4) [6].

Although the world has made strides in reducing child mortality, inequalities in child survival exist across regions and countries. Sub-Saharan Africa and South and Central Asia had the highest burden of child mortality in 2019, which accounted for more than 80% of global under-5 deaths[2]. The vast majority of child deaths are concentrated in low- and middle-income (LMIC) countries, e.g., Nigeria, India and Ethiopia. Previous child mortality assessment at subnational levels (provinces, districts or counties) also found extensive geographic inequalities in sub-Saharan Africa, Brazil, Iran and China[6].

To sustain global progress in child mortality reductions, the United Nations (UN) adopted the Sustainable Development Goal (SDG) 3.2.1 to reduce the U5MR to as low as 25 per 1,000 live births in every country by 2030[9]. The SDG agenda was built upon the successes of the MDG era with a broader lens reflecting the intersectional nature of health outcomes with infrastructural considerations[10]. The shift from setting a relative target of two-thirds reductions in the U5MR in the MDG to an absolute target in the SDG requires the identification of the causes of preventable mortality with the most potential for improvement and also a shift in resource allocation[10, 11].

1.2 China’s success and effort in reducing child mortality

Over the past seven decades, China emerged from a poor country to become one of the fastest developing middle-income countries in the world. Along with rapid economic growth, China has also seen substantial transformations in child mortality which are continuing. The U5MR in China was 3.6 times the average U5MR of European areas in 1955-59, but only 1.8 times this rate in 1985-89[12]. During the MDG era (1990-2015), China revitalised efforts to reduce child deaths and became one of the few countries to have achieved MDG 4 of reducing the U5MR by two thirds[13]. China’s decline in child mortality was reported to be one of the most rapid in documented global history [14, 15]. Due to the great success during the MDG era, the World Health Organization (WHO) rated China as one of the top 10 fast-track LMICs in maternal and child health (MCH) [16].

China’s achievements in child health benefited from multiple contributors, including political will, social and economic development, poverty alleviation, the strengthening of health systems and the building of health information systems[17]. The coverage for most of the essential MCH services reached 90% nationwide in 2018, including antenatal care, post-partum visits, disease screening, expanded immunization programmes and integrated management of childhood diseases[17].

China’s long-term strategy in encouraging large scale facility-based birth, establishing effective referral channels to emergency obstetric care and extending financial protection through delivery care expenditure reimbursement has resulted in great successes in reducing the neonatal mortality rate (NMR) [18, 19]. The NMR in China was 3.7 times the average NMR of European areas in 1990, but only 1.7 times this rate in 2015 [20]. With improvements in neonatal care, neonatal deaths caused by infectious diseases decreased dramatically in China [21]. Preterm births and congenital abnormalities became the main causes of neonatal deaths in 2018 [17].

While ensuring access to skilled care in health facilities has been a key strategy for neonatal health, social determinants and access to primary care may be more important for child health[15, 22]. China was widely recognized for its robust health delivery system and major gains in coverage of effective interventions associated with infant and child survival before 1980. Babiarz and colleagues [15], analysing a provincial dataset between 1950 and 1980, found that the education expansion in the 1950s across China and the public health campaigns during the 1960s and 1970s, could explain 55~70% reduction in China’s infant and under-5 child mortality rates controlling for other medical and non-medical determinants of health.

1.3 Rationale for focus on child mortality and health workforce

Child health is the cornerstone for the healthy development of a society. Although child mortality reductions have been documented in the literature, it remains unclear how and why child mortality has fallen across generations in China. Most robust and large-scale studies examining child mortality reductions appeared since the 1990s when high-quality mortality data became available. Less is known about the full progress from 1949 onwards, when the People's Republic of China was created. Given that China experienced fast socioeconomic change, exceptional declines in the birth rate, and environmental and health systems changes in the past decades, a long-period perspective is needed to observe and to explain the decline of child mortality over time.

Many studies have suggested various hypotheses as to why infant and child mortality declined in China. These were mostly based on a description of the health systems and policy changes that coincided with the period of mortality decline, but without any effort of attribution. For example, many authors have suggested that the under-5 mortality decline during the 1960s-1970s was attributable to the introduction of barefoot doctors (“chijiao yisheng”) and a focus on primary health care [23, 24]. Others have suggested that the program of integrated management of childhood illness, implemented in the late 1990s, has contributed to the reduction in the U5MR [25]. However, few studies used rigorous methods in support of their hypotheses, and it remains uncertain whether the decline in mortality was due to the stated investments in health systems. Furthermore, there is an increasing awareness that non-health system factors such as income and education have a larger impact on child health than health system factors [26], but it remains methodologically challenging to study the many interconnected factors.

For the health system, China’s focus has been on health workforce development, primary health care, financial protection, equity and quality of services. Despite the undisputable importance of the health workforce in ensuring a well-functioning health system, few studies have looked at how the health workforce evolved in China, and how health workers were trained or certified to deliver MCH services. Like in other middle-income countries, the “health worker plurality”[27], mixing formal and informal care and traditional and modern medical training, poses a challenge to understand the whole picture.

Existing evidence showing the importance of health worker density to population health (including child survival) have become an important stimulus for increasing the density of health workers [28-30]. China’s priority in developing the health workforce in recent decades has been to increase the density of health workers[31]. As the most populous country, China has the largest health workforce in the world according to data from the WHO in 2010[32]. But it remains unclear if or how the massive increase in the number of health workers, and a shift from barefoot doctors to professionally trained medical doctors between 1949 and today has contributed to the child mortality reductions over the same period. While many epidemiological studies have investigated the socio-demographic determinants of child mortality, few have attempted to quantify the strength of association between doctor density and child mortality over time.

The shortage of health workers still limits the coverage of MCH services in many countries that have not achieved the MDG4, most evidently in sub-Saharan African countries [33]. Increasing the supply of health workers through professional training and education is costly and time-consuming. To achieve time-bound targets like the SDG, all countries can accelerate health gains through investing in health workforce more strategically. Understanding the contribution of the health workforce to China’s success in reducing child mortality is important, because the experience in improving child health might inform evidence-based policy options for other countries with high child mortality.

For China, despite substantial declines in child mortality, the absolute number of under-5 deaths remains high. With approximately 132,000 deaths among children under five in 2019, China is one of the top ten countries with the highest burden of under-5 mortality in the world [2]. Understanding whether and how the health workforce contributed to child mortality declines in the past might provide evidence on what policies might be the most effective in reducing child mortality in the future.

1.4 Aims and objectives

The overall aim of the study is to examine the progress in child mortality declines in China and to understand how the health workforce contributes to that progress in order to show the achievements and lessons of the past, and to share lessons with other countries with high child mortality.

Objective 1: Systematically review the literature reporting on the profile and density of MCH workers in China from 1949 onwards.

Objective 2: A scoping review of the literature reporting on national trends in infant and child mortality and the medical causes of child mortality in China between 1949 and 2019, to improve understanding of the determinants that underpinned the achievement, and to identify knowledge gaps.

Objective 3: Describe the levels of infant and child mortality and the trends of the health systems and socio-demographic status over time and across 27 provinces in China between 1950 and 2017 based on an updated longitudinal database; and to quantify the speed of decline in the infant and child mortality rate aged 1-4 across all provinces between 1950 and 2017 and examine the variation in speed of mortality decline by province and by socio-demographic development of provinces.

Objective 4: Investigate whether and to what extent the strength of association between doctor density and the infant and child mortality rate aged 1-4 changed by periods of time (1950-1964, 1965-1980, 2000-2016); and to examine the health systems and socio-economic determinants of the infant and child mortality rate aged 1-4 across 27 provinces in China over the same periods.

1.5 Thesis outline

An overview of the chapters is provided below.

Chapter 1 introduces the global burden of child mortality, including the global targets, public health importance and challenges. It provides the rationale of the research questions, aims and objectives of the thesis.

Chapter 2 introduces the configuration of China's health systems and MCH services. I introduce the concepts of the health workforce and describe the development of the health workforce in China by historical period. This is followed by definitions and measurement issues of child mortality.

Chapters 3-6 present the studies for each objective as specified in section 1.4. Each chapter includes background, methods, results, discussions and conclusions.

Chapter 3 addresses the first objective of this thesis by presenting the findings from the systematic review on the MCH workforce profile and MCH workforce density, which has been published.

Chapter 4 addresses the second objective of the thesis by reporting on a scoping review. In this chapter I present the data sources that have been used to measure child mortality in China. I document the national trends in infant and child mortality in China between 1949 and 2019 and I summarize the medical causes and determinants of infant and child mortality that have been reported in the literature.

Chapter 5 addresses the third objective of the thesis and presents the results of an analysis of the speed of decline in infant and child mortality. I start the chapter outlining the data sources, including how I updated an existing longitudinal province-level dataset (1950-1980) to a longer period of time (1950-2017). Then I describe the levels of infant and child mortality and the trends of health systems and socio-demographic status over the period 1950-2017. This is followed by the analysis of speed of child mortality decline using Fractional Polynomials and an investigation of variation by province and by a generated socio-demographic index.

Chapter 6 addresses the fourth objective of the thesis and presents the results of an analysis investigating the strength of association between doctor density and infant and child mortality in China over the period 1950-2016. The relative importance of doctor density to child mortality decline is assessed by comparing the strength of association between the two in different periods of time.

The thesis concludes with Chapter 7 to summarize the study findings and to give an overall discussion and conclusion.

Chapter 2. Background

Chapter 2 introduces the background of China’s health system, the main features of MCH services and the health workforce – including definitions, density, sufficiency and potential measurement challenges for MCH workforce. It draws on the broad literature reading for chapter 1. A review of the literature on the development of the health workforce in China by historical period is included, highlighting the varied health systems and health workforce policies. In addition, more detailed information regarding the measurement of child mortality is provided.

2.1 Configuration of China’s health system and MCH services

Since the establishment of the People's Republic of China in 1949, China created a health system similar to that of the Soviet Union[34]. China’s medical care has been gradually organized into a three-tiered network [35]. The three-tiered network includes tertiary hospitals, secondary hospitals and primary health institutions [36]. Tertiary (teaching hospitals) and secondary hospitals (district hospitals in urban areas/county hospitals in rural areas) mainly offer comprehensive medical services [37]. Primary health institutions, including community health centres and stations in urban areas, and township hospitals and village clinics in rural areas, mainly provide primary medical and basic public health services[36]. The government owned and ran all the health facilities under Chairman Mao (1949-1976)[34]. Health services were nearly free. In the 1960s and 1970s the expansion of primary healthcare made China a successful model in “good health at low cost”[24].

The reform of the economic system which started in 1978 brought dramatic changes to the health system. Due to the withdrawal of government subsidies, public hospitals became increasingly commercial [38]. The government still owned the public hospitals but exerted little control over the organizations of health services [34]. The three-tier system and the network of primary healthcare providers was dismantled, which resulted in neglecting prevention and primary care[38]. In the absence of gatekeeping, people were more likely to utilise hospital services. Tertiary and secondary hospitals became the dominant provider of health services resulting in escalating healthcare costs and low efficiency of the health system [36]. The fact that hospital services were expensive and the population was largely uninsured drove many patients into poverty[34]. By the end of the 1990s, discontent with lack of health services fuelled public anger and threatened social stability [34].

In order to mitigate popular discontent with the health system, China shifted the health system’s design from the market to the government and initiated a series of health reforms trying to introduce a gatekeeping system following the principle of “ensuring basic services, strengthening primary health institutions and building effective mechanisms” [36] (Figure 2.1). China also re-emphasized the strengthening of primary healthcare as an overall strategy to achieve further MCH progress [39].

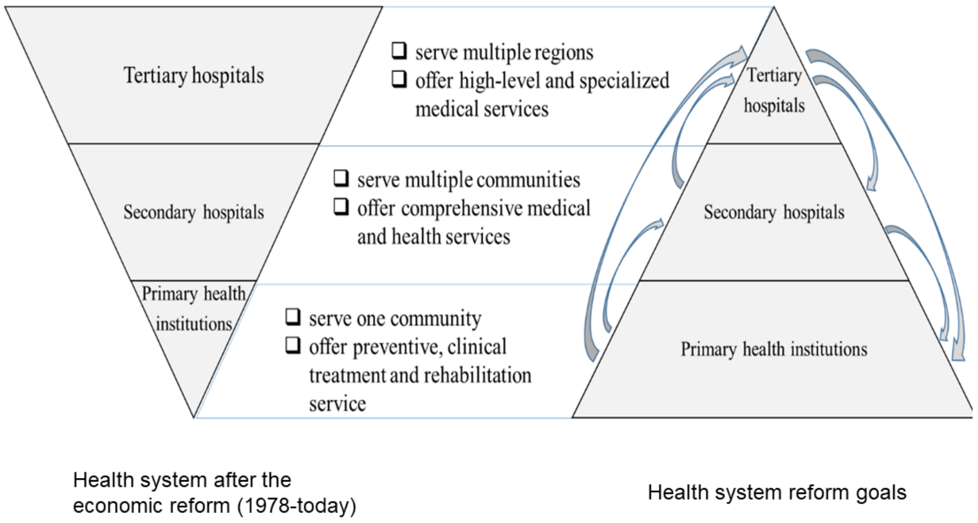


Figure 2.1: Overview of China's health system in transition

Source: Developed by author (HZ), according to *People's Republic of China Health System Review* (p. 133), by Q.Y. Meng, et al. 2015, Geneva. Copyright 2015 by the World Health Organization.

Parallel to the above general health system, China has a public health system consisting of “MCH institutions, disease control and prevention centres, health information institutions, health supervision institutions, among others”[36]. Such configuration of health services has made MCH service delivery characterized in two ways: (i) the MCH service delivery system is imbedded in the health system with a three-tiered network in both urban and rural areas [18, 40]. (ii) multiple institutions simultaneously provide MCH services, including primary health institutions, maternity hospitals (only maternity services), children’s hospitals (only child health services), general hospitals, traditional Chinese medicine hospitals, family planning institutions and designated MCH institutions (an extensive hospital network providing obstetric and neonatal care) [36, 41] (Figure 2.2).

Women and children today can choose any health institutions without referral requirement. MCH institutions, general hospitals, specialized hospitals and traditional Chinese medicine hospitals provide antenatal, childbirth, postnatal, neonatal and childhood care services [40]. Primary healthcare institutions mainly provide antenatal care, postnatal care, immunization and basic treatment of childhood illness [36]. Some township hospitals with obstetric departments are able to provide normal delivery care and basic obstetric care but few of them do so now[40]. Family planning institutions mainly undertake tasks in family planning and reproductive health related services [36].

Since the focus of this thesis is on child mortality and MCH services, family planning services are not further discussed. The classification in Figure 2.2 does not differentiate between public and private institutions. Considering the limited role of the private sector in MCH services in China before 2015 (less than 10% market share) [38, 42], it is not the main focus of the thesis.

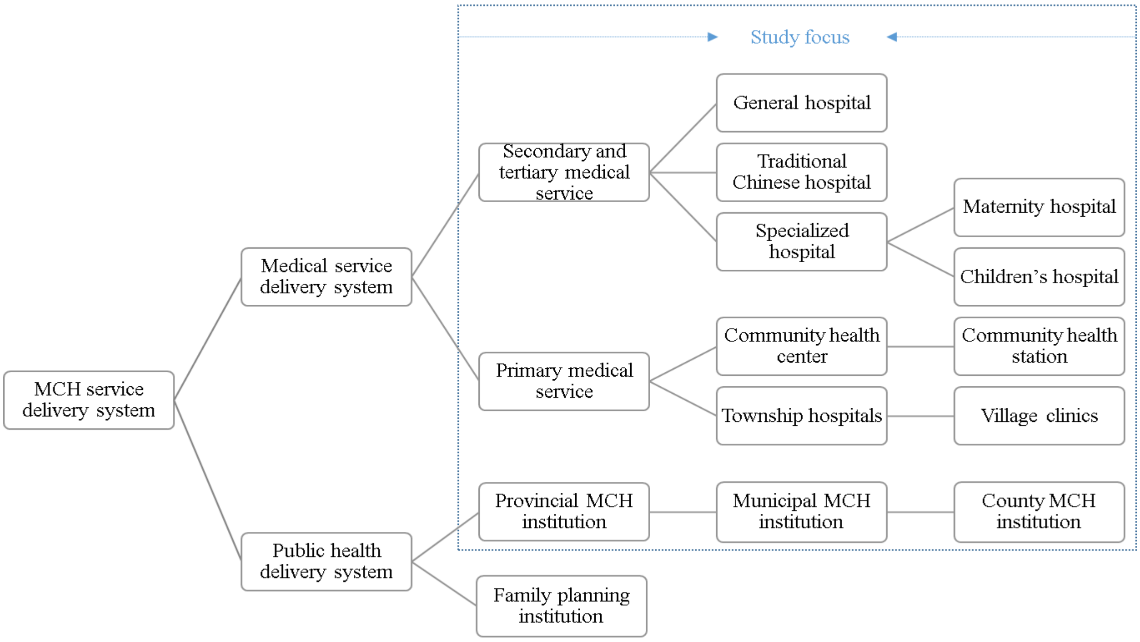


Figure 2.2: MCH service delivery system in China and study focus

Source: Developed by author (HZ), according to ***People's Republic of China Health System Review*** (p. 133), by Q.Y. Meng, et al. 2015, Geneva. Copyright 2015 by the World Health Organization.

2.2 The health workforce in the world

2.2.1 Defining the health workforce

The modern health workforce has evolved over the past century throughout the world, starting with the milestone Flexner Report (1910) in medical education[43]. The development of the health workforce has focused on strengthening medicine, nursing, public health and allied health professions[44]. Over the past two decades, the health workforce repeatedly emerged as the most important barrier in the global response to health crises[29]. The international community has therefore begun to look for new understanding of the health workforce.

The importance of the health workforce was articulated in the 2006 World Health Report with a creation of the Global Health Workforce Alliance[45]. The report considers that health workers are those "who primarily engage in actions with the primary intent of enhancing health". This broad definition includes health workers with varied skills and qualifications. They are divided into clinical and non-clinical staff responsible for public and individual health interventions [46]. Clinical staff are also called “health service providers”; non-clinical staff refer to people not directly engaged in service provision and are under the term “health management and support workers”[28].

A doctor or a nurse is usually defined as someone with appropriate training and qualifications recognized in his or her own country [32]. Globally there is little uniformity with respect to length of training and competency of medical doctors [47]. A medical doctor degree could be granted with highly variable length of training, training content and competency achieved[47]. The length of medical training in a country is usually a legacy of history rather than an evidence-based decision[48]. For example, the length of medical training for a doctor in the US is 8 years after high school while that in Europe is 5 or 6 years[32]. Globally, the majority of nurses attend vocational schools or on-the-job training[47]. Nursing education becomes more varied now, ranging from vocational training to doctoral programs[32].

2.2.2 Classifying health workers

To classify cadres of health workers, many countries have developed their own classification systems based on the International Standard Classification of Occupations (ISCO, earliest version adopted in 1987). The WHO also accepted the classification of cadres by the ISCO. According to the Global Health Workforce Statistics, there are nine cadres including doctors (generalists or specialists), nurses and midwives, dentists, pharmacists, laboratory technicians, public and environmental health workers, community health workers, as well as health management and support workers and other health workers[49]. The range of cadres necessary to classify health workers is extensive, integrating many aspects such as occupation, training and certification.

Classifications provide a framework for the classification of health workers by according to shared characteristics[50]. For example, community health workers have a widely accepted definition by a WHO Study Group since 1989 as “members of the communities where they work, should be selected by the communities, should be answerable to the communities for their activities, should be supported by the health system but not necessarily a part of its organization, and have shorter training than professional workers”[51]. Community health workers were first trained in China in the 1950s as “barefoot doctors” to fill the gap in human resources[52]. Since then, the community health worker programs have evolved over the years in many countries with varying degrees of success. The role of community health workers varies across countries, and can be preventive, curative or developmental[53]. The terms used in classifying cadres are dependent on the health systems in a given country, and often mask the variation in their medical training and qualification [53]. This highlights the need to consider the variations when examining particular cadres of health workers in each country.

The cadre classification in a given country will also be dependent on the relevance of the classification to the scope of analysis. One example is that in many countries there are no clear cadre distinctions between nurses and midwives[54]. In line with the statistics of WHO, the nurses and midwives are usually counted as one cadre because nurses and midwives receive similar training and undertake overlapping tasks in many countries. Such cadre classifications enable countries to map their health workforce and may be useful for the purpose of health workforce planning.

2.2.3 Health workforce density

The health workforce density is defined as the number of health workers for every 10,000 population, e.g. a number of health professionals, doctors, nurses or midwives per 10,000 population. Official information on the health workforce density is often available only for doctors and nurses. Although easy to calculate and straightforward to communicate, the health workforce density is based on simple headcounts that do not necessarily reflect the health system context or variability in service delivery.

The total health-worker density is a crude metric because it counts all the cadres of health workers in the health systems without accounting for the differences in medical training. Doctors have been viewed as the most critical cadre of health workers which cannot be easily substituted by other cadres, so doctor density is preferred to total health-worker density when estimating the contribution of different cadres of health workers to the goals of the health systems[55]. A cross-country study by Anand and Baernighausen showed that doctor density was most significant in explaining variation in the IMR and the U5MR across 83 countries, more so than density of nurse and midwives, density of the sum of health professionals [56].

There is large variation among regions and countries in the health workforce density. Among world regions, the density of health workers (including doctors and nurses) varies by a factor of 10, from 12.3 per 1,000 population in the US to 1.6 per 1,000 population in India in 2014 [32]. The health workforce density is strongly related to the sociodemographic development[57]. The WHO estimated that 57 poor countries have insufficient number of health workers to meet minimum needs in 2006 [28]. Many high-income countries also suffer from shortages of health workers [47]. The expected shortage in Europe is anticipated to reach 4.1 million in 2030 (0.6 million doctors, 2.3 million nurses and 1.3 million other cadres of health workers)[58]. One target of the SDG 3 stated to “substantially increase the recruitment, development, training and retention of the health workforce in developing countries, especially in least developed countries and small island developing States” but with no quantitative target[59].

Many efforts have been made to examine the sufficiency of the health workforce in relation to essential health needs, but there is no universal standard. The Joint Learning Initiative did a global workforce assessment in 2004 and suggested a threshold of 2.50 health workers (including only doctors, midwives and nurses) per 1000 population as the minimum level to achieve 80% coverage of measles immunization or skilled attendance at delivery[60]. The WHO updated the global workforce dataset in 2004 and arrived at a minimum workforce density (including only doctors, nurses and midwives) of 2.28 per 1,000 population, with 2.02 and 2.54 as the lower and upper bounds for uncertainty. Other benchmark estimates of health workforce density have been set but vary considerably by decisions to reach some desired health system objectives or health services requirements[61]. For example, in 2016, WHO quantified an indicative minimum density of 4.45 doctors, nurses and midwives per 1,000 population to achieve a median performance on an SDG index composed of 12 tracer indicators[61]. Attempts have also been made to arrive at a benchmark based on an estimation of workload. Using evidence that midwives working in a team can assist at least 175 births per year, the World Health Report 2005 suggested that 3 part-time doctors with obstetric skills or 20 midwives per 3600 births are required per year to provide essential maternal and newborn care. The transferability of the recommended standards to country-specific context requires caution as the cadres and competencies of health workers vary.

2.3 The health workforce in China

2.3.1 Historical perspectives on the health workforce

The definition of the ‘health workforce’ varies qualitatively in China’s contemporary history as the medical education system was modernized over time [62]. Before going any further, it is useful to understand the changing health workforce policies in relation to the wider trends in China’s politics and health policies (Figure 2.3) [63]. Figure 2.3, which was adapted from the Lancet Commission on 70 years of women’s reproductive, maternal, newborn, child, and adolescent health in China [17], shows the national policies on the health workforce as well as national policies in relation to MCH. The periods were chosen to reflect China’s changing macro-health policies.

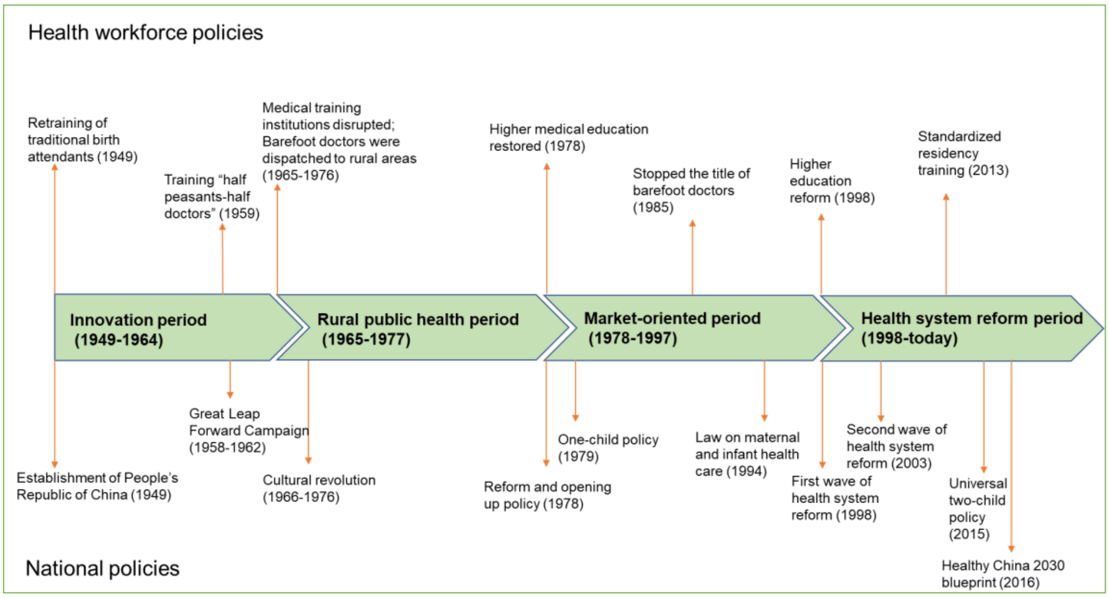


Figure 2.3: Health workforce-related national policies in China

Source: Qiao, Jie, et al. 2021. "A lancet commission on 70 years of women's reproductive, maternal, newborn, child, and adolescent health in China." The Lancet, (2021), 1-40.

1949-1964 Innovation period

Health worker shortage was a pressing problem in 1949. The government operated all health facilities and employed all health workers at the time[34, 38]. Private health facilities disappeared through a massive nationalization movement in the 1950s[38]. The supply of health workers was constrained by limited financial resources. In 1952, there were only 0.09 licensed doctors and 0.12 licensed assistant doctors per 1,000 population[31]. The shortage of health workers was particularly challenging in rural areas where there were only 0.04 doctors and 0.09 assistant doctors per 1,000 population.

A distinctive characteristic of this period was the innovation to resolve health workforce shortages. At that time, few Chinese people had secondary education necessary for the medical training[64]. To meet the urgent demand for health workers, the government built over 320 secondary technical schools (*Zhongzhuan*, 3 years of study or less) to produce health workers with a secondary vocational diploma[65]. Another innovation was to utilize traditional health practitioners and "*half peasants-half doctors*" (*ban nong ban yi*) [34, 66]. Nearly 800,000 traditional birth attendants were retrained to deliver antenatal and delivery care from 1949 to 1959 [17]. The "*half* peasants-half doctors" were farmers who received very short medical training and delivered health care in the rural area, later widely known as the "barefoot doctors" [66]. At the time, China had few qualified specialists[38]. The barefoot doctors provided the most basic primary healthcare, including immunisation, delivery care and improvement in sanitation, in rural areas despite the persisting poverty across the country [17, 23].

1965-1977 Rural public health period

In 1965, Chairman Mao criticized the Ministry of Health for favouring urban areas in health care[67]. The Cultural Revolution began in the health sector, which became a devastating period for medical education and was later referred to as “the ten years of going backward” (*daotui de shinian*, 1966-1976)[68]. At the time, medical colleges and universities were closed[69]. It was compulsory for almost all medical graduates to serve in rural areas. Specialist departments in hospitals also closed[69]. Professionalization of health workers was de-emphasized in the health system during the Cultural Revolution [31]. Within health facilities, professional hierarchy by titles was overturned and promotion of any kind stopped[31, 70]. The quality of medical education deteriorated seriously[71].

In 1968, the programme of barefoot doctors became a national policy focusing on the mass production of barefoot doctors to meet rural needs[23]. Many licensed doctors in urban areas were sent to disadvantaged rural communities to deliver health care and train barefoot doctors [66, 72]. The density of barefoot doctors reached 2.5 per 1,000 rural residents in 1975. Later in 1978, the WHO cited the barefoot doctor programme as a successful example for primary health care at the Alma Ata conference [23].

1978-1997 Market-oriented period

The economic reform in 1978 enabled medical institutions to ramp up medical training, making 1978-1997 a period of rehabilitation and readjustment[71]. On the one hand, higher medical training was restored in this period and medical student enrolment increased due to the economic boom [66]. On the other hand, the promotion of doctors was revived with a relaxed criteria after the Cultural Revolution (1966-1976). The bareroot doctors were allowed to be upgraded to “village doctors” if they passed an examination comparable to that required of graduates from secondary technical schools[71]. In 1985, the government stopped using the title of barefoot doctors and kept around 0.6 million village doctors[73]. The promotion of assistant doctors in the late 1970s and early 1980s brought substantial growth in numbers of doctors who were made “qualified doctors” after serving for a few years but had no pre-service medical training[31].

During this period, the government prioritized hospitals, resulting in a huge decline in primary health care[23, 74]. Most health institutions at township level or above were government-owned and had a dual personnel system [35]. Health workers could be divided into either ‘tenure (bianzhi) staff’ or ‘contract staff’. The tenure staff are regarded as state employees in a way similar to civil servants [65]. The quota for tenure staff was determined by local governments, involving health sector, personnel sector and planning sector. Health institutions had increased autonomy and decided themselves how many contract staff they wanted to recruit [35]. During the 1980s, many health workers in rural areas with pre-service medical training migrated to urban areas and new medical graduates were unwilling to serve in rural areas[31]. The township hospitals experienced a brain drain of their best health workers due to the lack of finance and professional prospects[74]. The health workforce in rural areas deteriorated rapidly, undermining the prior efforts in strengthening primary health care[74].

1998-today Health system reform period

This period represents a time of economic growth and reforms in education and health systems to balance social development with economic growth[62]. Starting from 1998, the major educational reform was aimed to improve the quality of medical training by enhancing tertiary education [65, 75]. Even today, there is little uniformity with respect to the tertiary education of health professionals[47]. The length of training varies between different medical or health-related programs, ranging from three to eight years (Figure 2.4). The standard undergraduate program in China takes five years to complete (sometimes 4 years for a bachelor degree in science); The standard Master’s program takes three years to complete; The standard Doctor of Medicine program takes three years to complete for candidates holding a Master’s degree; There are also 5-year Doctor’s programs for candidates holding a bachelor degree; There are 8-year Doctor’s degree programs, and 6-year or 7-year Master’s programs once students pass the National College Entrance Exam [76]. China launched the standardised residency training post undergraduate training in 2013 as a national strategy to produce competent doctors [65].

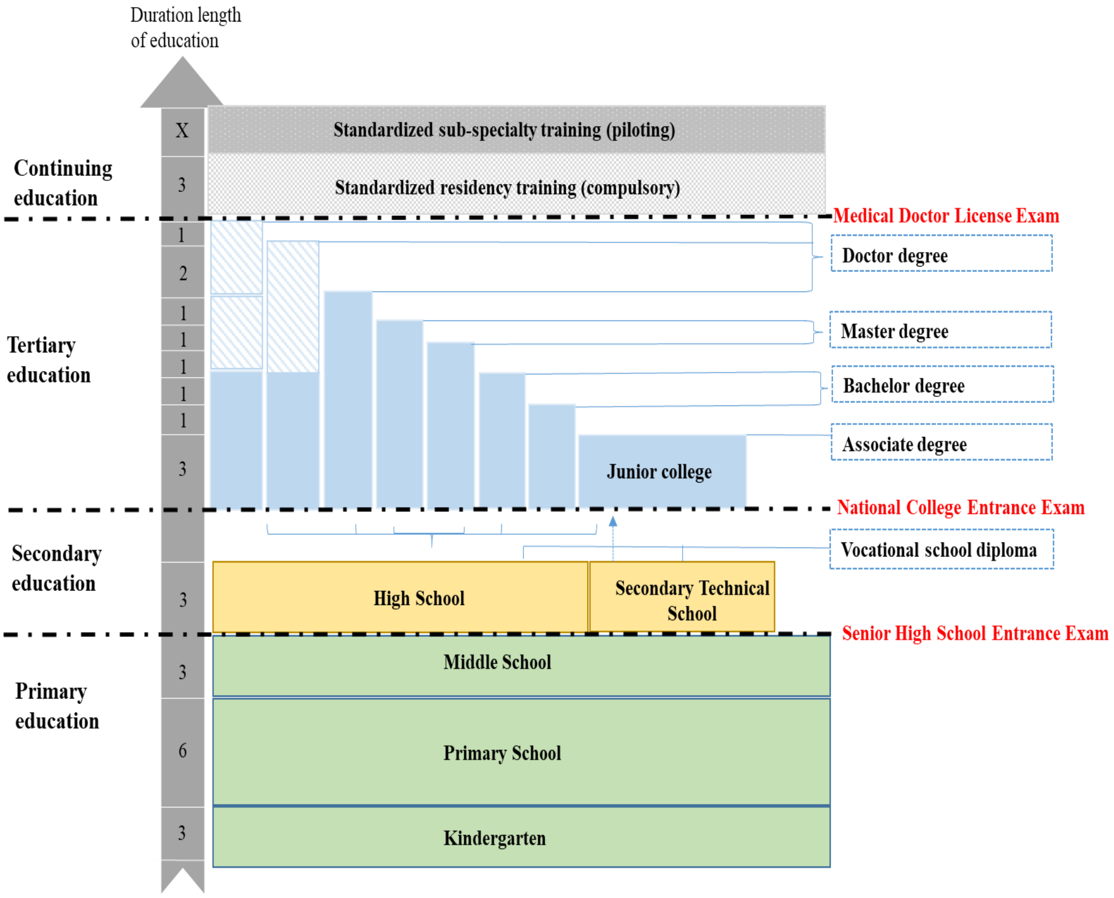


Figure 2.4: Graphical presentation of China’s Medical education system, 1998-today

Source: Developed by author (HZ) according to two sources: (1) Anand, Sudhir, et al. "China's human resources for health: quantity, quality, and distribution." The Lancet 372.9651 (2008): 1774-1781. (2) Zhu, Jiming, et al. “Doctors in China: Improving quality through modernisation of residency education. The Lancet, 388 (2016), 1922-29.

Between 1998 and 2005, the number of admissions to health-related training programs to tertiary medical institutions expanded by 350%[72]. But national statistics between 2000 and 2005 showed that the number of medical graduates from all educational institutions greatly exceeded the increase in health workforce density, suggesting inefficiency of graduates entering into medical practice[62]. Although the 3 years’ secondary technical school training is receding, the process of replacing the health workforce with the college-level graduates is extremely slow[65]. Even in 2020 a large proportion of registered doctors (42.6%) have not achieved a bachelor degree[25].

2.3.2 Data on health workers in China

In China’s Health Statistics Yearbook, the Ministry of Health publishes health workforce density data by cadre (health professionals, doctors, nurses) at national level each year, which is based on annual organization-based administrative surveys[25]. Different cadres of health workers in China are defined mostly according to education and qualifications, as shown in Table 2.1. The medical licensing process is run by the Ministry of Health. At the end of medical training, the medical graduates who pass the National Medical Licensing Examination will obtain a doctor license. Before 2002, there was no requirement of a particular degree to register for the examination. But after 2002, only medical graduates who have a bachelor degree can register for the examination. Midwives do not exist as a separate cadre in China and some nurses may do the work of midwifery.

Table 2.1: Cadre classification of health workers in China since 1998

Cadre	Doctors	Nurses	Pharmacists	Technicians	Village doctors	Management staff	Supportive workers
Classified as health professional Yes/No	Yes	Yes	Yes	Yes	No	No	No
Definition	Health professionals titled either licensed doctor or assistant licensed doctor based on the medical practitioner certificate. Licensed doctors have bachelor or higher degree in medicine. Assistant licensed doctors are graduates of three-year junior college, or secondary technical school with a school diploma. One-year internship in health facilities is required for the registration of licensed (assistant) doctor.	Health professionals who have obtained nursing certification with a junior college degree or higher, or graduated from secondary education programs with a diploma.	Health professionals who have received medical training in pharmacy and provide health knowledge of pharmaceutical services in health facilities.	Health professionals who have received training laboratory science or radiology.	Those who have a village doctor certificate and practice in rural clinics. Before 1985 this cadre referred to barefoot doctors.	Those who engage in personnel management, financial management or information management for health facilities.	Those who engage in logistic support for health facilities.

Source: Summarized by the author HZ based on two sources: (1) Health Statistics Yearbook 2021. (2) Anand, Sudhir, et al. "China's human resources for health: quantity, quality, and distribution." The Lancet 372.9651 (2008): 1774-1781.

2.3.3 Health workforce density in China

The latest official statistics in 2020 showed that China had 10.7 million health professionals (including licenced doctors, nurses, pharmacists and technicians) and 0.8 million village doctors (classified as barefoot doctors before 1985) [25]. Figure 2.5 displays the density of health professionals, the density of doctors and nurses respectively at national level in 1949-2020 from the Health Statistics Yearbooks. The increase in the density of health professionals in China has been driven by the increase of doctors and nurses[65]. In 2020, the densities of registered doctors and nurses were 29 and 33 per 10,000 population respectively [25]. The densify of doctors is similar compared to the UK's at 28 and the US's 26 per 10,000 population in 2018. The density of nurses is one third of that in the UK (103) and Europe (96) in 2018[77]. The distribution of health professionals in China is imbalanced between urban and rural areas. In 2020, doctor density in urban areas (42.5 per 10,000 population) was more than twice that in rural areas (20.6 per 10,000 population), with nurse density having 2.6 times difference [25].

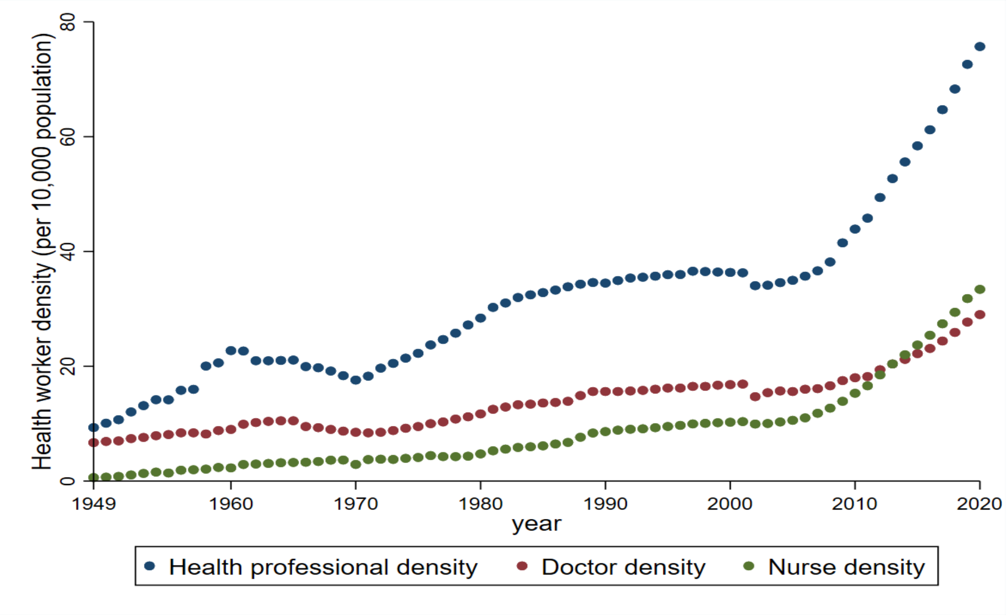


Figure 2.5: National statistics of health professional density, doctor density and nurse density, 1949-2020

Source: China Health Statistics Yearbook 2021 and China Statistical Data Compilation 1949-2003.

2.4 The MCH workforce in the world

2.4.1 Defining MCH workforce

The term MCH workforce is used as an umbrella term for any cadre of health workers that provide continuous care for pregnant women and their babies, from pregnancy, to delivery and childhood care. International efforts to measure MCH progress and resource tracking (e.g. Countdown to 2015 to achieve MDGs) have mostly centred on pregnancy and early childhood [78]. I adhere to the following definitional scope of MCH services in this thesis: antenatal care, childbirth care, postnatal care, care during infancy and for children under five. Where possible, I refer specifically to the cadre of MCH workforce, e.g. obstetricians or paediatricians, not the entire workforce.

High-income countries emphasize the roles of doctors, nurses and midwives and their specialised skills for the entire continuum of care. For example, the MCH workforce in Canada includes family physicians, midwives, nurses and specialists such as obstetricians, neonatologists, paediatricians and surgeons[79]. In contrast, the MCH workforce in LMICs have fewer health professionals but more community health workers or informal care providers, for example traditional birth attendants—women who were from the community and traditionally dealt with childbirth[80].

A key SDG indicator related to the MCH workforce is the “proportion of births attended by skilled health personnel” (SDG 3.1.2)[59]. According to the WHO, a skilled birth attendant is defined as “A midwife, doctor or nurse—who has been educated and trained to proficiency in the skills needed to manage normal (uncomplicated) pregnancies, childbirth and the immediate postnatal period, and in the identification, management and referral of complications in women and newborns”[81]. Much attention globally has been paid to the definition of skilled birth attendants. However, skilled birth attendant is not always a useful concept because it does not relate to a clear framework of training and certification in countries.

2.4.2 The MCH workforce density

The numerator for the MCH workforce density is the number of any cadre of MCH workers. Different population denominators have been given to estimate MCH workforce density [82]. The commonly used denominators include annual live births, total population, total number of births, number of children, and annual pregnant women [83, 84]. MCH workers per births are more preferable in the area of MCH because the total population cannot accurately reflect the MCH care needs[85]. In the systematic review, I use the number of live births as well as the number of population in my denominators to examine MCH worker density.

2.4.3 The shortage of MCH workforce

The health workforce shortage has often been cited in global reports and research literature and the MCH workforce is no exception [28, 29, 86, 87]. The shortage of MCH workers is one of the key factors contributing to inadequate progress in reducing infant and child mortality across many but not all developing countries [33]. Internationally, most countries still have too few specialist MCH doctors(e.g. neonatologists, obstetricians and paediatricians) and nurses, with far lagging medical training for theses cadres particularly in low-income countries[45, 88].

The health financing methods used and level of detail rarely allow investment in the MCH workforce to be disentangled from general health workforce investments. For example, there is little controversy about the need to invest in the training and deployment of skilled birth attendants. But in many developing countries the investment in community health workers has been at the expense of funds for the skilled birth attendants, resulting in a global shortage of midwives [80, 89].

2.5 Monitoring child mortality

2.5.1 Child mortality indicators

Measuring progress in child mortality reductions requires a set of valid indicators. The estimation of child mortality has focused on measuring the probabilities of dying between certain age bands. The most commonly presented age bands are the neonatal period (from birth to 28 days of age), the post-neonatal period (first month after birth and the end of the first year), infancy (0-1 years) and the under-5 period (under 5 years). The denominator is the number of surviving children at the beginning of the specified age range during the specified time period.

The indicators for monitoring MDG4 on child survival are the U5MR and the IMR [90]. As an indicator in the MDGs, the U5MR is defined as “the number of deaths to children under the age of five per 1,000 live births”. The IMR is defined as “the number of deaths to infants under one year of age per 1,000 live births”. The two indicators are widely used as child mortality indicators and quantitative goals of population health reflecting health system performance [4, 91, 92]. In addition, a wider range of indicators have been required to adequately track progress, including the NMR (the probability of death before age 1 month), the post-neonatal rate (the probability of death before age 1 year conditional on surviving to age one month) and the CMR1-4 (the probability of death before age 5 years conditional on survival to age 1 year)[93]. I will term the CMR1-4 as child mortality rate aged 1-4 throughout the thesis to make the three outcomes (IMR, U5MR, CMR1-4) easy for interpretation.

2.5.2 Child mortality estimation methods

The estimation methods for child mortality depend on the available data. Complete registration data on births and deaths provide the best basis for direct estimation of child mortality[12]. The registration systems in developing countries are usually poor or non-existent. If there are survey data of complete birth histories, indirect techniques based on life tables are applicable. The probabilities of dying can be derived from reported deaths and the numbers of children at certain age bands exposed to the risk of dying over a specified period, for example 10 or 15 years before a survey[12]. When the only data available are from mothers of reproductive age reporting information on children ever born and the proportion of children surviving, a commonly-used procedure is the Brass method, by which the childhood survivorship probabilities can be calculated [94].

When different estimation methods are used, child mortality estimates for the same time period may differ due to sampling and non-sampling errors[12]. The magnitude of the variation in the estimates is dependent on the variation in the data sources as well as the choice of methods of analysis. Standard methodological methods for dealing with discrepancies in child mortality estimates have not yet been finalized. Simple averaging and more sophisticated regression techniques have been used to obtain a series of consistent estimates of child mortality over time[95-97].

2.5.3 Medical causes of child mortality

Efforts to reduce child mortality can only be effective if they are based on accurate data on causes of child deaths. If available, vital event registration that includes cause-of-death data is the primary source to establish causes of deaths[5, 98]. Alternative sources are nationally-representative surveys and special study populations. With these, verbal autopsy is usually used to establish the causes of child death[5].

Once the official cause of death has been determined, child deaths are categorized according to the chapters of the International Classification of Diseases (ICD-11 most recent version) coding classification developed by the WHO[99]. The WHO’s work on the global burden of diseases stipulates one cause of death to be the “disease or injury which initiated the train of morbid events leading directly to death”, which ensures that the sum of deaths from all possible causes do not exceed the total number of child deaths[5]. The grouping of causes of death is used for the analysis of mortality data and routine surveillance reporting.

2.5.4 Determinants of child mortality

To understand the non-medical factors on health, researchers have focused on understanding the factors that affect people's health, often referred to as health determinants[100]. In this thesis, I will refer to non-medical factors as determinants of child mortality. Key determinants of child mortality include income, education, housing condition, access to improved water sources and sanitation facilities[101].

Income and education are probably the most well-known country-level determinants of infant and child mortality[102, 103]. Cross-country studies have consistently found national income, as measured by gross domestic product (GDP) per capita or gross national income per capita, to be the strongest determinant of infant and child mortality among the determinants included for analysis[104]. A study of global trends in child mortality found that over 50 percent of the decline in 1970-2009 could be attributed to gains in the mean years of maternal education[105].

Much of the implied causation attributed to income or education relies on their "distal" nature, i.e. these determinants are regarded as prerequisite to more proximate determinants of child mortality. The most influential analytical framework in the study of child mortality is developed by Mosley and Chen[106]. For child mortality, the determinants at the distant level, including income and education, work through factors at the intermediate level (such as environmental and behavioural risk factors). Factors at the intermediate level work through the proximal causes of child deaths, such as infectious diseases, non-communicable diseases and injuries[106].

2.5.5 Tracking progress in child survival

In addition of child mortality indicators, a wider range of indicators are advocated to adequately track child survival progress. Before 2000, many child survival programmes set loosely defined strategies to achieve certain child mortality reduction targets[12]. To strengthen the information base for child survival, the global *Countdown* monitoring focuses on coverage of effective child survival interventions [4]. Many instances of infant and child deaths could be averted by health interventions such as vaccinations, antibiotics treatment and bednet use[56]. There are five component areas developed for the *Countdown* monitoring in 2005: nutrition interventions, vaccination, case management of illness, newborn health and other prevention interventions (Table 2.2). To measure progress within each component, the *Countdown* monitoring includes a set of valid indicators which are listed behind each component areas in Table 2.2. For example, to provide useful information on nutrition interventions, the *Countdown* monitoring includes exclusive breastfeeding to 6 months, breastfeeding with complementary food at 6-9 months and continued breastfeeding at 20-23 months [4].

Achieving high coverage with the recommended interventions would prevent the majority of child deaths from undernutrition. In the global monitoring of progress in child survival, the intervention coverage is a good indicator because progress in coverage means policies, delivery strategies, adequate human and financial sources are in place[4].

Table 2.2: Tracking indicators for child survival, the *Countdown* 2005

Component areas	Coverage indicators
Nutrition interventions	1. Exclusive breastfeeding to 6 months 2. Breastfeeding with complementary food at 6-9 months 3. Continued breastfeeding at 20-23 months
Vaccination	4. Measles immunization coverage 5. Diphtheria, pertussis and tetanus (DPT3) immunization coverage 6. Hib immunization coverage
Newborn health	7. Skilled attendant at delivery 8. Neonatal tetanus protection 9. Timely initiation of breastfeeding 10. Postnatal visit within three days of delivery 11. Prevention of mother-to-child transmission of HIV
Case management of illness	12. Care seeking for pneumonia 13. Antibiotic treatment for pneumonia 18. Oral rehydration and continued feeding 19. Antimalarial treatment
Other prevention interventions	20. Vitamin A supplementation coverage 21. Use of improved drinking water sources 22. Use of improved sanitation facilities 23. Insecticide-treated net coverage

Chapter 3. Systematic review of the MCH workforce in China

Chapter 3 addresses the first objective of the thesis by presenting a systematic review of the profile and density of MCH workers in China. The main purpose of this study is to examine how MCH workers are trained or certified to deliver MCH services.

This chapter begins with the article presenting the main findings from the systematic review, which was published in the Human Resources for Health in October 2021. By examining the MCH workers’ education, certification and density, I provide insights into how China is addressing its MCH workforce needs. By comparing the MCH worker density to the internationally suggested health workforce thresholds, I also discuss the sufficiency of the MCH workforce in China.

The version of the article presented in this chapter was edited to incorporate a longer results section providing more details on the meta-analysis of the education level of MCH workers by cadre and by level of facility.

3.1 Published article - A systematic review of the profile and density of the maternal and child health workforce in China

Article reference: Huan Zhang, Xiaoyun Liu, Loveday Penn-Kekana, Carine Ronsmans. A systematic review of the profile and density of the maternal and child health workforce in China. Human Resources for Health. 2021, 19: 125.

3.2 Article

3.2.1 Abstract

Background To track progress in MCH understanding the health workforce is important. This study seeks to systematically review evidence on the profile and density of MCH workers in China.

Methods We searched 6 English and 2 Chinese databases for studies published between 1 October 1949 and 20 July 2020. We included studies that reported on the level of education or the certification status of all the MCH workers in one or more health facilities and studies reporting the density of MCH workers per 100000 population or per 1000 births. MCH workers were defined as those who provided MCH services in Chinese mainland and had been trained formally or informally.

Results Meta analysis of 35 studies found that only two thirds of obstetricians and paediatricians (67%, 95% CI: 59.6%-74.3%) had a bachelor or higher degree. This proportion was lower in primary level facilities (28% (1.5%-53.9%)). For nurses involved in MCH care the proportions with a bachelor or higher degree were lower (20.0% (12.0%-30.0%) in any health facility and 1% (0.0%-5.0%) in primary care facilities). Based on 18 studies, the average density of MCH doctors and nurses was 11.8 (95% CI: 7.5-16.2) and 11.4 (7.6-15.2) per 100000 population respectively. The average density of obstetricians was 9.0 (7.9-10.2) per 1000 births and that of obstetric nurses 16.0 (14.8-17.2) per 1000 births. The density of MCH workers is much higher than what has been recommended internationally (three doctors with obstetric skills or 20 midwives per 3600 births).

Conclusions Our review suggests that the high density of MCH workers in China is achieved through a mix of workers with high and low educational profiles. Many workers labelled as “obstetricians or “paediatrician” have lower qualifications than expected. China compensates for these low educational levels through task-shifting, in-service training and supervision.

3.2.2 Introduction

Maternal and child mortality levels have fallen substantially in China since the Liberation in 1949. China's maternal mortality ratio was estimated to be around 1500 deaths per 100 000 live births in 1950[107], dropping to 17.8 in 2019[108]. The under-five mortality rate dropped from 210.7 to 7.8 deaths per 1000 live births over the same period[107, 108]. Investment in health systems has no doubt accelerated the progress in reducing maternal and child mortality[109, 110]. Key to this success has been the training and deployment of MCH workers, which are seen as the cornerstone of successful MCH programmes[111]. Understanding who they are, and how many (per unit of population), is critical to the planning of such services.

Defining what constitutes an "MCH worker", and what their qualifications should be, remains a challenge internationally as well as in China. A joint report issued by the WHO and the United Nations Population Fund, defined sexual, reproductive, maternal, newborn and adolescent health workers as those including but not limited to "midwives, nurses, nurse-midwives, general practitioners, specialist doctors (such as obstetrician/gynaecologist, neonatologists, paediatricians), auxiliary staff, community health workers, and support workers (including traditional birth attendants)"[83]. The joint report did not define the health workers by cadre, and advised national workforce assessments to categorize health workers according to the cadre titles used in their own country. However, the full complexity and dynamics of the MCH workforce within each country is difficult to capture. So far, most of the research in this area has focused on the definition and measurement of particular cadres of MCH workers, e.g. midwives or paediatricians, not the entire workforce[112-117]. The WHO, for example, has recently updated its definition of a skilled birth attendant[118], but that definition does not necessarily help with human resource planning, since the criteria used are not well aligned with in-country training or qualification systems.

In China, there is no consensus on what constitutes an MCH worker. The health system allows extensive variation in education, roles and responsibilities between health workers, and definitions vary over time and between geographical locations[72]. Terms such as "obstetrician" or "paediatrician" are used loosely, and there is no standard definition. To our knowledge, there has not been a comprehensive assessment of the profile of MCH workers in China.

Education level, health-related discipline and certification are most commonly used to understand the profile of health workers in China[41, 62, 72]. Education levels generally move from primary or middle school to high school or secondary technical school, junior college, Bachelor's degree, Master's degree, and Doctoral degree[72].

The length of medical training varies between different disciplines, ranging from three to eight years. The tracking of health-related disciplines is also important, because China's educational reforms in 1998 redesigned medical training from the former Soviet model, which was based on empirical clinical training to a Western model, where categorizations are based on disciplines from the natural sciences[62]. Certification, and in particular the "MCH care certificate" (*Muying baojian jishu hegezheng,* thereafter referred to as certification), is critical in allowing MCH workers to perform certain duties. All MCH workers who are directly involved in prenatal diagnosis, delivery care and termination of pregnancy need to be certified by law to be allowed to perform these tasks[119]. To be eligible for a certificate, applicants need to have graduated from secondary technical schools or higher education and hold a valid medical doctor, nurse/midwife, or medical technician license. Candidates are certified by county-level or higher-level health authorities after passing a theoretical and skill examination, which is regulated by National Health and Family Planning Commission (previously the Ministry of Health).

The density of health workers is widely used as an indicator of health systems inputs[28, 56]. The Chinese government uses the "density of doctors per 1,000 population" as a performance indicator, but there is very little information on the density of MCH workers. Work within the MCH field has suggested that the total population may not accurately reflect the obstetric or paediatric needs of a population. Maternal health worker density, for example, should be expressed over total number of births, while child health worker density should be counted per number of children[82, 88, 120]. This is particularly relevant for China since fertility rates are low[121]. Using births as the reference population, the World Health Report 2005 suggested a minimum requirement of 20 midwives or 3 doctors (at least part time) per 3600 births per year to ensure essential maternal and newborn care[122].

The lack of information on the profile and density of MCH workers in China greatly restricts evidence-informed policy making to address potential workforce issues. The aim of this study is to systematically review the literature reporting on the profile and density of MCH workers in Chinese mainland.

3.2.3 Methods

Search strategy

We combined three search terms 'human resources for health', 'MCH services', and 'China' with both thesaurus and free text words (see Appendix A for the full search strategy). We searched six English databases (EMBASE, MEDLINE, The Cochrane Central Register of Controlled Trials, EconLit, Global Health and Web of Science) and two Chinese databases (China National Knowledge Infrastructure [CNKI] and Wanfang) with no limitation on language. We searched the literature between October 1, 1949 (founding of the People’s Republic of China), and July 20, 2020. We combined the search results and removed duplicate papers.

Study selection

We screened studies based on information in their titles and abstracts. All potentially relevant studies were retrieved for the full texts and reviewed for inclusion. Studies were eligible for inclusion if they reported on MCH workers active in any aspect of MCH care from pregnancy to childhood, including antenatal care, childbirth care, postnatal care, care during infancy and care for children under five. MCH workers were defined as those who provided MCH services in China and had been trained formally or informally. The services could be either preventive or curative: for example, vaccination or prescribing medication for diarrhoea. The studies could be peer-reviewed articles (English/Chinese) or Chinese Masters or Doctoral theses. We did not add reports published by the Chinese government such as the Health Statistics Yearbook, the National Health Survey Report, the National Survey of Health Resources and Medical Services, because these reports do not provide the profile, or the total count or the density of any cadre of MCH workers within a defined geographic area. Studies were excluded if published as conference abstract, poster or editorial.

For studies reporting on MCH workers’ profile, we included facility-based as well as population-based data, adding the following inclusion criteria: (1) Studies needed to be based on a census or a sample of one or more cadres of MCH workers either from communities or from one or multiple units within one or multiple health facilities. Health facilities were defined as hospitals, health centres or clinics. (2) Reporting the numbers of at least one cadre of MCH workers, broken down by the level of education, health-related discipline or certification.

For studies reporting on the density of MCH workers, we only included population-based data, adding the following inclusion criteria: (1) the numerator was the whole count of any cadre of MCH workers in a population in a given geographical area, either from a population census with health occupation data, or from a health workforce survey with application of a sampling weight to calibrate for population representation. The denominator was either total population or specific subgroups such as total number of women, children or births for the same geographical area. (2) The studies either reported the density of any cadre of MCH workers directly or reported both the numerator and the denominator allowing us to calculate the density of MCH workers.

Data extraction

We used a standard data extraction form in Excel to extract the following information: study source; study setting; data collection methods; MCH worker cadre and definition; MCH worker profile; MCH worker density. We compared author names, study setting, sampling methods, and time of study to detect duplicate studies.

Risk of bias assessment

We used the component approach outlined in the Cochrane Handbook to assess the risk of bias of eligible studies[123]. We assessed the rigor of the study design (e.g. whether the sampling strategy for a survey was clearly described), the definition of the MCH workers and the completeness of data. We classified studies as having a low risk or high risk or unclear risk of bias. For example, a study was classified as having high risk of bias for study design if a cross-sectional survey in a single facility was claimed to be based on random sampling of MCH workers without information on the units from which the workers were sampled. The risk of bias was deemed to be unclear if the authors did not report the information for the above criteria.

Data analysis

Profile of MCH workers

We grouped the education levels into three categories: bachelor or higher-level degree, junior college education, and secondary technical school or lower-level education. We categorized health facilities into three levels: tertiary (provincial- or municipal-level facilities), secondary (county-level facilities), and primary level (community health centres, township hospitals, village clinics).

We combined proportions of MCH workers by each education level using meta-analysis. To generate confidence intervals within admissible values, we used Clopper-Pearson exact method to compute the study specific confidence intervals. We performed the Greeman-Tukey double arcsine transformation method to compute the weighted pooled estimates. In the subgroup meta-analyses, studies were stratified by level of health facility (tertiary/secondary/primary). Due to the variation between study characteristics, we used random-effects models in the meta-analysis to pool the proportions by each education level, presenting forest plots. We inspected I^2 values and p values from the test of heterogeneity to assess evidence of between-study variation in the individual proportion estimates not due to random variation.

Density of MCH workers

For studies using total population as denominator, we converted the units of the density of MCH workers to per 100 000 population and presented the density by detailed cadre using forest plots. For studies using number of births as denominator, we summarized the studies in a forest plot. The method for the meta-analysis of density was exactly the same as what we did for the analysis on education level. Where data were available, we calculated the ratio of maternal health workers to child health workers or the ratio of doctors to nurses within individual studies.

All statistical analyses were performed using STATA (Version 14: Stata Corp).

3.2.4 Results

Description of the included studies

Figure 3.1 shows the results of the study search and selection. The database search identified 4999 English references and 27256 Chinese references. After removing duplicates, 3392 English references and 25958 Chinese references were excluded through title and abstract screening. We could not trace the full texts of 11 potentially relevant studies. Of the 178 English studies and 371 Chinese studies reviewed in full text, 48 studies were included. We reviewed the automatic e-mail updates of search results on a weekly basis until July 20, 2020, and added two English papers. We finally included a total of 50 studies: 35 reporting on MCH workforce profiles[41, 124-160], 18 reporting on the MCH workforce density[41, 151, 159, 161-175] and three covering both[41, 151, 159]. Most studies were peer-reviewed articles (n=39, 78.0%) while the remaining were from Masters theses (n=11, 22.0%).

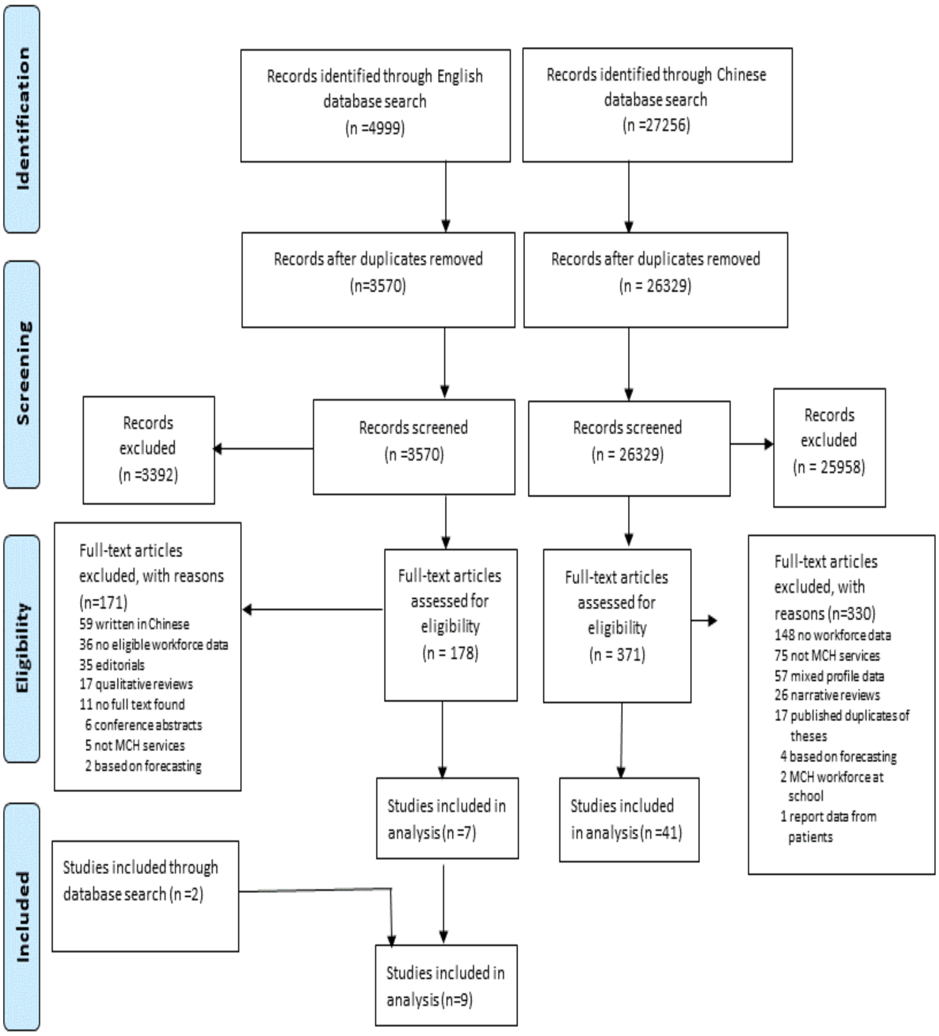


Figure 3.1: The flow diagram of study selection based on English and Chinese database searching (PRISMA 2009)

Quality of included studies

For studies reporting on MCH workers' profile, only eight were judged to be at low risk of bias across all the domains in the risk of bias assessment[131-133, 144, 146-148, 155]. For studies on MCH workforce's density, all were judged to have unclear risk of bias (see Appendix A for quality assessment results).

Studies reporting the profile of MCH workers

Study Characteristics：Of the 35 studies, 33 (94.3%) were done after 1990, and 32 (91.4%) were done within a single province. Only one study was nationally representative, reporting on the education level of maternal and child health workers separately[41]. The MCH workforce in China covers an array of cadres, including obstetricians, gynaecologists, paediatricians, nurses, midwives, general practitioners, specialised public health workers, vaccinators, barefoot doctors, and traditional birth attendants (see Tables 3.1-3.3 for doctors, nurses and midwives, other cadres respectively).

Table 3.1: Studies reporting on doctors: study design and profile

Study	Area (period)	Care setting	Data source	Sampling of facilities	Sampling of health workers	Definition of health workers	Sample size	Educational level
Doctor								
Liao et al, 2017 (E)	28 provinces, except Shanxi, Hainan, Tibet (2010)	Neonatal units (Undefined) in 61 tertiary hospitals either class A provincial or ministerial affiliated hospitals (20 child hospitals, 29 general hospitals, 12 MCH institutions)	Unclear ("reported by hospital administrator")	Unclear (data submitted by facilities as part of "a request for proposals aiming to evaluate national key clinical subspecialty indicators"; sampling method not known)	Unclear ("not random sampling")	"Full-time professionals with certificates issued by the Ministry of Health" and "practice at a single hospital (dual practice excluded)". Excluded those in training and excluded "assistant doctors, respiratory therapists, physiotherapists, pharmacists, and nutritionists"	1369	Doctoral (M.D./PhD) degree 20.4% (279); Master degree 50.1% (686); Bachelor degree 29.5% (404)
Fu, 2012 (C)	Yunnan province, autonomous prefecture of Chuxiong (2008)	Units (Undefined) in MCH institutions (excluding prefecture-level institution; number not given)	Unclear ("Health bureau data")	Census	Census	Undefined	229	Bachelor degree or above 22.3% (51); Junior college 48.0% (110); Secondary technical school 27.5% (63); High school 1.7% (4); Middle school 0.4% (1)
Chen, 2016 (C)	Fujian province (2015)	Units (Undefined) in 1 MCH institution (provincial level)	Unclear ("reported by hospital administrator")	Non-random sampling	Census	Undefined	408	Master degree or above 31.6%; Bachelor degree 64.2%; Junior college or below 4.2%
Xiao, 2011 (C Thesis)	Sichuan province, randomly selected 20 out of 60 counties (2008)	Units (Undefined) in 20 MCH institutions (county level)	Structured questionnaire to health workers	Census	Census	Undefined	Undefined	Master degree or above 0.0%; Bachelor degree 14.3%; Junior college 40.1%; Secondary technical school 45.6% (number not given)

Study	Area (period)	Care setting	Data source	Sampling of facilities	Sampling of health workers	Definition of health workers	Sample size	Educational level
Wang et al, 2014 (C)	Guangxi province, 39 poor counties (2012)	Units (Undefined) in 39 MCH institutions (county level)	Structured questionnaire to health workers	Census	Census	Undefined	1105	Master degree or above 0.2% (2); Bachelor degree 22.9% (253); Junior college 58.4% (646); Secondary technical school or below 18.5% (204)
Obstetrician or gynaecologist								
Huang, 2009 (C)	Guangxi province, Baise city (2008)	Obstetrics or gynaecology department (Undefined) in 150 township hospital (Undefined)	Structured questionnaire to health workers	Census	Census	"worked in the clinical departments”	321	Bachelor degree or above 5.9% (19); Junior college 42.4% (136); Secondary technical school 51.7% (166)
Feng, et al, 2012 (C)	Guangxi province, 7 ethnic minority counties (2010)	Units (Undefined) in 112 county hospital and township hospital (Undefined)	Structured questionnaire to health workers	Census	Census	"worked in the clinical departments”	320	Bachelor degree 16.3% (52); Junior college 27.5% (88); Secondary technical school 56.3% (180)
Obstetrician only								
Lu et al, 2010 (C)	Jiangxi province, Nanchang city (2008)	Outpatient, inpatient and emergency wards (Undefined) in 98 health facilities “capable of providing obstetric services"	Structured questionnaire to health workers	Census	Census	"provided outpatient, inpatient, emergent or ambulatory obstetric services”	369	Bachelor degree or above 39.8%; Junior college 33.9%; Secondary technical school 26.3% (number not given)
Zhu et al, 2008 (C)	Shanghai (2006)	Obstetrics department (including inpatient, outpatient and emergency ward) in 3 MCH institution (tertiary level)	Structured questionnaire to health workers	Census	Census	Undefined	83	Postgraduate degree 41.0% (34); Bachelor degree 57.8% (48); Junior college 1.2% (1); Secondary technical school or below 0.0% (0)
		Obstetrics department (including inpatient, outpatient and emergency ward) in 14 general hospitals (tertiary level)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	194	Postgraduate degree 40.2% (78); Bachelor degree 58.8% (114); Junior college 0.5% (1); Secondary technical school or below 0.5% (1)

Study	Area (period)	Care setting	Data source	Sampling of facilities	Sampling of health workers	Definition of health workers	Sample size	Educational level
		Obstetrics department (including inpatient, outpatient and emergency ward) in 9 MCH institutions (secondary level)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	164	Master degree or above 6.1% (10); Bachelor degree 76.2% (125); Junior college 14.0% (23); Secondary technical school or below 3.7% (6)
		Obstetrics department (including inpatient, outpatient and emergency ward) in 43 general hospitals (secondary level)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	616	Master degree or above 6.0% (37); Bachelor degree 62.4% (385); Junior college 27.5% (170); Secondary technical school or below 4.1% (25)
		Obstetrics department (including inpatient, outpatient and emergency ward) in 15 primary health institutions (Undefined)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	99	Master degree or above 0.0% (0); Bachelor degree 27.7% (27); Junior college 60.4% (60); Secondary technical school or below 11.9% (12)
		Obstetrics department (including inpatient, outpatient and emergency ward) in 3 private hospitals (Undefined)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	10	Master degree or above 20.0% (2); Bachelor degree 80.0% (8)
Paediatrician								
Feng, et al, 2012 (C)	Guangxi province, 7 ethnic minority counties (2010)	Units (Undefined) in 112 county hospital and township hospitals (Undefined)	Structured questionnaire to health workers	Census	Census	Undefined	119	Bachelor degree 30.2% (36); Junior college 43.7% (52); Secondary technical school 26.1% (31)
Guo et al, 2015 (C)	Guangdong province, Guangzhou city (2011)	Paediatric department (Undefined) in “all of the 48 tertiary, secondary and primary health facilities capable of providing paediatric care in central city”	Unclear ("data from previous survey")	Undefined	Undefined	Undefined	1157	Doctoral degree 9.8% (114); Master degree 34.6% (400); Bachelor degree 52.7% (610); Junior college or below 2.9% (33)

Study	**Area (period)**	**Care setting**	**Data source**	**Sampling of facilities**	**Sampling of health workers**	**Definition of health workers**	**Sample size**	**Educational level**
		Paediatric department (Undefined) in “all of the 31 tertiary, secondary and primary health facilities capable of providing paediatric care in rural-urban continuum”	*Same as above*	*Same as above*	*Same as above*	*Same as above*	205	Doctoral degree 4.8% (10); Master degree 18.4% (38); Bachelor degree 72.7% (149); Junior college or below 4.1% (8)
		Paediatric department (Undefined) in “all of the 23 tertiary, secondary and primary health facilities capable of providing paediatric care in outer suburbs”	*Same as above*	*Same as above*	*Same as above*	*Same as above*	187	Master degree 7.0% (13); Bachelor degree 83.4% (156); Junior college or below 9.6% (18)
Liu, 2010 (C Thesis)	Guangdong province (2008)	Units (Undefined) in 21 tertiary hospitals (including general hospitals and MCH centres)	Structured questionnaire to health workers	Non-random sampling ("Purposive sampling")	Census	Undefined	539	Doctoral degree 1.7% (9); Master degree 15.4% (83); Bachelor degree 76.3% (411); Junior college or below 2.4% (13); No degree 4.3% (23)
		Units (Undefined) in 32 secondary hospitals (including general hospitals and MCH centres)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	575	Doctoral degree 0.2% (1); Master degree 5.7% (33); Bachelor degree 65.6% (377); Junior college or below 25.9% (149); No degree 2.6% (15)
		Units (Undefined) in 6 primary hospitals (including general hospitals and MCH centres)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	80	Doctoral degree 0.0% (0); Master degree 0.0% (0); Bachelor degree 51.3% (41); Junior college or below 48.8% (39); No degree 0.0% (0)

Study	Area (period)	Care setting	Data source	Sampling of facilities	Sampling of health workers	Definition of health workers	Sample size	Educational level
Shao, 2016 (C)	Zhejiang province (2015)	Paediatric department (Undefined) in 265 general hospitals, MCH institutions, specialized paediatric hospitals and primary care institutions (Undefined)	Unclear ("online survey to health worker")	Undefined	Undefined	"work in internal wards"	3662	Master degree or above 22.6%; Bachelor degree 73.2%; Junior college 4.2% (number not given)
Yang, 2017 (C Thesis)	Guangdong province, Guangzhou city (2014)	Paediatric department (Undefined) in 110 health facilities “capable of providing paediatric care"	Structured questionnaire to health workers	Unclear	Census	Undefined	2247	Doctoral degree 4.8%; Master degree 23.2%; Bachelor degree 65.1%; Junior college or below 6.9% (number not given)

Table 3.2: Studies reporting on nurses and midwives: study design and profile

Study	Area (period)	Care setting	Data source	Sampling of facilities	Sampling of health workers	Definition of health workers	Sample size of health workers	Educational level
Nurse								
Liao et al, 2017 (E)	28 provinces, except Shanxi, Hainan, Tibet (2010)	Neonatal units (Undefined) in 61 tertiary hospitals either class A provincial or ministerial affiliated hospitals (20 child hospitals, 29 general hospitals, 12 MCH institutions)	Unclear ("reported by hospital administrator")	Unclear (data submitted by facilities as part of "a request for proposals aiming to evaluate national key clinical subspecialty indicators"; sampling method not known)	Unclear ("not random sampling")	"full-time professionals with certificates issued by the Ministry of Health" and "practice at a single hospital (dual practice excluded)". Excluded those "in training such as interns, trainee nurses, fellows, and ward care workers."	3443	Doctoral degree 0.1% (2); Master degree 1.2% (40); Bachelor degree 36.9% (1272); Junior college 61.8% (2129)
Fu, 2012 (C)	Yunnan province, autonomous prefecture of Chuxiong (2008)	Units (Undefined) in MCH institutions (excluding prefecture-level institution; number not given)	Unclear ("Health bureau data")	Census	Census	Undefined	119	Bachelor degree or above 8.4% (10); Junior college 59.7% (71); Secondary technical school 24.4% (29); High school 6.7% (8); Middle school 0.8% (1)
Feng, et al, 2012 (C)	Guangxi province, 7 ethnic minority counties (2010)	Units (Undefined) in county hospitals and 112 township hospitals (Undefined)	Structured questionnaire to health workers	Census	Census	"worked in the obstetrics or gynaecology departments"	337	Junior college 29.4% (99); Secondary technical school 70.6% (238)
		Same as above	*Same as above*	*Same as above*	*Same as above*	"worked in the paediatric departments"	135	Junior college 27.4% (37); Secondary technical school 72.6% (98)

Study	**Area (period)**	**Care setting**	**Data source**	**Sampling of facilities**	**Sampling of health workers**	**Definition of health workers**	**Sample size of health workers**	**Educational level**
Liu, 2013 (C Thesis)	Hunan province (2012)	Units (Undefined) in 1 MCH institution (Undefined)	Structured questionnaire to health workers	Undefined	Random sampling	"provide clinical services at the frontline"	275	Bachelor degree or above 70.9% (195); Junior college 25.1% (69); Secondary technical school or below 4.0% (11)
Liu, 2010 (C Thesis)	Guangdong province (2008)	Units (Undefined) in 21 tertiary hospitals (including general hospitals and MCH institutions)	Structured questionnaire to health workers	Non-random sampling ("Purposive sampling")	Census	Unclear (Paediatric nurse)	726	Master degree or above 0.1% (1); Bachelor degree 9.4% (68); Junior college 43.7% (317); Secondary technical school 39.8% (289); No degree 7.0% (51)
		Units (Undefined) in 32 secondary hospitals (including general hospitals and MCH institutions)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	840	Master degree or above 0.0% (0); bachelor degree 4.8% (40); Junior college 40.0% (336); Secondary technical school 53.0% (445); No degree 2.3% (19)
		Units (Undefined) in 6 primary hospitals (including general hospitals and MCH institutions)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	105	Master degree or above 0.0% (0); Bachelor degree 1.0% (1); Junior college 40.0% (42); Secondary technical school 59.1% (62); No degree 0.0% (0)
Sun et al, 2014 (C)	Guangdong, Hainan, Beijing, Jilin, Jiangsu, Shandong and Zhejiang (2012)	Neonatal units (Undefined) in 468 tertiary or secondary hospital (Undefined)	Structured questionnaire to health workers	Unclear ("multistage sampling")	Census	Undefined	5582	Master degree or above 1.0% (45); Bachelor degree 39.0% (2190); Junior college 48.0% (2686); Secondary technical schools 12.0% (661)

Study	Area (period)	Care setting	Data source	Sampling of facilities	Sampling of health workers	Definition of health workers	Sample size of health workers	Educational level
Zheng, 2015 (C Thesis)	Fujian province, Fuzhou city (2014)	Paediatric department (internal wards, surgery wards and intensive care units) in 8 tertiary hospital (capable of providing paediatric service, including 5 general hospitals, 2 specialized children's hospitals and 1 traditional Chinese medicine hospital)	Structured questionnaire to health workers	Unclear ("selected only those with paediatric departments and permanent staff")	Undefined	"provided child health care"; excluding those "have not been formally registered and those who were on leave during the investigation"	439	Master degree or above 0.0% (0); Bachelor degree 17.5% (73); Junior college 71.1% (288); Secondary technical school or below 11.4% (44)
Yang, 2017 (C Thesis)	Guangdong province, Guangzhou city (2014)	Paediatric department (Undefined) in 110 health facilities “capable of providing paediatric care"	Structured questionnaire to health workers	Unclear	Census	Unclear (Paediatric nurse)	2820	Master degree 0.2%; Bachelor degree 29.6%; Junior college 47.6%; Secondary technical school or below 22.6% (number not given)
Wu et al, 2017 (C)	Shanghai (2016)	Outpatient, inpatient, emergency and administrative departments, intensive care units, medical laboratory and operating room (Undefined) in 1 tertiary hospital (specialized children's hospital)	Unclear ("reported by hospital administrator")	Census	Census	Unclear (Paediatric nurse)	665	Doctoral degree 0.3% (2); Master degree 1.2% (8); Bachelor degree 31.9% (212); Junior college 55.0% (366); Secondary technical school 11.6% (77)
Chen, 2016 (C)	Fujian province (2015)	Units (Undefined) in 1 MCH institution (provincial level)	Unclear ("reported by hospital administrator")	Non-random sampling	Census	Undefined	391	Master degree or above 0.3%; Bachelor degree 46.3%; Junior college or below 53.5%
Xiao, 2011 (C Thesis)	Sichuan province, 20 out of 60 counties (2008)	Units (Undefined) in 20 MCH institutions (county level)	Structured questionnaire to health workers	Census	Census	Undefined	Undefined	Master degree or above 0.0%; Bachelor degree 7.8%; Junior college 43.8%; Secondary technical school 48.4% (number not given)

Study	Area (period)	Care setting	Data source	Sampling of facilities	Sampling of health workers	Definition of health workers	Sample size of health workers	Educational level
Wang et al, 2014 (C)	Guangxi province, 39 poor counties (2012)	Units (Undefined) in 39 MCH institutions (county level)	Structured questionnaire to health workers	Census	Census	Undefined	1351	Bachelor degree 3.4% (46); Junior college 49.7% (671); Secondary technical school 46.9% (634)
Midwives								
Li et al, 2014 (C)	Sichuan province, Leshan city (2013)	Units (Undefined) in 75 health facilities “capable of providing obstetric services" (public hospitals at municipal level 3, county level 29, township level 38, private hospital 5)	Structured questionnaire to health workers	Census	Census	"held midwifery qualifications”; included both full-time and part-time staff.	259 (32 full-time, 227 part-time)	Master degree or above 0.8% (2); Bachelor degree 22.4% (58); Junior college 35.5% (92); Secondary technical school 40.5% (105); High school 0.8% (2)
Ge et al, 2010 (C)	Shaanxi province (2008)	Units (Undefined) in 68 out of 69 eligible health facilities "capable of providing midwifery services at county or higher level "; excluded MCH institutions at provincial level; excluded health facilities with annual number of natural deliveries less than 100	Structured questionnaire to health workers	Non-random sampling (Purposive sampling)	Census	Unclear ("Full-time midwife staff")	367	Bachelor degree 3.5% (13); Junior college 65.9% (242); Secondary technical school 30.4% (112)
Wang, 2012 (C Thesis)	Jilin province, all urban districts in Changchun city (2011)	Obstetrics department (Undefined) in 28 health facilities "capable of providing midwifery services and at county level or above"	Structured questionnaire to health workers	Census	Census	“(a) held nursing certificate and qualification for MCH care; (b) working in obstetric department in the past one year; (c) midwifery working experience was more than half an year; (d) not on leave during investigation”	197	Master degree or above 11.2% (22); Bachelor degree 52.8% (104); Junior college 26.4% (52); Secondary technical school 9.6% (19)

Table 3.3: Studies reporting on other cadres: study design and profile

Study	Area (period)	Care setting	Data source	Sampling of facilities	Sampling of health workers	Definition of health workers	Sample size	Educational level
Specialized public health worker								
Yu et al, 2015 (C)	Zhejiang province, Xiaoshan district in Hangzhou city (2009)	Units (Undefined) in 61 township hospital and community health centre (Undefined)	Structured questionnaire to health workers	Census	Census	"provided primary health care for children"	61	Junior college or above 75.4% (46); Others (Undefined)
	Same area as above (2014)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	*Same as above*	82	Junior college or above 90.2% (74); Others (Undefined) 9.8% (8)
He et al, 1997 (C)	Jiangsu province, Jiang du district (1996)	Units (Undefined) in 41 township hospitals (Undefined)	Structured questionnaire to health workers	Census	Census	"provide child healthcare and practice full-time"	45	Secondary technical school 35.6% (16); High school 15.5% (7); Secondary school 48.9% (22)
Shao, 2016 (C)	Henan province (2015)	Paediatric department (Undefined) in 265 general hospitals, maternal and health institutions, specialized paediatric hospitals and primary care institutions (Undefined)	Unclear ("online survey to health workers")	Undefined	Undefined	"provide primary healthcare for children"	510	Master degree or above 11.5%; Bachelor degree 69.4%; Junior college or below 19.1% (number not given)
Liao, 2008 (C)	Chongqing municipality, Nanan district (2007)	Units (Undefined) in 1 MCH institution (tertiary level)	Structured questionnaire to health workers	Census	Census	Undefined	10	Bachelor degree or above 50.0%; College degree 50.0% (number not given)

Study	Area (period)	Care setting	Data source	Sampling of facilities	Sampling of health workers	Definition of health workers	Sample size	Educational level
		Units (Undefined) in 23 MCH institutions (secondary level)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	42	Bachelor degree or above 19.1% (8); Junior college 45.2% (19); Secondary technical school or high school 31.0% (13); Middle school or below 4.7% (2)
Lu et al, 2013 (C)	Zhejiang province, Huzhou (2012)	Units (Undefined) in 67 township hospital and community health centre (Undefined)	Structured questionnaire to health workers	Census	Census	Undefined	224	Bachelor degree or above 18.3% (41); Junior college 50.5% (113); Secondary technical school or high school 28.1% (63); Middle school or below 3.1% (7)
Guo et al, 2015 (C)	Zhejiang province, 4 randomly selected counties in Hangzhou (2013)	Units (Undefined) in 62 community health centres (Undefined)	Structured questionnaire to health workers	Unclear ("multi-stage cluster sampling")	Census	Undefined	205	Master degree 0.9% (2); Bachelor degree 49.8% (102); Junior college 40.5% (83); Secondary technical school or below 8.8% (18)
Chen, 1988 (C)	Hunan province, all the 25 townships in Hengshan county (1987)	Units (Undefined) in MCH institutions (county level; number not given)	Structured questionnaire to health workers	Census	Census	Undefined	10	Junior college 20.0% (2); Secondary technical school 60.0% (6); Middle school 10.0% (1); Primary school 10.0% (1)
		Units (Undefined) in MCH institution (township level; number not given)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	25	Junior college 8.7% (2); Secondary technical school 78.3% (20); Middle school 13.0% (3)

Study	Area (period)	Care setting	Data source	Sampling of facilities	Sampling of health workers	Definition of health workers	Sample size	Educational level
Vaccinator								
Shen, 1991 (C)	Anhui province, rural counties (1990)	Rural clinics or vaccination posts (Undefined; number not given)	Structured questionnaire to health workers	Unclear	Random sampling	Undefined	280	Junior college or secondary technical school 20.4%; Medical training length one year or above without degree 24.3%; Medical training length less than one year 25.4%; Not any training 29.3% (number not given)
Zan et al, 2016 (C)	Zhejiang province, Yinzhou district in Ningbo city (2014)	Units (Undefined) in 24 child vaccination posts (Undefined)	Unclear ("reported by hospital administrator")	Census	Census	Undefined	155	Bachelor degree 70.9% (110); Junior college 15.5% (24); Secondary technical school or below 13.6% (21)
Pharmacist								
Chen, 2016 (C)	Fujian province (2015)	Units (Undefined) in 1 MCH institution (provincial level)	Unclear ("reported by hospital administrator")	Non-random sampling	Census	Undefined	36	Master degree or above 19.4%; Bachelor degree 69.4%; Junior college or below 11.1%
Xiao, 2011 (C Thesis)	Sichuan province, randomly selected 20 out of 60 counties (2008)	Units (Undefined) in 20 MCH institutions (county level)	Structured questionnaire to health workers	Census	Census	Undefined	Undefined	Master degree or above 12.5%; Bachelor degree 12.5%; Junior college 12.5%; Secondary technical school 62.5% (number not given)
Medical technician								

Study	Area (period)	Care setting	Data source	Sampling of facilities	Sampling of health workers	Definition of health workers	Sample size	Educational level
Chen, 2016 (C)	Fujian province (2015)	Units (Undefined) in 1 MCH institution (provincial level)	Unclear ("reported by hospital administrator")	Non-random sampling	Census	Undefined	77	Master degree or above 20.8%; Bachelor degree 54.5%; Junior college or below 24.7%
Xiao, 2011 (C Thesis)	Sichuan province, randomly selected 20 out of 60 counties (2008)	Units (Undefined) in 20 MCH institution (county level)	Structured questionnaire to health workers	Census	Census	Undefined	Undefined	Junior college 42.9%; Secondary technical school or below 57.1% (number not given)
Wang et al, 2014 (C)	Guangxi province, 39 poor counties (2012)	Units (Undefined) in 39 MCH institutions (county level)	Structured questionnaire to health workers	Census	Census	Undefined	622	Bachelor degree 9.5% (59); Junior college 45.8% (285); Secondary technical school 44.7% (278)
Health information worker								
Liu et al, 2012 (C)	Jilin province (2009)	Units (Undefined) in MCH institutions (provincial level; number not given)	Structured questionnaire to health workers	Census	Census	"work in MCH information monitoring and statistics"	13	Junior college or above 100% (13)
		Units (Undefined) in MCH institutions (municipal level; number not given)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	47	Junior college or above 74.5% (35); Secondary technical school 25.5% (12); High school or below 0% (0)
		Units (Undefined) in MCH institutions (county level; number not given)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	167	Junior college or above 58.1% (97); Secondary technical school 41.9% (70); High school or below 0% (0)

Study	Area (period)	Care setting	Data source	Sampling of facilities	Sampling of health workers	Definition of health workers	Sample size	Educational level
		Units (Undefined) in 167 township hospitals (Undefined)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	702	Junior college or above 25.9% (182); Secondary technical school 70% (491); High school or below 4.1% (29)
Village doctor								
Liao, 2008 (C)	Chongqing municipality, Nanan district (2007)	67 village clinics (Undefined)	Structured questionnaire to health workers	Census	Census	"practice in the village clinics and provide MCH services"	67	Junior college 7.5% (5); High school 58.2% (39); Middle school 29.9% (20); Primary school 4.4% (3)
Ye, 1992 (C)	Jiangsu province, Dongtai city (1991)	30 village clinics (Undefined)	Structured questionnaire to health workers	Unclear ("random cluster sampling")	Census	"provide maternal health in the villages and are all female"	588	Secondary technical school 0.5%; High school 32.3%; Middle school 50.2%; Primary school 17.0% (Number not given)
Barefoot doctor								
Wang, 1975 (E)	Zhejiang province, one commune named "Four Season Green commune" in the outskirts of Hangzhou (1973)	1 commune hospital	Unclear ("interviewed a cross-section of health workers")	Unclear	Census	Those "selected by the people in the communes and are trained in their locale" and "take on large responsibilities in caring for the health of the mother after birth and the child"	2	One-year medical training 50.0%; Four-month medical training 50.0%

Study	Area (period)	Care setting	Data source	Sampling of facilities	Sampling of health workers	Definition of health workers	Sample size	Educational level
Chen, 1988 (C)	Hunan province, all the 25 townships in Hengshan county (1987)	NA ("in village")	Structured questionnaire to health workers	Census	Census	"work as part-time birth attendants")	109	Junior college 9.2%; Secondary technical school 16.7%; Middle school 44.0%; Primary school 38.5%; No schooling 1.8%
Traditional birth attendant								
Chen, 1988 (C)	Hunan province, all the 25 townships in Hengshan county (1987)	NA ("in village")	Structured questionnaire to health workers	Census	Census	Undefined	215	Secondary technical school 13.0% (28); Middle school 18.5% (40); Primary school 51.8% (111); No schooling 16.7% (36)
Maternal health worker								
Cheung et al, 2011 (E)	Zhejiang Province, 7 cities (2009)	Maternity units (Undefined) in 9 hospitals (Undefined)	Structured questionnaire to health workers	Unclear ("the units and hospitals were chosen by the researchers because they have personal contacts there")	Unclear ("not random sampling")	“offer midwifery services including all midwives, nurses, doctors, doulas”)	241	_
Huang, 2009 (C)	Guangxi province, Baise city (2008)	Obstetrics or gynaecology department (Undefined) in 150 township hospitals (Undefined)	Structured questionnaire to health workers	Census	Census	"work in the preventive medical departments and provide maternal healthcare”	163	Bachelor degree or above 3.7% (6); Junior college 27.6% (45); Secondary technical school 68.7% (112)
Zhao, 2007 (C)	Xinjiang Uygur Autonomous Region, Xinyuan county (2004)	Obstetrics or paediatric department (Undefined) in 112 health facilities “capable of providing maternal care at county	Structured questionnaire to health workers	Census	Census	"provide frontline maternal health care”	78	College degree or above 33.3% (26); Secondary technical school 61.5% (48); Others (Undefined) 5.2% (4)

Study	Area (period)	Care setting	Data source	Sampling of facilities	Sampling of health workers	Definition of health workers	Sample size	Educational level
		level or township level"						
Ren et al, 2015 (E)	332 randomly selected districts and counties in 27 provinces (2010)	Units (Undefined) in all general hospitals (Undefined; number not given)	Structured questionnaire to health workers (answered by hospital administrator)	Clustered random sampling ("All the medical and health institutions providing MCH services in randomly selected districts/cities")	Census	"provide curative and preventive healthcare for women and hold at least one legal health qualification certificate."	Undefined	Master degree or above 3.2%; Bachelor degree 32.7%; Junior college 40.9%; High school or below 23.1% (Number not given)
		Units (Undefined) in all MCH institution (Undefined; number not given)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	*Same as above*	Master degree or above 1.4%; Bachelor degree 28.2%; Junior college 38.1%; High school or below 32.4% (Number not given)
		Units (Undefined) in all township hospitals/ Community health centres (Undefined; number not given)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	*Same as above*	Master degree or above 0.1%; Bachelor degree 12.3%; Junior college 45.4%; High school or below 42.3% (Number not given)
		Units (Undefined) in all family planning service stations (Undefined; number not given)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	*Same as above*	Master degree or above 0.0%; Bachelor degree 16.2%; Junior college 48.5%; High school or below 35.3% (Number not given)
Child health worker								

Study	**Area (period)**	**Care setting**	**Data source**	**Sampling of facilities**	**Sampling of health workers**	**Definition of health workers**	**Sample size**	**Educational level**
Ren et al, 2015 (E)	332 randomly selected districts and counties in 27 provinces (2010)	Units (Undefined) in all general hospitals (Undefined; number not given)	Structured questionnaire to health workers (answered by hospital administrator)	Clustered random sampling ("All the medical and health institutions providing MCH services in randomly selected districts/cities")	Census	"provide curative and preventive healthcare for children and hold at least one legal health qualification certificate."	Undefined	Master degree or above 4.6%; Bachelor degree 37.4%; Junior college 39.5%; High school or below 18.4% (Number not given)
		Units (Undefined) in all MCH institutions (Undefined; number not given)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	*Same as above*	Master degree or above 0.9%; Bachelor degree 30.4%; Junior college 41.6%; High school or below 27.1% (Number not given)
		Units (Undefined) in all township hospitals/ Community health centres (Undefined; number not given)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	*Same as above*	Master degree or above 0.1%; Bachelor degree 13.6%; Junior college 46.5%; High school or below 39.8% (Number not given)
		Units (Undefined) in all family planning service stations (Undefined; number not given)	*Same as above*	*Same as above*	*Same as above*	*Same as above*	*Same as above*	Master degree or above 0.0%; Bachelor degree 17.6%; Junior college 58.8%; High school or below 23.5% (Number not given)

Education level：Education level was reported in nearly all the studies (n=34, 97.1%). In the meta-analysis, the weighted average proportions of doctors having bachelor degree or above, junior college education, and secondary technical school or below were 67.0% (95% CI: 59.6%-74.3%), 23.0% (10.0%-40.0%), and 14.0% (5.0%-28.0%) respectively (Table 3.4). The total was not exactly 100% because not all studies contributed data to each of the three categories. For example, a study may solely report the proportion of doctors holding bachelor degree or above and the aggregate proportion of junior college education or below, contributing only to the meta-analysis of the proportion of bachelor degree or above. For nurses, the estimated proportions were 20.0% (12.0%-30.0%), 46.4% (41.2%-51.5%) and 33.1% (24.2%-41.9%) respectively. For other cadres, the estimated proportions were 18.0% (5.0%-36.0%), 18.0% (6.0%-34.0%) and 71.0% (46.0%-91.0%) respectively.

Table 3.4: Meta-analyses of the proportion of education level, stratified by cadre and level of facility

	Bachelor or above		Junior college		Secondary technical school or less	
	Proportion, %	**I^2, %**	**Proportion, %**	**I^2, %**	**Proportion, %**	**I^2, %**
Doctor						
Primary	27.7 (1.5-53.9)	97.2	47.0 (42.0-51.0)	89.8	41.0 (37.0-46.0)	98.7
Secondary	61.3 (31.7-90.9)	99.6	32.0 (10.0-59.0)	99.3	8.0 (1.0-20.0)	98.1
Tertiary	97.4 (94.9-100.0)	92.3	0.0 (0.0-2.0)	0.0	0.0 (0.0-1.0)	0.0
Mixed	65.1 (54.9-75.3)	99.7	29.0 (9.0-55.0)	99.1	34.0 (20.0-50.0)	96.1
Overall	67.0 (59.6-74.3)	99.8	23.0 (10.0-40.0)	99.6	14.0 (5.0-28.0)	99.1
Nurse						
Primary	1.0 (0.0-5.0)	-	40.0 (30.3-49.7)	-	59.0 (49.3-68.8)	-
Secondary	4.0 (2.7-5.3)	53.8	44.9 (35.4-54.4)	94.8	51.0 (42.9-59.2)	92.9
Tertiary	34.0 (20.9-50.0)	99.3	50.4 (38.5-62.2)	98.3	23.7 (7.8-39.6)	99.2
Mixed	20.0 (9.0-33.0)	99.9	44.6 (38.0-51.1)	96.4	31.0 (20.1-42.0)	99.2
Overall	20.0 (12.0-30.0)	99.8	46.4 (41.2-51.5)	97.6	33.1 (24.2-41.9)	99.4
Other cadres						
Primary	3.0 (0.0-12.0)	96.4	11.1 (1.0-29.0)	98.1	83.0 (51.0-100.0)	99.7
Secondary	10.0 (3.0-19.0)	44.5	44.0 (37.0-52.0)	43.7	47.0 (32.0-62.0)	75.4
Tertiary	77.0 (58.0-91.0)	69.9	50.0 (18.7-81.3)	-	-	-
Mixed	63.0 (38.0-85.0)	97.1	15.5 (10.2-22.2)	-	29.0 (23.0-35.0)	98.6
Overall	18.0 (5.0-36.0)	99.4	18.0 (6.0-34.0)	98.7	71.0 (46.0-91.0)	99.7

Notes: - indicates statistics cannot be calculated, due either to no observation or only one study included. All the p values from the test of heterogeneity between groups are less than 0.001.

Subgroup meta-analyses stratified by facility level showed that lower-level health facilities had lower proportions of MCH workers with bachelor or higher-level degrees (Table 3.4, Figures 3.2-3.10). Subgroup meta-analyses lowered the I^2 statistics for almost all the groups. For doctors, the pooled weighted average proportion of having bachelor or higher-level degrees was 27.7% (1.5%-53.9%) at primary level facilities (Figure 3.2). The proportion for nurses was 1.0% (0.0%-5.0%), while that for other cadres was 3.0% (0.0%-12.0%).

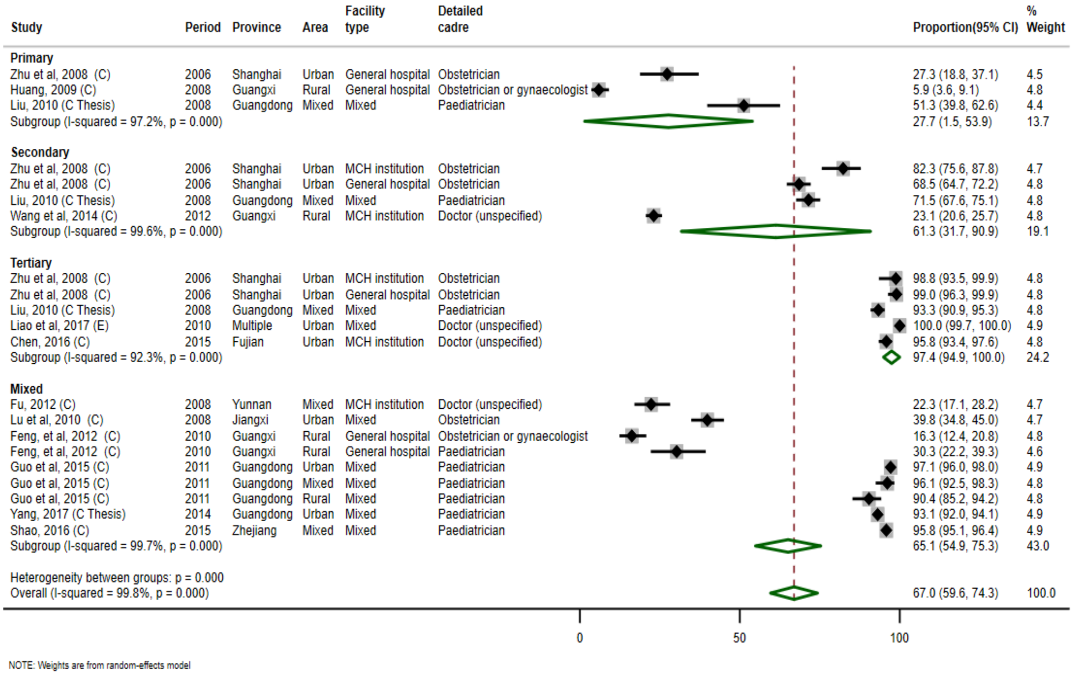


Figure 3.2: Forest plot showing the proportion of doctors holding bachelor or higher-level degrees

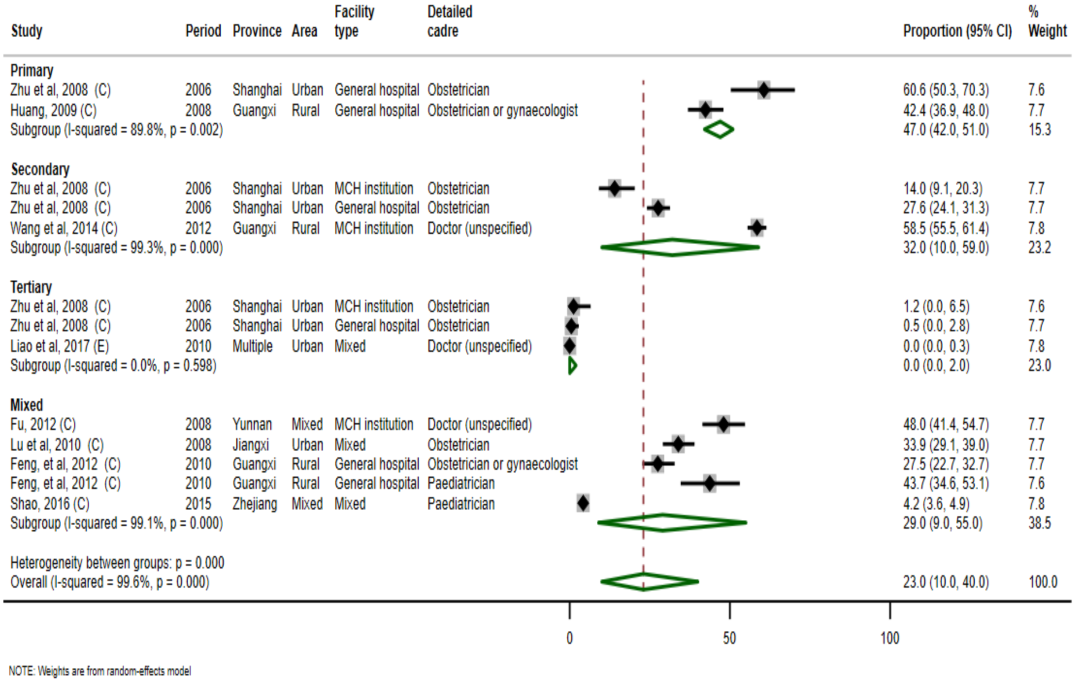


Figure 3.3: Forest plot showing the proportion of doctors holding junior college education

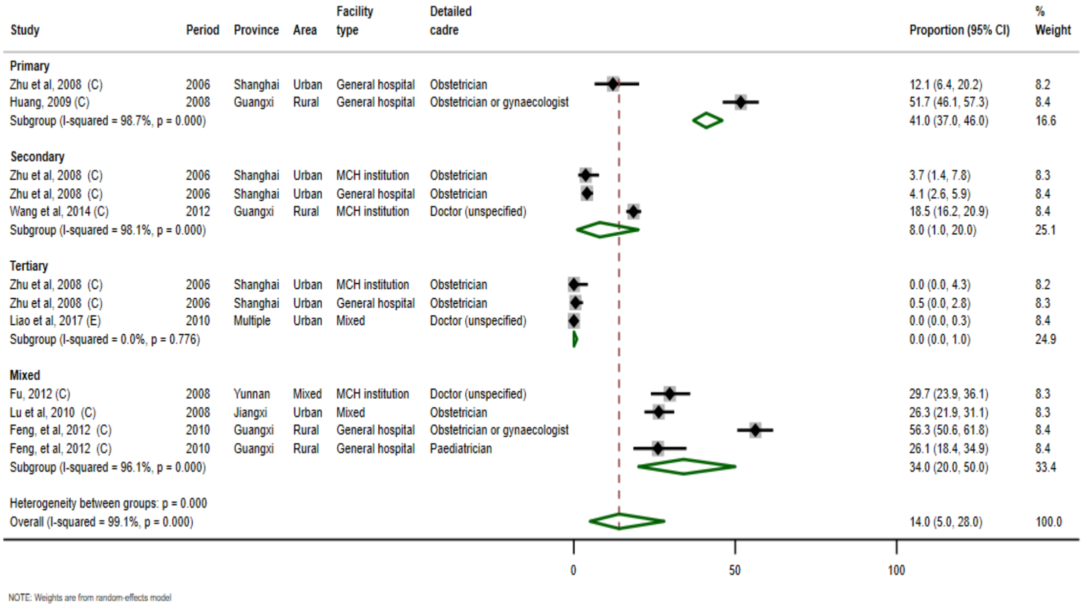


Figure 3.4: Forest plot showing the proportion of doctors with secondary technical school education or below

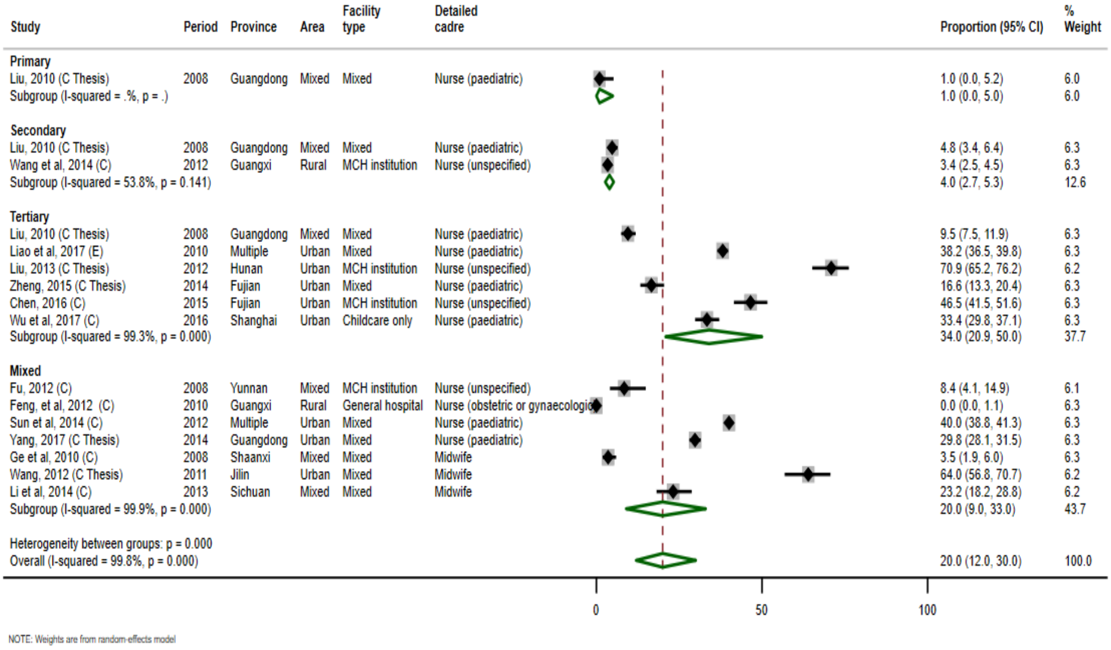


Figure 3.5: Forest plot showing the proportion of nurses (including midwives) holding bachelor or higher-level degrees

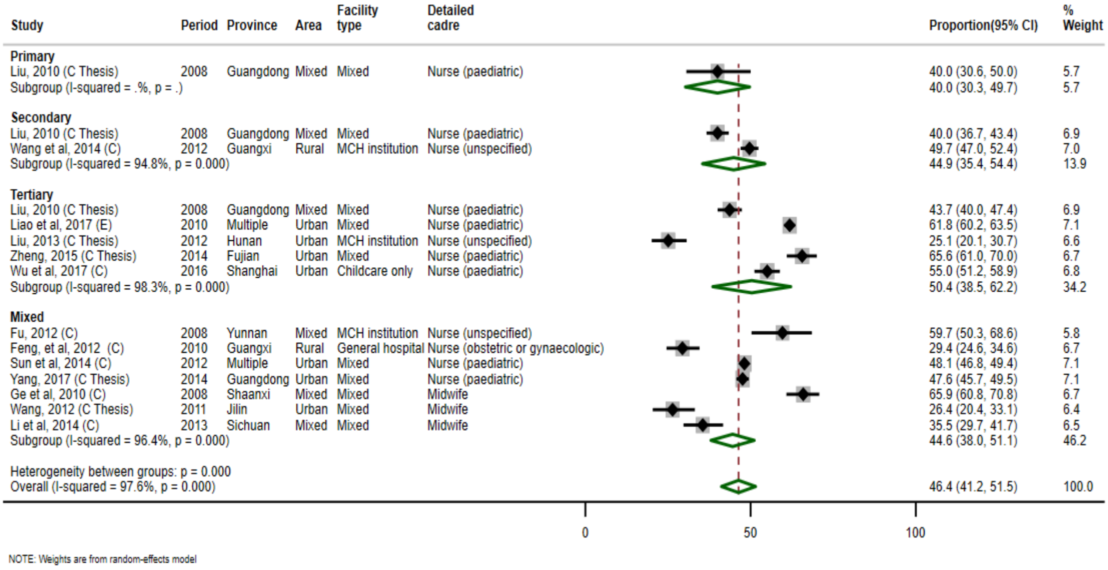


Figure 3.6: Forest plot showing the proportion of nurses (including midwives) holding junior college education

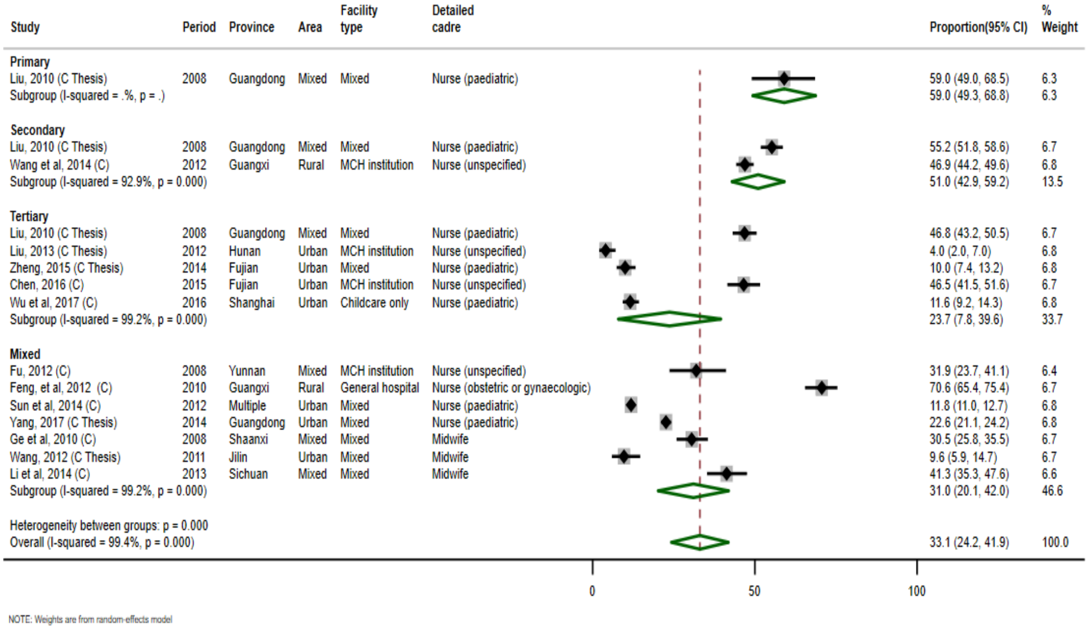


Figure 3.7: Forest plot showing the proportion of nurses (including midwives) with secondary technical school education or below

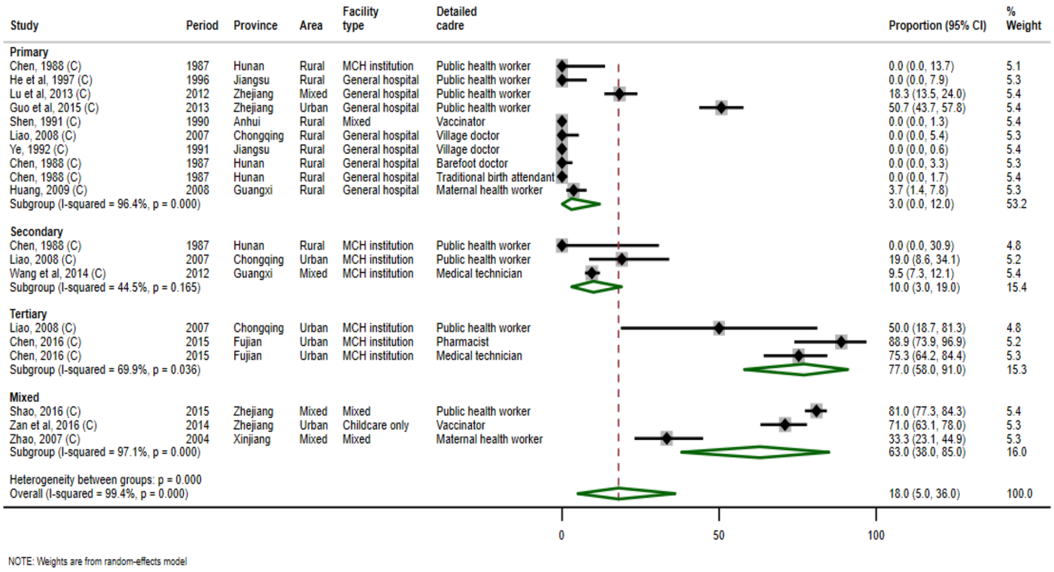


Figure 3.8: Forest plot showing the proportion of other health workers holding bachelor or higher-level degrees

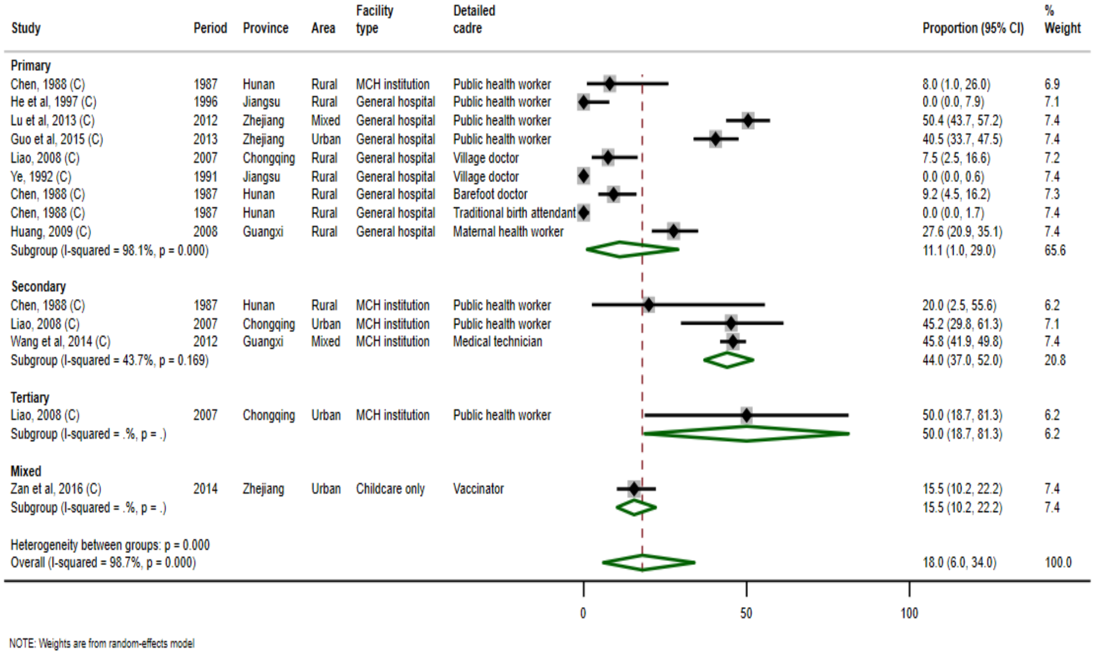


Figure 3.9: Forest plot showing the proportion of other health workers holding junior college education

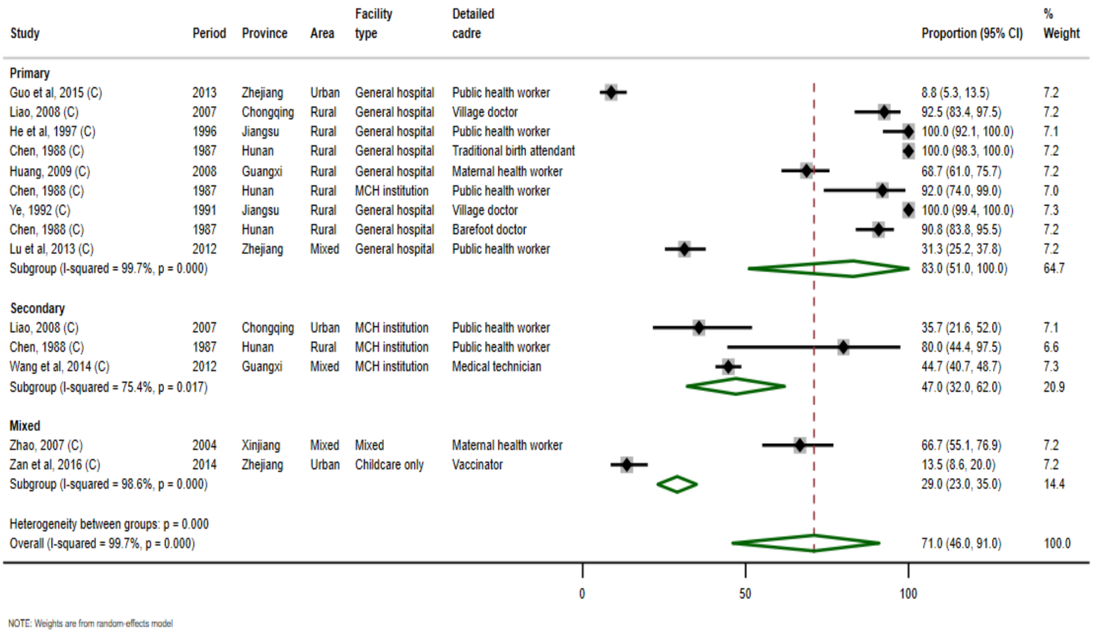


Figure 3.10: Forest plot showing the proportion of other health workers with secondary technical school education or below

<u>Health-related discipline</u>： Twelve studies provided information on MCH workers’ health-related discipline (Table 3.5) [132, 144-148, 151, 153-157]. The one study reporting on paediatricians suggested that they had all studied clinical medicine whilst obstetricians and gynaecologist had degrees from either “Clinical medicine” or “Maternal and child health” (a subarea of “Public health”).

Table 3.5: Health-related discipline training received by MCH workers

Cadre (number of studies)	**Health-related discipline**
Obstetrician or gynaecologist (1)	Clinical medicine, Maternal and child healthcare
Paediatrician (1)	Clinical medicine
Nurse (1)	Nursing
Midwife (3)	Midwifery, Nursing, Clinical medicine
Specialized public health worker (3)	Clinical medicine, Nursing, Public health, Auxiliary medicine, Maternal and child healthcare
Vaccinator (2)	Clinical medicine, Traditional Chinese medicine, Nursing, Midwifery, Public health, Non-medical specialty
Health information worker (1)	Clinical medicine, Nursing, Health sciences, Computer sciences
Maternal health worker (1)	Nursing, Midwifery, Maternal and child healthcare, Clinical medicine

Notes: The total number of studies exceeds 12 because two studies provide information for different cadres of MCH workers

Certification：Only two studies provided information on MCH workers' certification. One study in 2013 reported that only half (52.4%, 714 out of 1364) of the MCH workers from Chongqing held valid certification[160]. Among the other half of the MCH workers, 37.5% were incorrectly certificated not for the role in which they worked, and 10.1% provided MCH services without holding any certification. Similarly, another study surveyed all the obstetricians, obstetric nurses and midwives from township hospitals in Baise city, Guangxi, in 2008, finding that respectively 7.5% (24 out of 321 obstetricians), 68.5% (102 out of 149 obstetric nurses) and 4.7% (2 out of 43 midwives) of the MCH workers did not hold any certificate[131].

Studies reporting the density of MCH workers

Study Characteristics：The included studies are summarized by cadre (Tables 3.6-3.8). Of the 18 studies on density, 17 (94.4%) were done after 1990, and 5 (27.8%) were nationally representative[41, 161, 162, 170, 174]. The single-province studies included Zhejiang (n=3), Anhui (n=2), Guangdong (n=2), Yunnan (n=2), Shanghai (n=1), Jiangsu (n=1), Xinjiang (n=1), and Liaoning (n=1).

Table 3.6: Studies reporting on doctors: study design and density

Study	Area (period)	Care setting	Definition of health workers	No. of health workers	Data source of health worker number	Population denominator	Size of population	Data source of population denominator	Density
Doctor (Obstetrician or gynaecologist)									
Ren et al, 2018 (E)	332 randomly selected districts and counties in 27 provinces (2010)	Obstetrics or gynaecology department (Undefined) in all the medical and health institutions providing MCH services, including general hospital, MCH institution, Township hospital, Community health centre, Family planning service station, Other facility (Undefined; number not given)	"work in the obstetric or gynaecology departments" and "hold professional certificates"	26776	Structured questionnaire to health facilities (answered by hospital administrator)	Unclear ("total population")	Undefined	Unclear ("from local government")	2.01 per 10,000 population
Xue et al, 2003 (C)	"All the administrative units defined as county representative of the rural areas at national level" (2000)	Undefined	Undefined	Undefined	Unclear (Record review of data collected by Health statistical centre, National bureau of statistics)	Unclear ("total population in rural area")	Undefined	Unclear (Record review of "National health statistics yearbook")	0.8 per 10,000 population
Doctor (Obstetrician)									
Tao et al, 2011 (E)	Anhui Province, 2 rural counties (2006)	All the 23 facilities in county A and 44 in B including village clinic, township hospital, county hospital (Undefined)	"with three-to-five years of medical training and work in obstetrics"	82 in county A; 95 in county B	Unclear ("Health bureau data")	Number of women of reproductive age (aged 15-49 years)	121,483 in county A; 220,187 in county B	Unclear ("data from local health bureau")	0.67 per 1,000 women of reproductive age in A county; 0.43 per 1,000 women of reproductive age in in B

Study	Area (period)	Care setting	Definition of health workers	No. of health workers	Data source of health worker number	Population denominator	Size of population	Data source of population denominator	Density
									county
Chen et al, 2017 (C)	Jiangsu province, Nantong city (2016)	Obstetrics department (Undefined) in all the 97 health facilities "capable of providing obstetrics services"	Undefined	710	Unclear ("Health bureau data")	Unclear ("total population")	7,282,835	Record review of the “sixth National census”	0.97 per 10,000 population
Hu et al, 2010 (C)	Zhejiang province, Hangzhou city (2007)	Units (Undefined) in all the 70 health facilities "capable of providing obstetrics services"	Undefined	675	Structured questionnaire to health facilities	Number of annual live births	72,098	Undefined	9.4 per 1,000 annual live births
Ji et al, 2017 (C)	Anhui province (2017)	Units (Undefined) in all the 1358 health facilities "capable of providing obstetrics services"	Undefined	6798	Unclear ("Health bureau data")	Number of population actually residing in the area	61,440,000	Unclear (Record review of "Anhui statistics yearbook 2015")	1.11 per 10,000 population
Zhu, 2013 (C)	Shanghai (2012)	Units (Undefined) in all health facilities “capable of providing obstetric services" (number not given)	Undefined	1164	Structured questionnaire to health facilities	Number of population actually residing in the area	23,804,300	Record review of “Shanghai Statistics Yearbook 2012”	0.49 per 10,000 residential population
Yang et al, 2016 (C)	Yunnan province, Kunming city (2014)	Units (Undefined) in all the 125 health facilities “capable of providing obstetric services"	Undefined	952	Structured questionnaire to health facilities	Number of annual births	96,325	Unclear (Record review of "Annual report of MCH 2014")	9.9 per 1,000 annual births
Wang, 2015 (C Thesis)	Xinjiang province, Yecheng county (2013)	Units (Undefined) in all health facilities “capable of providing obstetric services" (number not given)	Undefined	62	Structured questionnaire to health facilities	Number of annual births	Undefined	Unclear (Record review of "Annual report of MCH in Xinjiang 2007-2012")	6.9 per 1,000 annual births

Study	Area (period)	Care setting	Definition of health workers	No. of health workers	Data source of health worker number	Population denominator	Size of population	Data source of population denominator	Density
	Xinjiang province, Shache county (2013)	*Same as above*	*Same as above*	42	*Same as above*	*Same as above*	Undefined	*Same as above*	2.3 per 1,000 annual births
Doctor (Paediatrician)									
Song et al, 2016 (E)	332 randomly selected districts and counties in 27 provinces (2010)	Units (Undefined) in all medical and health institutions providing MCH services, including general hospital, MCH institution, Township hospital, Community health centre, Family planning service station, Other facility (Undefined; number not given)	"provide child healthcare in the frontline"	16830	Structured questionnaire to health facilities (answered by hospital administrator)	Unclear ("total population")	Undefined	Undefined	1.26 per 10,000 population
Chen et al, 2017 (C)	Jiangsu province, Nantong city (2016)	Paediatric department (Undefined) in all the 58 health facilities "capable of providing paediatric care"	Undefined	430	Unclear ("Health bureau data")	Unclear ("total population")	7,282,835	Record review of the "sixth National census"	0.59 per 10,000 population
Jin, 2016 (C Thesis)	Yunnan province, Eshan county (2015)	Paediatric department (Undefined) in all the 2 county hospitals (Undefined)	Undefined	15	Unclear ("Health bureau data")	Number of children aged 0 and 14	30,200	Unclear ("data from local health bureau")	0.49 per 1000 children aged between 0 and 14
Xue et al, 2003 (C)	"All the administrative units defined as county representative of the rural areas at national level" (2000)	Undefined	Undefined	Undefined	Unclear (Record review of data collected by Health statistical centre, National bureau of statistics)	Number of rural population	Undefined	Unclear (Record review of "National health statistics yearbook")	0.4 per 10,000 population

Study	Area (period)	Care setting	Definition of health workers	No. of health workers	Data source of health worker number	Population denominator	Size of population	Data source of population denominator	Density
Zhang et al, 2019 (E)	31 provinces, 2733 counties (2016)	Units (Undefined) in all the 76 children's hospital, 2184 MCH institutions and 43922 primary hospitals, capable of "providing paediatric care"	"a doctor certified by the National Health Commission and licensed as specializing in medical care for children"	135524	Structured questionnaire to health facilities (answered by senior hospital manager)	Number of children aged under 14	Undefined	Undefined	4 per 10,000 children aged under 14

Table 3.7: Studies reporting on nurses and midwives: study design and density

Study	Area (period)	Care setting	Definition of health workers	No. of health workers	Data source of health worker number	Population denominator	Size of population	Data source of population denominator	Density
Nurse									
Song et al, 2016 (E)	332 randomly selected districts and counties in 27 provinces (2010)	Units (Undefined) in all medical and health institutions providing MCH services, including general hospital, MCH institution, Township hospital, Community health centre, Family planning service station, Other facility (Undefined; number not given)	"provide child healthcare in the paediatric department”	18134	Structured questionnaire to health facilities (answered by hospital administrator)	Unclear ("total population")	Undefined	Undefined	1.36 per 10,000 population
Ren et al, 2018 (E)	332 randomly selected districts and counties in 27 provinces (2010)	Obstetrics or gynaecology department (Undefined) in all medical and health institutions providing MCH services, including general hospital, MCH institution, Township hospital, Community health centre, Family planning service station, Other facility (Undefined; number not given)	"work in the obstetric or gynaecology departments” and "hold professional certificates".	23465	Structured questionnaire to health facilities (answered by hospital administrator)	Unclear ("total population")	Undefined	Unclear ("from local government")	1.76 per 10,000 population
Chen et al, 2017 (C)	Jiangsu province, Nantong city (2016)	Obstetrics department (Undefined) in all the 97 health facilities "capable of providing obstetrics services"	Unclear (“Obstetric nurse”)	968	Unclear ("Health bureau data")	Unclear ("total population")	7,282,835	Record review of the “sixth National census”	1.33 per 10,000 population
		Paediatric department (Undefined) in 58 health facilities “capable of providing paediatric care”	Unclear (“Paediatric nurse”)	631	*Same as above*	*Same as above*	7,282,835	Record review of the “sixth National census”	0.86 per 10,000 population
Hu et al, 2010 (C)	Zhejiang province, Hangzhou city	Units (Undefined) in all the 70 health facilities "capable of providing obstetrics services"	Unclear (“Obstetric nurses including	1109	Structured questionnaire to health facilities	Annual live births	72,098	Undefined	15.5 per 1,000 annual births

Study	Area (period)	Care setting	Definition of health workers	No. of health workers	Data source of health worker number	Population denominator	Size of population	Data source of population denominator	Density
	(2007)		midwives")						
Zhu, 2013 (C)	Shanghai (2012)	Units (Undefined) in all health facilities “capable of providing obstetric services" (number not given)	Unclear (“Obstetric nurse”)	2032	Structured questionnaire to health facilities	Number of population actually residing in the area	23,804,300	Record review of “Shanghai Statistics Yearbook 2012”	0.85 per 10,000 residential population
Yang et al, 2016 (C)	Yunnan province, Kunming city (2014)	Units (Undefined) in all the 125 health facilities “capable of providing obstetric services"	Unclear (“Obstetric nurse”)	1597	Structured questionnaire to health facilities	Number of annual births	96,325	Unclear (Record review of "Annual report of MCH 2014")	16.6 per 1,000 annual births
Midwives									
Tao et al, 2011 (E)	Anhui Province, 2 rural counties (2006)	All the 23 facilities in A county and 44 facilities in B county including village clinic, township hospital, county hospital (Undefined)	"with three-year midwifery training”	29 in county A; 56 in county B	Unclear ("Health bureau data")	Number of women of reproductive age	121,483 in county A; 220,187 in county B	Unclear ("data from local health bureau")	0.24 per 1,000 women of reproductive age in A county; 0.25 per 1,000 women of reproductive age in in B county;
Ren et al, 2018 (E)	332 randomly selected districts and counties in 27 provinces (2010)	Obstetrics or gynaecology department (Undefined) in all the medical and health institutions providing MCH services, including general hospital, MCH institution, Township hospital, Community health centre, Family planning service station, Other facility (Undefined; number not given)	"work in the obstetric or gynaecology departments” and "hold professional certificates".	9966	Structured questionnaire to health facilities (answered by hospital administrator)	Unclear ("total population")	Undefined	Unclear ("from local government")	0.75 per 10,000 population

Study	Area (period)	Care setting	Definition of health workers	No. of health workers	Data source of health worker number	Population denominator	Size of population	Data source of population denominator	Density
Ji et al, 2017 (C)	Anhui province (2017)	Units (Undefined) in all the 1358 health facilities "capable of providing obstetrics services"	Undefined	4674	Unclear ("Health bureau data")	Number of population actually residing in the area	61,440,000	Unclear (Record review of "Anhui statistics yearbook 2015")	0.77 per 10,000 population

Table 3.8: Studies reporting on other cadres: study design and density

Study	**Area (period)**	**Care setting**	**Definition of health workers**	**No. of health workers**	**Data source of health worker number**	**Population denominator**	**Size of population**	**Data source of population denominator**	**Density**
Specialized public health worker									
Hu et al, 2014 (E)	Zhejiang Province, 90 counties (2013)	All the immunization clinic (Undefined; number not given)	"full-time vaccination personnel and part-time public health workers who work in childhood immunization."	Undefined	Unclear ("Health bureau data")	Unclear ("total population")	Undefined	Undefined	0.13 per 10,000 population (SD 0.28, ranging from 0.03 to 3.74 in different counties)
Guo et al, 2015 (C)	Zhejiang province, 4 randomly selected counties in Hangzhou city (2013)	Units (Undefined) in all the 62 community health centres (Undefined)	“provide MCH services”	205	Structured questionnaire to health facilities	Population actually residing in the area	2,570,300 permanent residential population	Unclear ("data provided by surveyed facilities")	0.8 per 10,000 permanent residential population
Zou et al, 2016 (C)	Guangdong province, Guangzhou city (2009)	Units (Undefined) in all community health institutions (Undefined; number not given)	“provide maternal health services”	297	Unclear (Record review of "Guangzhou annual report of MCH and healthcare")	Annual number of pregnant women	Undefined	"Annual report of maternal health in Guangzhou 2009"	3.14 per 1000 pregnant women
	Same as above	*Same as above*	“provide child health services”	321	*Same as above*	Annual number of children aged between 0 and 6 by actual residence	Undefined	Unclear (Record review of "Annual report of child health (<7 years old) in Guangzhou 2009")	0.51 per 1000 children aged between 0 and 6
	Guangdong province,	*Same as above*	“provide MCH	404	*Same as above*	Annual number of	Undefined	Unclear (Record review of "Annual	3.38 per 1000

Study	Area (period)	Care setting	Definition of health workers	No. of health workers	Data source of health worker number	Population denominator	Size of population	Data source of population denominator	Density
	Guangzhou city (2013)		services”			pregnant women		report of maternal health in Guangzhou 2013")	pregnant women
	Same as above	*Same as above*	“provide MCH services”	415	*Same as above*	Annual number of children aged between 0 and 6 actually residing in the area	Undefined	Unclear (Record review of "Annual report of child health (<7 years old) in Guangzhou 2013")	0.52 per 1000 children aged between 0 and 6
Vaccinator									
Chen et al, 2010 (C)	Guangdong province, Guangzhou city (2003)	All the 174 village clinics (Undefined)	"who provided outpatient immunization services for children”	939	Unclear ("Health bureau data")	Unclear ("total population")	7,272,034	Undefined	1.29 per 10,000 population
	Same area as above (2009)	All the 210 village clinics (Undefined)	*Same as above*	1356	*Same as above*	*Same as above*	7,989,937	*Same as above*	1.70 per 10,000 population
Barefoot doctor									
Wang, 1975 (E)	Liaoning province, Shenyang city (1973)	All the 15 health stations (Undefined)	"selected by the people in the communes and are trained in their locale" and "take on large responsibilities in caring for the health of the mother after birth and the child"	26	Unclear ("interviewed health workers"）	Number of population actually residing in the area	28,053	Undefined	9.3 barefoot doctors per 10,000 population

Study	**Area (period)**	**Care setting**	**Definition of health workers**	**No. of health workers**	**Data source of health worker number**	**Population denominator**	**Size of population**	**Data source of population denominator**	**Density**
Traditional birth attendant									
Wang, 1975 (E)	Liaoning province, Shenyang city (1973)	All the 15 health stations (Undefined)	"give care and regular check-ups to pregnant women, attend to deliveries at home and give postnatal care to mother and child"	16	Unclear ("interviewed health workers"）	Number of population actually residing in the area	28,053	Undefined	5.7 midwives per 10,000 population
Maternal and child health worker									
Ren et al, 2015 (E)	332 randomly selected districts and counties in 27 provinces (2010)	Units (Undefined) in all the 5168 medical and health institutions providing MCH services, including general hospital, MCH institution, Township hospital, Community health centre, Family planning service station, Other facility (Undefined)	"provide curative and preventive healthcare for women and children and hold at least one legal health qualification certificate."	77248	Structured questionnaire to health facilities (answered by hospital administrator)	Unclear ("total population")	Undefined	Undefined	5.5 per 10,000 population at national level (5.7 for the east, 5.7 for the west regions, and 5.1 for the central region)
Maternal health worker									
Ren et al, 2015 (E)	332 randomly selected districts and counties in 27 provinces (2010)	Units (Undefined) in all the medical and health institutions providing MCH services, including general hospital, MCH institution, Township hospital, Community health centre, Family planning service station, Other facility	"provide curative and preventive healthcare for women and hold at least one legal health qualification certificate."	315382	Structured questionnaire to health facilities (answered by hospital administrator)	Unclear ("total population")	Undefined	Undefined	2.23 per 10,000 population at national level (2.13 for the east, 2.31 for the west regions, and 2.24 for the central region)

Study	Area (period)	Care setting	Definition of health workers	No. of health workers	Data source of health worker number	Population denominator	Size of population	Data source of population denominator	Density
		(Undefined; number not given)							
Child health worker									
Ren et al, 2015 (E)	332 randomly selected districts and counties in 27 provinces (2010)	Units (Undefined) in all the medical and health institutions providing MCH services, including general hospital, MCH institution, Township hospital, Community health centre, Family planning service station, Other facility (Undefined; number not given)	"provide curative and preventive healthcare for children and hold at least one legal health qualification certificate."	19853	Structured questionnaire to health facilities (answered by hospital administrator)	Unclear ("total population ")	Undefined	Undefined	1.41 per 10,000 population at national level (1.21 for the east, 1.76 for the west regions, and 1.33 for the central region)

Density by cadre：For studies using total population as the denominator (Figure 3.11), the weighted average density of MCH doctors was 11.9 (95% CI: 7.5-16.2) per 100 000 population (n=5) and that of MCH nurses was 11.4 (7.6-15.2) (n=6). For studies using number of births as the denominator (Figure 3.12), the weighted average density of obstetricians was 9.0 (95% CI: 7.9-10.2) per 1000 births (n=3) and that of obstetric nurses was 16.0 (14.8-17.2) per 1000 births (n=2).

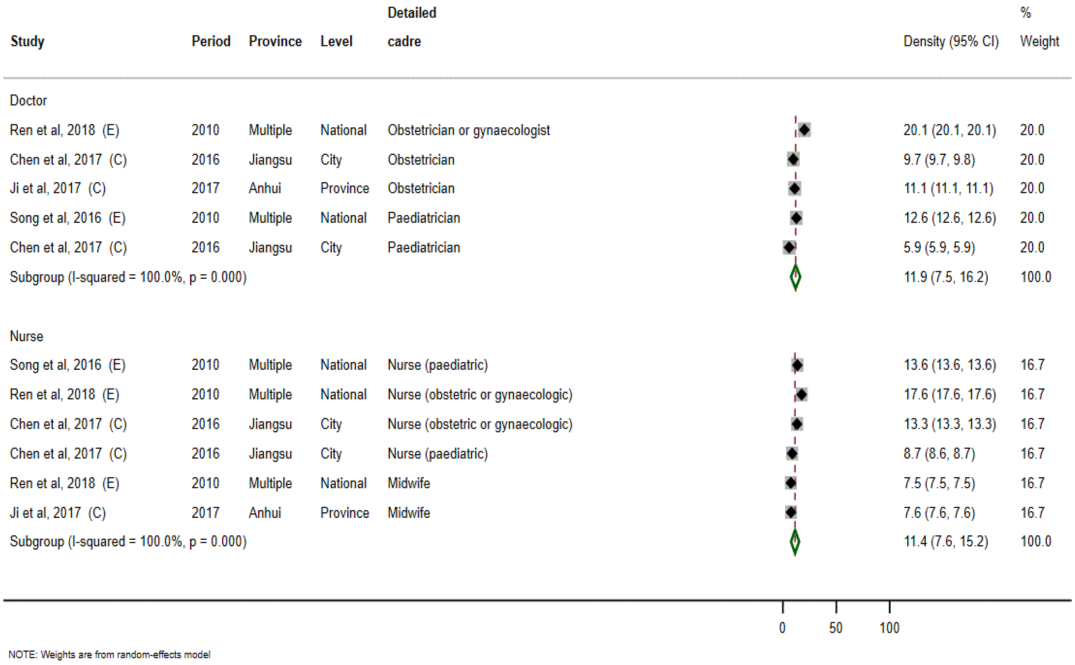


Figure 3.11: Forest plot showing the density of MCH workers by cadre, per 100 000 population

Study	Period	Province	Level	Detailed cadre	Density (95% CI)	% Weight
Doctor						
Hu et al, 2010 (C)	2007	Zhejiang	City	Obstetrician	9.4 (8.7, 10.1)	38.5
Yang et al, 2016 (C)	2014	Yunnan	City	Obstetrician	9.9 (9.3, 10.5)	39.7
Wang, 2015 (C Thesis)	2013	Xinjiang	County	Obstetrician	6.9 (5.3, 8.8)	21.8
Subgroup (I-squared = 79.7%, p = 0.007)					9.0 (7.9, 10.2)	100.0
Nurse						
Yang et al, 2016 (C)	2014	Yunnan	City	Nurse (obstetric)	16.6 (15.8, 17.4)	51.5
Hu et al, 2010 (C)	2007	Zhejiang	City	Nurse (obstetric)	15.4 (14.5, 16.3)	48.5
Subgroup (I-squared = 73.2%, p = 0.054)					16.0 (14.8, 17.2)	100.0

NOTE: Weights are from random-effects model

Figure 3.12: Forest plot showing the density of MCH workers by cadre, per 1000 births

Ratios of MCH workers：Three studies allowed us to calculate the ratio of maternal to child health workers (Figure 3.13). The density of the maternal health workers was between 1.6 and 6.5 times higher than the density of child health workers. Six studies allowed us to calculate the ratio of MCH nurse density to MCH doctor density (Figure 3.14). The ratio of obstetric nurses to obstetricians ranged from 1.4:1 to 1.7:1. The ratio of paediatric nurses to paediatricians ranged from 1.1:1 to 1.7:1.

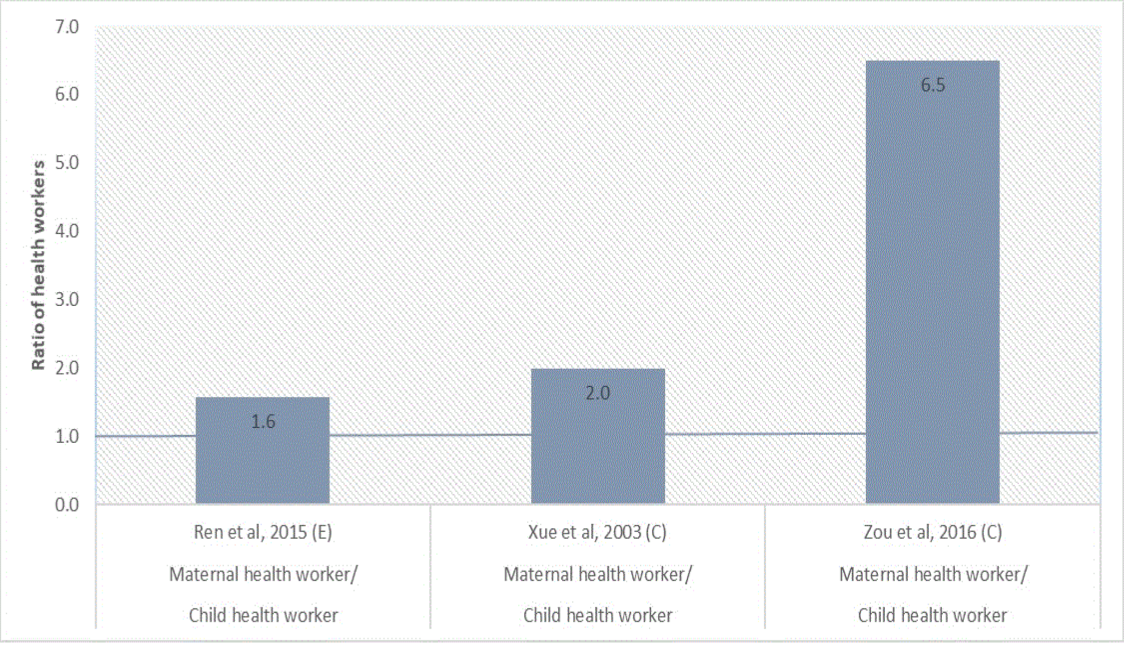


Figure 3.13: Maternal-to-child health worker ratio

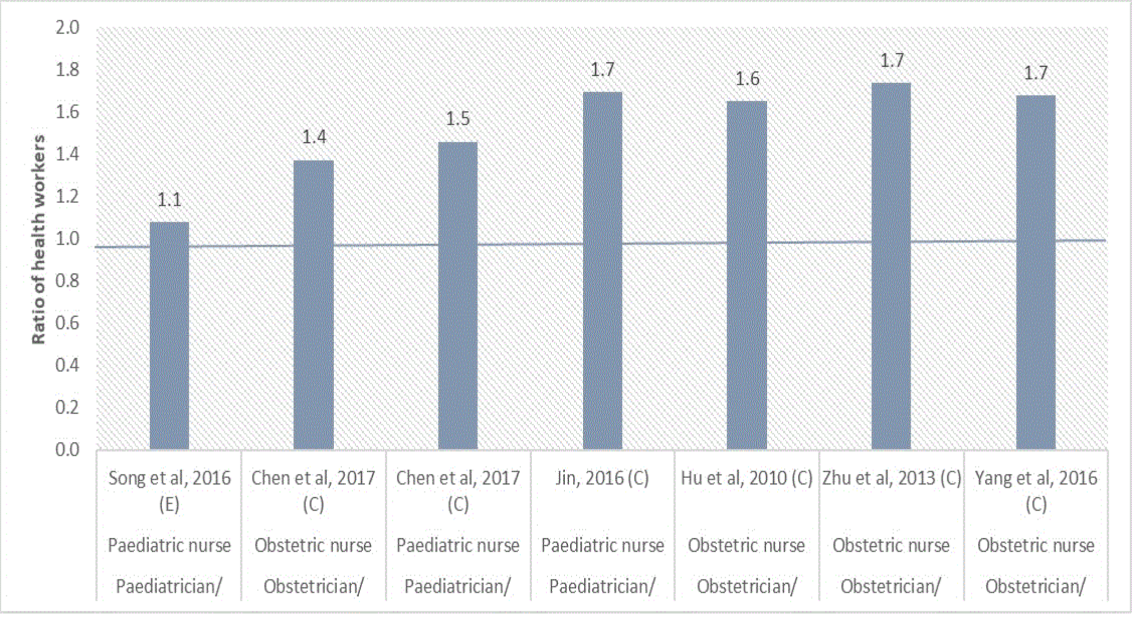


Figure 3.14: Nurse-to-doctor ratio

3.2.5 Discussion

The aim of the review was to describe the profile and density of MCH workers in China and to help understand how the MCH workforce development contribute to China's achievement in MCH. The study has three main findings. First, only two thirds of obstetricians and paediatricians had a bachelor or higher degree. This proportion was lower in primary level facilities (28%). For nurses involved in MCH care the proportions with a bachelor or higher degree were lower (20.0% in any health facility and 1% in primary care facilities). Second, the proportions of MCH workers who held a certificate – a rigorous system introduced by the Chinese Government to regulate who can perform MCH tasks – ranged from 32% (47 of 149 obstetric nurses) to 95% (41 out of 43 midwives) in primary care facilities. Third, the average density of obstetricians was 9.0 (7.9-10.2) per 1000 births and that of obstetric nurses 16.0 (14.8-17.2) per 1000 births. The density of MCH workers is much higher than what has been recommended internationally (three doctors with obstetric skills or 20 midwives per 3600 births).

Obstetricians, paediatricians and other MCH worker cadres were much less educated at the primary level than at the tertiary level. That is partly because most medical school graduates in China compete to join large hospitals, where their salaries, working conditions and career opportunities are superior to those offered by primary-level health facilities[176]. The mobility rate of experienced and qualified health workers in primary-level health facilities is high[177]. The lower capacity of MCH workers at the primary level is also seen in other LMICs. China's strategy has been to achieve widespread deployment of the workforce first and then to upgrade the skills of the providers to improve the standard of care gradually. Such strategy contributed to the higher density of obstetricians and obstetric nurses as compared to the international benchmark. Similar strategies are also seen in the expansion of the insurance schemes, where universal health insurance coverage is achieved first and an improvement of the benefit package follows[178].

Although the education level of MCH workers is variable, China achieved near-universal access to childbirth in health facilities with low maternal mortality and neonatal mortality as a result[19, 109]. Childbirth is now concentrated in well-staffed hospitals at secondary and tertiary levels, whereas primary level facilities focus on antenatal care and screening of high-risk pregnancies[109]. Concentrating births in large facilities facilitates an efficient and effective midwifery and obstetric skill mix, with providers being highly trained and equipped to ensure safe birth. The government no longer allows caesarean sections to be provided at township hospitals, where maternal health workers now focus on home visits, birth preparedness, and postpartum follow-up. In addition, accredited obstetricians from tertiary facilities regularly visit secondary or primary level facilities to provide in-service training and supervision[109]. Evidence from other countries has shown that some MCH tasks do not require advanced skills and health workers with no advanced training can perform well provided that they get supervision from higher-level facilities[179]. Another example is immunization, which is not a complex intervention. Although primary level facilities are poorly staffed for highly medicalised services, immunization is offered largely at primary care level. In rural areas, immunization is actively promoted by village doctors, who only have basic levels of education.

Certification of MCH workers is an important strategy to ensure that particular tasks are only performed by those skilled and equipped to do so [180, 181]. We found that not all MCH workers held a valid certificate. The finding does not necessarily imply that this is a failure of certification mechanism. Health facilities are required to comply with the regulations relating to certification of MCH workers. But there is a lack of information on the degree of compliance of health facilities with the regulations. It could be partly due to the fact that limited resources have been put in place to enforce the certification law. Although rare evidence exists, this problem might also occur in private hospitals, which are often less regulated.

Our study has found that for density of MCH workers, the population denominator has been used more often than birth denominator. The weighted average density of MCH doctors reported in our study (11.9 per 100 000 population) was similar to that in Sweden and France in 2012 – 12.1 and 12.3 respectively[182]. However, fertility in these countries is higher than in China, so comparisons may not be valid. We echo Gabrysch and colleagues' recommendations about the need to enhance discriminatory power of density indicators and measure density of different cadres of MCH workers according to specific demographic profile, for example, define density of obstetricians using per births instead of per population[82].

Through the analysis of MCH worker ratio, we found a larger maternal health workforce than child health workforce, and more nurses than doctors. Although no gold standard exists for the ratio of maternal to child health workers, the shortage of child health workers in China has been a long concern. Paediatrics is not a popular choice for medical students due to the heavy workload, low salary compared with other medical professions and intense doctor-patient relationships[183]. The revealed deficit in the availability of child health workers needs to be addressed through implementing targeted human resource policies, such as through the salary and bonus systems or improved working conditions. Compared with the optimal 2:1 nurse-to-doctor ratio as recommended by WHO[28], the nurse-to-doctor ratio in MCH area was less than optimal. China has a long history of having a low nurse-to-doctor ratio. The nurse-to-doctor ratio was estimated around 1:10 in the early 1950s (WHO, 2015)[36]. The situation was reversed with an estimated nurse-to-doctor ratio of 1.1:1 in 2019[25]. China still needs to step up its training of nurses to perform the MCH services.

In the era of SDGs, many countries address MCH workforce challenges through task-shifting and creating cadres capable to provide antenatal care, intrapartum care, postpartum care and paediatric care[184]. It is necessary to look at the MCH workforce as a whole in country systems to complement to the measurement of particular cadres of MCH workers. While the presented MCH workforce analysis was confined to Chinese mainland, the analysis we have done is likely to apply to many LMICs which do not apply international training standards, e.g. Vietnam, Myanmar and Zambia[185]. As countries try to address MCH workforce gaps, reliable and up-to-date information on the profile and density of MCH workers is urgently needed for evidence-based policy making. This calls for improved methods in future primary data collection, including clear definitions of MCH workers and robust measurement of MCH workforce density.

Our study has several limitations. First, we found no studies reporting on the private sectors, where the profile of MCH workers may be different from those working in the public sector. Second, we only focused on the length of education without analysing the content of training, so we did not assess the skills of the MCH workers. Third, we did not separate the data by year for the meta-analysis because that would result in too few studies for each cadre and each subgroup. Given that 94% of the included studies were done after 1990 and health workforce usually takes a decade or a generation to develop[87], the difference in time period was unlikely to change the results. Fourth, there were relatively too few studies contributing to each subgroup (less than 10 studies). Subgroup proportions need to be interpreted with uncertainty. Fifth, there could be some mis-reporting given the methods used to report on MCH workers. Last, the quality of the included studies needs careful scrutiny, because there is unclear and high risk of bias in almost all studies.

3.3 Conclusion

The high density of MCH workers in China is achieved through a mix of workers with high and low educational profiles. Many workers labelled as “obstetricians or “paediatrician” have lower qualifications than expected. China compensates for these low educational levels through task-shifting, in-service training and supervision. In a global context, particularly in the area of maternal and newborn health, many countries are pushing for degree level qualification of skilled health professionals. China’s experience in training and optimising the roles of less educated MCH workers can be further explored as a strategic option for poor-resourced settings.

Chapter 4. Levels, trends and determinants of child mortality in China from 1949 to 2019: a scoping review

To address the second objective of the thesis, this chapter begins by presenting the existing data sources on child mortality from 1949 to 2019, with a description of the data quality. It further describes the national trend and medical causes of child mortality in the same period. The ecological and individual-level determinants of child mortality levels are then described. Lastly, the determinants of child mortality decline are described separately from the determinants of child mortality levels.

4.1 Introduction

Most robust large-scale studies on infant and child mortality appeared after 1990 when high-quality mortality data became available[21, 186, 187]. A recent review of China's progress in reproductive, maternal, newborn, child and adolescent health in the past 70 years only showed actual data on child mortality (including the NMR, IMR and U5MR) at national level between 1990 and 2019 [17]. Less is known about trends in infant and under-5 mortality from 1949 to the present, leaving a knowledge gap. Even less is known about the medical causes or determinants of child deaths than about trends in child mortality. A comprehensive review of the levels, trends and determinants of the IMR and the U5MR over a long time period is important to inform priority setting for interventions and research in the coming decades. In view of the large number of countries still struggling with high infant and child mortality levels in the world, an in-depth case study of China may also help other LMICs to learn lessons on how mortality could be reduced.

4.1.1 Objectives

The objective of this chapter is to assess China's progress in reducing infant and under-5 mortality by evaluating trends from 1949 to 2019 using published and unpublished data, to improve understanding of the determinants that underpinned the achievement, and to identify knowledge gaps by a scoping review.

Specific objectives are:

(1) to summarize the data sources on the levels and medical causes of infant and under-5 mortality in China, to highlight differences between the sources and to describe their quality; and

(2) to present the levels of the infant and under-5 mortality rate at the national level based on available data from the reviewed data sources; and

(3) to identify the determinants of infant and under-5 mortality at the ecological and at the individual level, and the determinants of mortality decline.

4.2 Methods

4.2.1 Study design

I chose to do a scoping review instead of a systematic review because the study purpose is to identify the extent of evidence on the IMR and the U5MR decline in China rather than to answer a precise question regarding a certain intervention or practice. I followed the guidelines listed in the Preferred Reporting Items for Systematic Reviews and Meta- Analyses Extension for Scoping Reviews (PRISMA- ScR) to perform the review[123].

4.2.2 Search Strategy

I undertook parallel searches of both bibliographic databases and the grey literature. For bibliographic databases, I searched two English databases (EMBASE and MEDLINE) and two Chinese databases (China National Knowledge Infrastructure [CNKI] and Wanfang) for published studies on 4 April 2021, with no limitation on language. The full search strategy is shown in Appendix B. Reference lists of potentially relevant articles were manually searched. For the grey literature, I consulted official government websites (including the State Council and the National Health Commission) and websites of international organisations (the World Health Organization, the United Nations and the Institute for Health Metrics and Evaluation) for records on levels of infant or child mortality and the medical causes of infant or child deaths. Age groups were defined as infancy (0-11 months) or childhood (under 5 years). I used the keywords “infant mortality rate”, “child mortality” and “under-5 mortality rate” to search for records in the websites. All the data searches in the official government websites were done in Chinese while the searches in the non-government websites were done in English.

4.2.3 Document selection

I included reports issued by the government or international organizations or peer-reviewed studies reporting nationally representative data with sufficient quality on the levels or medical causes of infant or child mortality for any year or period after 1949.

I included peer-reviewed studies attempting to quantitatively analyse the determinants of the level of infant or child mortality. I included ecological studies if authors reported the IMR or the U5MR with associated determinants either nationally representative or sub-nationally representative from any subnational context (region/province/county) in China. In addition, measures of association (crude regression coefficient, adjusted regression coefficient, relative risk) needed to be reported. I also included individual level studies (national and subnational) if authors reported numerical data on infant deaths or deaths under 5 with an appropriate denominator, having a sample size of at least 30 children, and reported relative risks of mortality comparing different characteristics of children, e.g. children living under a defined poverty line versus those living over the poverty line. Systematic reviews, cohorts, case-control studies, cross-sectional studies and ecologic studies were all eligible for inclusion.

I also included peer-reviewed studies attempting to quantitatively explain the decline in infant or child mortality. I included both ecological studies and individual level studies if authors quantitatively attributed child mortality decline in a defined period of time to a determinant, and reported attributable proportions with confidence intervals. I had no restrictions for study design for studies on the determinants of the decline in child mortality.

Conference abstracts or studies without a clear description of data collection methods were excluded. Titles and abstracts were screened for relevant studies. Full texts of potentially relevant records were screened to identify data that met the inclusion criteria.

4.2.4 Data extraction

All relevant data on the levels or the medical causes of infant or child mortality were extracted into an Excel spreadsheet. For peer-reviewed studies on the levels or medical causes of infant or child mortality, I only extracted data which I had not captured from routine reports identified from the grey literature. I extracted the year of data collection, data collection methods, the numerator and the denominator, and a quality assessment of the data sources. Where a description of the data source was provided, but the quality of data was not described, I left the description of the quality of data empty.

For studies investigating the determinants of child mortality levels, I extracted the following information: study design, unit of analysis, study period, definition and measurement of determinants, mortality outcome of interest and definition, data source, methods used to estimate the strength of association, measures of association and confidence intervals, confounders adjusted for (if adjusted regression coefficient reported), p value of statistical tests for association, fitness of regression model (R^2).

For studies investigating the determinants of child mortality decline, I extracted the following information: study design, unit of analysis, study period, definition and measurement of determinants, mortality outcome of interest and definition, data source, method used to measure the factors associated with trends in mortality, the proportion of the decline in child mortality that is attributable to the examined determinant (with the 95% confidence intervals), confounders adjusted for, p value of statistical tests.

4.2.5 Data analysis

I analysed data using a numeric summary and thematic analysis. I categorized information into four domains: available data sources on the levels and medical causes of infant or child mortality, trends and medical causes of infant and child mortality, determinants of the levels of infant or child mortality, and determinants of the decline of infant or child mortality. I plotted data on the levels of infant and child mortality using scatter plots.

4.3 Results

4.3.1 Study characteristics

Study and report selection is provided in Figure 4.1. The bibliographic database search yielded 1,793 records, of which 1,398 remained after duplicates were removed. A further 1,305 records were removed after title and abstract screening. Of the 93 studies screened in the full texts, 59 were excluded, leaving 34 studies. A further 17 studies were added using manual search of the reference lists of the included articles. The grey literature search identified 41 records. After screening for relevance and removing duplicates, five routine reports were finally added. The final review comprised 56 records: 51 peer-reviewed studies (8 in Chinese and 43 in English) and 5 routine reports (2 in Chinese and 3 in English). Most of the studies were published after 2000 (90%, n=46), so are the reports (80%, n=4). Of the studies on the determinants of infant and under-5 mortality (n=25), more than half were conducted at the ecological level (n=17, 68%) whilst only a few studies were done at the individual level (n=8, 32%). I only found two studies on the determinants of the infant or child mortality declines.

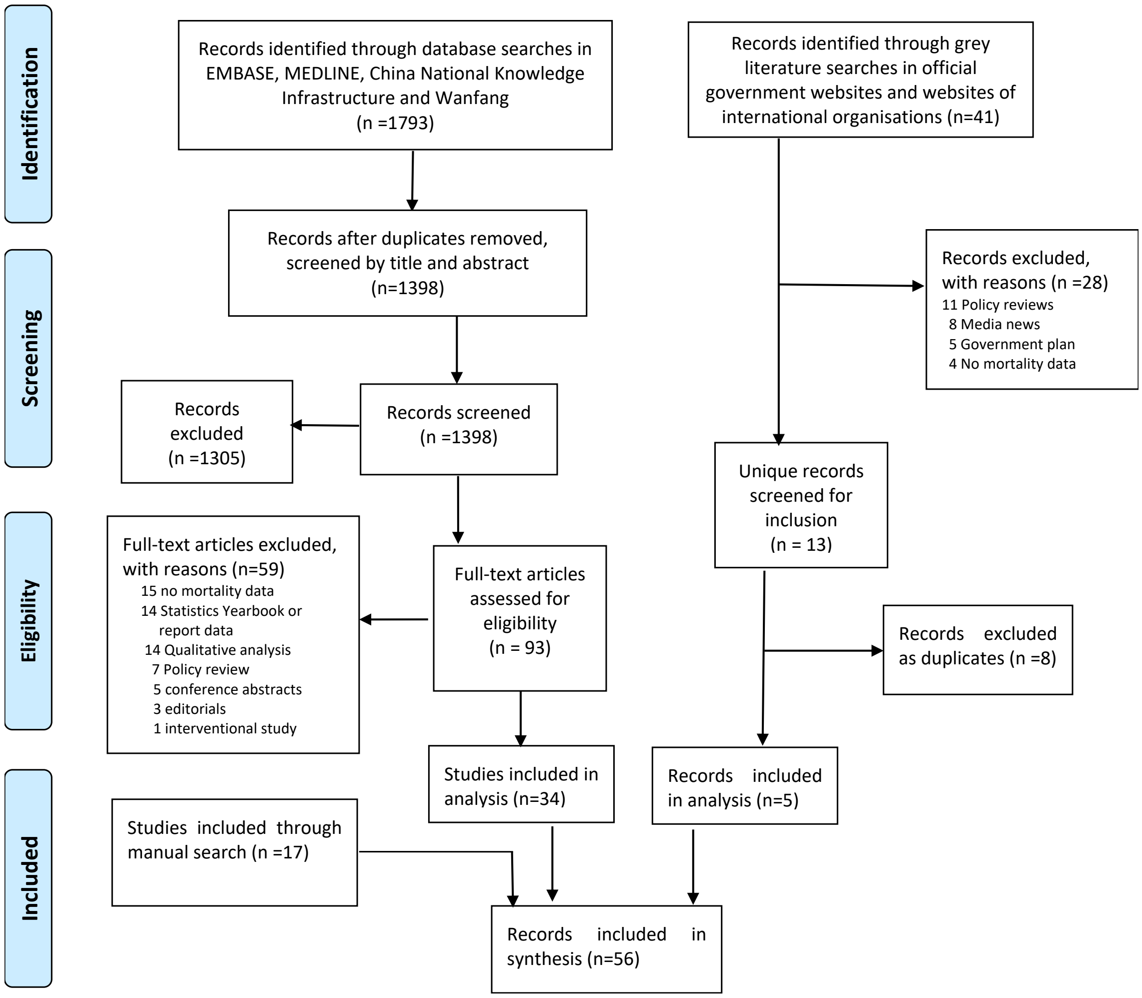


Figure 4.1: PRISMA diagram. The search and selection process applied during the scoping review.

4.3.2 Key data sources on levels of infant and under-5 mortality

The following five data sources were reported to have recorded the levels of infant and under-5 mortality: household registration, census and micro-census, retrospective surveys, national surveillance and report system, and international reports of infant and under-5 mortality.

Household Registration

The household registration system has existed since the 1950s, mainly serving administrative purposes [188]. The system relies on self-reporting, whereby every citizen must register with the local security office. The head of the household is responsible for reporting the births, deaths and migration that each individual has experienced. Deaths and population numbers are aggregated at local levels and then reported up to provincial and national levels [189].

Collecting accurate birth information became more difficult since the 1990s for two main reasons[188]. First, there is a massive rural-to-urban migration in China. Many women migrated away from the place where they were registered to urban areas for job opportunities, and people became less concerned about updating their registration. Second, under-registration became common because of the one-child policy introduced in 1979. Illegal birth was often misreported or reporting was delayed. Accordingly, the usefulness of the household registration data has been limited in the study of infant or child mortality.

Census and Micro-census

Nationwide censuses (1953, 1963, 1982, 1990, 2000, 2010, 2020) have been an important source of data for infant and child mortality in China [189]. Censuses report deaths by 5-year age group (0+, 1-4, 5-9, 10-14, …,85+) and number of births in the household at a particular point in time. Knowledge about the first two waves of censuses (1953 and 1964 censuses) is limited because the central government only released highly aggregated data[188]. Household-level data (1982, 1990, 2000) have only been made available to researchers upon research request in recent years through platforms like the Integrated Public Use Microdata Series (IPUMS).

China also carried out micro-censuses between the censuses (1987, 1995, 2005, 2015) on a 1% population sample (also called ‘inter-census’ surveys). The micro-censuses followed the same procedures and questionnaires as those used in the censuses [190]. The micro-censuses covered all the counties using a three-stage cluster sampling method at township, village, and district level, and are broadly representative of the total population [190]. However, the government only released under-5 mortality data at the national level, which made this primary data source under-explored in under-5 mortality studies. From the information on child deaths collected in the micro-censuses, the IMRs and the U5MRs between 1973 and 2015 have been derived using demographic techniques [10].

Because of the under-reporting of illegal births, collecting accurate information on infant and under-5 mortality through censuses and micro-censuses is challenging. The numbers of births and child deaths as reported by the censuses and micro-censuses have often been adjusted upward based on underreporting assumptions before they were used to calculate mortality rates. Many authors have compared the underreporting rates of infant and under-5 mortality between various data sources and found that except the 1982 census, the direct (vs modelled) estimates of infant and under-5 mortality released from all the censuses were underestimated and need to be adjusted for underreporting[191, 192]. Using the 1990 census data and comparing the underreporting of death rates by age, authors found that the underreporting of the IMR is more severe than that of the U5MR[191, 192]. Comparing census data with data from the annual survey of infant and under-5 mortality designed by the Ministry of Health in 1991, 1995 and 2000 (see below), Banister et al estimated that only 61%, 87% and 77% of infant deaths were recorded in the 1990 census, 1995 micro-census and 2000 census respectively [193]. After comparing data from the censuses (1982, 1990, 2000), fertility surveys (1982, 1988), and disease and mortality surveillance systems (1990-2000), Banister and Hill concluded that the levels of under-5 mortality estimated from the 1990 census, the 1995 micro-census and the 2000 census appear unrealistically low and mutually inconsistent [189].

Retrospective surveys

The civil unrest caused by the Cultural Revolution (1966-1976) posed challenges to collecting reliable estimates on infant and under-5 mortality. The most useful source of infant and under-5 mortality data in the 1970s was a nationwide retrospective mortality survey (also called the 1973-75 Cancer Epidemiology Survey or the National Mortality Survey), which was conducted in 2392 counties across Chinese mainland by the Ministry of Health, attempting to record all deaths in the sampled households and causes of deaths by age and sex during the period 1973-1975 [194]. Data on the deceased were collected through a retrospective enquiry of all sampled households by a team of doctors [195]. The quality of the survey results is relatively high and has been regarded as a reliable death data source [195]. The survey provides age-specific mortality rates from 1973 to 1975, but I was not able to access the primary data. The method of estimating the IMR or the U5MR based on the survey is unclear from the literature nor is the source for the number of births.

The State Family Planning Commission (after 2003 named National Population and Family Planning commission) and the National Statistics Bureau have conducted a number of fertility surveys (1982, 1985, 1988, 1992, 1997, 2001) [15, 189]. The fertility surveys retrospectively collect the complete reproductive history of women of childbearing age, including questions about children ever born and children surviving.

The 1982 and 1988 fertility surveys sampled one and two million people respectively while the later surveys had much smaller sample sizes [188]. The data collected in the 1982 and 1988 fertility surveys are considered to be of high quality and have been used to derive estimates of the IMR and the U5MR for 1940-1982 and 1950-1988 periods[15, 196, 197]. Estimates of national IMR and U5MR are derived from the probabilities of dying of children ever born using demographic models [189]. The quality of the 1992 survey is low with substantial undercounting of births in comparison with census data [188]. But the 2001 survey was of high quality and has been used for in-depth analysis of child survival for 1989-2001[198]. The 2001 survey used stratified multistage cluster sampling, collecting information on demographics, complete pregnancy history, children’s death and age at death in each sampled household. A community survey was also conducted to collect information on the community-level socio-demographic characteristics of infant deaths from each village head in the rural area[198].

National surveillance and report system

After 1990, the most commonly used data sources for the IMR and the U5MR were the National Maternal and Child Health Surveillance System (MCHSS) and the national Annual Report System on Maternal and Child Health (hereafter referred to as Annual Report System). In order to get more complete reporting of child deaths, the Ministry of Health in concert with the United Nations Children's Fund (UNICEF) designed a mortality surveillance system, the MCHSS, to record the IMR, U5MR and maternal mortality ratio for China and its regions [189]. Based on a multistage, stratified, clustered sampling design, the MCHSS routinely collects data on the number of births and the levels and causes of infant and under-5 mortality at the national level from 1991 [21, 199]. In 2013 the MCHSS came to its current structure, covering a population of 47.1 million representative of the national population [2]. Maternal and child health workers at each surveillance site (urban district or rural county) are responsible for filling death cards when receiving notifications of infant or child deaths [187]. The information is compiled by each surveillance site and reported to higher-level (city, prefecture, and province) maternal and child health centres on a quarterly basis [21]. The number of live births each year are recorded for each county in the MCHSS [21]. Active searches are done to identify unreported cases and assess the possibility of underreporting [187]. To improve the completeness and validity of data, the reported livebirths and deaths in the MCHSS are cross-validated through multiple sources, including the Center for Disease Control and Prevention (CDC), local health facilities and public security bureaus[21]. The data are often adjusted because underreporting of deaths may vary by region. The adjustment is done by weighting the data with a 3-year average under-reporting rate for each stratum, i.e., the eastern urban, eastern rural, central urban, central rural, western urban, and western rural area [21, 187]. Since 2000, almost all the provinces (except Tibet) have set up independent surveillance systems at the provincial level, which can provide estimates of the IMR and the U5MR at the provincial level. The national CDC has released some of the yearly estimates of the IMR and the U5MR for each province through annual reports, but these are for internal use only and not accessible to the public.

Evidence has shown that the estimates of the IMR and the U5MR from the MCHSS are not reliable for the early 1990s[189, 191]. Because the surveillance sites in the early 1990s were mostly located in the economically more developed areas, Zhao et al suggested that the national estimation of the IMR and the U5MR was plausibly underreported [191]. In contrast, after comparing the U5MR estimates from multiple data sources, including censuses of 1990 and 2000, the 1973-75 Cancer Epidemiology Survey, the Fertility Survey 1992, the 1987 Micro-census, and the disease Surveillance system, Bannister and Hill noted the high estimates from the MCHSS for the early 1990s and suggested that the national U5MR from the MCHSS was overestimated at that time[189]. The reliability of province-level IMR and U5MR estimates from the MCHSS was much improved in the later 1990s when rigorous quality control measures were introduced[22].

The Annual Report System was established in the 1980s recording births and deaths of mothers and children by place of birth in all counties and districts in China [109]. Community doctors in urban districts and village doctors in rural counties recorded births and deaths in their catchment area, and then reported data to the county-level health department. Reliable data started only from 1997 onwards when rigorous quality control mechanisms were established, including standardisation of data collection, data audits and supervision. [109] Tabulated data on livebirths and number of under-5 deaths were reported to health bureaus at provincial level and then to the national level. The system provides province-level U5MR. However, the government only released highly aggregated data, so they have been restricted to use by government researchers. I am not able to access the province-level data from the Annual Report System, as these data are not publicly available.

International reports of infant and under-5 mortality

To track progress towards the MDGs, the UN Inter-agency Group for Under-5 mortality Estimation (IGME) annually reports national data on infant and under-5 mortality, including those for China. An independent Technical Advisory Group of the UN IGME, composed of demographers and statisticians, developed data quality assessment and estimation methods. There is a country consultation process. Time-series regression models are fitted to all data of acceptable quality from multiple sources to produce time series of infant and under-5 mortality estimates [96]. Data from the household registration system, the surveillance system, the census, the micro-census, and fertility surveys are the sources for UN IGME estimation. The UN IGME data series have been regarded of high quality and widely reanalysed by scholars to show trends in infant and under-5 mortality at national level (no subnational data) from 1969 to the present.

The Institute for Health Metrics and Evaluation provides another source of modelled under-5 mortality data. They have published trends in under-5 mortality from 1990 to 2017 in the Global Burden of Disease (GBD) 2017 study [200]. Data are derived primarily from the Disease Surveillance Point system; censuses and micro-censuses; the Annual Survey on Population Change; Maternal and Child Health Surveillance system; the National Fertility Survey. The GBD study is different to UN IGME with respect to the inclusion and exclusion of data, trend modelling and adjustment procedures, but the method released is not transparent enough to conclude which source is more reliable. Substantial differences in under-5 mortality estimates have been noted between UN IGME and the GBD study[97]. Authors proposed that as more primary data become available and methods become more transparent, the differences are likely to decrease[97].

4.3.3 Data sources on medical causes of deaths

Data on causes of deaths are primarily derived from surveillance systems, including the MCHSS, the Disease Surveillance Point system (started in 1978) and the CDC cause-of-death reporting system (2004) [10]. Although other systems exist, the MCHSS is the official data source for the Ministry of Health [201]. The MCHSS records high quality data on causes of death from a representative sample of communities and is regarded as the highest quality data source [202]. Causes of death are determined from death certificates in the case of children who died in hospital, from hospital-reported medical diagnoses in the case of children who used healthcare before death, or from verbal autopsies in the case where no medical record is available [21]. Verbal autopsies on infant deaths were reported more likely to meet the diagnostic gold standard compared with under-5 deaths[201].

The Disease Surveillance Point system is a sample-based mortality surveillance system based on surveillance sites using a multi-stage stratified cluster sampling strategy, ensuring a nationally and regionally representative sample [203, 204]. Since 2001, each surveillance site was expanded to the whole county or district [194].

Causes of death are determined in the same manner as done in the MCHSS [194]. Death certificates from the surveillance sites are validated and checked by local CDCs and then reported to the national CDC [204]. Underreporting of deaths is a challenge for the Disease Surveillance Point system, and particularly for children aged under 5, which is partly due to population migration and partly due to the poor quality of death reports [205]. In order to assess the quality of the reporting data, every 3 years a survey is done to evaluate the underreporting by sampling five percent of the surveillance population and collecting death information from household inquiries. The surveys have shown good reliability of the Disease Surveillance Point System [194]. Data from the Disease Surveillance Point system have been extensively used to examine the national and regional burden of diseases [204].

The cause-of-death reporting system is another data source for causes of deaths, combining community registration at provincial and county level and in-hospital cause-of-death reporting. The collection of data on cause-specific mortality in the registration system is similar to the Disease Surveillance Point system [204]. Besides nearly all hospitals in China report information on causes of death to China CDC [203]. Since 2008, coverage and completeness of recording has increased substantially for the cause-of-death reporting system. In 2016, the system covered more than 80% of the deaths nationally [206].

4.3.4 National trends in infant and under-5 mortality in China between 1950 and 2019

Infant mortality rate

Using the multiple data sources described above, Figure 4.2 presents levels and trends in infant mortality between 1950 and 2019 (Figure 4.2). I used the household registration data for 1991-2018, census data for 1954, 1963, 1981, 1990, 2000 and 2010, micro-census (1987, 1995, 2005, 2015) data for 1973-2014 (inferred through the use of synthetic cohort concepts), Cancer Epidemiology Survey data for 1974, the UN IGME estimates between 1969 and 2019, 1982 fertility survey data for 1970-1980 (inferred through the use of synthetic cohort concepts), 1988 fertility survey data for 1950-1987, and the 1992 fertility survey for 1992. Where available, multiple sources of data are reported for the same year.

The Health Statistics Yearbook 2020 reported a level of infant mortality of 200 deaths per 1,000 live births before 1949, but they did not state the data source [25]. Based on the 1953 census, the IMR was 138.5 deaths per 1,000 live births in 1953, which was included in the UN IGME database. The Great Leap Forward (a campaign to divert people from agricultural work to industries) and the following famine (1959-1961) impacted all regions of China [25]. The literature suggests a temporary reversal of death rates of all ages in the famine times, returning to previous levels by 1962 [207]. Based upon the 1988 National Survey of Fertility, authors estimated that the IMR during the famine period increased to 135 deaths per 1,000 live births during 1958-1959, equivalent to the mortality levels in the early 1950s [15]. Existing evidence has shown that the IMR continued to decline during the Cultural Revolution (1966-1976) [189]. Analysis of the 1973-75 Cancer Epidemiology Survey revealed that the IMR during 1973-75 was 47.0 deaths per 1,000 live births[25]. The 1982 census collected information about deaths and live births in the preceding year 1981, estimating the level of infant mortality at around 34.7 deaths per 1,000 live births. According to the official statistics based on the MCHSS, the IMR at the national level declined from 32.2 deaths per 1,000 live births in 1991 to 5.6 deaths per 1,000 live births in 2019[25, 208].

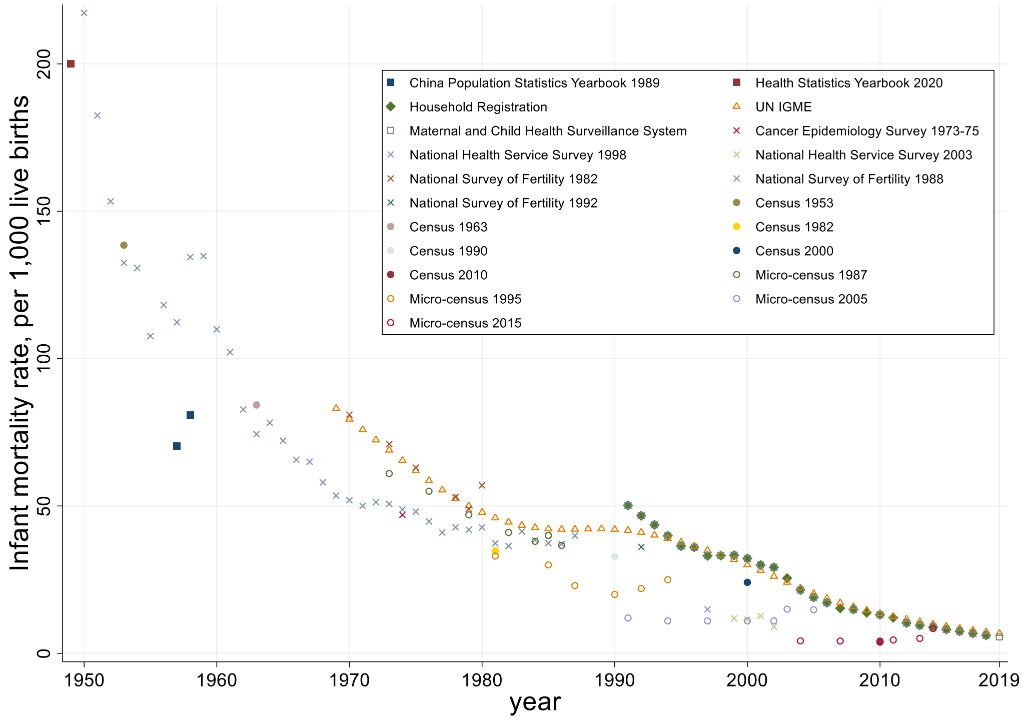


Figure 4.2: National estimates of the IMR from multiple sources

Under-5 mortality rate

Figure 4.3 shows the available estimates of under-5 mortality between 1950 and 2019. I used household registration data for 1991-2018, census data for 1981, 2000 and 2010, micro-census (1987, 1995, 2005, 2015) data for 1973-2014 (inferred through the use of synthetic cohort concepts), the UN IGME estimates for 1969-2019, 1982 fertility survey data for 1970-1980, 1988 fertility survey data for 1950-1987, 1992 fertility survey for 1992, and the GBD 2017 study for 1990-2017.

The U5MR declined from 308.5 deaths per 1,000 live births in 1950 to 57.5 deaths per 1,000 live births in 1980 based on fertility history data collected in the 1988 fertility survey [209]. During the famine period, there was an abrupt increase in the U5MR to around 201 deaths per 1,000 births in 1958 based on the 1988 fertility survey, followed by a sharp decline in 1961 to around 144 deaths per 1,000 live birrths [209]. The U5MR was estimated to be about 70 in 1981 based on the 1982 census, which was reasonably consistent with the estimate from the 1982 fertility survey [189]. According to the official statistics based on the MCHSS, the U5MR at the national level declined from 48.3 deaths per 1,000 live births in 1991 to 7.8 deaths per 1,000 live births in 2019 [25, 208]. According to the GBD study, the U5MR declined from 50 deaths per 1,000 live births in 1990 to 12 deaths per 1,000 live births in 2017, very similar to the data trends from the MCHSS [200].

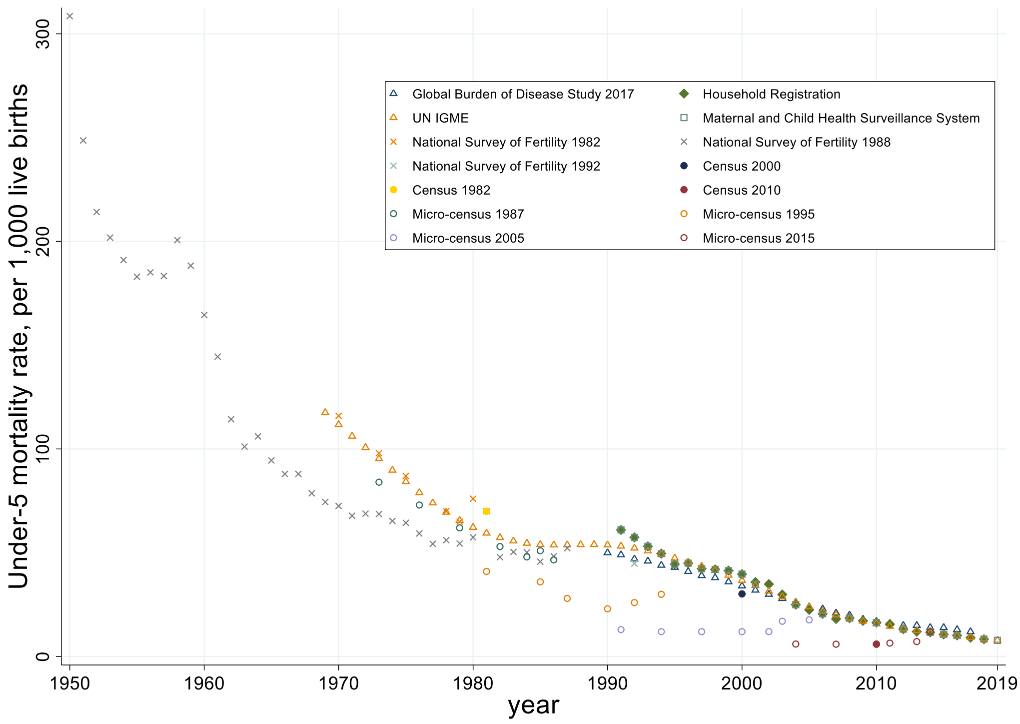


Figure 4.3: National estimates of the U5MR from multiple sources

4.3.5 Medical causes of infant and child deaths

Leading causes of death in infants and children have changed since 1950. Before 1990, there were few quantitative estimates of the causes of deaths for infants and children. Before 1960 the leading cause of death for infants was tetanus, which may have been caused by unsafe delivery modes [18]. Communicable diseases, such as pneumonia, tuberculosis, and diarrhoea were the major threat to children’s health in the 1950s [18, 210]. Using data from the Fertility Survey in 1985, Ren et al found that between 1949 and 1959, 35% of under-5 child deaths occurred during the neonatal period [211]. In contrast, the data between 1980-85 showed that 65% of under-5 child deaths occurred in the neonatal period, indicating that the burden of diseases from the post-neonatal and early childhood period is declining[211].

Since 1990, there has been a proliferation of analyses on causes of infant and child deaths. Using data from the Disease Surveillance Point system, Ming found that infant deaths from all causes dropped dramatically between 1990 and 2000, except from intrapartum-related events and sudden infant death syndrome[212]. As discussed in the data sources, the surveillance data from MCHSS are susceptible to under reporting. To account for such possible inaccuracy, data on causes of under-5 mortality also needed to be adjusted by age group and the sampling probabilities of the total population [21]. Based on adjusted empirical data in the MCHSS, He et al compared the leading causes of under-5 child deaths from 1996 to 2015 and found that the cause-of-death composition changed massively. In 1996, the leading causes of under-5 mortality in China were pneumonia (22.6%), injuries (17.9%), intrapartum-related events (14.0%), preterm birth complications (12.6%) and other conditions (12.6%). In 2015, the leading causes of under-5 mortality became congenital abnormalities (19.5%), preterm birth complications (17.0%), other conditions (16.0%), injuries (14.6%) and intrapartum-related events (14.1%) [21]. Major communicable diseases, such as diarrhoea and measles had declined in significance, while congenital abnormalities became increasingly important[21, 98, 213]. The authors also compared cause-of-death composition across age groups and found that the contribution of injuries to deaths in children aged under five increased after infancy and became the leading cause of death for children aged between 1-4 (47.5%, 95% CI: 45.1-50.2%) in 2015 [21]. Based upon a systematic review of 205 longitudinal community-based peer-reviewed studies from multiple databases, Rudan et al., estimated that pneumonia (16.5%), birth asphyxia (16.4%), preterm birth complications (15.2%), congenital diseases (10.8%) and accidents (10.1%) were the leading causes of deaths in children aged under five in 2008, indicating decreased significance of communicable diseases [214].

4.3.6 Determinants of infant and child mortality at the ecological level

Geographical variation of infant and child mortality

Geographic variation of the IMR and the U5MR has been well documented in the last seven decades. Great inequality persists in the IMR and the U5MR across regions, provinces, counties, and in urban versus rural areas [13]. Abundant evidence has shown large disparities in the IMR/U5MR between different regions[186, 215, 216]. Take the U5MR for example. In 1991, the U5MR in the western region was 100 deaths per 1,000 live birth, 3.0 and 1.5 times that of the eastern and central regions[186]. In 2006, the rate ratio became 3.7 and 2.1 respectively [216]. Inequality at the province and county levels is also well established. Using the 1985 National Fertility Survey, Shen et al compared the IMR for three provinces (Hebei, Shaanxi, Shanghai) and found that between 1965 and 1979, Shanghai (from the eastern region) had consistently the lowest IMR while Shaanxi (western region) had the highest[217]. In 2008, the U5MR ranged from five per 1,000 live births in Shanghai to more than 38 deaths per 1,000 live births in Sichuan and Guizhou—eight times higher [214]. Similarly, the U5MR between counties in 2012 ranged from 3.3 per 1000 livebirths in the Huangpu, Shanghai to 104.4 deaths per 1000 livebirths in Zamtang, Sichuan [13]. According to the latest official statistics from the MCHSS, the IMR and the U5MR in rural areas were 1.9 and 2.3 times higher than the rates in urban areas in 2019 [25]. A study showed that the IMR was approximately five times higher in China’s poorest rural areas compared to the richest areas during 1996-2004 [208]. Similarly, by classifying administrative units into two urban and four rural types based on socioeconomic circumstances, authors found that children born in poor rural areas had three to six times risks of dying under five years old than those born in better-off rural areas or in urban areas during 2000-04 [214]. Most studies did not report statistical tests, but this is not a major cause of concern because the numbers of live births are large.

Socio-economic determinants

Ecological research suggests a number of determinants that may explain geographical variation in infant and under-5 mortality. Economic status and educational attainment were consistently associated with low infant mortality in ecological analyses and are generally accepted as determinants [211]. Using data at province level from 1990 to 2006, Feng et al ran mixed-effects regression models to estimate the association between distal social determinants and the variability of the U5MR across provinces. By comparing the regression coefficients and the R^2 resulting from the regression models, they showed that the crude birth rate, maternal education, the proportion of minority population, household crowding, and the percentage of household coverage with clean water and sanitation were persistently associated with the U5MR when different time lags, from zero to three years, were applied in the adjusted models [22]. Based on data from the 2000 census in Yunnan, Li et al found that after adjusting for total population and fertility rates, the gross domestic product (GDP), the proportion of the total population that was illiterate (defined as knowing 300 or fewer characters), the proportion of women who had antenatal examination, immunisation against tetanus, and hospital delivery were significant predictors of the IMR and the U5MR[218]. The authors also examined the levels of infant and under-5 mortality at the prefecture level and found that the rate ratio was 1.5 for both the IMR and the U5MR comparing the autonomous prefectures (prefectures with large ethnic minority populations, designated as autonomous) to the non-autonomous prefectures (Han ethnicity people as the majority) [218]. Disparities remained between minority and non-minority areas, which have been consistently found in other studies including a systematic review[219, 220].

Health worker density as determinant of infant or child mortality

Investments in health systems are important determinants of infant and under-5 mortality[56]. As the prerequisite for healthcare, the availability of health workers (usually measured as density of health workers as defined in the chapter 2) has been examined for its effect on infant or under-5 mortality. Other investments in health systems, such as hospital bed density, have not been examined as primary exposures in the statistical analyses[15, 72, 221, 222].

Ecological studies have shown that populations with a higher density of doctors have lower infant and under-5 mortality[72, 221, 222]. Most of the studies were done using county-level data. Based on county-level data from the 2000 census, Anand et al regressed infant mortality in 2000 separately against density of health professionals (census data using occupation classification), and density of healthcare workers (data from Ministry of Health, excluding private-sector health workers), while controlling for the female adult illiteracy rate, the land size of the county, the proportion of households with extreme low income (less than 10,000 yuan per year), and the proportion of households with improved water and cooking fuel[72]. All dependent and independent variables were log transformed. The authors only reported the adjusted effect of health worker density on infant mortality, which showed that there was strong statistical evidence that both measures of health worker density statistically explained variation of infant mortality between counties ($p<0.001$). A 1% increase in health professionals density was associated with a 0.13% (95% CI or standard error not reported) decrease in the IMR, while a 1% increase in healthcare worker density was associated with a 0.10% decrease in the IMR. The results of the separate regressions corroborated the importance of health worker density in explaining infant mortality, regardless of the choice of the variables of health worker density.

The effect of health worker density on the IMR and the U5MR has been found in both rural and urban areas. Using cross-sectional data from 114 counties collected through a multi-stage sampling survey of five remote and poverty-stricken provinces (including Jilin, Xinjiang, Guizhou, Hunan and Hainan) during 1998-1999, Guo et al found that doctor density, hospital bed density and the proportion of MCH workers having associate or higher education jointly explains 21% of variations in infant mortality between counties in the adjusted model[221]. The confounders in the model included GDP per capita, health expenditure, population density to maternal health service utilization during antenatal, delivery and postpartum [221]. One study based on a 3-year panel data from all urban districts in Guangdong province also found that the density of doctors working in district-level hospitals was negatively associated with the levels of the IMR and the U5MR, although statistically insignificant after controlling for the utilization rate of primary care services by people, which might be on the causal pathway [223]. But the choice of the covariates was not justified.

There is some evidence of an interaction between health worker density and the level of socio-economic development when analysing the effect of health worker density on under-5 mortality. A panel data analysis conducted by Liang et al showed that health worker density was negatively associated with the U5MR in rural counties from 2008 to 2014 after adjusting for GDP per capita, female illiteracy rate, health expenditure as a proportion of government expenditure and value of medical equipment per hospital bed[222]. Liang et al also found a modification effect of the economic status (grouped GDP per capita) on the effect of health worker density on the U5MR – one extra unit increase in health worker density was associated with a 6.8% decline in poor counties but only a 1.1% decline in non-poor counties[222].

Evidence on the effect of health worker density on infant or child mortality in China has not been fully conclusive. Using aggregated mortality data from the 1982 census, the 1990 census, the 1995 micro-census and socio-economic data from statistics reports, Banister and Zhang analysed the determinants of under-5 mortality (ages 1-4) across provinces. By comparing the variance explained (R^2) from different sets of regression models, Banister and Zhang concluded that doctor density and the illiteracy rate among adults aged 15 and above were the most important determinants of child mortality across provinces during 1981-1995, after adjusting for region, rural-urban inequality, share of education and healthcare expenditure, GDP per capita and year[193]. However, using province-level data between 1950 and 1980, Babiarz et al found no significant association between doctor density and infant/under-5 mortality after controlling for primary and secondary education enrolment rate, public health campaigns (principal component indices), hospital bed density, GDP, population size, crude birth rate, per cent of urban population, proportion of employed population, proportion of male population, proportion of population aged over 60, retail price index, province (as categorical variable) and year. To explain the lack of evidence of the effect, the authors tested a hypothesis of the existence of reverse causality (i.e. whether changes in the outcomes affected the explanatory variables) and they found evidence showing that increases in doctor density in some provinces were preceded by high infant or under-5 mortality rates, which was aligned with Chairman Mao’s policy emphasis on addressing perceived development imbalance between provinces and posting more doctors in disadvantaged areas [15]. However, the model for the reverse causality had more than 40 parameters, so estimates may have been unstable.

4.3.7 Individual-level analysis of infant and child mortality

Only three studies have assessed the individual-level determinants that are associated with infant or child mortality in China [198, 211, 224]. Using data from the 2001 National Survey of Fertility, Song et al used multiple logistic regression to examine the association between infant mortality and characteristics of the household (urban/rural residence, ethnicity), the child (sex of the infant) and the mother (length of education, maternal age at childbirth, parity, previous adverse pregnancy outcome, prenatal care and professional delivery assistance) [224]. The authors did not report univariable results but they found that, after adjusting for urban residence, ethnicity, sex of the child, maternal age, parity, and birth cohort (1971-1980, 1986-1990, 1991-1995, 1996-2001), each one-year increase in maternal education was associated with decreased odds of infant deaths (OR=0.93, 95% CI: 0.92-0.94) between 1970 to 2001. However, the choice of the covariates was not justified. After adding prenatal care and delivery assistance into the adjusted model, the association between maternal education and infant survival disappeared, suggesting that the association between maternal education and infant survival was largely because mothers with higher education were more actively seeking professional care [224].

Another study provides contradictory findings based on the same survey. Chen et al found differentials in the IMR by maternal education (categorized as no education, primary education, secondary education), income and parity in rural China between 1989 and 2000 [198]. The authors did not report crude effects, but adjusted models showed that compared to mothers with no education, mothers having secondary or higher education had decreased odds of infant deaths (OR=0.63, 95% CI: 0.43-0.93), after adjusting for maternal age, ethnicity, paternal education, parity, prenatal care and skilled assistance at birth. The adjusted model also showed that ethnic minorities have an increased odds of infant deaths (OR=1.63, 95% CI: 1.15-2.32), and prenatal care is associated with decreased odds of infant deaths as well (OR=0.68, 95% CI: 0.51-0.90).

There is also individual-level evidence on the potential consequences of health care access and utilization on infant and under-5 mortality. Using birth history data from two waves (1998, 2003) of National Health Service Surveys, Luo et al found that living far from a health clinic (more than one mile) and household health expenditure were significantly associated with infant deaths using chi-square tests[225]. But in their multivariable analysis, the geographic accessibility to healthcare did not retain statistical significance. The effect of household health expenditure on infant deaths persisted after adjusting for the sex of the infant, type of drinking water, maternal education (categorical from no education to high school graduates or above) and maternal ethnicity[225]. Using raw data from the 2006 China Agricultural Census (a rarely used data source), Chen et al found that New Cooperative Medical System-insured households on average have lower under-5 mortality than do uninsured households[226]. After controlling for the propensity score (construction method unclear), the authors compared the two groups − the insured and non-insured households, finding that the effect of access to insurance on under-5 deaths disappeared. Using data from a household survey of minority populations from Yunnan province and by conducting multiple logistic regression analysis, Foggin et al found that use of a health facility in the past two weeks was negatively associated with under-5 deaths, after controlling for family income, family history of tuberculosis, age at weaning, religious belief, social supporting network and geographic mobility[227]. The same conclusion was also reached in another study conducted in Guizhou province[228]. In addition, there is also evidence showing that the location of delivery and the kinds of birth attendants were associated with the level of infant mortality, but confounders have not been adequately adjusted for[228].

4.3.8 Determinants of the decline in infant and child mortality

A dearth of studies have quantitatively assessed the contribution of determinants to mortality declines in different eras of development[15, 229]. Based on a province-level dataset from 1950 to 1980 and by using ordinary least squares regressions, Babiarz and colleagues examined the contribution of the primary and secondary education enrolment rate (%) improvement during the period 1950-1959 to the 10-year lagged infant and under-5 mortality declines between 1960 and 1980 after controlling for other medical and non-medical determinants of health, such as total population, GDP and public health interventions. By estimating the mortality levels in the counterfactual scenario in which education enrolment rates had stayed at their 1950 levels, the authors estimated that the education enrolment gains during 1950-1959 were associated with 70% of infant mortality decline and 55% of under-5 mortality decline between 1960 and 1980 [15]. Based on under-5 mortality data at national level from the 1995 micro-census and a child survey on malnutrition (Statistical Bureau) in 1992, Ross et al estimated the population attributable risk of under-5 mortality related to malnutrition, which was 30% in 1992 and 22% in 2001[229]. By modelling the scenario assuming no improvement in nutrition between 1992 and 2001, the authors found that the reduction in the proportion of under-5 children who were underweight contributed to 10% of the reduction in U5MR during the same period[229].

4.4 Discussion

In this scoping review, I provided a detailed assessment of the levels of infant and child mortality in China over a 70-year period. Despite the data gaps and limitations, there is evidence of a continuous decline in both the IMR and the U5MR in the past seven decades, with the only exception during the Great Leap Forward famine (1959-1961) when mortality increased. From 1949 to 2019, the IMR declined by about 97%, from 200 per 1000 live births in 1949 to 5.6 per 1000 live births in 2019. The U5MR declined from 308 deaths per 1000 live births in 1950 to 7.8 deaths per 1000 live births in 2019, which also equates to a 97% decline. Behind the remarkable progress, geographic variation of infant and under-5 mortality persisted across generations, across regions, provinces and between urban and rural areas. During the studied period, existing evidence showed that the relative burden of injuries and non-communicable diseases grew while the burden of communicable diseases declined, causing shifts in causes of death. There was contradictory evidence about the importance of health worker density for infant and child survival. What drives the declines in infant and under-5 mortality remains unclear in the literature.

Many efforts have been made to ascertain the levels of infant and child mortality[13, 15, 199]. The task of estimating levels and trends in infant and child mortality is particularly challenging before 1990 because data was not routinely available. Estimates of the IMR and the U5MR are generally inferred from special surveys, notably the National Survey of Fertility, and are therefore affected by known biases and errors[96]. There is reasonable progress in data availability after 1990[199, 212]. Comprehensive surveillance and death report systems are able to generate timely and reliable estimates of infant and under-5 mortality routinely. International monitoring of infant and child mortality based on modelling are also important sources of data, but knowledge about their quality is scarce because of the lack of transparency in data inclusion and adjustment. Reliable empirical measurement of infant and child mortality is still central to the general improvement of data quality, which requires overcoming obstacles (e.g., underreporting for livebirths and child deaths) in data collection. As the MCHSS and the Annual Report System become the main sources for the IMR and the U5MR in current days, the data quality control measures and the cross-validation of data from different sources will potentially lead to higher data validity.

The results show both infant and under-5 mortality declined rapidly in China between 1949 and 1990. An early attempt at measuring country performance in improving health dates back to the "Good health at low cost" study published in 1985 [12]. In this study, China was cited as one of the exemplar countries in reducing child mortality levels (particularly infant mortality levels) from the early 1950s to the early 1980s. That time has been described as a watershed period for health with impressive infant mortality reductions [24]. However, after the impressive mortality reductions in this period, China's impressive gains in lowering infant mortality levels halted for a decade from 1985 to the late 1990s, stabilizing at a rate of approximately 40 deaths per 1,000 live births[24]. Results from this scoping review show that at the start of the MDG in 1990, the levels of infant and under-5 mortality were around 30 and 50 deaths per 1,000 live births. From 1990 to 2019, the decline in both infant and under-5 mortality has been modest. Few studies have compared the speed of decline for the IMR and the CMR1-4 by province in different periods when contextual and health systems factors changed dramatically.

In the industrialised countries the decline in child mortality was apparent at the end of 19th century, while that in developing countries occurred during the second half of 20th century [12]. In 1955-1959, the global range of the 5-year estimates of the U5MR was between 381 per 1,000 live births in Sierra Leon and 21 per 1,000 live births in Sweden[12]. Over the same period, the corresponding rate in China was 225 per 1,000 live births, which was higher than the global mean 180 per 1,000 live births. In 1965-1969, China reached the global mean of the U5MR, around 140 per 1,000 live births and continued to be lower than the global mean thereafter[12].

Very little is known about the medical causes of infant and child deaths in China before 1990 when data is rare. After 1990, existing evidence showed that the relative burden of non-communicable diseases grew while infectious causes of deaths declined, which aligns with global trends. Globally, recent patterns of child deaths are shifting away from infectious causes towards non-communicable diseases and injuries[98, 230]. In 2000-2010, the infectious causes of under-5 deaths worldwide decreased more rapidly than did non-communicable causes, with causes by pneumonia, diarrhoea and measles decreasing the most[230]. The escalating toll of non-communicable diseases highlights the need to collect reliable data on cause-specific mortality and to measure how the burden of disease is changing, for which longitudinal data is particularly in need.

Evidence from individual-level studies shows that infants and children of mothers with relatively low education level, being ethnic minority, being migrant, and those who are residing in remote and rural areas were more likely to die than their counterparts. Infants and children from the under-privileged population groups are often those who are invisible from the health information systems[231]. For example, the health of left-behind children (referring to children who live with neither parent) has increasingly become a policy concern. According to the census, it is estimated that the total number of left-behind children is about 61 million in 2010. But it is difficult to identify the true left-behind children using the current information systems, which makes this subgroup of children invisible and impedes specific intervention at the individual level[232].

The persisting geographic variation of the IMR and U5MR through decades indicates that much remains to be done to reduce inequality. Most reviewed studies have used province-level or county-level data to study geographic variation, and the most consistent finding has been the association between level of socio-economic development and infant/under-5 mortality[15, 22, 211]. Inequalities in child survival have been well documented globally. Children who are poor are more likely than their richer peers to be exposed to many disease risks and less likely to receive either preventive interventions or treatments for the most common diseases[233]. In 2000, more than 99% of under-5 deaths occurred in poor settings[12].

The need to reduce socio-economic inequalities of infant and under-5 mortality has been repeatedly noted, yet it is challenged by the increasing inequality in the social determinants of health in recent decades[234]. The ecological studies yield multiple social determinants that can explain geographic variation, including GDP per capita, increased educational length, health worker density, hospital bed density, public health interventions, decreased fertility rates, rural or urban residence, and availability of public services (including transportation and tele-communication) [15, 72]. Existing evidence constitute sufficient grounds to call for equity lens in reducing child mortality. The strategies to reduce child deaths consist of specific healthcare interventions, such as delivery care and vaccination, but also multisectoral efforts outside the health system, including education, transportation and environment.

The variable association between health worker density and child mortality raises interesting questions about the role of health workers in reducing infant and child mortality. From the health system perspective, it has been proposed that to further reduce neonatal and infant mortality, increasing the accessibility and utilization of key interventions (such as skilled care for child birth, neonatal resuscitation, initiation of kangaroo mother care for low birth weight infants) is the key [86]. The demand to set national infant and child health priorities is rapidly gaining importance in the quest for evidence about the health gains through health intervention programs or investment in health workforce. The magnitude of the increase in health worker density needed to make these gains and the relative importance of different cadres of health workers remains unexplored.

It is not surprising that China’s socio-economic development over the past seven decades has been accompanied by a decrease in infant and under-5 mortality. It is reasonable to assume that economic growth contributes substantially to the decline of infant and under-5 mortality[211, 218]. But evidence is rare about how much contribution economic growth contributes to the decline of infant and under-5 mortality over the studied period and how the contribution varies by time. Besides economic growth, China experienced many social and health system changes over the last seventy years: eradicating extreme poverty and hunger, reducing fertility rates, achieving universal primary education, building roads and reducing large infrastructure gaps, health system reforms in 2003 and 2009[69, 234-236]. Little is known regarding the relative contributions of general economic growth, investments in health systems and social changes to the decline of infant and under-5 mortality during the study period. In tracking progress, most studies measured infant and under-5 mortality without linking these to determinants that contribute to mortality reductions[13, 198, 225]. The lack of longitudinal data for provinces or counties has restricted the studies to examining the contextual changes and infant/under-5 mortality decline.

The scoping review had several strengths. First, the comprehensive search of peer-reviewed articles and grey literature have allowed me to present the longitudinal trends in infant and under-5 mortality for a very long period of time. Second, I provided each data source with one or multiple references to inform the quality of data about infant or under-5 mortality, in the hope that the data quality information can help improve understanding of the conflicting estimates. Third, the findings provide a great opportunity for the research community to look into what determinants have been shown to be associated with the mortality levels or the declines and consider what might be worth further exploring to maintain progress in reducing infant and child mortality.

This review has several limitations. First, since I only searched databases and grey literature from online, relevant documents with only printed versions may have been missed. Second, due to the large number of data sources on infant and under-5 mortality identified, it was beyond the scope of the review to validate which data source provides the closest estimates to the true but unknown mortality rates. A more comprehensive assessment of the data quality can certainly guide data selection for future longitudinal studies. Third, the categorization of the determinants of the levels and the declines of infant and under-5 mortality is arbitrary. Determinants could have been categorized into different domains.

The scoping review could be used by both researchers and policy makers, to inform their selection of data for longitudinal analysis of infant and under-5 mortality in China. A review of the data sources suggested that strengthening of national capacities in health statistics need to be continuously funded and supported by the government authorities. The review also highlights the research agenda on infant and under-5 mortality decline.

4.5 Conclusion

Infant and under-5 mortality kept declining between 1949 and 2019, except during the Great Leap Forward famine (1959-1961). Few studies have compared the speed of decline for the IMR and the CMR1-4 by province throughout the study period. Geographic variation in infant and under-5 mortality has been well documented between regions, provinces, counties, and between urban and rural areas over the studied period, which is closely related to socioeconomic circumstances. New and effective policies are needed to take into account inequalities. Evidence on the effect of health worker density on infant or child mortality in China has not been fully conclusive. Determinants of infant and child mortality decline in China represent an important area for research.

Chapter 5. Analysis of child mortality by province in 1950-2017: levels, trends and speed of decline

Chapter 5 addresses the third objective of the thesis, by analysing a province-level dataset in 1950-2017.

In this chapter, I begin by introducing an existing dataset (1950-1980) which was constructed by researchers from Stanford University. The update of the dataset to a more recent year (2017) is carried out in two steps: first I validated the data in the original dataset by comparing the data to the original sources; then I updated all the variables in the original dataset to 2017 following the same sources of data.

Based on the updated dataset (1950-2017), I examine the speed of decline in the infant and child mortality across 27 provinces between 1950 and 2017. I developed a socio-demographic index, a composite measure of general domestic income, primary and secondary education enrolment ratio, and per cent of urban population, to examine variation in the speed of child mortality declines by levels of development.

5.1 Introduction

Despite the massive declines in infant and child mortality, a comprehensive assessment of the speed of child mortality decline in different time periods is not available. During the past seven decades, China has seen unprecedented economic growth, education expansion and rapid urbanization, which have raised concerns over increasing inequalities in child survival. In this chapter, a province-level longitudinal dataset provides a unique opportunity to comprehensively assess the levels, trends and speed of decline of child mortality across provinces over time.

5.2 Objectives

The overall objective of this chapter is to examine levels and trends in the IMR, CMR1-4 and U5MR across 27 provinces in China between 1950 and 2017.

Specific objectives are to:

(1) Update an existing province-level dataset on China’s infant and child mortality and socio-economic and health systems determinants in 1950-1980 to a longer period of time 1950-2017.

(2) Describe the levels of infant and child mortality and the health systems and socio-demographic status over time and across 27 provinces in China between 1950 and 2017.

(3) Quantify the speed of decline in the IMR, CMR1-4 and U5MR across all provinces between 1950 and 2017 by:

   a. Pooling all provinces and examining the five-yearly speed of decline across provinces.

   b. Examining whether the five-yearly speed of decline varies by province and estimating the speed of decline for typical provinces based on the starting levels of mortality in 1950.

   c. Grouping the 27 provinces into four groups based on socio-demographic characteristics in 1952 and examining the five-yearly speed of decline by socio-demographic development of provinces.

5.3 Methods

5.3.1 Data for the period 1950-1980

Data sources

The initial dataset, covering the period 1950-1980, was created by Babiarz and colleagues from the Centre for Health Policy at Stanford University [15]. The dataset contains information on infant and child mortality and non-medical determinants for 27 provinces over 30 years. Babiarz et al. combined data from three sources.

First, the 1988 fertility survey is among the largest ever conducted in China, containing provincially representative data from 459,000 ever-married women aged between 15 and 57 across all 30 provinces of Chinese mainland [237]. Using fertility history data collected in the survey, Babiarz and colleagues employed cohort life table methods to construct annual IMR and U5MR for each province between 1950 and 1980.

Second, China’s official provincial yearbooks and the “China Statistical Data Compilation, 1949–2003”, assembled by the National Bureau of Statistics, provide annual provincial data for a large number of demographic and socio-economic variables since 1949 (or earliest available year). The *Laonian Renkou Ditu Ji* was issued in 1986 providing data on the age structure of the population in each province which were interpolated from three censuses: 1953, 1964 and 1982.

Third, the provincial *Weishengzhi* provides information on the introduction of specific public health campaigns in a given year, under the auspices of the provincial bureau of health. Babiarz and colleagues acquired printed versions of the *Weishengzhi* from book dealers and in a few cases directly from the provincial bureaus of health. Electronic versions were uncommon and only available for two provinces, Shandong and Inner Mongolia.

Study population

The study population are all live births between 1950 and 1980 reported by more than 450,000 ever-married women aged 15-57 in 1988 in 27 provinces in Chinses mainland. The 1950-80 dataset includes 22 provinces (Anhui, Fujian, Guangdong, Gansu, Guizhou, Henan, Hubei, Hebei, Hainan, Heilongjiang, Hunan, Jilin, Jiangsu, Jiangxi, Liaoning, Qinghai, Sichuan, Shandong, Shaanxi, Shanxi, Yunnan, Zhejiang) and five autonomous regions (Guangxi, Inner Mongolia, Ningxia, Xinjiang, Tibet) - all are termed provinces throughout this thesis. Beijing, Chongqing, Shanghai, Tianjin, Hong Kong Special Administrative Region, Macao Special Administrative Region and Taiwan province are not included in the data presented here.

The Chinese Government classifies all provinces in Chinese mainland into three regions (Eastern, Central and Western China). This classification was first established in 1986 and was based on the geographical location and level of economic development [238]. In this study, eight provinces were in Eastern China, eight were in Central China and eleven were in Western China (Figure 5.1). According to the 2010 census, the population aged under 1 year in the 27 provinces was 13,197,898, representing 95.7% of the national population of this age in Chinese mainland. The number of children under 5 years in the 27 provinces was 72,025,851, representing 95.36% of the national population of these children in 2010.

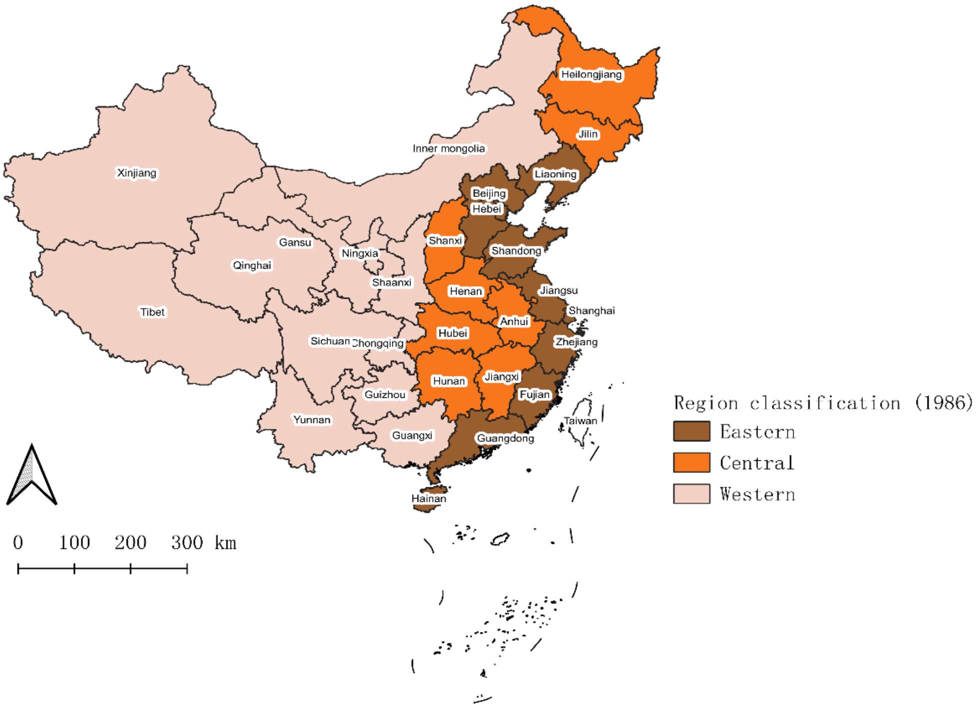


Figure 5.1: Traditional classification of provinces in China (1986).

Note that boundaries changed for several provinces since 1950. The geographic boundaries of Inner Mongolia were reduced and much of Inner Mongolia was distributed to its neighbouring provinces Heilongjiang, Jilin, Liaoning, Gansu, Ningxia in 1969 and then this was reversed in 1979. Tianjin split into its own municipality from Hebei province in 1967. Hainan island was separated from Guangdong province and became a separate province in 1988. Chongqing split into its own municipality from Sichuan province in 1997. The official statistics given by the statistics bureau have been adjusted for these changes in province boundaries so that the named provinces represent the definition of that province in a particular year.

Variable description

Tables C.1-C.9 in Appendix C cover all the variables in the original dataset 1950-1980 and in the updated dataset 1981-2017.

Outcome variables：The outcome variables are the IMR and the U5MR for each province and year. The IMR is defined as the number of infant deaths per 1,000 live births and the U5MR is the number of under-5 deaths per 1,000 live births (Table C.1, Appendix C).

Demographic variables：Demographic variables include the following: total population, per cent of the population over 60 and under 5, per cent of the population who are male, per cent of urban population, crude death rate, crude birth rate (Table C.2, Appendix C). The per cent of the population over 60 and under 5 are extracted from *Laonian Renkou Ditu Ji*. All the other demographic variables are extracted from the official provincial yearbooks and the “China Statistical Data Compilation, 1949–2003”.

Education variables：The dataset has two education variables: the gross enrolment ratio of primary education and the gross enrolment ratio of secondary and higher education (Table C.3, Appendix C). According to the definition given by the UN, gross enrolment ratio is the ratio of the total number enrolled in a primary, secondary or higher education, regardless of age, to the population of the age group that officially corresponds to the level of education[239]. The gross enrolment ratio can exceed 100% due to the enrolment of over-aged and under-aged students. A higher general enrolment ratio means higher degree of participation at a given level of education. The numerators are the numbers of students enrolled in primary, secondary and higher education. Because enrolment in higher education was so low between 1950 and 1980 the authors combined the categories of secondary and higher-education. To generate the denominator of the enrolment ratio, the authors estimated the population aged 6-11 for primary education and 12-18 for secondary and higher education from the 1953, 1964, and 1982 censuses. Because the censuses only provided grouped data for those aged 5–9, 10–14, and 15-19, they assumed that the numbers within each age group were equally distributed across the 5 years. It was unclear how they interpolated the numbers between the census years.

Health system input variables：Doctor density and hospital bed density are defined as the number of doctors and hospital beds for every 10,000 members of the population (Table C.4, Appendix C). The numerator of doctor density is licensed or assistant licensed doctors, referring to medical providers who have obtained the licenses of qualified doctors and are employed in medical treatment, disease prevention or healthcare institutions, excluding the licensed doctors engaged in a management job. Barefoot doctors are not included in the numerator (see Section 2.3.2 for more cadre classification details). The denominator is the number of people based on counts from household registration from the Ministry of Public Security.

Socio-economic development variables：The socio-economic development variables include gross domestic product (GDP), fixed asset investment, general retail price index, local revenue per capita, and agricultural output (Table C.5, Appendix C).

Public health campaign variables：The public health campaign variables are coded according to the brief descriptions provided in the provincial *Weishengzhi*. The authors coded all the public health campaign variables as binary variables. A variable is coded "0" if *Weishengzhi* explicitly states that there was no such intervention in the given year; otherwise it is coded "1". Missing data is also coded "0" as the authors justified that "the provincial yearbooks are not consistent among each other in whether they mention how long specific campaigns continued, and any explicit mention is usually tied to whether any other major public health event took place at that time. Low-intensity campaigns get more attention when little else is going on in that province." Principal component analysis (PCA) is then used to create indices for some major categories of public health interventions. The details of how Babiarz and colleagues applied principal component analysis was not explained but the resulting indices were given in the dataset. The resulting indices measure the following: sanitary campaigns (ranged from -1.2 to 7.4), vaccination (-1.1 to 6.0), mosquito vector control (-1.3 to 8.4), other infectious disease control campaigns (-1.4 to 5.8), and reproductive health (-1.0 to 2.2). See Appendix C for a summary of the variables on sanitary campaigns (Table C.6), vaccination (Table C.7), mosquito vector control and other infectious disease control campaigns (Table C.8), and reproductive health (Table C.9). To measure large-scale nutrition programmes, a single binary variable "malnutrition" is used (Table C.9).

5.3.2 Data update for the period 1981-2017

Data sources

I updated the 1950-80 dataset to the year 2017 based on data availability. I relied on multiple sources.

To obtain the data for infant and under-5 mortality, I bought the "Annual report on maternal and child health" (edition 2012, 2015, 2017) from second-hand bookstores and extracted all the available province-level data on the IMR and the U5MR, which added 11 years of data (2000, 2002, 2004, 2006, 2008, 2010, 2012, 2013, 2014, 2015, 2016). In these reports, it was claimed that the data on infant mortality and under-5 mortality were estimated from the MCHSS. The MCHSS was described in detail in Chapter 4 (see Section 4.3.2). Reliable data started only from the later 1990s when rigorous quality control mechanisms were established, including standardisation of data collection, data audits and supervision[22].

In addition, I reviewed other open sources for infant and under-5 mortality: censuses, health statistics yearbooks and the IHME website [240]. I examined the population censuses of 1982, 1990, 2000, 2010, which report deaths by 5-year age group (0+, 1-4, 5-9, 10-14, …,85+) in the household in the past 12 months. Starting from the 2000 census, provincial estimates on the IMR and the U5MR can be directly calculated. I divided the number of deaths in the age group (0-1 and 0-4) by the number of live births in the same period to estimate the period IMR and U5MR for the year 2000 and 2010. The Health Statistics Yearbook 2011 provided estimates of the IMR by province in 1982 and 1990 derived from censuses (process not mentioned). The 2017 Global Burden of Disease (GBD) study also provides estimates for under-5 mortality at provincial level from 1990 to 2017 [200]. GBD data were derived from various sources including the Disease Surveillance Point system; censuses; surveys (including the Annual Survey on Population Change and the Intercensal Survey); the Maternal and Child Health Surveillance system; and the One-per-thousand Population Fertility Sample Survey. How the GBD group combined the data from the data sources and arrived at the estimates of under-5 mortality is not clear.

To generate the CMR1-4, I followed the formula suggested in the UN IGME report “Levels and Trends of Child mortality” [209].

Given that: ${}_nq_x$ = probability of dying between age x and age x+n,

$${}_5q_0 = 1- (1-{}_1q_0)(1-{}_4q_1),$$

Then: $CMR1\text{-}4 = 1-(1-U5MR)/(1-IMR) = (U5MR-IMR)/(1-IMR)$ [Formula 1]

I searched the data sources that Babiarz and colleagues used for demographic and socio-economic variables. The provincial yearbooks (available at http://www.stats.gov.cn) typically report data from the 1990s onwards while the “China Statistical Data Compilation, 1949-2003” have earlier records. The two sources are issued by the National Bureau of Statistics and provide the same data in overlapping years (1993-2003).

For public health campaign data sources, the *Weishengzhi* used by Babiarz and colleagues was discontinued after 1990s but the volume, “Public health in China: implementation” provides a good alternative. The volume is written by a committee of public health and government officials, summarizing public health projects, programs and policy implementation for the past six decades (1949-2010). This volume aims to “improve the understanding of the changes in population health and the developments in the field of public health” [241]. I also searched yearbook databases in the Chinese National Knowledge Infrastructure (CNKI) database, which is a repository of various types of yearbooks, including health statistics yearbooks, yearbooks on environment, city statistical yearbooks, from different levels of government. Following what Babiaz and colleagues did in the 1950-1980 dataset, I used PCA techniques to create a single index—PCA scores for public health campaigns.

Study population

All relevant variables are estimated at the provincial level. The 1981-2017 dataset includes the same 27 provinces as the 1950-80 dataset.

Variable description

I updated all the variables that were in the 1950-80 dataset. In addition, I also added other variables such as the natural growth rate, health professional density and length of railways in operation (see newly added variables with * in Table C.2, Table C.4 and all the variables in tables C.10, C.11, Appendix C)

Outcome variables：For infant mortality, I extracted data primarily from the “Annual report on maternal and child health”, which provided data for 11 years (2000, 2002, 2004, 2006, 2008, 2010, 2012, 2013, 2014, 2015, 2016). I added two years from censuses (2000, 2010) and two years from the health statistics yearbook (1982, 1990)

For under-5 mortality, I extracted the 11-year data (2000, 2002, 2004, 2006, 2008, 2010, 2012, 2013, 2014, 2015, 2016) from the “Annual report on maternal and child health” and I added two years from the census (2000, 2010). I also extracted 28 years of data (1990-2017) from the GBD 2017 study. See Table D.1 (Appendix D) for outcome data availability of each province.

Demographic variables：I extracted all the demographic variables from the data sources issued by the statistics bureau except for the per cent of the population under 5 and over 60. Since the *Laonian Renkou Ditu Ji* was only published in a single volume in 1987, I relied on census data (1964, 1982, 1990, 2000, 2010) to extract the total population, the number of people under 5 and the number of people over 60, dividing the number of people under 5 and over 60 by the total population. To interpolate the per cent of the population under 5 and over 60 in the census intervals (1981, 1983-1989, 1991-1999, 2001-2009), I assumed a linear change in the per cent of the population between census years. To extrapolate the per cent of population under 5 and over 60 beyond 2010, I computed the average by which the per cent had changed from 2000 to 2010, and added the average for every year which has elapsed since 2010. See Table D.2 (Appendix D) for demographic data availability of each province.

Education variables：I adopted the way Babiarz and colleagues generated the gross enrolment ratio of primary education and the gross enrolment ratio of secondary and higher education and used the same definitions. I extracted the numerators from the provincial yearbooks and the denominators from the 1964, 1982, 1990, 2000 and 2010 censuses. I estimated the population aged 6-11 and 12-18 by assuming the population within the given age groups was equally distributed. To calculate the population aged 6-11 and 12-18 in the census interval (1981, 1983-1989, 1991-1999, 2001-2009), I assumed a linear change in the population between the census years. After the census of 2010, I applied the linear trend observed between 2000 to 2010. See Table D.3 (Appendix D) for availability of data on education for each province.

Health system input variables：I generated a new variable of hospital bed density as the "number of beds in health care institutions per 10,000 population"- dividing the number of beds in health care institutions by the population figure from household registration. The population figure from household registration is officially used to estimate health worker density. To align with that, I used the same denominator to generate all the health system input variables. I added two more variables into the dataset: health professional density and health institution density (definitions in Table C.4, Appendix C). See Table D.4 (Appendix D) for availability of data on health system input for each province. Health professionals include licensed doctors, nurses, pharmacists, technicians, excluding barefoot doctors (later referred to as village doctors), management staff and supportive workers. The health institutions include hospitals, health care institutions at grass-root level and specialized public health institutions.

Socio-economic development variables: I updated all the socio-economic development variables from the same data sources (Table C.5, Appendix C). The variable "local revenue (100 million yuan)" in the 1950-80 dataset is actually "local revenue per capita". This could be an error in the dataset. I renamed the variable and updated it to 2017 for all provinces. I added the following variables from the provincial yearbooks: GDP per capita, consumer price index, general budgetary expenditure, subsets of general budgetary expenditure, length of railways, navigable inland waterways and highways, possession of civil vehicles, ownership of the telephone, and radio and television coverage. See Table D.5 (Appendix D) for socio-economic data availability of each province.

Public health campaign variables: These data were coded following two steps. First, I reviewed the volume “Public health in China: implementation”. I assigned each province-year “1” if any policy or intervention was in place. Justification for coding was as follows:

- The Expanded Program on Immunization was launched in 1978, including four vaccines: Bacillus Calmette-Guerin vaccine (BCG), oral poliovirus vaccine (OPV), measles vaccine, and diphtheria-tetanus-pertussis vaccine (DTwP). These vaccines have been routinely administered to all infants in China. The following variables are coded “1” in all provinces since 1980: vaccination campaign against pertussis, measles, polio, diphtheria and tuberculosis.
- The China National Immunization Program was implemented in 1982, setting out population prevention and immunization on typhoid and meningitis. The variables vaccination campaign against typhoid and meningitis are coded “1” from 1982 onwards.
- The Surveillance system for specific infectious diseases was established in 1978. The functions include monitoring infectious disease epidemics, food and water monitoring and disease control efforts. The following variables are coded “1” from 1980 to the most recent year: water quality monitoring, disease prevention monitoring, food quality monitoring, public hygiene, provision of clean drinking water, sanitary campaign against dysentery, typhoid, diarrhoea, malaria, influenza, meningitis, tuberculosis, typhus, and malaria prevention.
- In 1987 the “Frontier health and quarantine law of the People's Republic of China” was formulated in order to prevent infectious disease including cholera. The variable vaccination campaign against cholera is coded “1” from 1987 onwards.
- The “Law of the People’s Republic of China on the prevention and treatment of infectious diseases” was enacted in 1989, dividing infectious diseases into three classes. Dengue fever was classified into the second class. The variable dengue prevention is coded “1” since 1989.

- China introduced the one-child policy in 1979. The policy was enacted to address the growth rate of the country's population, which the government viewed as being too rapid. The policy was enforced by methods ranging from offering financial incentives for compliant families and providing contraceptives to implementing forced sterilizations and forced abortions. The variable contraception is coded “1” throughout the later years.
- From 1981 onwards, China encouraged aseptic delivery and a clean home or facility birth environment. From 1995, the government started encouraging facility-based delivery. Although the conceptions behind midwifery, aseptic delivery and facility-based delivery differ, the variable midwifery in the 1950-80 dataset, as Babiarz and colleagues emphasized, represents ‘modern midwifery campaign involving intensive training in sanitary childbirth’. The variable midwifery is coded “1” from 1981.
- On 22nd of January 1986, the Ministry of Health issued a regulation, “Requirements for urban and rural children's health work”, to promote systematic child health care management. The “systematic management” includes routine management of infants and children under seven, particularly promoting the prevention and treatment of rickets, iron-deficiency anaemia and malnutrition caused by poor feeding. The variable malnutrition is coded “1” from 1986 onwards.

Second, for those variables which cannot be fully coded based on policy implementation, I carried out a systematic yearbook search in the Chinese National Knowledge Infrastructure (CNKI) database for relevant information on March 2nd, 2020 using the search terms (“dengue fever” OR “cholera vaccine” OR “cholera vaccination” OR “typhoid vaccine” OR “typhoid vaccination” OR “meningitis vaccine” OR “meningitis vaccination”). The reference sections of identified yearbooks from CNKI were then scrutinized for textual explanation of whether the intervention applied to a specific province-year. If the yearbook states that there was such an intervention in a specific area of the province or the whole province in the given year, I coded the variable in that particular province-year “1”. If a yearbook states that there was no such intervention in the given year, I coded the variable “0”.

The eradication of smallpox in China was achieved in the 1950s. The variable smallpox vaccination is considered not relevant and deleted from the dataset. Due to the comprehensive search and coding, the availability of data on public health campaigns for each province is 100%.

5.3.3 Data plausibility check

Since the dataset was compiled using archival data, there could be input errors. I checked the plausibility of the data in a number of ways.

First, for continuous variables, I used scatter plots to look for extreme values relative to the rest of the data. I checked the unusual values against the original records, and I corrected the data where relevant. If the original record was not plausible, I inserted a missing value code. For categorical variables (public health campaign variables), I did range checks (0/1).

Second, I did a number of logical checks:

- I checked whether the IMR and CMR1-4 were consistently lower than the U5MR. If higher I checked whether there was an error with data entry, which I corrected, or whether the data were unexpected, in which case I removed the data point(s).

- I checked whether the natural growth rate was equal to the crude birth rate minus the crude death rate.

- I plotted each individual province’s recorded values of gross domestic product per capita, investment in fixed assets and local revenue per capita by year to check whether the growth of the economy was reasonable. When there was an unusual decline, I checked the suspicious values against the original data sources. If there was no evidence of an input error, I left the data unaltered. I added up the various dimensions of government expenditure (culture, education, science and health care combined expenditure, general public service expenditure, social safety net and employment effort) and checked whether the sum of the variables was smaller than the variable “general government expenditure” for each province-year.

5.3.4 Comparison of outcome variables from different sources

I compared the updated mortality data from different sources. Figure E.1 (see Appendix E) shows the trends in the IMR for each province from 1981 onwards comparing data from the MCHSS and data from censuses. On average, the differences between the two sources were small. Figure E.2 to Figure E.28 display the scatter plots of the IMR for each province from 1981 onwards. The trends over time are mostly consistent but the census estimates tend to be lower than the other estimates, though not consistently so. To maximize the number of observations included in the study, I used data from the MCHSS for the years from 2000 onwards and data from censuses for 1981 and 1990.

Figure E.29 shows trends in the U5MR in each province from 1981 onwards, using data from the MCHSS, the censuses and the GBD study 2017. Figure E.30 to Figure E.56 display the scatter plots of the U5MR for each province. As shown in Figure E.29, for most provinces the trend in under-5 mortality is similar comparing the three data series. Estimates of under-5 mortality from the 2017 GBD study tended to be higher than the estimates from the MCHSS and censuses for 26 provinces (96.3%). Considering the documented under-reporting issues of the MCHSS and the censuses [15, 30], I decided to use the data from the 2017 GBD study for the U5MR.

5.3.5 Statistical analysis

Descriptive analysis

I made individual scatter plots of all the continuous variables over year by province. I used arithmetic means with standard deviations (SD) across provinces to summarize all continuous variables by year (1950, 1960, 1970, 1980, 1990, 2000, 2010, 2016). I divided the IMR by the U5MR to get the proportion of the IMR to the U5MR.

Modelling the speed of decline of child mortality across all provinces

I calculated the proportional reduction in infant, 1-4 and under-5 mortality by province between 1950 and 2016. To establish the functional form of the association between year and mortality outcomes, I first plotted the IMR, CMR1-4 and U5MR in each province between 1950 and 2017. I then fitted regression models with fixed effect of “province” and with fractional polynomials (FP) of “year” which are more flexible than ordinary polynomials in modelling non-linear functions. I re-scaled year to start at value one instead of zero to avoid problems with the use of logarithms and negative power transformations. For the IMR, a FP of degree m=2 with powers p=(0.5, 0.5) was selected with the lowest deviance (defined as twice the negative log likelihood). The estimated response curve is of the form $b_0+b_1x_p^{(0.5)}+b_2x_p^{(0.5)}\log(x_p)$. Year is expressed as x. Province is expressed as p. The regression coefficients are expressed as b_0, b_1 and b_2. For the CMR1-4, the best fractional polynomial has powers (1, 1) and is of the form $b_0+ b_1x_p+b_2x_p\log(x_p)$. For the U5MR, the best fractional polynomial has powers (0.5, 0.5) and is of the same form as that of the IMR $b_0+ b_1x_p(0.5)+b_2x_p(0.5)\log(x_p)$. Alternative approaches to FP include standard quadratic modelling and natural logarithmic transformation. I compared the three approaches by making graphical comparisons. After fitting a model using the FP-transformed year variables to the data, I predicted the yearly change (mathematically known as gradients) in the IMR, the

CMR1-4 and the U5MR at 5-year intervals by taking a linear combination of the estimated coefficients for the FP-transformed year variables using the “lincom” command in STATA.

Provincial variation in speed of decline of child mortality

First, to test whether the speed of decline varied by province, I added interaction terms between province and all the FP-transformed variables. I tested whether the decline in the IMR, CMR1-4 and U5MR varied by province using the partial F-test.

Second, I estimated the speed of decline using the “lincom” command for “typical” provinces, defined as provinces with the highest, median and lowest mortality levels based on the starting levels of mortality in 1950.

Third, I tested whether the speed of mortality decline varied by socio-demographic Index (SDI). By tradition, western=low socio-demographic status, central=moderate socio-demographic status, and eastern=high socio-demographic status. I did not use the traditional “Western, Central and Eastern” classification of provinces because this categorization was based solely on geographical location and economic development of a province in 1986. I followed the Human Development Index Method, which was developed by the UN to compute the SDI [242]. The information of variables (X1, X2, X3, X4) is reduced by principal components analysis (PCA) to an index score, which is then used to classify provinces into three SDI categories. The PCA is based on data in 1952 (not 1950, due to large missing data). The variables include GDP per capita (X1), primary education enrolment ratio (X2), secondary education enrolment ratio (X3) and per cent of urban population (X4). I selected the variables based on the three basic dimensions of human development as recommended by the UN, i.e. life expectancy at birth, gross national income per capita and years of schooling. I replaced life expectancy at birth with per cent of urban population for two reasons: (1) the purpose of the SDI analysis is to examine variation of child mortality related to socio-demographic status, so a variable measuring population health was not suitable; (2) The per cent of urban population captures rapid urbanization, which has been recognized as a key driver for increased inequalities in China [13, 14]. For each province, the index score is missing if any of the four variables are missing. I created a category for missing values (0=SDI could not be generated; 1=SDI could be generated). The provinces with value “1” are further grouped into three tertiles (low, medium and high) with approximately equal number of provinces on the basis of the distribution of the generated index score for the year 1952. I compared the SDI categorization of provinces with those using the government 1986 classification and counted the number of provinces that agree in the two classifications, e.g., agreement was met if a province in the eastern region was classified as SDI-high categorization. I tested the interactions between the SDI category and the FP-transformed year variables (see 4.3.2), using a partial F-test. To visualise the fitted model, I used the “predict” command in STATA to calculate the predicted IMRs/CMR1-4/U5MRs in each of the four categories of the SDI (missing, low, medium and high) and then plot these.

Fourth, I estimated the speed of mortality decline for the low, medium and high SDI categories using the “lincom” command. Analysis was repeated using only three variables (GDP per capita, primary education enrolment ratio and per cent of urban population) to compute the SDI. These analyses yielded similar results and only the SDI analyses using four variables are presented.

5.4 Results

5.4.1 Descriptive results of outcome variables

For the IMR, data are available for 44 years, with data missing for the following years: 1982-1989, 1991-1999, 2001, 2003, 2005, 2007, 2009, 2011, 2017. For the CMR1-4, data are available for 43 years, with data missing for the following years: 1981-1989, 1991-1999, 2001, 2003, 2005, 2007, 2009, 2011, 2017. For the U5MR, data are available for 59 years, with data missing for the following years: 1981-1989. Data on the IMR, the CMR1-4 and the U5MR vary in completeness between provinces (Table D.1 in Appendix D). Of the 27 provinces, 24 provinces have 100% of the years with data available for the outcomes. The three exceptions are Xinjiang, Sichuan and Tibet.

IMR

In 1950, all provinces had very high observed IMRs, ranging from 120.0 deaths per 1000 livebirths in Fujian to 368.4 deaths per 1,000 live births in Guangxi (Table F.1, Appendix F, Figure 5.2). At the time,15 provinces had IMRs over 200 deaths per 1,000 live births. By 2016, all the provinces had IMRs below 20 deaths per 1,000 live births. The mean of province-specific IMR was 217.3 deaths per 1,000 live births (SD 53.4) in 1950, declining to 6.1 (SD 3.4) in 2016 (Table F.2, Appendix F). The IMR declined by more than 90 per cent for all the provinces between 1950 and 2016. The highest proportional decline occurred in Guangxi (reduction 98.9%) and the lowest was in Xinjiang (92.1%). The absolute reductions in infant mortality were much steeper during 1950-80 than the later decades. The effects of the Great Leap Forward famine (1959-

1961) on infant mortality differed in extent across provinces. The IMRs in Henan, Hebei, Shandong, Anhui, Hubei, Guizhou peaked sharply during the famine, but this was not the case in other provinces (e.g. Zhejiang, Fujian, Jilin and Jiangxi). Most affected provinces were from north China, except Anhui, Hubei and Guizhou. Another moderate peak of the IMRs occurred in the 1981 (data source 1981 census).

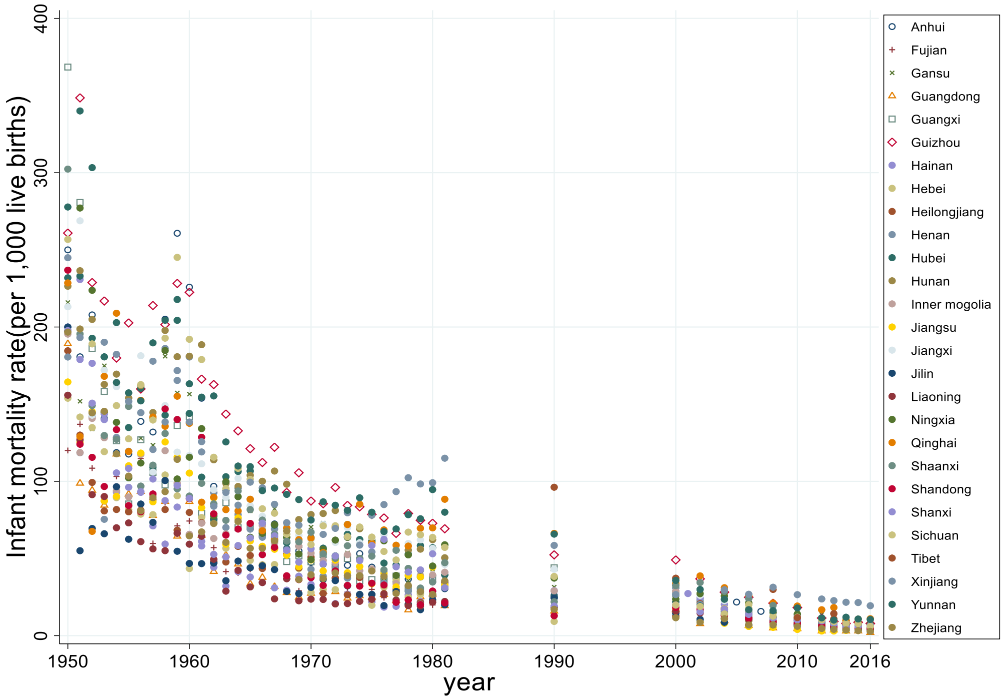


Figure 5.2: Infant mortality rate (per 1,000 live births) by province, 1950-2016

Infants born in less developed western regions had higher IMRs than children born in eastern or central region (Figures F.1, F.2, Appendix F). In 1950, the leading five provinces for infant mortality were Guangxi (368.4 deaths per 1,000 births), Shaanxi (302.3), Yunnan (277.8), Guizhou (260.9) and Sichuan (256.8), all from western China. In contrast the five provinces with the lowest IMRs at the time were Fujian (120.0), Hebei (153.9), Liaoning (155.8), Jiangsu (164.4) and Henan (180.6), four from eastern China and one from central China. In 2016, the leading five provinces for infant mortality were Xinjiang (19.4), Qinghai (11.0), Yunnan (10.5), Guizhou (7.9) and Ningxia (7.3), all from western China as well. The corresponding provinces with the lowest IMRs at the time were Guangzhou (2.0), Zhejiang (2.8), Jiangsu (3.0), Fujian (3.7) and Hunan (3.8), four from eastern China and one from central China.

CMR1-4

The CMR1-4 was lower than the IMR, and this was true throughout 1950-2016. In 1950, the observed CMR1-4 ranged from 19.2 in Jilin to 269.2 deaths per 1,000 children surviving to age one in Yunnan (Table F.1, Appendix F, Figure 5.3). At the time, four provinces had CMR1-4s over 200 deaths per 1,000 children surviving to age one. By 2016, all the provinces had CMR1-4s below 20 deaths per 1,000 children surviving to age one. The mean of observed province-specific CMR1-4 declined from 118.6 deaths per 1,000 children surviving to age one (SD 64.1) in 1950 to 8.2 (SD 3.1) in 2016 (Table F.2, Appendix F). The CMR1-4 declined by more than 70 per cent for all the provinces from 1950 to 2016. The highest proportional decline for the whole study period occurred in Yunnan (reduction 97.2%) and the lowest was in Jilin (73.4%). As with IMR, the CMR1-4 in some provinces peaked in the late 1950s, and then declined sharply in the 1960s across provinces. A few peaks of the CMR1-4 occurred in 1990 and 2000, most notably in Guizhou.

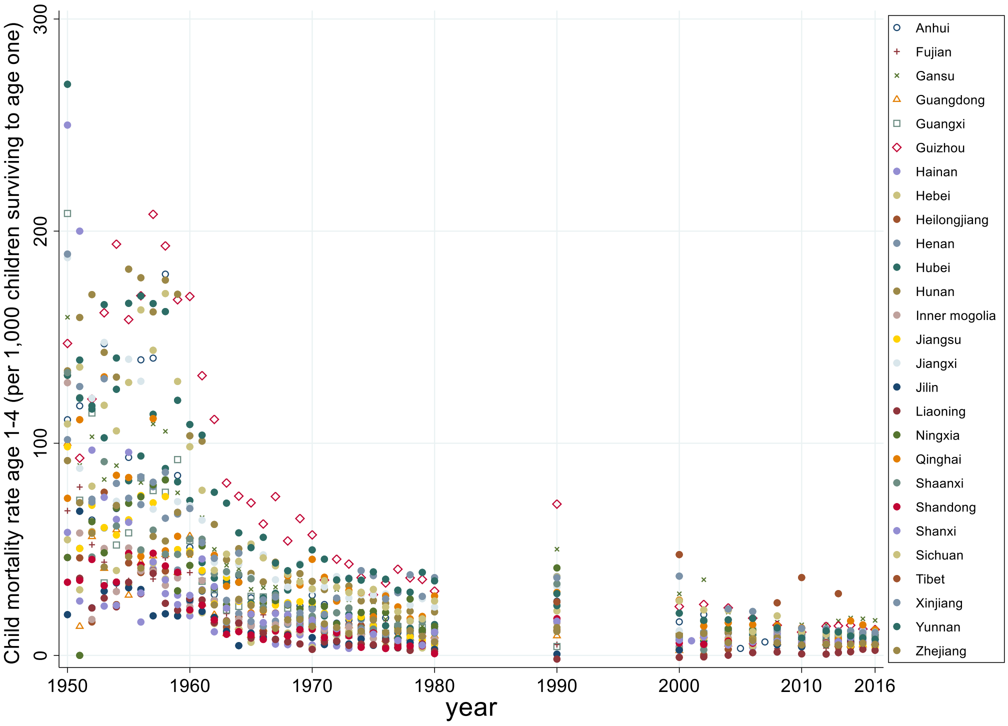


Figure 5.3: Child mortality rate aged 1-4 (per 1,000 children surviving to age one) by province, 1950-2016

In 1950, the leading five provinces with high CMR1-4 were Yunnan (269.2), Hainan (250.0) and Guangxi (208.3), Xinjiang (189.2) and Jiangxi (187.5), all from western and central China except Hainan (Figures F.3, Appendix F). In contrast the five provinces with the lowest CMR1-4 at the time were Jilin (19.2), Shandong (34.5), Liaoning (46.2), Ningxia (46.2) and Shanxi (58.0), four from eastern China and one from central China. In 2016, the leading five provinces for the CMR1-4 were Gansu (16.5), Qinghai (12.2), Guizhou (12.2), Sichuan (11.1) and Jiangxi (11.1), one from western region, two from central region and two from eastern region (Figures F.4, Appendix F). The corresponding provinces with the lowest CMR1-4 at the time were Liaoning (2.4), Jiangsu (4.0), Fujian (4.4), Jilin (5.1) and Zhejiang (5.2), four from eastern China and one from central China. Inequity between provinces persists in the study period. The province-specific estimates ranged from 19.2 in Jilin to 269.2 in Yunnan in 1950. Children in Yunnan had 14 times the risk of dying between age 1-4 than children in Jilin. In 2016, Gansu had the highest CMR1-4 (16.5 deaths per 1,000 children surviving to age one), whereas Liaoning had the lowest CMR1-4 (2.4 death per 1,000 children surviving to age one). The risk of infants dying between age 1-4 in Gansu was 6.9 times that of Liaoning.

Under-5 mortality rate

In 1950, all provinces had very high observed U5MRs, ranging from 180.0 in Fujian to 500.0 deaths per 1,000 live births in Guangxi (Table F.1, Appendix F). At the time, 12 provinces (44.4%) had U5MRs over 300 deaths per 1,000 live births. In 2017, all the provinces had U5MRs below 40 deaths per 1,000 live births. It is clear that under-5 mortality continued to decline in all provinces from 1950 to 2017 (Figure 5.4). The mean province-specific U5MR declined from 308.5 deaths per 1,000 live births (SD 81.7) in 1950 to 14.1 (SD 6.6) in 2017 (Table F.2, Appendix F). The U5MR declined by more than 90 per cent for all the provinces from 1950 to 2017. The highest proportional decline for the whole study period occurred in Guangxi (reduction 97.6%) and the lowest was in Ningxia (91.0%). The trends in the U5MR show a similar temporal pattern to the IMRs, with two peaks separately occurring in the late 1950s and in the late 1980s.

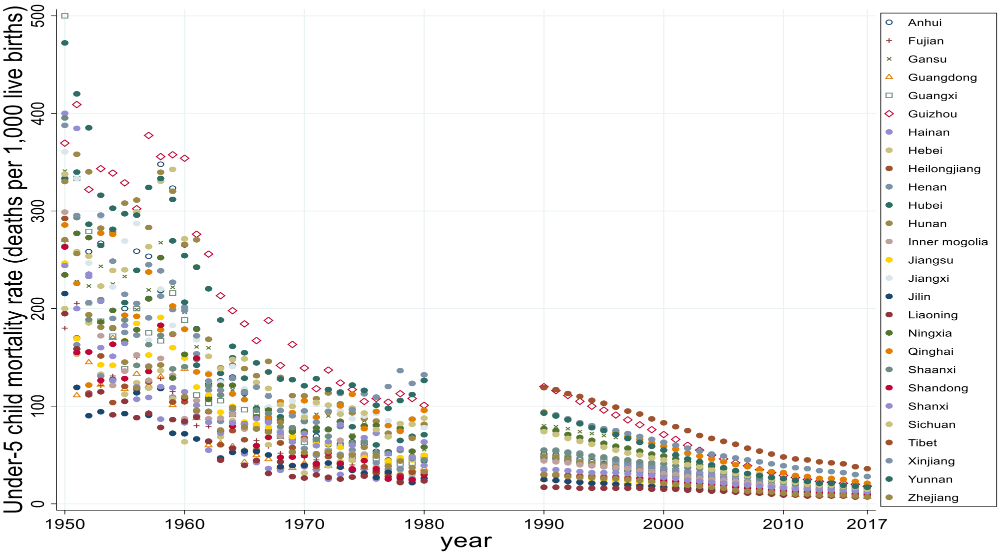


Figure 5.4: Under-5 child mortality rate (per 1,000 live births) by province, 1950-2017

In 1950, the leading five provinces of under-5 mortality were Guangxi (500.0 deaths per 1,000 births), Yunnan (472.2), Hainan (400.0), Shaanxi (395.4) and Xinjiang (387.8), four from western China and one from eastern China (Figure F.5, Appendix F). In 2017, the leading five provinces of under-5 mortality were Tibet (36.0), Xinjiang (28.0), Ningxia (21.0), Gansu (20.0) and Qinghai (20.0), all from western China. Inequity between provinces persists in the study period (Figure F.6, Appendix F). The province-specific estimates of under-5 mortality ranged from 180.0 deaths per 1,000 live births in Fujian to 500.0 in Guangxi in 1950. The risk of children dying before five years old in Guangxi was 2.8 times that of Fujian. In 2017, Tibet had the highest U5MR (36.0), whereas several provinces in east China (Liaoning, Jiangsu, Zhejiang, Fujian, Guangdong) had the lowest U5MR (7.0). The risk of children dying before five years old in Tibet was 5.1 times that of Guangdong.

5.4.2 Changes in the IMR relative to the CMR1-4

Figure 5.5 shows the mean of the IMRs and the CMR1-4s and the mean of the IMR/CMR1-4 ratios by stacked bars between 1950 and 2016. This also clearly shows the peak of the IMR/CMR1-4 during the Great Leap Forward famine (1959-1961). There is a generally increasing ratio of infant mortality to 1-4 mortality between 1950 and 1980 and a decreasing trend from 2000 afterwards. The mean of the IMR/CMR1-4 ratio across provinces is higher than 1.0 in most years except after 2014.

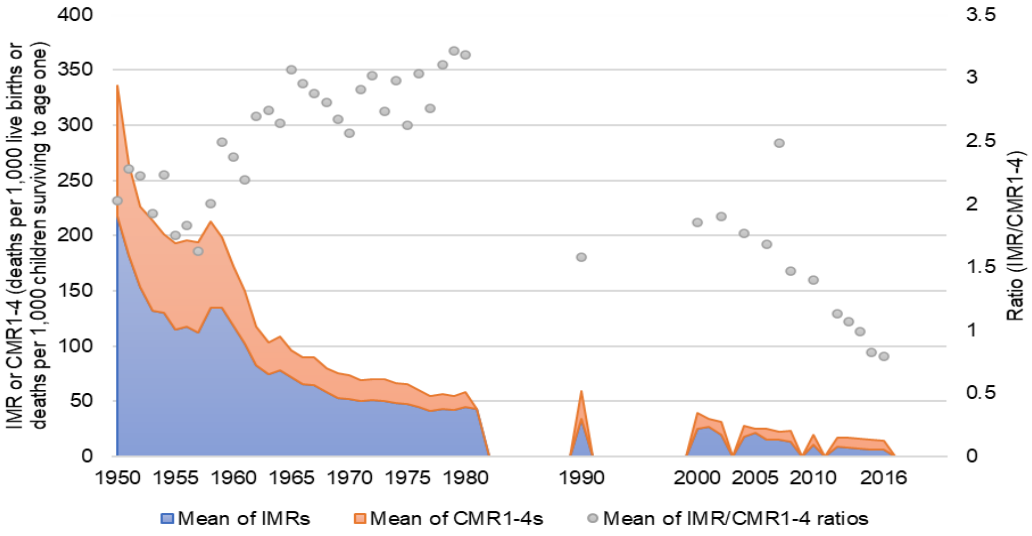


Figure 5.5: Stacked bar chart of the mean of the IMRs, CMR1-4s and IMR/CMR1-4 ratios across provinces over year, 1950-2016

5.4.3 Socio-demographic variables

The demographic profile of the population changed noticeably between 1950 and 2017. There was a big difference in total population across provinces and some provinces (e.g., Guangdong and Shandong) grew much more than others (Figure F.7 in the Appendix F). Figure 5.6 shows that there was a declining trend in the crude birth rate which reached a dip during 1959-1961 (Great famine period). After a peak in 1962-1965, the crude birth rate kept declining before the introduction of the one child policy in 1979. The crude death rate sharply rose due to the famine of 1959-1961 and showed fluctuations in the return to long-term equilibrium (Figure F.8). As expected, the natural growth rate is mostly above zero except in the early years of the 1960s (Figure F.9). Demographic changes also affect the age structure and other parameters of the population. The per cent of the population over 60 decreased from the 1950s to a slight dip in the 1960s, then increased gradually to 2017, with a particular sharp increase in the recent three decades (Figure F.10). The per cent of the population under 5 is decreasing, corresponding to the trend in the crude birth rate (Figure F.11). About 50 per cent of the population was male for the entire study period (Figure F.12). The per cent of urban population rose steadily in the study period (Figure 5.7). Whereas only 12 per cent of China’s population was urban in 1950, the urbanization level reached 56 per cent in 2017 (Table F.2, Appendix F).

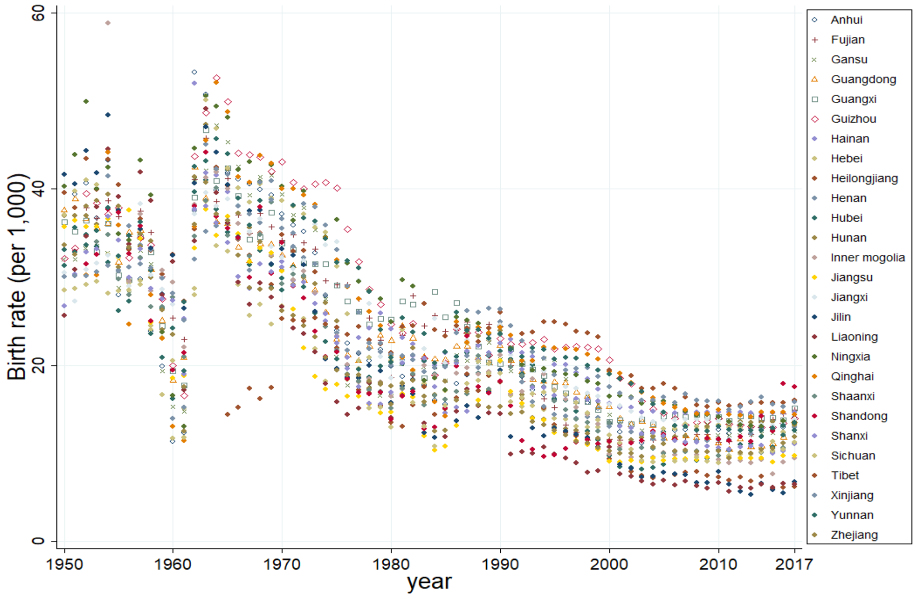


Figure 5.6: Crude birth rate (per 1,000 population) by province, 1950-2017

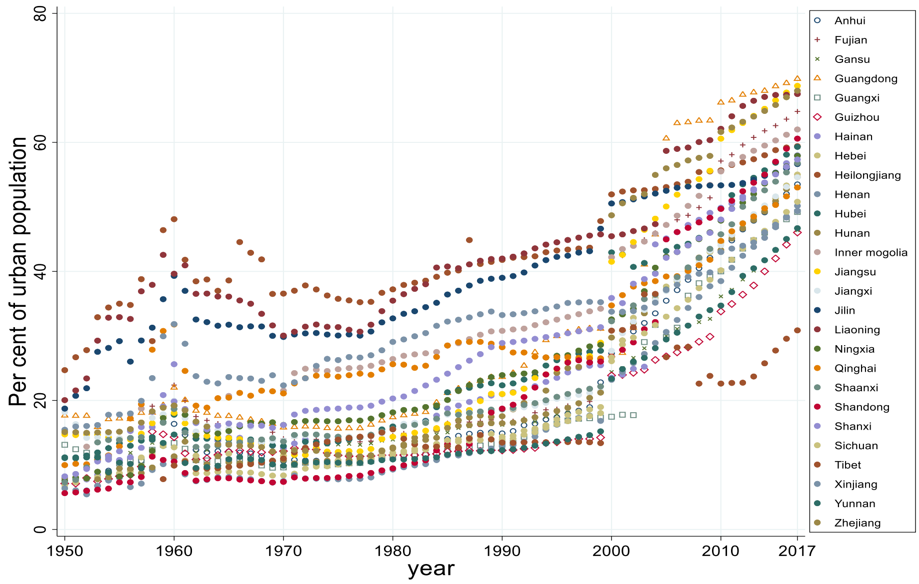


Figure 5.7: Per cent of urban population by province, 1950-2017

Although fluctuating, the gross enrolment ratio of primary education and that of secondary and higher education both continued growing to the end of the study period (Figures 5.8, 5.9). The enrolment ratio of primary education increased massively between 1970 and 1975. The mean of the gross enrolment ratio of primary education across provinces was 40% in 1950 and reached 100% by 1980, although there was a huge range across provinces (Table F.2, Appendix F). In comparison with primary education, the gross enrolment ratio of secondary and higher education rose more gradually between 1950 and 1975 and then declined between 1975 and 1980. The mean of the gross enrolment ratio of secondary and higher education was 2% in 1950 and reached 100% after 2010. Education differentials were huge between regions in 1950 (Figures F.13, F.14 in the Appendix F). By 2017, the education differentials mostly disappeared (Figures F.15, F.16 in the Appendix F).

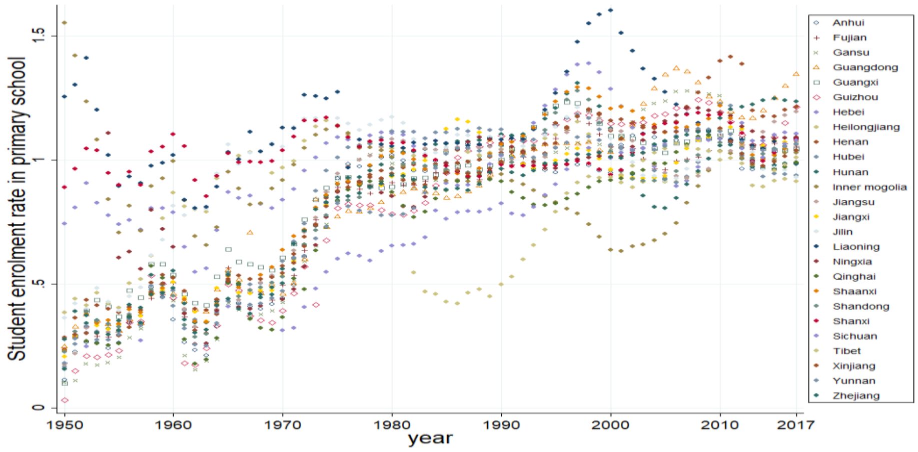


Figure 5.8: Gross enrolment ratio of primary education by province, 1950-2017

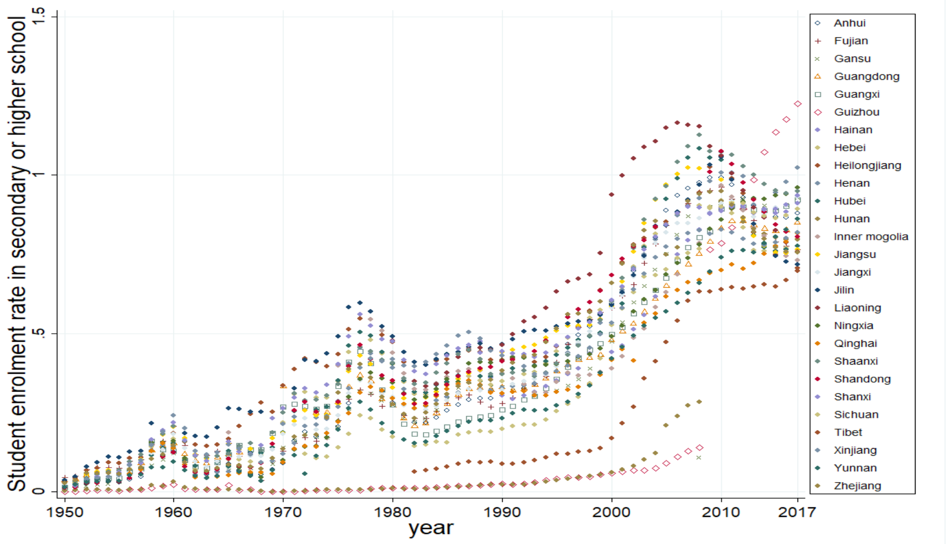


Figure 5.9: Gross enrolment ratio of secondary and higher education by province, 1950-2017

The health institution density increased slightly between 1950 and 1960, plateaued between 1960 and 2009 and rose sharply after 2010 (Figure 5.10). The huge peak in 1960 corresponded to the expansion of private hospitals. Hospital bed density grew from 2.2 units per 10,000 population in 1950 to 57.3 units per 10,000 population in 2017 (Table F.2, Appendix F). The increasing trends in hospital bed density far exceed the trends in health institution density (Figure 5.11). Health professional density grew from 4.8 persons per 10,000 population in 1950 to 63.9 persons per 10,000 population in 2017. The mean of health professional density increased 4-fold in the initial years (1950-1964) under Chairman Mao, from 4.8 in 1950 to 20.4 in 1964 (Figure F.17 in the Appendix F).

Doctor density grew gradually from 1950, then experienced two plateau periods, 1963-1973 and 1980-2000, and continued growing to 2017 (Figure 5.12). The mean of doctor density grew from 3.1 persons per 10,000 population in 1950 to 24.0 persons per 10,000 population in 2017. The mean of doctor density increased three-fold in the initial years under Chairman Mao, from 3.1 persons per 10,000 population in 1950 to 10.3 persons per 10,000 population in 1964 (Figure 5.12). Between 2010 and 2017, the mean of doctor density across provinces increased from 17.9 to 23.9 per 10,000 population. Provinces in east and south China (Heilongjiang, Jilin, Liaoning, Hebei, Zhejiang, Fujian, Guangzhou, Hubei, Hunan) had the highest doctor density in 1950 — more than 4.0 doctors per 10,000 population, while provinces in western China, for example Xinjiang, Yunnan, Qinghai, had the lowest doctor density — less than 1.0 doctor per 10,000 population (Figures F.18, F.19). In 2017 the inequality of doctor density distribution became less prominent (Figure F.20).

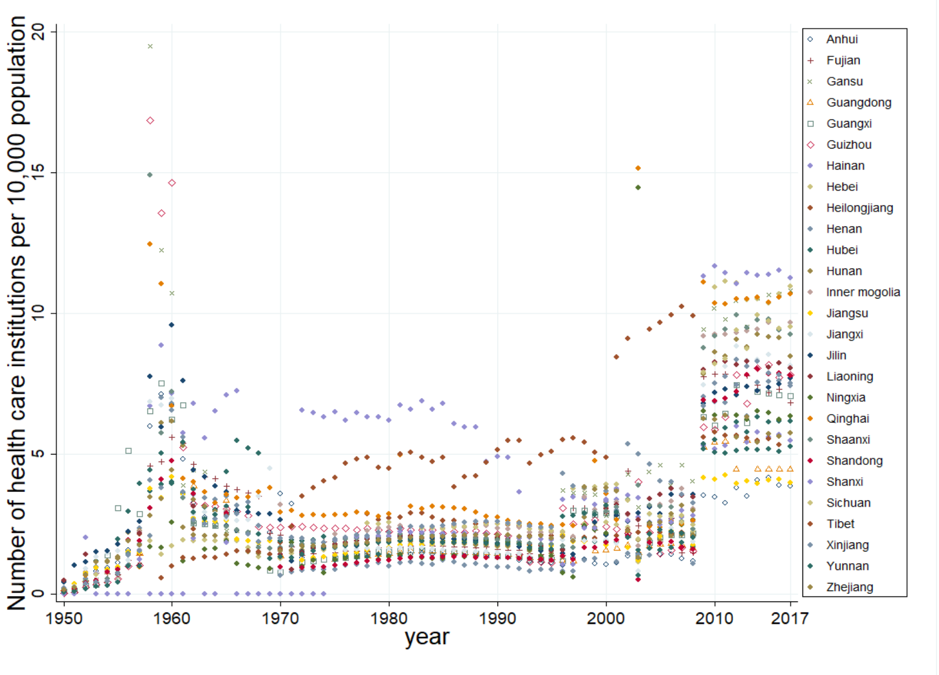


Figure 5.10: Health institution density, number of health care institutions per 10,000 population by province, 1950-2017

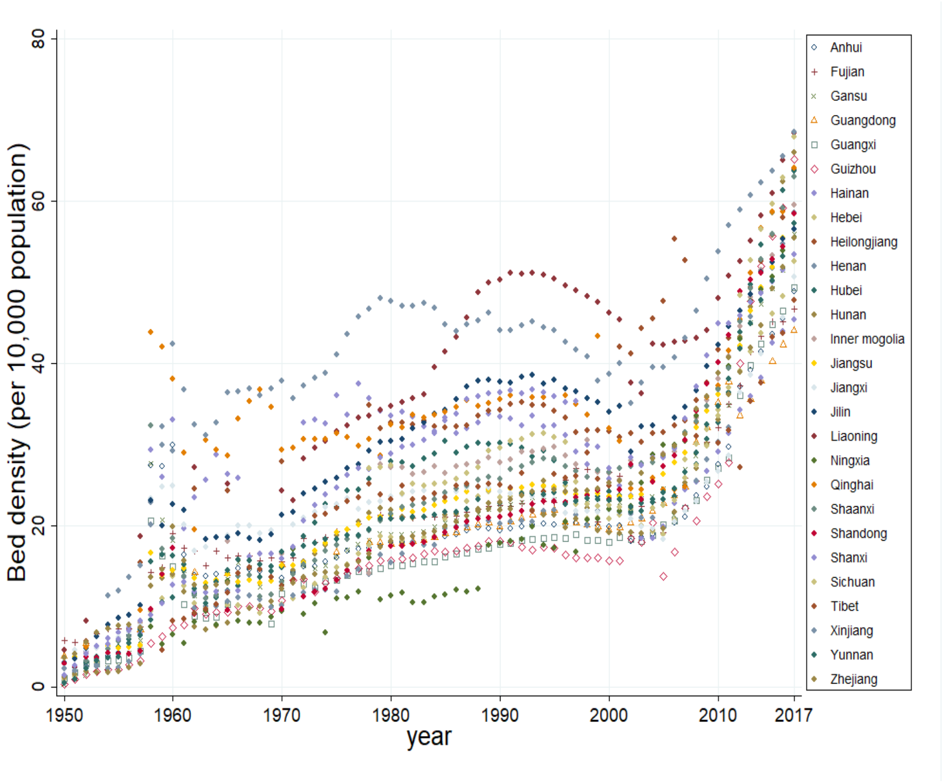


Figure 5.11: Hospital bed density (per 10,000 population) by province, 1950-2017

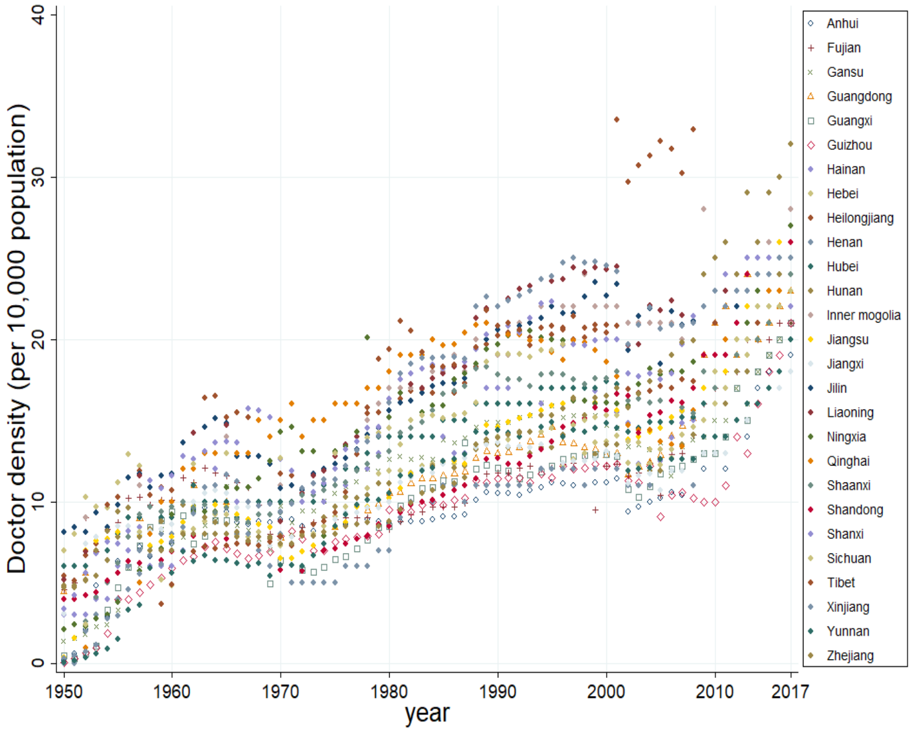


Figure 5.12: Doctor density (per 10,000 population) by province, 1950-2017

The GDP per capita was virtually flat between 1950 and 1990, though real changes are hidden by the massive increase in GDP per capita after 1990 (Figures 5.13, 5.14). GDP per capita increased from a mean of 70.0 yuan (around U.S.＄25.5) in 1950 to a mean of 1537.3 yuan (＄321.4) in 1990, with some variation between provinces. In 1952, provinces in northeast China had the highest GDP per capita (Figure F.21). From 1990 onwards, the mean GDP per capita increased massively from 1537.3 yuan (＄321.4) in 1990 to 53648.7 yuan (＄7936.2) in 2017, 766 times the GDP of 70.0 yuan (＄25.5) in 1950 (Table F.2, Appendix F). The GDP per capita varied widely between provinces. In 2017, eastern coastal provinces had the highest GDP per capita (Figure F.22).

Similar to the GDP per capita, local government general budgetary revenue, local revenue per capita, general budgetary expenditure remained stable between 1950 and 1990, but rose substantially after 1990 (Figures F.23-29). Two economic indicators, general retail price index and consumer price index, had some fluctuations between 1950 and 2017 (Figures F.30, F.31).

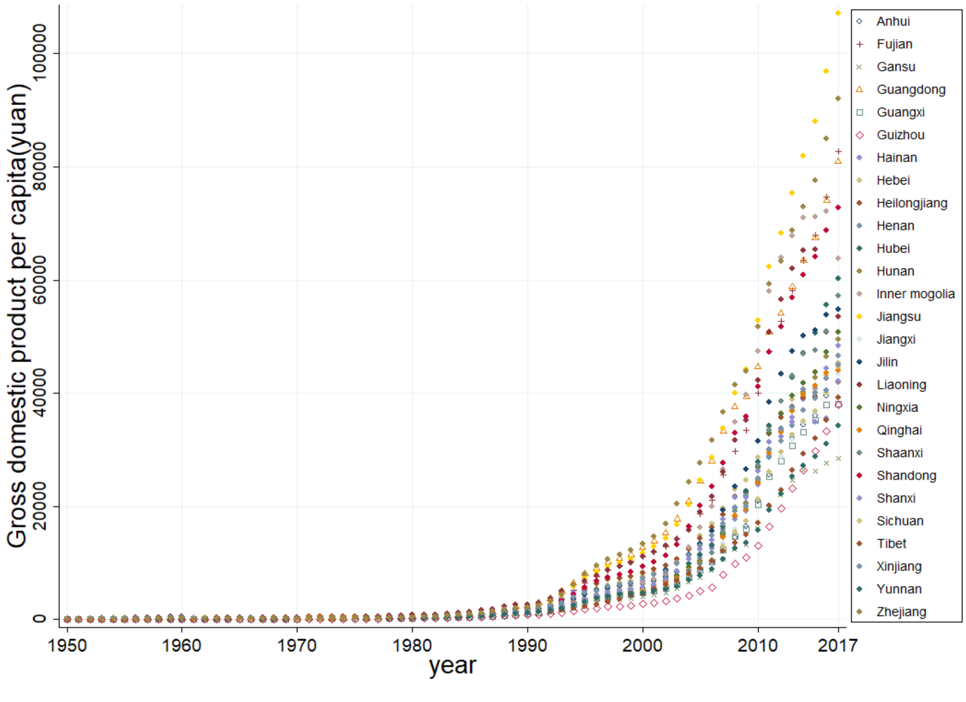


Figure 5.13: Gross domestic product per capita(yuan) by province, 1950-2017

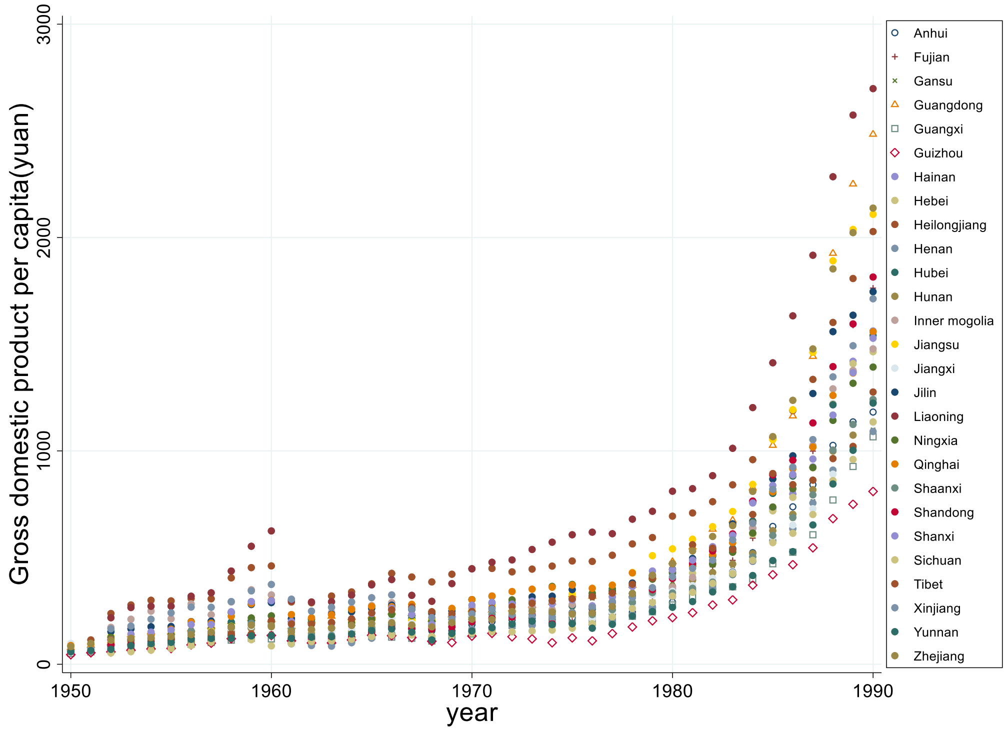


Figure 5.14: Gross domestic product per capita(yuan) by province, 1950-1990

The trends for other socioeconomic variables are much as anticipated. The production of grain per capita ranged from virtually flat between 1950 and 2000 to an increase for some of the provinces (Heilongjiang, Inner Mongolia, Jilin) from 2000 onwards (Figure 5.15). There was a slight decline in grain output which continued for several years after the 1959-1961 famine. Data on the production of fruit per capita were truncated between 1980 and 1995 due to incomplete data (Figure F.32). Before 1980, the production of fruit per capita did not really change. After 1995, the production of fruit per capita rose steadily. The length of railways and the length of navigable inland waterways did not change much from 1950 to 2017 (Figures F.33, F.34). The length of highways rose steadily from 1950 to the middle of the 2000s and then saw a dramatic increase from 2005 onwards (Figure 5.16). Possession of civil vehicles was very close to zero between 1950 and 1990 (Figure F.35), and rose sharply from 1990. The ownership of telephone was very close to zero between 1950 and 1990 (Figure F.36), then rose sharply from 1990. The mean of province-specific ownership of telephone reached 113.2 sets per 100 persons in 2017 (Table F.2, Appendix F). Radio coverage rate of the population rose steadily from 1950 to 2017 (Figure F.37). The mean of province-specific radio coverage rate reached 98.4% in 2017. Television coverage rate started rising from 1960 and shows the similar trend as that of radio coverage rate in the later decades (Figure F.38).

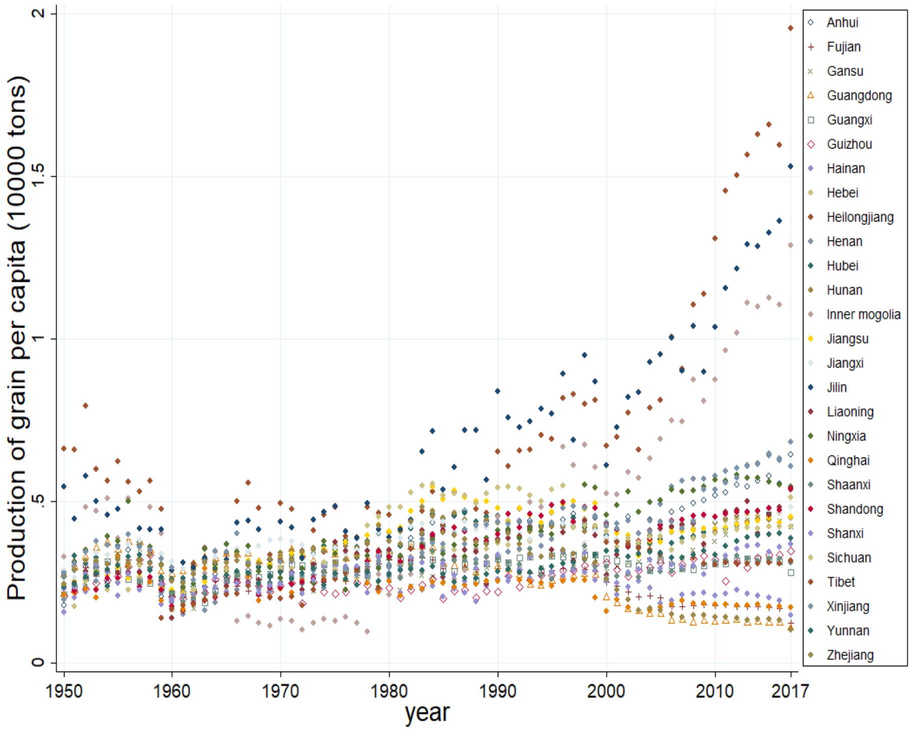


Figure 5.15: Production of grain per capita (10,000 tons) by province, 1950-2017

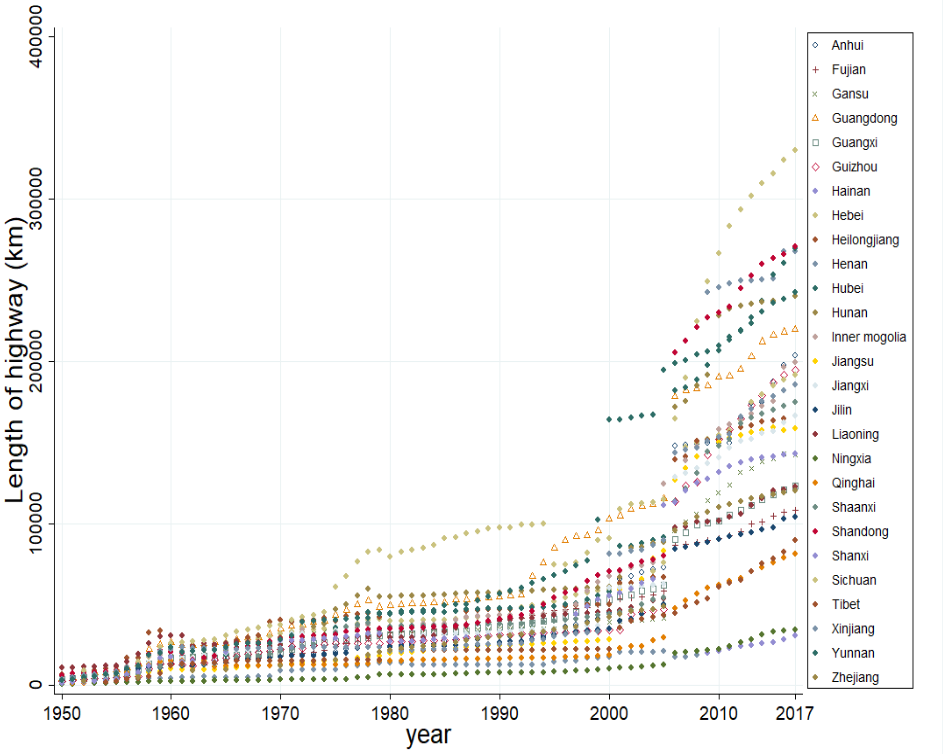


Figure 5.16: Length of highways (km) by province, 1950-2017

5.4.4 Speed of mortality decline

Ignoring provincial variation

The results comparing different models by year (including quadratic model, exponentiation of the natural logarithmic transformation modelling and fractional polynomials) are shown for the IMR and the CMR1-4 separately in Figures 5.17-5.18. The dots in Figures 5.17-5.18 are observed IMRs and CMR1-4s respectively for individual provinces over the years. The fitted curves from the quadratic model, although a statistically significantly better fit compared to a straight line (p<0.001, Wald test of the quadratic term), suggests implausibly that the IMRs/CMR1-4s are rising in recent years. The fitted curves from the exponentiation of the log transformation of the three separate mortality outcomes underestimates mortality rates before 1955. The fractional polynomials capture the relationship much better than the others (p<0.001, likelihood ratio test, Table 5.1).

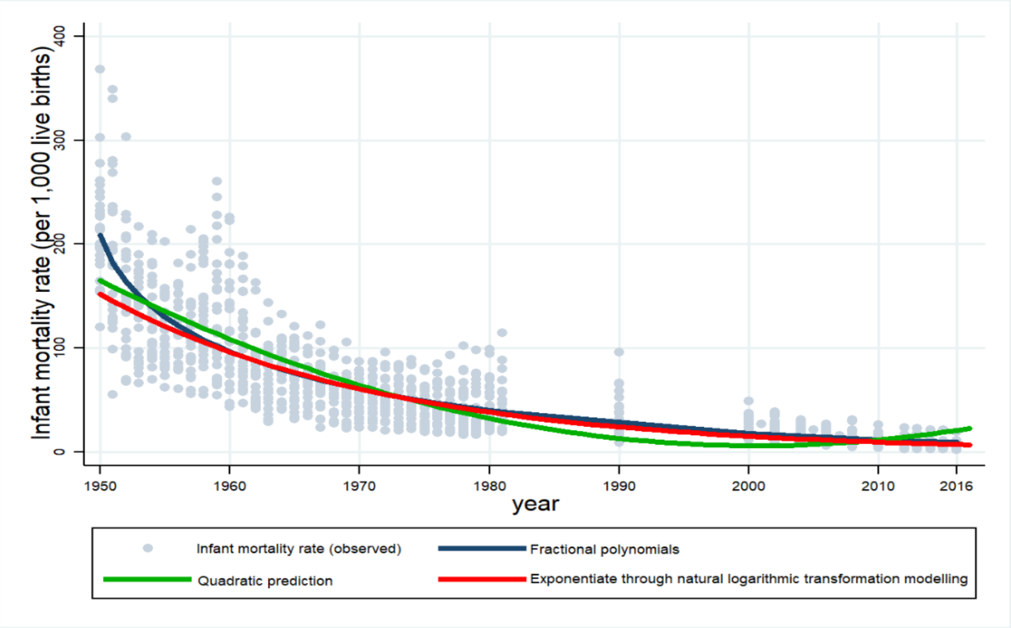


Figure 5.17: Observed infant mortality rates and estimates from fitted functions of year.

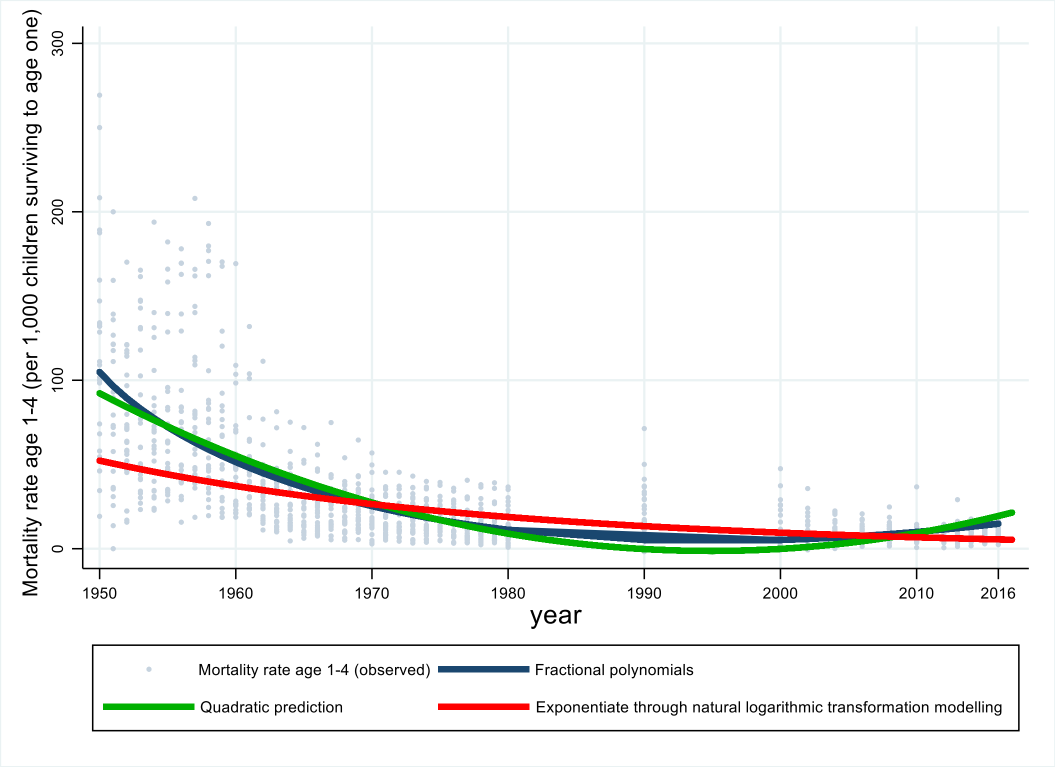


Figure 5.18: Observed mortality rate aged 1-4 and estimates from fitted functions of year.

Table 5.1: Fractional polynomial analysis for the variable “year”

Outcome	Year	Powers	Deviance	Deviance difference	P-value
IMR	Omitted		12596.76	1481.49	<0.001
(per 1,000 live births)	Linear	1	11670.26	555.00	<0.001
	m=1	0	11121.49	6.22	0.045
	m=2	**0.5 0.5**	**11115.27**	**0.00**	**-**
CMR1-4	Omitted		11381.34	794.51	<0.001
(per 1,000 children	Linear	1	10957.41	370.58	<0.001
surviving to age one)	m=1	0	10648.35	61.53	<0.001
	m=2	**1 1**	**10586.83**	**0.00**	**-**
U5MR	Omitted		18047.19	1971.72	<0.001
(per 1,000 live births)	Linear	1	16780.47	705.01	<0.001
	m=1	**0**	16104.06	28.59	<0.001
	m=2	**0.5 0.5**	**16075.47**	**0.00**	**-**

Notes: The preferred models with the lowest deviance are shown in bold.

The predicted yearly absolute change of mortality across provinces from regression models with only FP-transformed year variables at different time points is shown in Table 5.2. The predicted yearly absolute change in the mortality outcomes can be interpreted as the predicted change in the mortality rates from one year to the next. The most rapid decline in the IMRs/CMR1-4s/U5MRs occurred in 1950-1955. Between 1950 and 1951 the predicted yearly absolute change across all provinces was -26.7 (95% CI: -29.8, -23.5), and -39.7 (95% CI: -44.3, -35.0) deaths per 1,000 live births for the IMR and the U5MR, -8.4 (95% CI: -9.9, -6.9) deaths per 1,000 children surviving to age one for the CMR1-4 (Table 5.2). Between 1960 and 1961 this dropped to -4.9 (95% CI: -5.3, -4.4), -6.9 (95% CI: -7.7, -6.2) deaths per 1,000 live births, and -3.4 (95% CI: -4.0, -2.8) per 1,000 children surviving to age one. From 1985 onwards all yearly changes were below 2. The IMR declined massively in the early years, much more so than the CMR1-4.

Table 5.2: Levels of mortality and predicted yearly absolute change of mortality for all provinces

	Observed levels of mortality for the former year			**Predicted yearly absolute change of mortality across provinces**		
Year	**IMR**	**CMR1-4**	**U5MR**	**IMR**	**CMR1-4**	**U5MR**
1950-1951	217.3±51.1	118.6 ± 64.1	308.5 ± 81.7	-26.7 (-29.8, -23.5)	-8.4 (-9.9, -6.9)	-39.7 (-44.3, -35.0)
1955-1956	115.4 ± 33.3	77.6 ± 44.0	183.0 ± 64.9	-8.2 (-9.0, -7.3)	-4.8 (-5.6, -3.9)	-11.9 (-13.2, -10.6)
1960-1961	118.3 ± 53.2	53.9 ± 34.7	164.6 ± 74.0	-4.9 (-5.3, -4.4)	-3.4 (-4.0, -2.8)	-6.9 (-7.7, -6.2)
1965-1966	72.2 ± 25.2	24.3 ± 15.8	94.5 ± 37.0	-3.4 (-3.7, -3.1)	-2.5 (-2.9, -2.0)	-4.7 (-5.3, -4.2)
1970-1971	52.0 ± 17.5	21.9 ± 13.6	72.6 ± 28.4	-2.5 (-2.8, -2.3)	-1.8 (-2.2, -1.5)	-3.5 (-3.9, -3.1)
1975-1976	47.7 ± 18.8	17.7 ± 9.4	64.4 ± 26.3	-2.0 (-2.2, -1.7)	-1.3 (-1.6, -1.1)	-2.7 (-3.0, -2.3)
1980-1981	44.9 ± 21.8	13.4 ± 10.4	57.5 ± 30.8	-1.6 (-1.8, -1.4)	-0.9 (-1.0, -0.9)	-2.1 (-2.4, -1.7)
1985-1986	-	-	-	-1.3 (-1.5, -1.1)	-0.8 (-0.8, -0.8)	-1.6 (-2.0, -1.3)
1990-1991	33.9 ± 22.3	23.6 ± 16.5	55.5 ± 29.4	-1.1 (-1.3, -0.8)	-0.3 (-0.4, -0.2)	-1.3 (-1.6, -1.0)
1995-1996	-	-	46.7 ± 23.6	-0.9 (-1.1, -0.7)	0.0 (-0.1, 0.1)	-1.0 (-1.4, -0.7)
2000-2001	24.6 ± 9.1	13.2 ± 12.2	37.4 ± 17.9	-0.7 (-0.9, -0.5)	0.2 (0.1, 0.3)	-0.8 (-1.1, -0.5)
2005-2006	-	-	28.0 ± 12.7	-0.6 (-0.8, -0.4)	0.5 (0.3, 0.6)	-0.6 (-1.0, -0.3)
2010-2011	11.3 ± 5.1	8.9 ± 6.5	20.1 ± 9.5	-0.5 (-0.7, -0.3)	0.7 (0.5, 0.8)	-0.5 (-0.8, -0.2)
2015-2016	6.6 ± 3.7	8.6 ± 3.4	16.1 ± 7.6	-0.4 (-0.6, -0.2)	0.8 (0.7, 1.0)	-0.4 (-0.7, -0.1)

Notes: The IMR/U5MR are expressed in deaths per 1,000 live births. The CMR1-4 is expressed in deaths per 1,000 children surviving to age one. SD is standard deviation. For the predicted yearly absolute change estimates, 95% confidence intervals are reported in parentheses.

Variation by individual province

Table 5.3 presents the FP models for the IMR/CMR1-4 as a function of year with interaction terms. According to Model 1, there is very strong evidence that the decline in the IMR and the CMR1-4 varied by province based on regression models with interaction terms between the FP-transformed year variables and the variable “province” (partial F-test p<0.001, Table 5.3). There is very strong evidence that speed of mortality decline varied by SDI categories based on the regression model with interaction terms between the FP-transformed year variables and the categorical SDI variable between 1950 and 2016 (Model 2, partial F-test p<0.001, Table 5.3).

Table 5.3: Fractional polynomial models for mortality as a function of year with interaction terms (province and year in Model 1, SDI category and year in Model 2)

	Dependent variable	**IMR**	**CMR1-4**
Model 1	FP-transformed year variable 1[a]	-111.85 (-111.85, -111.85)	-16.18 (-16.18, -16.18)
	FP-transformed year variable 2[b]	16.22 (16.22, 16.22)	3.36 (3.36, 3.36)
	Constant	358.00 (358.00, 358.00)	153.77 (153.77, 153.77)
	Partial F test for the interaction terms between FP-transformed variables and province	p<0.001	p<0.001
Model 2	FP-transformed year variable 1[a]	-84.25 (-91.11, -77.40)	-7.24 (-8.34, -6.13)
	FP-transformed year variable 2[b]	13.23 (12.04, 14.42)	1.52 (1.28, 1.75)
	SDI categories		
	SDI-low category	108.30 (52.56, 164.05)	92.34 (46.46, 138.23)
	SDI-medium category	83.91 (10.47, 157.36)	48.38 (23.59, 73.18)
	SDI-high category	(ref)	(ref)
	SDI-missing indicator	60.25 (10.80, 109.70)	46.25 (8.56, 83.94)
	Interactions between FP-transformed year variable 1 and SDI categories		
	FP-transformed year variable 1 and SDI-low category	-20.33 (-39.98, -0.68)	-8.46 (-12.71, -4.22)
	FP-transformed year variable 1 and SDI-medium category	-27.88 (-63.88, 8.12)	-4.76 (-7.46, -2.05)
	FP-transformed year variable 1 and SDI-high category	-15.01 (-44.95, 14.93)	-4.27 (-9.19, 0.64)
	Interactions between FP-transformed year variable 2 and SDI categories		
	FP-transformed year variable 2 and SDI-low category	1.54 (-1.85, 4.92)	1.70 (0.84, 2.56)
	FP-transformed year variable 2 and SDI-medium category	4.26 (-2.37, 10.88)	0.97 (0.40, 1.55)
	FP-transformed year variable 2 and SDI-high category	1.91 (-4.18, 8.01)	0.88 (-0.19, 1.95)
	Constant	243.23 (223.89, 262.58)	67.41 (58.11, 76.70)
	Partial F test for the interaction terms between FP-transformed variables and province	p<0.001	p<0.001

Notes: Applying the fractional polynomial method in the data results in automatic calculation of the fractional powers of year, and automatic generation and naming of two variables (term_1 and term_2) in the dataset. a and b represent term_1 and term_2 separately and are termed FP-transformed year variables throughout the chapter. The regression coefficients were shown in the table with 95% confidence intervals in the brackets.

Table 5.4 shows the IMRs and the predicted yearly absolute change of the IMRs for three typical provinces for each of the 14 time periods selected. The typical provinces are selected with the highest (Guangxi, 368.4), the median (Hainan, 200.0) and the lowest (Fujian, 120.0) levels of infant mortality in 1950. The predicted yearly absolute change in the IMR in Guangxi is substantially higher than the predicted yearly absolute change in the other two provinces throughout the periods. Likewise, Hainan experienced more rapid yearly change of the IMR than that of Fujian. Table 5.5 shows the CMR1-4 and the predicted yearly absolute change of the CMR1-4 of three typical provinces for each of the 14 time periods selected. The typical provinces are selected with the highest (Yunnan, 269.2), the median (Sichuan,109.1) and the lowest (Jilin, 19.2) levels of 1-4 mortality in 1950. The predicted yearly absolute change in the CMR1-4 in the typical provinces show the similar pattern as that observed for the IMRs. Yunnan, starting with highest level of 1-4 mortality saw the most dramatic mortality decline.

Table 5.4: Levels of the IMR and predicted yearly absolute change of the IMR for three selected provinces

	Observed levels of mortality for the former year			**Predicted yearly absolute change of the IMR**		
Year	**Guangxi**	**Hainan**	**Fujian**	**Guangxi**	**Hainan**	**Fujian**
1950-1951	368.4	200.0	120.0	-51.7 (-51.7, -51.7)	-40.5 (-40.5, -40.5)	-18.9 (-18.9, -18.9)
1955-1956	85.4	96.2	95.5	-14.1 (-14.1, -14.1)	-10.7 (-10.7, -10.7)	-5.7 (-5.7, -5.7)
1960-1961	141.8	65.5	74.3	-7.6 (-7.6, -7.6)	-5.6 (-5.6, -5.6)	-3.3 (-3.3, -3.3)
1965-1966	70.5	38.0	43.0	-4.8 (-4.8, -4.8)	-3.4 (-3.4, -3.4)	-2.3 (-2.3, -2.3)
1970-1971	47.9	33.2	33.1	-3.2 (-3.2, -3.2)	-2.1 (-2.1, -2.1)	-1.7 (-1.7, -1.7)
1975-1976	36.4	21.9	30.0	-2.1 (-2.1, -2.1)	-1.3 (-1.3, -1.3)	-1.3 (-1.3, -1.3)
1980-1981	36.7	28.6	19.9	-1.4 (-1.4, -1.4)	-0.8 (-0.8, -0.8)	-1.0 (-1.0, -1.0)
1985-1986	-	-	-	-0.9 (-0.9, -0.9)	-0.4 (-0.4, -0.4)	-0.8 (-0.8, -0.8)
1990-1991	44.0	29.2	23.0	-0.5 (-0.5, -0.5)	-0.04 (-0.04, -0.04)	-0.7 (-0.7, -0.7)
1995-1996	-	-	-	-0.2 (-0.2, -0.2)	-0.2 (-0.2, -0.2)	-0.5 (-0.5, -0.5)
2000-2001	27.3	32.7	20.1	0.1 (0.1, 0.1)	0.4 (0.4, 0.4)	-0.4 (-0.4, -0.4)
2005-2006	-	-	-	0.3 (0.3, 0.3)	0.6 (0.6, 0.6)	-0.3 (-0.3, -0.3)
2010-2011	7.6	13.3	7.6	0.5 (0.5, 0.5)	0.7 (0.7, 0.7)	-0.3 (-0.3, -0.3)
2015-2016	4.4	6.0	4.6	0.6 (0.6, 0.6)	0.8 (0.8, 0.8)	-0.2 (-0.2, -0.2)

Notes: Mortality are expressed in deaths per 1,000 live births. SD is standard deviation. SD is standard deviation. For the predicted yearly absolute change estimates, 95% confidence intervals are reported in parentheses. The equal upper and lower confidence intervals are due to very small standard error.

Table 5.5: Levels of the CMR1-4 and predicted yearly absolute change of the CMR1-4 for three selected provinces

	Observed levels of mortality for the former year			**Predicted yearly absolute change of the CMR1-4**		
Year	**Yunnan**	**Sichuan**	**Jilin**	**Yunnan**	**Sichuan**	**Jilin**
1950-1951	269.2	109.1	19.2	-15.7 (-15.7, -15.7)	-10.8 (-10.8, -10.8)	-3.5 (-3.5, -3.5)
1955-1956	166.0	128.7	31.9	-9.1 (-9.1, -9.1)	-6.3 (-6.3, -6.3)	-1.9 (-1.9, -1.9)
1960-1961	108.8	98.4	26.2	-6.5 (-6.5, -6.5)	-4.5 (-4.5, -4.5)	-1.4 (-1.4, -1.4)
1965-1966	50.8	52.5	10.5	-4.9 (-4.9, -4.9)	-3.4 (-3.4, -3.4)	-1.0 (-1.0, -1.0)
1970-1971	49.7	31.4	8.4	-3.7 (-3.7, -3.7)	-2.6 (-2.6, -2.6)	-0.7 (-0.7, -0.7)
1975-1976	39.4	31.1	4.7	-2.8 (-2.8, -2.8)	-2.0 (-2.0, -2.0)	-0.5 (-0.5, -0.5)
1980-1981	*35.1*	*25.7*	*2.9*	-2.0 (-2.0, -2.0)	-1.5 (-1.5, -1.5)	-0.3 (-0.3, -0.3)
1985-1986	-	-	-	-1.3 (-1.3, -1.3)	-1.0 (-1.0, -1.0)	-0.2 (-0.2, -0.2)
1990-1991	29.1	37.0	0.6	-0.8 (-0.8, -0.8)	-0.7 (-0.7, -0.7)	0.0 (0.0, 0.0)
1995-1996	-	-	-	-0.2 (-0.2, -0.2)	-0.3 (-0.3, -0.3)	0.1 (0.1, 0.1)
2000-2001	19.9	25.7	2.6	0.2 (0.2, 0.2)	0.0 (0.0, 0.0)	0.2 (0.2, 0.2)
2005-2006	-	-	-	0.6 (0.6, 0.6)	0.3 (0.3, 0.3)	0.3 (0.3, 0.3)
2010-2011	8.2	11.1	4.0	1.0 (1.0, 1.0)	0.5 (0.5, 0.5)	0.4 (0.4, 0.4)
2015-2016	8.3	10.3	6.3	1.4 (1.4, 1.4)	0.8 (0.8, 0.8)	0.5 (0.5, 0.5)

Notes: Mortality are expressed in deaths per 1,000 children surviving to age one. SD is standard deviation. SD is standard deviation. For the predicted yearly absolute change estimates, 95% confidence intervals are reported in parentheses. The equal upper and lower confidence intervals are due to very small standard error.

Variation by region

The results of the PCA analysis for the SDI in year 1952 are presented in Table 5.6. The eigenvalue is presented in descending order. The component 1 explains 78% of the variance of the four original variables and is retained to compute the SDI. The SDI is given by the following linear combinations of the original variables:

$$Y(SDI) = 0.51X1+0.44X2+0.53X3+0.51X4$$

All the variables (X1 for GDP per capita; X2 for primary education enrolment ratio; X3 for secondary and higher education enrolment ratio; X4 for per cent of urban population) included in the PCA analysis have positive coefficients, and are therefore associated with higher socio-demographic status. Each variable is assigned a weight to calculate the SDI. The secondary and higher education enrolment ratio and the primary education enrolment ratio have the highest and lowest contribution to the SDI, with a weight of 0.53 and 0.44 respectively. GDP per capita and per cent of urban population have equal contributions to the SDI, with a weight of 0.51.

Table 5.6: Results from the principal component analysis for the socio-demographic index (SDI) in 1952

Component	Eigenvalue	Variance proportion	Cumulative variance proportion
Component 1	3.13	0.78	0.78
Component 2	0.54	0.14	0.92
Component 3	0.20	0.05	0.97
Component 4	0.14	0.03	1.00
Variable	Weight for component 1		
Primary education enrolment ratio	0.44		
Secondary and higher education enrolment ratio	0.53		
GDP per capita	0.51		
Per cent of urban population	0.51		

Based on the distribution of the generated SDI (Table 5.7), seven provinces are grouped into the SDI-low category (Anhui, Guizhou, Henan, Hubei, Hunan, Shandong and Yunnan) (Figure 5.19). Seven provinces are included in the SDI-medium category (Fujian, Guangxi, Jiangsu, Jiangxi, Shaanxi, Xinjiang and Zhejiang) and six provinces are included in the SDI-high category (Guangdong, Hebei, Heilongjiang, Inner Mongolia, Jilin and Shanxi). Seven provinces are included in the missing indicator category (Gansu, Liaoning, Ningxia, Qinghai, Sichuan, Tibet and Hainan).

Among provinces with complete data, there are only five in which the SDI category agrees with the 1986 government classification (Guizhou, Yunnan, Jiangxi, Guangdong and Hebei). The categorization of all the other provinces does not agree in the two classifications. For example, provinces from the northeast of China (Heilongjiang, Jilin, Inner Mongolia), which were categorised as the central region in the 1986 classification were categorized into the SDI-high category whilst some coastal provinces (Jiangsu, Zhejiang, Fujian), who belonged to the eastern region in the government 1986 classification were classified into the SDI-medium category.

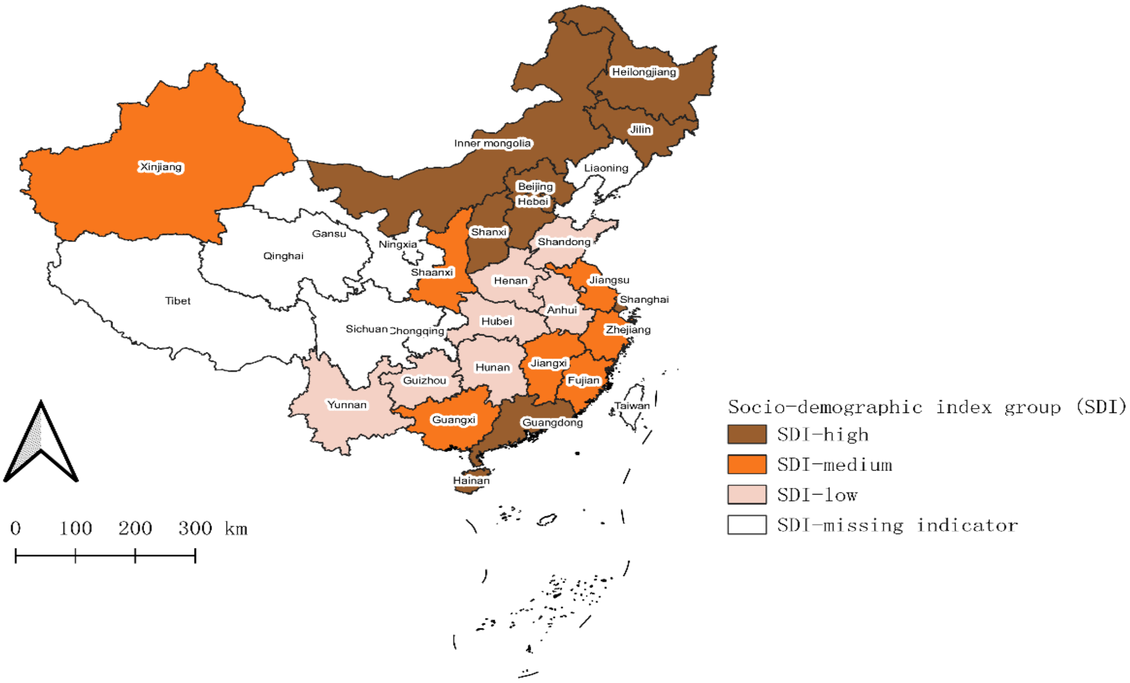


Figure 5.19: Socio-demographic index (SDI) grouping of provinces based on data in 1952

The mean and confidence intervals of the 4 variables in 1952 are summarized in Table 5.7. There is good evidence of variation in GDP per capita (yuan) between SDI-low category, which was 80 (95% CI: 70-90), and SDI-high category, which was 150 (95% CI: 100-200). There is a substantial difference in the primary education enrolment ratio between SDI categories, though the confidence intervals were mostly overlapping. There is also good evidence that the SDI-low category and SDI-medium had a lower secondary and higher education enrolment ratio and lower per cent of urban population than the SDI-high category.

Figures 5.20 and 5.21 present the mean IMR and the mean CMR1-4 separately by SDI category in 1950, 1960, 1970, 1980, 1990, 2000, 2010 and 2016. In 1950, the IMR and the CMR1-4 were generally lower in the SDI-high category than in the other two categories, but these differences disappeared over time (Table 5.8). The SDI-low category and the SDI-medium category had more or less equal estimates in the mean IMR, the mean CMR1-4 and the mean U5MR in 1950 and 2016, meaning that the SDI categorization captures one richer group and a larger group of poorer provinces. Partly due to very small sample sizes, I found no evidence of variation in IMR between SDI-groups in 1950 or in 2016 (Table 5.8).

Table 5.7: The SDI categories of provinces and the mean of the socio-demographic variables in 1952

SDI category	Included provinces	GDP per capita (yuan)	Primary education enrolment ratio (%)	Secondary and higher education enrolment ratio (%)	Per cent of urban population (%)
SDI-low	Anhui, Guizhou, Henan, Hubei, Hunan, Shandong, Yunnan	80 (70, 90)	32.48 (25.49, 39.48)	2.37 (1.17, 3.57)	8.00 (5.72, 10.28)
SDI-medium	Fujian, Guangxi, Jiangsu, Jiangxi, Shaanxi, Xinjiang, Zhejiang	110 (80, 140)	35.33 (32.13, 38.54)	4.89 (3.66, 6.12)	13.28 (11.14, 15.41)
SDI-high	Guangdong, Hebei, Heilongjiang, Inner Mongolia, Jilin, Shanxi	150 (100, 200)	73.00 (33.18, 112.81)	5.03 (2.86, 7.20)	16.24 (8.16, 24.31)
SDI-missing indicator	Gansu, Liaoning, Ningxia, Qinghai, Sichuan, Tibet, Hainan	120 (70, 180) (Hainan not counted)	52.73 (41.32, 146.79) (Ningxia, Tibet not counted)	1.97 (Only Gansu counted)	12.30 (0.39, 24.21) (Gansu, Sichuan, Tibet not counted)

Notes: numbers are mean (95% confidence intervals) across provinces for each summarized variable.

1 Chinese yuan was equivalent to around 0.4 US dollars during 1955-1971. The exchange rate was set at 2.46 yuan to the dollar until 1971.

Table 5.8: Absolute and relative differences in the IMR, CMR1-4 and U5MR between SDI categories in China in 1950 and 2016

	IMR		**CMR1-4**		**U5MR**	
	Year 1950	**Year 2016**	**Year 1950**	**Year 2016**	**Year 1950**	**Year 2016**
Mean (95% CI)						
SDI-low category	237.76 (198.45, 277.08)	5.84 (3.02, 8.68)	132.8 (82.64, 183.01)	8.06 (5.70, 10.42)	337.96 (272.33, 403.58)	13.86 (8.59, 19.13)
SDI-medium category	229.98 (190.66, 269.30)	6.51 (3.68, 9.34)	139.53 (89.35, 189.72)	7.69 (5.33, 10.05)	334.41 (234.29, 434.52)	14.14 (8.87, 19.41)
SDI-high category	186.79 (144.32, 229.25)	5.23 (2.17, 8.28)	82.07 (27.86, 136.27)	6.64 (4.09, 9.19)	253.50 (210.88, 296.12)	11.83 (6.14, 17.53)
Absolute difference in rates (95% CI)						
SDI-medium minus SDI-high category	43.19 (-14.68, 101.06)	1.28 (-2.88, 5.45)	57.47 (-16.40, 131.34)	1.05 (-2.43, 4.53)	80.91 (-10.28, 172.09)	2.31 (-5.45, 10.07)
SDI-low minus SDI-high category	50.98 (-6.90, 108.85)	0.62 (-3.54, 4.79)	50.76 (-23.11, 124.63)	1.42 (-2.06, 4.89)	84.46 (-6.73, 175.64)	2.02 (-5.74, 9.78)
Rate ratio (95% CI)						
SDI-medium to SDI-high category	1.17 (0.90, 1.52)	1.07 (0.61, 1.86)	1.89 (0.93, 3.85)	1.09 (0.66, 1.78)	1.27 (0.94, 1.71)	1.08 (0.67, 1.74)
SDI-low to SDI-high category	1.27 (0.97, 1.65)	1.13 (0.65, 1.97)	1.69 (0.83, 3.44)	1.20 (0.73, 1.96)	1.32 (0.98, 1.78)	1.16 (0.72, 1.87)

Notes: For the mean, numbers are mean (95% confidence intervals) across provinces for each SDI category.

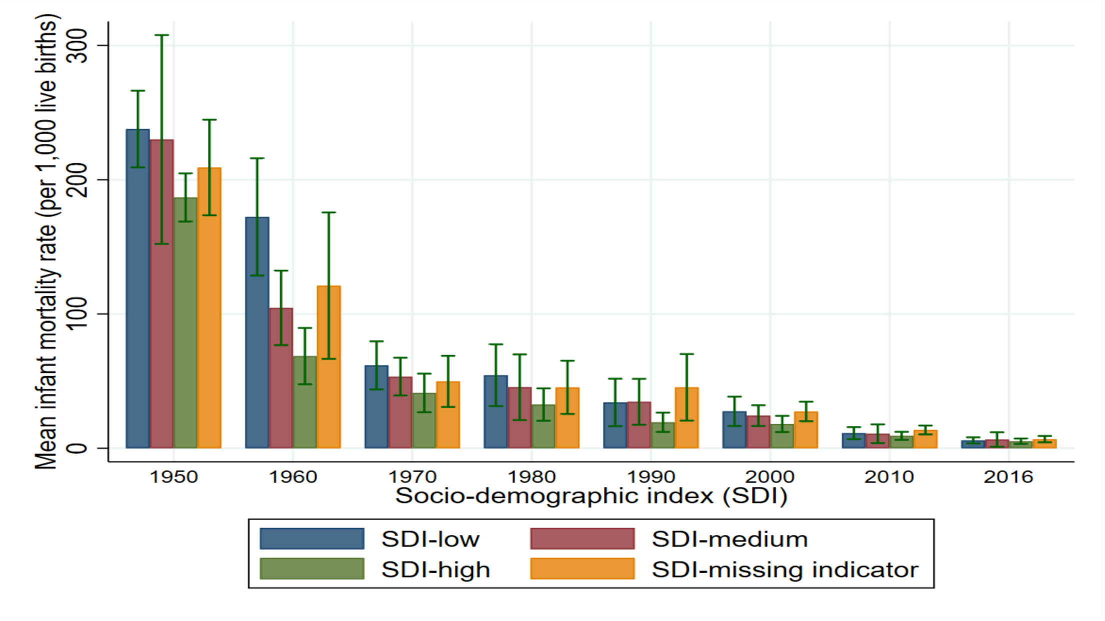


Figure 5.20: Infant mortality rate by SDI category, 1950, 1960, 1970, 1980, 1990, 2000, 2010 and 2016

Notes: Each bar represents the mean of infant mortality in the given year in the specified SDI category. The error bars represent the 95% confidence intervals of the means.

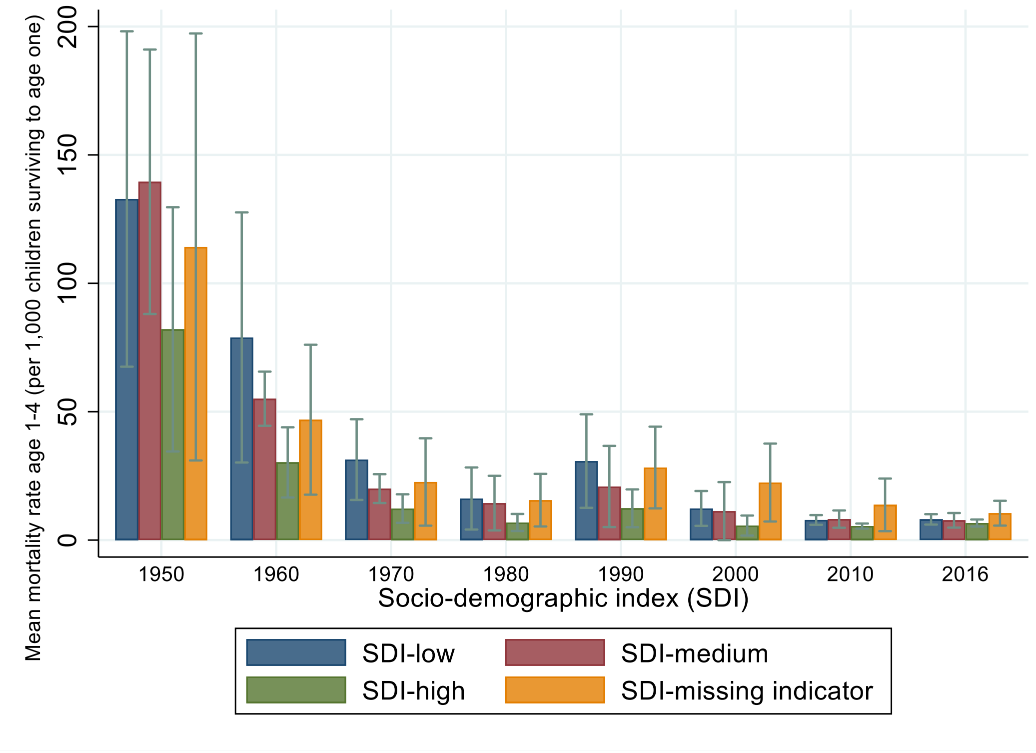


Figure 5.21: Child mortality rate aged 1-4 by SDI category, 1950, 1960, 1970, 1980, 1990, 2000, 2010 and 2016

Figure 5.22 shows that the absolute difference between the IMR in the lowest SDI category and highest SDI category narrowed between 1950 and 2016, suggesting convergence in IMR. For the CMR1-4, similar patterns were seen (Figure 5.23).

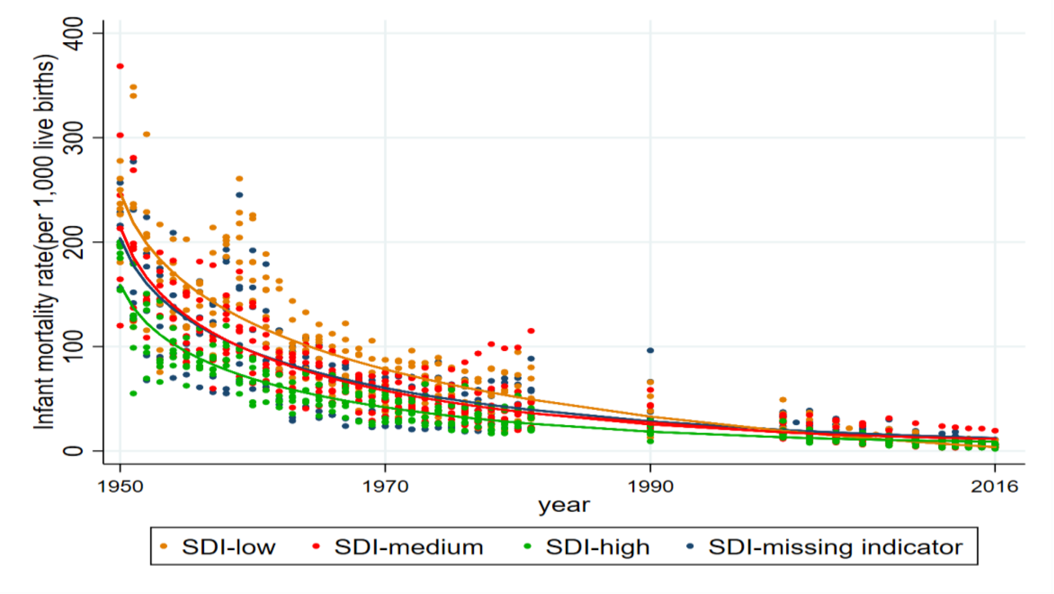


Figure 5.22: Infant mortality rate by socio-demographic (SDI) category, 1950-2016

Notes: Dots represent observed IMR for each province-year, which has been grouped by SDI categories. Lines represent the modelled trend in IMR from 1950 to 2016 by SDI categories.

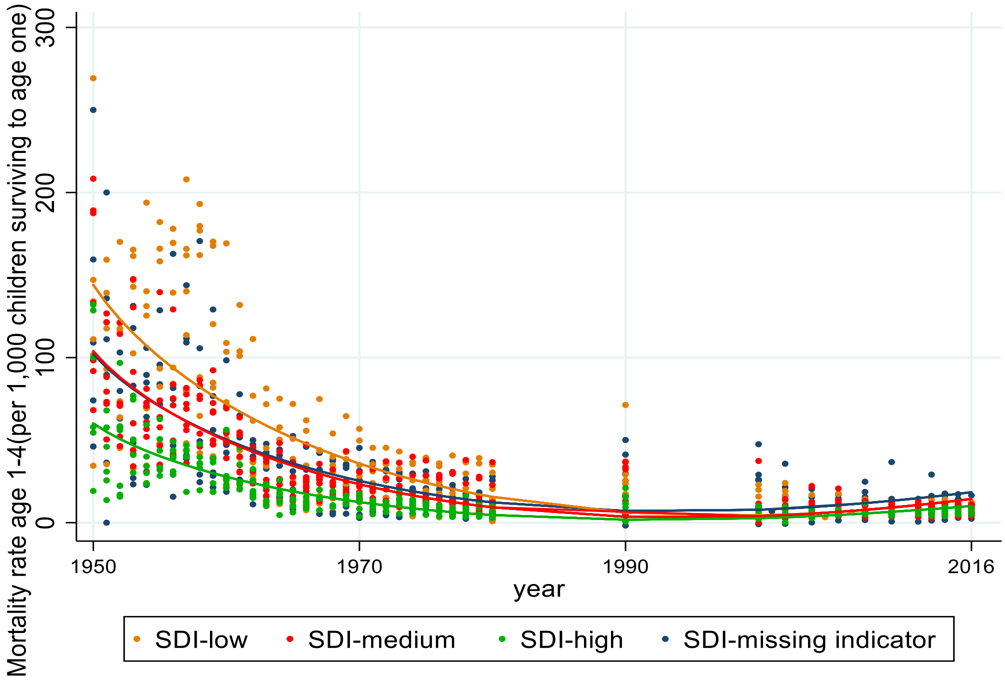


Figure 5.23: Child mortality rate aged 1-4 by socio-demographic (SDI) category, 1950-2016

Notes: Dots represent the CMR1-4 for each province-year, which was calculated using the IMR and the U5MR following the formulae, CMR1-4=(U5MR-IMR)/(1-IMR)

When looking at the confidence intervals, the analysis suggests that the predicted yearly absolute change of the IMR differed consistently between the SDI-low category and the SDI-high category throughout the predicted years (Table 5.9). The difference in the predicted yearly absolute change of the IMR between the SDI-low category and the SDI-medium category was only statistically significant during 1980-1981, 1985-1986, 1990-1991 and 1995-1996, with the SDI-low category having more rapid yearly decline in the IMR, confirming that the SDI-low category and the SDI-medium category are not that different. The difference in the predicted yearly absolute change of the IMR between the SDI-medium category and the SDI-high category was statistically significant during 1965-1966, 1970-1971, 1975-1976 and 1980-1981, with the SDI-medium category having more rapid yearly decline in IMR.

For the CMR1-4, the predicted yearly absolute change of mortality differed consistently between the SDI-low category and the SDI-high category, and between the SDI-medium category and the SDI-high category during the 1950-1951, 1955-1956, 1960-1961, 1965-1966, 1970-1971, 1975-1976, 1980-1981, 1985-1986 and 1990-1991, with the SDI-high category having the slowest yearly decline (Table 5.9). By looking at the confidence intervals, I found no evidence of difference in the predicted yearly absolute change of the CMR1-4 between the SDI-low category and the SDI-medium category throughout the predicted years.

Table 5.9: Predicted yearly absolute change of the IMR and the CMR1-4

Year	Predicted yearly absolute change of the IMR (deaths per 1,000 live births)			Predicted yearly absolute change of the CMR1-4 (deaths per 1,000 children surviving to age one)		
	SDI-low category	**SDI-medium category**	**SDI-high category**	**SDI-low category**	**SDI-medium category**	**SDI-high category**
1950-1951	-28.8 (-33.5, -24.2)	-29.3 (-37.6, -21.0)	-21.9 (-23.7, -20.2)	-11.4 (-14.2, -8.3)	-8.6 (-10.3, -6.8)	-5.1 (-5.9, -4.4)
1955-1956	-9.3 (-10.7, -8.0)	-8.7 (-10.7, -6.7)	-6.5 (-7.0, -6.0)	-6.5 (-8.2, -4.7)	-4.8 (-5.8, -3.9)	-2.9 (-3.3, -2.5)
1960-1961	-5.7 (-6.6, -4.9)	-5.1 (-6.1, -4.1)	-3.8 (-4.1, -3.5)	-4.6 (-5.9, -3.4)	-3.4 (-4.1, -2.7)	-2.0 (-2.3, -1.7)
1965-1966	-4.1 (-4.7, -3.6)	-3.5 (-4.0, -2.9)	-2.5 (-2.8, -2.3)	-3.5 (-4.4, -2.5)	-2.5 (-3.0, -2.0)	-1.5 (-1.7, -1.3)
1970-1971	-3.2 (-3.7, -2.7)	-2.5 (-2.9, -2.2)	-1.9 (-2.0, -1.7)	-2.6 (-3.4, -1.8)	-1.8 (-2.2, -1.5)	-1.1 (-1.2, -0.9)
1975-1976	-2.6 (-3.0, -2.2)	-1.9 (-2.2, -1.7)	-1.4 (-1.6, -1.2)	-1.9 (-2.5, -1.3)	-1.3 (-1.6, -1.1)	-0.7 (-0.9, -0.6)
1980-1981	-2.1 (-2.5, -1.8)	-1.5 (-1.7, -1.3)	-1.1 (-1.2, -0.9)	-1.4 (-1.9, -0.9)	-0.9 (-1.1, -0.7)	-0.5 (-0.6, -0.4)
1985-1986	-1.8 (-2.1, -1.5)	-1.2 (-1.4, -1.0)	-0.8 (-1.0, -0.7)	-0.9 (-1.3, -0.5)	-0.5 (-0.6, -0.4)	-0.3 (-0.3, -0.2)
1990-1991	-1.6 (-1.8, -1.3)	-0.9 (-1.2, -0.7)	-0.7 (-0.8, -0.5)	-0.5 (-0.8, -0.2)	-0.2 (-0.3, -0.1)	-0.1 (-0.1, 0.0)
1995-1996	-1.3 (-1.6, -1.1)	-0.7 (-1.0, -0.5)	-0.5 (-0.6, -0.4)	-0.1 (-0.4, 0.1)	0.1 (-0.1, 0.2)	0.1 (0.0, 0.2)
2000-2001	-1.2 (-1.4, -0.9)	-0.6 (-0.9, -0.3)	-0.4 (-0.5, -0.3)	0.2 (-0.1, 0.5)	0.3 (0.2, 0.5)	0.3 (0.2, 0.3)
2005-2006	-1.0 (-1.3, -0.8)	-0.4 (-0.8, -0.1)	-0.3 (-0.4, -0.2)	0.5 (0.2, 0.8)	0.6 (0.4, 0.7)	0.4 (0.3, 0.5)
2010-2011	-0.9 (-1.2, -0.6)	-0.3 (-0.7, 0.0)	-0.2 (-0.3, -0.1)	0.8 (0.5, 1.1)	0.8 (0.5, 0.9)	0.5 (0.4, 0.7)
2015-2016	-0.8 (-1.1, -0.5)	-0.2 (-0.6, 0.1)	-0.1 (-0.2, 0.0)	1.0 (0.7, 1.4)	0.9 (0.7, 1.2)	0.7 (0.5, 0.8)

Notes: 95% confidence intervals reported in parentheses.

5.5 Discussion

Over the period 1950 to 2016, mortality rates for infants, children age 1-4 and children under 5 have declined substantially, with the greatest absolute decline occurring in 1950-1955. Between 1950 and 1951 the predicted yearly absolute change across all provinces was -26.7 (95% CI: -29.8, -23.5), and -39.7 (95% CI: -44.3, -35.0) deaths per 1,000 live births for the IMR and the U5MR, -8.4 (95% CI: -9.9, -6.9) deaths per 1,000 children surviving to age one for the CMR1-4. From 1985 onwards all yearly absolute changes were below 2 deaths per 1000 live births (or per 1,000 children surviving to age one). There were marked differences in the levels of mortality and the speed of decline between provinces and socio-economic regions. The SDI-low category and provinces with the highest burden of mortality made the greatest absolute progress.

Across all provinces, the magnitude of the change in infant and child mortality was greatest in the 1950s, slowing down thereafter. Unlike most western countries, where child mortality declined steadily from the late nineteenth century into the 1950s[243], China still had extremely high levels of under-5 child mortality in 1950, with some provinces having levels as high as 500 child deaths per 1,000 live births. The timing of the rapid mortality decline in China coincided with the availability of antibiotics, immunization and sanitation and specific disease control programmes after the Second World War (1939-1945)[244]. In western countries, for example the US and Canada, the declines in child mortality were more gradual in the early decades of the 1900s, and were largely explained by improved nutrition, sanitation and environmental improvements[12]. As Omran developed the epidemiologic transition theory, he classified countries such as China, South Korea, Sri Lanka, Chile, Cuba, under the Rapid Model in epidemiologic transition[244]. The Rapid Model countries had very high child mortality rates after the second world war, but the mortality rates declined massively thereafter. Omran argued that this was attributable to the successful child survival programmes and specific disease control programs, which were mostly sponsored by international organizations[244].

Rather than relying on international organizations, China explicitly politicized MCH under Chairman Mao and used MCH efforts to improve population health, in order to further develop economy[210]. The government viewed traditional midwives positively, designated a series of aseptic procedures for home births and supported access to contraception in the 1950s[210]. A series of MCH policies and programs appeared remarkably effective in reducing infant mortality between 1950 and 1965, although the effects are impossible to verify. Lim estimated that 60% of rural births and 9% of urban births were attended by trained health workers by 1959[245]. Accompanying the success of MCH policies and programs, the health systems performed well in infectious disease control through vaccination, hygiene, sanitation, and the control of disease vectors, such as mosquitoes and rats[38]. By the end of 1950s, multiple infectious diseases had been severely curtailed, including diphtheria, typhus and relapsing fever[210].

The famine during the Great Leap Forward in 1959-1961 severely interrupted the rapid decline of infant and child mortality. The accurate estimations of infant and child mortality during the famine cannot be known with certainty because even at that time, the extent and the severity of the crisis was questioned by Chairman Mao among others[246, 247]. But the impact was so profound that the level of infant and 1-4 child mortality almost reversed back to the levels in the early 1950s. Researchers suggested that food availability does not necessarily decline for famine to occur. Nevertheless, researchers usually look for an explanation of famine by examining food availability[248]. The production of grain per capita in my data suggest that there was not a huge drop in food output in 1959-1961. But caution is needed in interpreting these data because agricultural statistics are subject to manipulation and pressures to report success during the Great Leap Forward[246]. Ashton and his colleagues estimated that there was a drop in grain output of more than 25 percent in 1960-1961[246]. Equally marked have been the heterogeneous impact of the famine in some provinces (Henan, Hebei, Shandong, Anhui, Hubei, Guizhou) more than others and the heterogeneous levels of infant and child mortality during the crisis. Extensive interviews with refugees by authors revealed that the crisis was far worse in rural areas than in urban areas and more prolonged in the north than in the south[249]. There is now little doubt that child mortality was also far worse in provinces from the North. The drought in north China could have lowered the grain output in the worst affected provinces. But the worst droughts in modern China in the 1990s had a marginal effect on the food supply[250]. Data on the production of grain per capita tell us little about the reason why some provinces from the south, for example Anhui and Guizhou, had higher child mortality and others did not. The abilities to obtain food could have explained the variable suffering from the famine. Authors argued that the absence of an effective food distribution mechanism could be particularly important in regard to the regional and provincial disparities[246].

China’s massive progress in child survival occurred at a time when China was extremely poor. By 1978, China’s real GDP per capita was 307.1 US dollars, one-tenth of that in Brazil[251]. Economic growth has been treated as the main contributor to improved child health traditionally though its role remains much debated [252, 253]. It is widely hypothesized that increased income has an indirect effect on mortality through enabling the society to afford better housing, education, food and health services[254]. However, some have suggested that mortality may become dissociated from economic levels because of the diffusion of education investment, urbanization, health resources that could be improved largely independent of absolute economic level [252]. Previous evidence from Latin America showed that the relationship between income level and mortality applied only prior to 1930s not thereafter [252]. In 1985, four countries or regions (China, Costa Rica, Sri Lanka and the state of Kerala in India) were seen as superior health performers in achieving improvements in health with fairly low income, which dispelled the long-believed myth that economic growth was necessary for health gains. After examining the four cases, researchers identified contributing factors to the success, including political commitment to health equity, expanded education and well-performing basic health systems[24]. But researchers failed to present a solid evaluation of the obvious trap that good health could be achieved in unfavourable economic circumstances [255].

It is important to note that hospitals were built under the Mao era, particularly in 1950-1964, with hardly any expansion over time (relative to population increases) except after 2010. Health professional density and doctor density increased quite a lot in the initial years under Chairman Mao (1950-1964). The rapid expansion of doctor density—three-fold increase between 1950 (3.1 doctors per 10,000 population) and 1964 (10.3 doctors per 10,000 population)—kept up with a growing number of total population (563 million in 1950 to 705 million in 1964). Between 2010 and 2017, the mean of doctor density across provinces increased from 17.9 to 23.9 per 10,000 population. In 2020, the national estimate of doctor density was 29 per 10,000 population[25], which is similar compared to the UK’s at 28 and the US’s 26 per 10,000 population in 2018. Progressive realisation of high doctor density is a long effort, which usually takes a few decades. The short time involved in the training of doctors, particularly for the period 1950-1964 is impressive, meaning that the expansion of medical education can be achieved in a short space of time to address workforce shortages for a country with rapidly growing populations. The production of doctors in China follows government imperatives rather than responding to labour market demand[72], which made the workforce expansion possible in 1950-1964.

The basic education was fairly achieved before the economic reform (1978) despite the fact that the economy was very poor and stagnant[15, 38]. Before economic reforms, the Chinese economy was described as “on the brink of disaster” due to its negligible growth and poor incentives[256]. However, the gross enrolment ratio of primary education rose steadily before economic growth. In 1977 the mean gross enrolment ratio of primary education across provinces was 94%. The enrolment ratio in China were much higher than in other Asian countries, for example South Korea, at the early stage of economic take-off[254]. According to Babiarz and colleagues' analysis of the data in 1950-1980, 55-70% of China's rapid decline in the IMR and U5MR can be explained by gains in education enrolment (measured as enrolment ratio of primary education, enrolment ratio of secondary and higher education) and public health campaigns[15]. There is substantial evidence from international literature that primary education is the key driver of child mortality decline[105]. The MDG 2 also called for universal primary education[90]. The updated data shown in this chapter underscores the importance of primary education and suggests that, primary education changed in such a way as to promote the rapid decline in infant and child mortality in 1950-1964. The rise in primary education in China without economic growth is probably attributable to increased domestic financing of education[105], which is a demonstration of how national policies emphasising the expansion of primary education. When comparing to primary education, the role of secondary education is uncertain in the rapid decline in child mortality, because the enrolment ratio of secondary and higher education did not change considerably in 1950-1964.

By contrast, the transportation (e.g. length of highways and possession of civil vehicles) and communications infrastructure (e.g. ownership of telephone and television coverage rate) developed more rapidly after the economic reforms. After opening to the outside world, the government invested more heavily on the construction of highways and communications facilities[254], resulting in rapid growth in infrastructure as seen in GDP per capita. Although improvements in transportation and communications contributed to a striking decline of mortality rates in general and of child mortality after the industrial revolution, notably in Western Europe, the US, Canada and later in Japan[257], substantial improvements in transportation and communication might not be a necessary condition for the rapid decline in child mortality in China.

The geographic variations in the IMR, the CMR1-4 and the U5MR persisted across regions and provinces over the entire period. Better-off regions and provinces in terms of GDP, education and urbanisation continued to have comparatively lower infant and child mortality burden than their counterparts. Take Liaoning for example, Liaoning was one of the first provinces in China to industrialize, ranking top three among provinces in terms of GDP per capita (87 US dollars) and primary education enrolment ratio (141%) in 1952. Liaoning remained among the top in having the lowest infant and child mortality rates in 1950-2016. An opposite example is Guizhou, one of the least developed provinces in western China, ranking low in GDP per capita (23 US dollars) and primary education enrolment ratio (21%) in 1952. Guizhou persisted having very high infant and child mortality rates in 1950-2016. Even the rural health policies pursued during the Cultural Revolution, including establishment of medical stations, training barefoot doctors and building pharmaceutical sales network into villages could not eliminate the inequalities between provinces[66]. According to my data, the U5MR was 139 deaths per 1,000 live births in Guizhou in 1970, while that for Liaoning was 26 deaths per 1,000 live births. In 2017, several provinces in east China (Liaoning, Jiangsu, Zhejiang, Fujian, Guangdong) had the lowest U5MR (7.0 deaths per 1,000 live births), which was equivalent to the estimates in north America (6.3) but higher than the estimates in Western Europe (3.8) in 2019[258]. In contrast, Tibet had the highest U5MR (36.0) in 2017, equivalent to the level of under-5 mortality in South Asia (40.2) in 2019[258]. The potential for further improvement in China's child mortality rates exists. This finding also suggests that to further reduce child mortality, it will be necessary for policy makers at the national and provincial levels to aim for overall system strengthening, with a particular focus on equity, rather than simply focusing on individual priorities.

Compared to the CMR1-4, infant mortality represents a larger share of under-5 mortality in most years, consistent with the observations seen in many countries[6]. For example, the proportion of the IMR to the U5MR was 54.4% (95% CI: 52.4-56.6) in Senegal in 2000 and became 73.2% (95% CI: 70.3-75.8) in 2017[6]. According to data from the MCHSS in 2019, 62.5% of infant mortality happens in the neonatal period in China[17]. Better pregnancy care, skilled birth delivery and postnatal care have been proved to be critical to reducing neonatal and infant mortality worldwide [10]. To sustain progress in infant survival, particularly for neonates with preterm birth complications and congenital malformations, increasing the accessibility and the utilization of key interventions (such as skilled care for child birth, neonatal resuscitation and initiation of kangaroo mother care for low birth weight infants) is very important [10, 259]. It is relatively unclear why in recent years, particularly after 2000, the shift towards mortality predominantly affecting infants was not evident. China has used various public health programs and interventions to target communicable, maternal and neonatal conditions from 2000, including the Reducing Maternal Mortality Program and Eliminating Neonatal Tetanus Program, which have probably driven the rapid decline of infant mortality [200]. These factors could have explained the greater-than-expected progress in infant mortality reductions after 2000. As for child survival, it is important to reiterate the importance of the multisector determinants of health. The SDI analysis in this chapter suggests the need to augment efforts to address social determinants of health, such as income and education, and improve child survival along the entire SDI spectrum.

By the mid-1970s China already achieved very low infant and child mortality and was already undergoing epidemic transition, which was years ahead of other developing countries of similar economic status[260]. Sub-Saharan Africa had the highest U5MR in the world in 1970–74 (more than 200 deaths per 1,000 live births), but in the years since has had the slowest decline in child mortality. Over the period 1960-1990, the worldwide number of child deaths fell by 2.5% annually, compared with 1.1% annually over the period 1990-2001[261]. The slowdown in the speed of child mortality decline appeared to be a world phenomenon, which is now a key concern to the global public health community. Further work is needed to better understand how to achieve further declines in child mortality.

The study has several limitations. First, although I have systematically searched potential sources of data for infant and child mortality, it is possible that I have not identified all data sources, particularly those not publicly accessible. Second, the adoption of fractional polynomials to model the speed of mortality decline, although better than the alternative modelling methods as shown in the chapter, is not perfect. The predicted yearly absolute change of mortality turned out to an “increase” in some of the selected years, which is against intuition. The approaches in analysing speed of decline can be expanded in the future. Third, despite the contributions of multiple variables discussed, I am unable to explain much of the actual decline in the infant and child mortality by changes observed in the variables.

Last but not least, there could be bias in the estimates of child mortality, because this study relies on point estimates of the IMR, CMR1-4 and U5MR generated with both direct and indirect estimation methods. Data from earlier years (1950-1980) estimated using cohort life table methods need particular scrutiny. Based upon survey responses of mothers aged 15-57, the 1988 National Survey of Fertility and Contraception was the main data source for my mortality analysis before 1980. It is useful to consider the bias that may arise from such retrospective recalls and the indirect demographic techniques. Selection bias can come from the selective mortality among women because only mothers who survived to 1988 were able to report her birth history in the survey. The direction of the bias is likely downward, i.e., the levels of infant and child mortality have been underestimated, because mother’s death is usually associated with increased death risks for infants/children[262-264]. This also explains why an unreal peak of the IMRs occurred in 1981 using the census data. Information bias can simply arise from the misreporting of the number of live births and the number of surviving children, including the report of a stillbirth as live birth or aversion to mentioning a dead child [94]. There is also a potential bias from the fact that there is only contributing information from women in the age interval 15-19 for the earliest year 1950, which can lead to high estimates of the IMR and the U5MR because there is established association between young maternal age with higher risk of child death[265]. The mortality estimates for the recent three decades (1990-) are largely based upon the MCHSS and the GBD study, which are subject to retrospective adjustment.

The potential biases could influence the accuracy in the absolute mortality level estimates, but are unlikely to affect time trends or provincial variations because biases might have masked short-term trends. The longitudinal trend based on the updated dataset agree reasonably well with the national trend in the scoping review (Chapter 4), which is encouraging. Although there are imperfections of the data, the provincial estimations are sufficiently robust to support the basic conclusions in this chapter.

5.6 Conclusion

Across all the provinces, the declines in infant and child mortality were greatest in 1950-1955 and slowed down thereafter. Although all provinces experienced declines in child mortality over the period studied (1950-2017), better-off regions and provinces had consistently lower child mortality levels, suggesting that as long as there are regional and provincial variation in child survival, the potential for further improvement in China’s child mortality rates exists. The largest reductions in infant and child mortality happened when China was extremely poor, suggesting that the GDP per capita did not play an important role in lowering infant or child mortality. In the absence of major economic changes, rapid expansion in health workforce, public health campaigns and expansion of primary education made rapid decline in infant and child mortality possible.

Chapter 6. The contribution of doctor density to child mortality: a provincial analysis between 1950-2016

Based upon the updated dataset 1950-2017, Chapter 6 addresses the fourth objective of the thesis by using multivariable regression across provinces to investigate the strength of association between doctor density and child mortality by period of time, while controlling for other determinants of child mortality.

6.1 Introduction

The epidemiological transition in causes of deaths suggests that the determinants of infant and child mortality between 1949 and 2019 may have changed over time (Chapter 4). Notwithstanding the potential importance of increasing health workforce density, many questions remain regarding the strength of association, especially when the changing determinants of child mortality are taken into account. The relationship between health workforce density and child survival could differ between these periods. The evidence supporting the increase of health workforce density in the reductions of child mortality in China is largely based on either cross-sectional data or historical data spanning two or three decades[15, 72], which cannot capture changes over the 70 years postulated here.

In an era of slower decline in child mortality (Chapter 5), investigating the effect of health workforce density on child survival by period of time in China might provide opportunities for shared learning on how to make progress within the resource constraints. This rich volume of information in the updated dataset 1950-2017 provides an opportunity to examine evidence of effect and clear accountability for child mortality declines due to the increase in doctor density by period of time.

6.2 Objectives

To investigate whether and to what extent the strength of association between doctor density and the IMR/CMR1-4 changed by periods of time (1950-1964, 1965-1980, 2000-2016); and to examine the health systems and socio-economic determinants of the IMR/CMR1-4 across 27 provinces in China over the same periods.

6.3 Methods

6.3.1 Data sources

Data on the IMR and CMR1-4 as well as data on doctor density and other determinants of child mortality at provincial level are readily available in 1950-2016 from the updated dataset (see Section 5.3.2 in Chapter 5 for more details of data sources; see Appendix D for the table summaries of missing data).

6.3.2 Variables on child mortality

Given the different underlying causes of deaths for infants and children aged 1-4 (Chapter 4), I used the IMR and the CMR1-4 as separate outcome variables to allow for the possibility that the strength of association between doctor density and the two child mortality variables might differ. The IMR is expressed as the number of deaths per 1,000 live births. The CMR1-4 is expressed as the number of deaths per 1,000 children surviving to age one.

6.3.3 Variables on health workforce density

I focus on doctor density because the data for doctor density are more complete than data on specialist MCH workers and nurses. I would have liked to include nurse density but these data are not available at provincial level. Doctor density is expressed as the number of doctors per 10,000 population. Before 2002, the numerator counts the number of licensed doctors, licensed assistant doctors and intern doctors who are practising in medical treatment, disease prevention or healthcare institutions. Since 2002, doctors only include licensed doctors and assistant licensed doctors based on the medical practitioner certificate[25]. Licensed doctors have a bachelor or higher degree in medicine. Assistant licensed doctors are graduates of three-year junior college, or secondary technical school with a school diploma. Barefoot doctors or village doctors are not included in this variable.

The doctor density by province in 1950-2017 and the period classification are shown in Figure 6.1. The period classification is according to the conceptual framework and data availability, particularly data availability for the IMR and the CMR1-4 (large missing data in 1981-1999). The data on doctor density are based on year-end administrative surveys from the Ministry of Health that follow the same standardised procedures (survey tools, interviewer training, data collection and analysis) in all health facilities[25, 72], therefore the data are comparable across provinces. In addition, the health workforce data from the Ministry of Health have shown good reliability. Anand and colleagues cross-checked the Ministry of Health data with census data in 1990 and 2000 and they found that the counts of health professionals agreed reasonably well between the two sources [72].

In addition to the constantly changing medical education programs and the variable components of “doctors” in China’s contemporary history as I explained in Chapter 2, it is noteworthy that the definition and the measurement of doctor density changed a few times. Figure 6.1 also illustrates the likely sources of measurement bias. First, during the Cultural Revolution (1966-1976), many licensed doctors were reallocated the status of barefoot doctors by health authorities and excluded from the count of doctors, leading to a decrease in reported doctor density. Second, there was a change in the definition of the health workforce statistics in China in 2002 to include only the licensed (assistant) doctors from public and private sectors[72], excluding the interns who were practising but not registered or licensed by the health authorities. Third, after finding a small mismatch between the counts of health professionals from the Ministry of Health data and those from the census data (1990 and 2000), authors argued that the year-end administrative survey may have missed private practitioners before 2000[72]. The three sources of measurement bias will all have caused underestimation of doctor density.

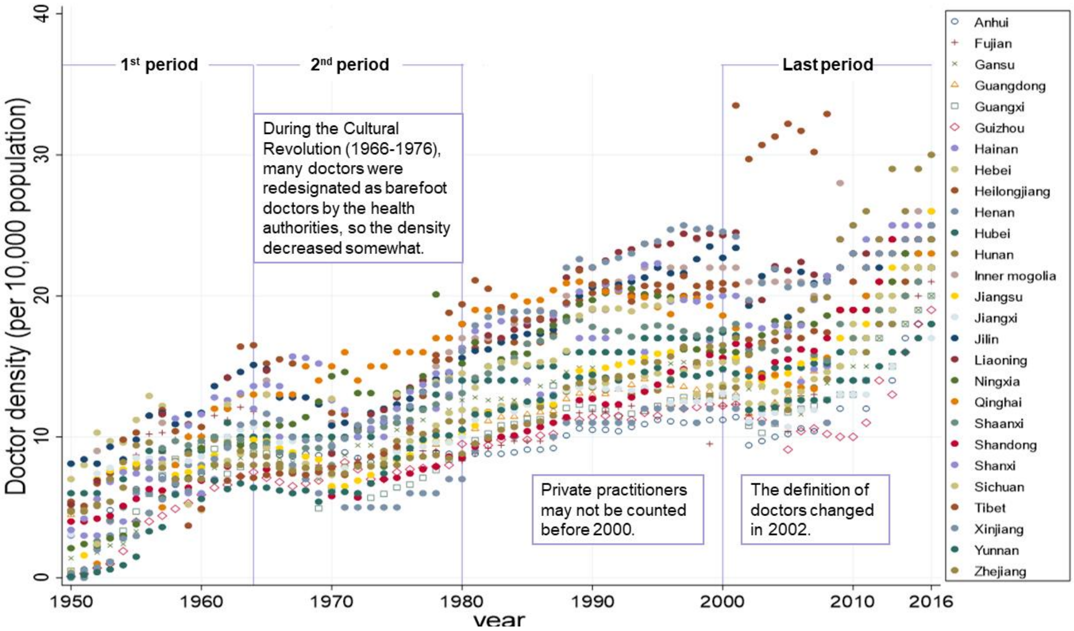


Figure 6.1: Doctor density by province, period classification for analysis and measurement changes, 1950-2016

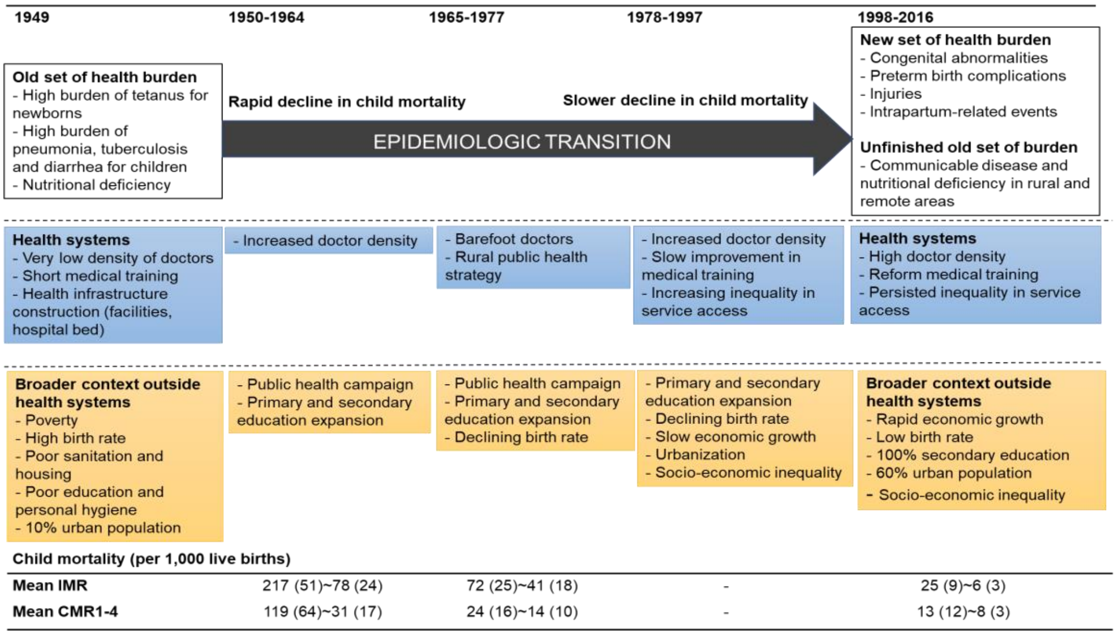
6.3.4 Other determinants of child mortality

I selected potential determinants based on (1) the findings of the scoping review in chapter 4; and (2) a conceptual framework (Figure 6.2) that I adapted from Abdel R.Omran's updated version of the Epidemiologic Transition Theory [244]. I used the framework because it is capable of applying epidemiologic inference to changing mortality over time and links to socio-demographic, environmental and health workforce changes relating to health outcomes; and (3) data availability.

Figure 6.2 shows the substantial epidemiologic transition in child mortality in China over the last few decades. I classified the transition into four periods based on the timing of important socio-demographic changes and health workforce policies as described in Chapter 2. The start of contemporary China in 1949 was a time of high child mortality, high burden of communicable diseases and nutritional deficiency in a context of very low density of doctors, short medical education and poverty. The first period from 1950 to 1964 saw very rapid declines in the IMR and the CMR1-4, coinciding with changes in increased doctor density, public health campaigns and education expansion. The second period 1965-1977 saw continued declines in the IMR and the CMR1-4 despite the social and economic disruptions caused by the Cultural

Revolution. The health system started to focus on rural public health following the call from Chairman Mao to really serve the people. Doctors were sent to rural areas and could not leave without permission, which kept trained doctors in rural facilities[31]. The third period 1978-1997 was a period of rehabilitation and readjustment for both the health system and the whole society. The last period 1998-2016 was a time of economic growth and reforms in education and health systems to balance social development with economic growth. Over time, a shift occurred in the causes of child deaths whereby communicable diseases and malnutrition were progressively, albeit not entirely, displaced by a new set of causes, including congenital abnormalities, preterm birth complications, injuries and intrapartum-related events.

I borrowed the idea of separating determinants in the health system and determinants in the broader context outside the health system from a systems framework centred on health workers [55]. In the first place I put doctor density before other characteristics of the health systems, including medical education, health system infrastructure and health service accessibility, because any function of the health system operates through the health workforce to achieve the ultimate health goals [28, 29, 58].



Child mortality (per 1,000 live births)	1950-1964	1965-1977	1978-1997	1998-2016
Mean IMR	217 (51)~78 (24)	72 (25)~41 (18)	-	25 (9)~6 (3)
Mean CMR1-4	119 (64)~31 (17)	24 (16)~14 (10)	-	13 (12)~8 (3)

Figure 6.2: Framework adapted from the Epidemiologic Transition Theory by Abdel R.Omran

Notes: Means (SDs in parenthesis) of the IMR and the CMR1-4 are simple averages of the province estimates from my dataset, showing the means of the IMR and the CMR1-4 for the cut-off years (1950 and 1964, 1965 and 1977, 1998 and 2016) across provinces.

Since the health workforce density is the primary focus of the chapter, other determinants within the health systems and the broader socio-economic determinants are important covariates to consider for modelling. Within the health system, I considered hospital bed density as a potential covariate but not the health facility density because both doctor density and hospital bed density increased in the past decades within a fixed infrastructure, i.e. health institutions became bigger but the density of health institutions did not change much in the study period. Moreover, hospital bed density has been proposed by WHO as an indicator of health system investments and is most commonly used in analytical endeavours [266, 267]. Outside the health system I considered GDP per capita (adjusted for inflation), the gross enrolment ratio of primary education, the enrolment ratio of secondary education, the per cent of urban population, crude birth rate, the production of grain per capita, the PCA scores for public health campaigns, the length of highways and the local government expenditure in culture, education, science and health care (adjusted for inflation, thereafter referred to as government expenditure) as potential covariates.

The number of variables in the updated dataset 1950-2017 was far too large in relation to the number of provinces, and it was necessary to reduce the number to get a more manageable set of relevant covariates. The relevant covariates were selected based upon a full examination of all the variables in the data. Initial analyses using simple correlations between each of the variables and the IMR/CMR1-4 partly guided the selection of the alternative variables. I placed particular emphasis on selecting relevant covariates based upon the intrinsic importance of the variables, for example, the length of highways versus the length of railways in operation, the former of which is generally considered to be more relevant.

The traditional classification of region in 1986 (Eastern, Central and Western China) was based on the geographical location and level of economic development as explained in Chapter 5. I did not consider region as a potential covariate because the effect of region on child mortality would be captured through having socio-economic determinants. Nevertheless, in the appendix I report the results adjusting for region.

6.3.5 Statistical analysis

Analysis strategy

Requiring the exact year cut-offs as shown in the conceptual framework would have resulted in too few observations, particularly for the period 1978-1997. I therefore divided the period 1950-2016 into three: 1950-1964, 1965-1980 and 2000-2016. Data on the IMR and the CMR1-4 were not available between 1981 and 1999 so I excluded that period. In the appendix, I report the analysis results for the U5MR to provide evidence for the missing period 1990-1999 (no data for the IMR or the CMR1-4).

To examine the strength of association between doctor density and the IMR/CMR1-4 in different periods, I decided *a priori* to put the interaction term between the categorical variable “period” and doctor density in all models. The estimated coefficients represent the association between doctor density and the IMR/CMR1-4 on average in the first period, the differences in the associations between the first and second periods (i.e. one of the interactions), and the difference in the associations between the first and the third periods (i.e. the other estimated interaction). I calculated linear combinations of these coefficients to get the associations within each of the periods.

Correlation analysis

I checked the pairwise correlation between all the potential covariates to have an understanding of the possible multicollinearity between the variables before moving to the modelling. I did not decide which covariates to include or exclude at this step. I considered correlation coefficient values less than -0.8 or greater than +0.8 as significant.

The strong correlation between “period” and a few important potential covariates (the PCA score for public campaigns and the enrolment ratio of secondary education) led to my decision of not having interaction terms between them in the model. According to the conceptual framework and theoretical considerations, it makes sense to include interaction terms between all the potential covariates and “period” under the assumption that the determinants of child mortality are changing by period. But the correlation analysis prevented me having too many interactions in the modelling, because adding interaction terms between strongly correlated variables will bring more severe multicollinearity to the modelling. Therefore, I made an assumption in the modelling that the effect of the covariates was common between different periods.

Selection of regression models and model interpretation

Two classes of models are applicable, i.e. hierarchical regression models and growth curve models. Hierarchical regression models are most commonly used in longitudinal data, while growth curve models provide some extensions which are more relevant to latent constructs. I adopted the hierarchical regression approach which has the benefit of allowing me to compare my results with the study published by Babiarz and colleagues [15].

Based on the scatter plots of the IMR/CMR1-4 versus doctor density overlaid with separate lines for different provinces showing the relationship between doctor density and the IMR/CMR1-4, I found no reason to assume the shape of the association (or the regression slope) differs between provinces over the whole period 1950-2016, so there was no need to add random slopes in the modelling. To assess the association between doctor density and mortality, I fitted a multivariable regression model with fixed effects of provinces using Maximum Likelihood. I expected to see correlation of data within provinces, so I used robust standard errors to address this. I did not consider random effects because I am assuming that doctor density has a common relationship with child mortality across all provinces. The general form of the model is as follows:

$$Ln(Mortality_{it})=\alpha+ \beta_0{*}period_{it}+ \sum_c \gamma_c Covariate_{cit}+\sum_d \delta_d Doctor_{it}{*}period_{it} + \beta_1{*}Doctor_{it} + \varepsilon_{it},$$

$$\text{where } \varepsilon_{it} \sim N(0,\omega_2) \qquad \textbf{(Equation 6.1)}$$

Where $mortality_{it}$ is measured by infant or 1-4 mortality for province i and at time t. α is the constant term. β_0 represents the effect of the first period of time. There are three levels of period. Covariate represents a vector of the health systems and social determinants (see Section 6.3.4) measured at the level of provinces and over time. c is the number of covariates. γ_c is the set of coefficients relating to each of the covariate. Doctor represents doctor density. d is the number of coefficients relating the interaction terms between period and doctor density. δ_d is the set of coefficients relating to the interaction terms. β_1 represents the main effect for doctor density. ε_{it} is the residual error term.

The natural log transformation of child (or infant) mortality is to satisfy the assumption that the outcome residuals must be normally distributed for the linear regression model. The non-linearity between child mortality and most of the determinants can be adequately captured by a log transformation[104]. After exponentiation, the coefficients become multiplicative effects of one unit change in the independent variable on the mortality outcome, i.e. relative risk (RR) of the IMR and the CMR1-4. The association is estimated using crude and adjusted RR, 95% CI and Wald test p values. I present the effect of doctor density within each period. This can be done for a particular period by taking the linear combination of the main effect of doctor density and adding the relevant estimated interaction coefficient. I tested the interaction between doctor density and period using the joint Wald test. I considered p values less than 0.05 as statistically significant.

Model building process

Finding the proper function of each covariate: I made simple scatter plots between the potential covariates and the ln-transformed outcomes to determine the function (linear or curvilinear) of each covariate (see Figures G.1-G.10 in the Appendix G). The log transformation of the outcomes did not fully capture the curvilinearity between GDP per capita and child mortality. GDP per capita turned out to have clear curvilinear relationships with both the ln-transformed outcomes. Considering that GDP per capita is a prerequisite for many determinants of infant and child mortality such as nutrition, housing and sanitation [56, 104], I decided to refine the curvilinearity by including an interaction term between the categorical variable “period” and GDP per capita. I modelled the other covariates using the linear function for simplicity and ease of interpretability.

Variable selection method: I used the forward selection method to build the multivariable models. I decided to include GDP per capita and one of the two education variables (the gross enrolment ratio of primary education and the gross enrolment ratio of secondary and higher education) in the adjusted models as forced variables because they are critical determinants of infant and child mortality and have been always controlled for as covariates in previous studies[56, 72]. I took forward the smaller set of variables (doctor density, the forced variables and the interaction terms) to the modelling stage. Using the change-in-estimate method[268], I compared the estimates from the adjusted models with those from the model with the smaller set of variables to examine whether the effect of doctor density on the IMR/CMR1-4 was confounded by any covariate. If the adjusted RR changed more than 10% of the unadjusted estimates of the RR, I regarded it as good evidence of confounding. At each step, only one covariate that causes the largest change among the forced variables is added to the model. For covariates having minimal confounding effect, I also included them in the multivariable model to improve the statistical power in explaining outcome variance. The inclusion of very long list of covariates would have substantially reduced sample size without adding much to the explanatory power of the models. I chose a stopping rule that when the proportion of missing data reached 40%, I stopped adding in further covariates.

Identifying multicollinearity: There were signs of multicollinearity for a few variables (GDP per capita, the gross enrolment ratio of secondary and higher education, the per cent of urban population, government expenditure, PCA score for public health and period) based on previous correlation analysis. In the modelling process, I added in the covariates one by one to check the standard error of the log rate ratios to examine the change of multicollinearity. I decided to drop the per cent of urban population only because it introduced multicollinearity in the multivariable analysis.

Missing data assumptions

I assume that data are missing at random given the covariates that I include in the model. This means that model covariates are able to predict missingness which is a relaxation of the strong missing data assumption that is made by the unadjusted model. For example, if a province has very low GDP per capita, the province will probably have more missing data. By including GDP per capita as covariate, GDP per capita is able to predict the missingness. Therefore, I can assume data are missing at random. If there is missingness in the data that is predicted by variables that I don’t have, then it means data are not missing at random.

Understanding the confounding effect from GDP per capita

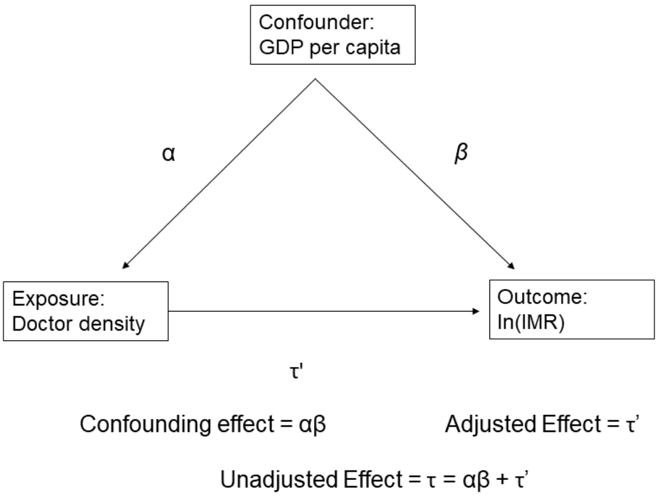


Figure 6.3: The triangle model examining the confounding effect of GDP per capita

I relied on the classic confounder triangle to understand GDP per capita as a single confounder by period. In examining the confounding effect, the relationship between the exposure doctor density and the ln(IMR) and the confounder GDP per capita is shown in Figure 6.3. The τ and τ' are log risk ratios. The τ represents the unadjusted effect of doctor density on the outcome. The τ' represents the adjusted (adjusting for GDP per capita) effect of doctor density on the outcome. The confounding effect can be calculated as either the difference between two regression parameters ($\tau - \tau'$), or the multiplication of two regression parameters ($\alpha\beta$)[269], which is also a log risk ratio.

$$\ln(IMR)=\beta_{01} + \tau X + \varepsilon_1 \qquad \text{(Equation 6.2)}$$

$$\ln(IMR)=\beta_{02} + \tau' X + \beta Z + \varepsilon_2 \qquad \text{(Equation 6.3)}$$

$$Z= \beta_{03} + \alpha X + \varepsilon_3 \qquad \text{(Equation 6.4)}$$

Where ln(IMR) is the transformed outcome variable, X represents doctor density, Z represents the confounder variable GDP per capita, β_{01}, β_{02} and β_{03} are intercepts, and ε_1 and ε_2 are unexplained variability. The standard error of the confounding effect can be estimated using Equation 6.5.

$$\sigma_{\alpha\beta} = \sqrt{\sigma_\alpha^2 \beta^2 + \sigma_\beta^2 \alpha^2} \qquad \text{(Equation 6.5)}$$

Sensitivity analysis

The education variables can influence the mortality outcomes in a time lag, as suggested by previous studies[15], so education was also modelled using the lagged variables (9-year lag for primary education enrolment ratio and 3-year lag for secondary and higher education enrolment ratio) as a sensitivity analysis. The reason for using the 9-year lag is that the denominator of the primary education enrolment ratio is the population aged 6-11, some of whom need 9 years to reach the reproductive age 15. The reason for using the 3-year lag is that the denominator of the secondary and higher education enrolment ratio is the population aged 12-18, some of whom need 3 years to reach the reproductive age 15.

6.4 Results

6.4.1 Correlation analysis

Table 6.1 shows the pairwise correlation matrix of potential covariates. The secondary education enrolment ratio, the per cent of urban population and the government expenditure are significantly correlated with GDP per capita (correlation coefficient>0.8).

Table 6.1: Pairwise correlation matrix of potential covariates

	Doctor density	GDP per capita (adjusted for inflation)	Primary education enrolment ratio	Secondary education enrolment ratio	Per cent of urban population	PCA score for public health campaign	Birth rate	Production of grain per capita	Hospital bed density	Length of highways	Government expenditure (adjusted for inflation)	Period
Doctor density	1(1699)											
GDP per capita (adjusted for inflation)	0.63(1649)	1(1773)										
Primary education enrolment ratio	0.66(1596)	0.59(1672)	1(1702)									
Secondary education enrolment ratio	0.67(1601)	**0.82**(1629)	0.73(1617)	1(1655)								
Per cent of urban population	0.74(1686)	**0.84**(1723)	0.62(1665)	**0.83**(1638)	1(1775)							
PCA score for public health campaign	0.72(1581)	0.59(1638)	0.69(1598)	0.65(1551)	0.59(1648)	1(1700)						
Birth rate	-0.62(1674)	-0.56(1750)	-0.72(1645)	-0.72(1645)	-0.62(1745)	-0.78(1671)	1(1792)					
Production of grain per capita	0.40(1678)	0.30(1726)	0.28 (1675)	0.43(1630)	0.40(1756)	0.34(1676)	-0.36(1751)	1(1784)				
Hospital bed density	0.79(1686)	0.56(1667)	0.66(1622)	0.64(1623)	0.65(1699)	0.61(1594)	-0.61(1691)	0.38(1690)	1(1717)			
Length of highways	0.50(1651)	0.58(1624)	0.75(1724)	0.55(1654)	0.73(1607)	0.67(1727)	-0.55(1738)	0.33(1736)	0.48(1669)	1(1778)		
Government expenditure (adjusted for inflation)	0.25(1389)	**0.88**(1416)	0.36(1366)	0.66(1320)	0.59(1428)	0.46(1346)	-0.50(1423)	0.18(1434)	0.29(1399)	0.77 (1414)	1(1462)	
Period	0.75(1186)	0.67(1260)	0.76(1209)	**0.81**(1150)	0.73(1262)	**0.87**(1225)	-0.77(1279)	0.22(1290)	0.69(1204)	0.69(1265)	0.62(969)	1 (1323)

Notes: Correlation coefficient values less than +0.8 and greater than -0.8 are not considered significant. Number of observations are reported in parentheses. Government expenditure is short for local government expenditure in culture, education, science and health care (100 million yuan). GDP per capita and government expenditure have been adjusted for inflation.

6.4.2 Graphical relationship between doctor density and the IMR/CMR1-4 by period

The graphical relationship between doctor density and the IMR/CMR1-4 by period is shown in Figure 6.4. Two findings emerged from the graphs. First, the relationship between doctor density and child mortality was non-linear, suggesting that the crude association between doctor density and the IMR/CMR1-4 varies by period. Second, doctor density was negatively associated with the IMR/CMR1-4 over the period 1950-1964, but this was much less apparent in 1965-1980 and in 2000-2016.

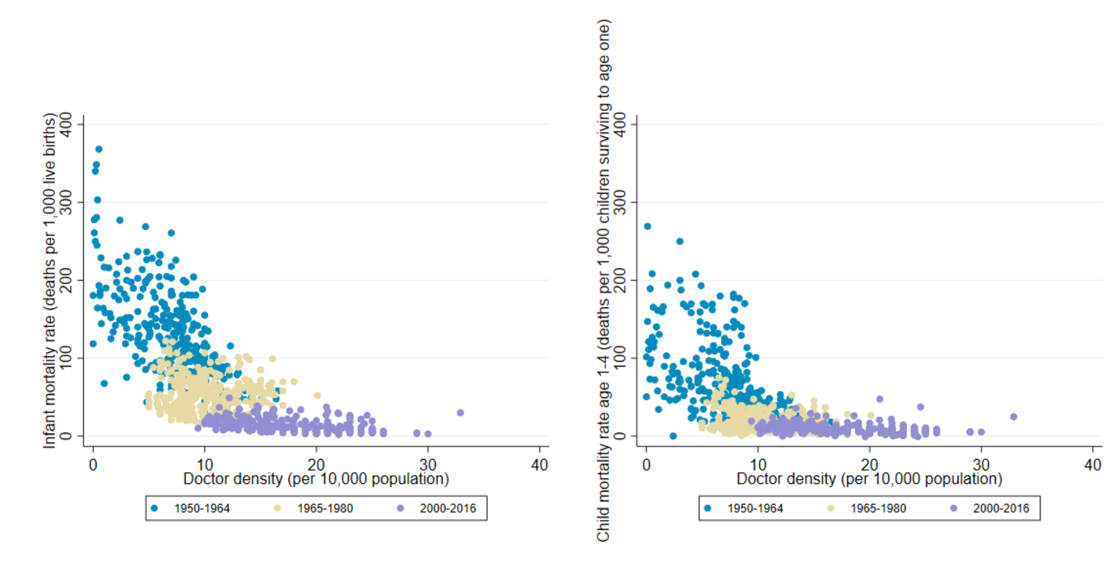


Figure 6.4: Scatter plots between the IMR and doctor density (left), the CMR1-4 and doctor density (Right)

6.4.3 Univariable and multivariable analysis results

IMR

There was very strong evidence from the crude analysis (Model 0 in Table 6.2) that doctor density was negatively associated with the IMR during 1950-1964 (crude RR=0.91, 95% CI: 0.90-0.93, p<0.001) and during 2000-2016 (crude RR=0.94, 95% CI: 0.91-0.96, p<0.001). There was no evidence that doctor density was associated with the IMR (crude RR=0.99, 95% CI: 0.94-1.03, p=0.54) during 1965-1980 (Table 6.2). Take the period 1950-1964 for example, the result can be interpreted as the RR of infant mortality changed by 0.91 with each additional doctor per 10,000 population.

Table 6.2 also shows the RR of the IMR adjusting one covariate at a time in Models 1-10. By comparing the change of estimates, I found some evidence of confounding from

GDP per capita over the periods 1965-1980 and 2000-2016 (Model 0 versus Model 1), but not much confounding from other covariates.

In Table 6.3, the sequence from Model 11 to Model 21 represents exactly the steps in the multivariable model building. Models 11-13 show the multivariable analysis results using only the forced variables (interaction between GDP per capita and period, the gross enrolment ratio of primary education and the gross enrolment ratio of secondary and higher education). The interaction between GDP per capita and period was statistically significant (p<0.001) throughout the models. There was very strong evidence from Model 13 that doctor density was negatively associated with the IMR over the period 1950-1964 (adjusted RR=0.91, 95% CI: 0.90-0.93, p<0.001). There was very strong evidence that doctor density was positively associated with the IMR over the period 1965-1980 (adjusted RR=1.06, 95% CI: 1.03-1.09, p<0.001; Model 13). There was no evidence of association over the period 2000-2016 (adjusted RR=1.03, 95% CI: 0.99-1.06, p=0.09; Model 13).

A multicollinearity problem was detected in Models 14 and 15 after adding the per cent of urban population, which was then removed from the subsequent models. After adjusting for the interaction between GDP per capita and period, the primary education enrolment ratio and the secondary education enrolment ratio, none of the further covariates shown in Models 16-20 were found to be significant and the strength of association between doctor density and the IMR in Table 6.3 was basically unaffected. Thus, the models presented in Tables 6.3 are robust and the interpretation of the strength of association between doctor density and the IMR is invariant to the inclusion of further covariates. Model 21 has more than 44.8% missing data and is shown at the end of multivariable analysis, so that model is ignored in interpretation.

Model 20 is chosen as the final multivariable model for the IMR adjusting for a full set of covariates (interaction between GDP per capita and period, gross enrolment ratio of primary education, gross enrolment ratio of secondary education enrolment ratio, PCA score for public health campaign, crude birth rate, production of grain per capita, hospital bed density and length of highways). One important finding from Model 20 is that there is still very strong evidence that doctor density is negatively associated with the IMR over the period 1950-1964 (adjusted RR=0.91, 95% CI: 0.89-0.93, p<0.001), independent of GDP per capita (adjusted RR=1.54, 95% CI: 0.36-6.61, p=0.49). There is also strong evidence that doctor density is positively associated with the IMR over the period 1965-1980 (adjusted RR=1.06, 95% CI: 1.03-1.09, p<0.001). There is no evidence of association between doctor density and the IMR over the period 2000-2016 (adjusted RR=1.01, 95% CI: 0.99-1.04, p=0.32).

CMR1-4

There was very strong evidence from the crude analysis (Model 0 in Table 6.4) that doctor density was negatively associated with the CMR1-4 over the period 1950-1964 (crude RR=0.88, 95% CI: 0.86-0.91, p<0.001). There was no evidence of association over the period 1965-1980 (crude RR=0.96, 95% CI: 0.89-1.04, p=0.33). There was good evidence that doctor density was negatively associated with the CMR1-4 over the period 2000-2016 (crude RR=0.96, 95% CI: 0.93-0.99, p=0.03).

Table 6.4 also shows the RR of the CMR1-4 adjusting one covariate at a time in Models 1-10. I found some evidence of confounding from GDP per capita over the periods 1965-1980 and 2000-2016, but not much confounding from other covariates.

The interpretation of model results in Table 6.5 is basically the same as that for Table 6.3, but this time for the CMR1-4. The strength of association between doctor density and the CMR1-4 remained relatively unchanged across models. Model 20 is chosen as the final multivariable model for the CMR1-4, adjusting for the same set of covariates as those for the IMR (interaction between GDP per capita and period, gross enrolment ratio of primary education, gross enrolment ratio of secondary education enrolment ratio, PCA score for public health campaign, crude birth rate, production of grain per capita, hospital bed density and length of highways). Based on Model 20, there is very strong evidence that doctor density is negatively associated with the CMR1-4 over the period 1950-1964 (adjusted RR=0.88, 95% CI: 0.86-0.91, p<0.001), independent of GDP per capita (adjusted RR=1.94, 95% CI: 0.30-12.45, p=0.49). There is good evidence that doctor density is positively associated with the CMR1-4 over the period 1965-1980 (adjusted RR=1.06, 95% CI: 1.00-1.12, p=0.048). There is no evidence of association between doctor density and the CMR1-4 over the period 2000-2016 (adjusted RR=0.99, 95% CI: 0.94-1.04, p=0.80).

Adding region as a covariate did not modify the findings, except for the positive association between doctor density and the IMR/CMR1-4 in the second period which does not retain statistical significance (Table G.1 in appendix G). In the appendix, I also report the multivariable analysis for the U5MR, adjusting for the same set of covariates as those for the IMR and the CMR1-4 (Table G.2). The estimates of the strength of association between doctor density and the U5MR are similar to those for the IMR/CMR1-4 for the periods 1950-1964, 1965-1980 and 2000-2017. There is no evidence of association between doctor density and the U5MR over the period 1990-1999 (adjusted RR=1.00, 95% CI: 0.97-1.03, p=0.41).

Table 6.2: Unadjusted and adjusted (one covariate at a time) relative risks of the IMR

	Model 0 (N=979, 10.8% missing)	Model 1 (N=929, 15.4% missing)	Model 2 (N=928, 15.5% missing)	Model 3 (N=913, 16.8% missing)	Model 4 (N=966, 12.0% missing)	Model 5 (N=935, 14.8% missing)
Doctor density (per 10,000 population)						
(1950-1964)	0.91 (0.90, 0.93)***	0.92 (0.90, 0.93)***	0.93 (0.92, 0.95)***	0.92 (0.91, 0.94)***	0.94 (0.92, 0.96)***	0.92 (0.90, 0.93)***
(1965-1980)	0.99 (0.94, 1.03)	1.06 (1.02, 1.10)**	1.01 (0.98, 1.05)	1.02 (0.99, 1.05)	1.03 (0.99, 1.08)	1.00 (0.96, 1.04)
(2000-2016)	0.94 (0.91, 0.96)***	1.02 (0.99, 1.06)	0.95 (0.93, 0.98)**	0.97 (0.94, 1.00)	0.98 (0.95, 1.01)	0.93 (0.91, 0.96)***
Period						
(1950-1964)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)
(1965-1980)	0.25 (0.17, 0.37)***	0.29 (0.22, 0.38)***	0.29 (0.21, 0.42)***	0.24 (0.18, 0.32)***	0.20 (0.13, 0.29)***	0.22 (0.15, 0.32)***
(2000-2016)	0.16 (0.10, 0.25)***	0.08 (0.06, 0.12)***	0.24 (0.15, 0.38)***	0.23 (0.14, 0.40)***	0.20 (0.13, 0.29)***	0.27 (0.12, 0.60)**
GDP per capita adjusted for inflation (1,000 yuan)						
(1950-1964)		0.80 (0.31, 2.09)				
(1965-1980)		0.01 (0.00, 0.03)***				
(2000-2016)		0.76 (0.72, 0.81)***				
Primary education enrolment ratio			0.99 (0.99, 0.99)***			
Secondary education enrolment ratio				0.99 (0.98, 0.99)***		
Per cent of urban population					0.97 (0.96, 0.98)***	
PCA score for public health campaign						0.95 (0.89, 1.01)
Birth rate (per 1,000 population)						
Production of grain per capita (10,000 tons)						
Hospital bed density (per 10,000 population)						
Length of highways (km)						
Government expenditure adjusted for inflation (100 million yuan)						

Notes: GDP per capita and government expenditure have been adjusted for inflation, i.e. GDP per capita has been divided by the inflation rate. *p<0.05, **p<0.01, ***p<0.001.

Table 6.2: (Cont.)

	Model 0 (N=979, 10.8% missing)	Model 6 (N=960, 12.6% missing)	Model 7 (N=977, 11.0% missing)	Model 8 (N=969, 11.7% missing)	Model 9 (N=931, 15.2% missing)	Model 10 (N=769, 30.0% missing)
Doctor density (per 10,000 population)						
(1950-1964)	0.91 (0.90, 0.93)***	0.91 (0.89, 0.92)***	0.91 (0.90, 0.93)***	0.92 (0.91, 0.94)***	0.91 (0.90, 0.93)***	0.91 (0.90, 0.93)***
(1965-1980)	0.99 (0.94, 1.03)	0.99 (0.96, 1.03)	0.99 (0.94, 1.03)	0.99 (0.96, 1.03)	0.99 (0.94, 1.03)	0.98 (0.93, 1.03)
(2000-2016)	0.94 (0.91, 0.96)***	0.94 (0.91, 0.96)***	0.94 (0.91, 0.97)***	0.96 (0.93, 0.99)**	0.95 (0.92, 0.98)**	0.98 (0.95, 1.01)
Period						
(1950-1964)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)
(1965-1980)	0.25 (0.17, 0.37)***	0.23 (0.16, 0.32)***	0.25 (0.17, 0.37)***	0.27 (0.18, 0.42)***	0.27 (0.18, 0.41)***	0.28 (0.18, 0.42)***
(2000-2016)	0.16 (0.10, 0.25)***	0.19 (0.12, 0.31)***	0.15 (0.10, 0.24)***	0.15 (0.09, 0.24)***	0.19 (0.12, 0.30)***	0.15 (0.09, 0.23)***
GDP per capita adjusted for inflation (1,000 yuan)						
(1950-1964)						
(1965-1980)						
(2000-2016)						
Primary education enrolment ratio						
Secondary education enrolment ratio						
Per cent of urban population						
PCA score for public health campaign						
Birth rate (per 1,000 population)		1.01 (1.01, 1.02)***				
Production of grain per capita (10,000 tons)			0.92 (0.57, 1.49)			
Hospital bed density (per 10,000 population)				0.99 (0.97, 1.00)		
Length of highways (km)					0.99 (0.99, 0.99)***	
Government expenditure adjusted for inflation (100 million yuan)						0.99 (0.99, 0.99)***

Notes: GDP per capita and government expenditure have been adjusted for inflation, i.e. GDP per capita has been divided by the inflation rate. $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$.

Table 6.3: Relative risks of the IMR from multivariable analysis

	Model 11 (N=903, 18.8% missing)	Model 12 (N=889, 19.0% missing)	Model 13 (N=877, 20.5% missing)	Model 14 (N=896, 18.4% missing)	Model 15 (N=867, 21.0% missing)	Model 16 (N=829, 24.5% missing)
Doctor density (per 10,000 population)						
(1950-1964)	0.92 (0.90, 0.94)***	0.91 (0.90, 0.93)***	0.91 (0.90, 0.93)***	0.92 (0.91, 0.94)***	0.92 (0.90, 0.94)***	0.92 (0.90, 0.94)***
(1965-1980)	1.06 (1.03, 1.09)***	1.06 (1.03, 1.09)***	1.06 (1.03, 1.09)***	1.07 (1.04, 1.10)***	1.07 (1.04, 1.10)***	1.06 (1.03, 1.09)***
(2000-2016)	1.02 (0.99, 1.05)	1.03 (0.99, 1.06)	1.03 (0.99, 1.06)	1.03 (0.99, 1.05)	1.03 (1.00, 1.06)*	1.02 (0.99, 1.06)
Period						
(1950-1964)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)
(1965-1980)	0.32 (0.24, 0.41)***	0.28 (0.22, 0.37)***	0.29 (0.22, 0.38)***	0.31 (0.24, 0.40)***	0.29 (0.23, 0.38)***	0.29 (0.22, 0.40)***
(2000-2016)	0.11 (0.07, 0.17)***	0.11 (0.07, 0.19)***	0.11 (0.06, 0.20)***	0.15 (0.09, 0.27)***	0.18 (0.10, 0.33)***	0.13 (0.06, 0.30)***
GDP per capita adjusted for inflation (1,000 yuan)						
(1950-1964)	1.47 (0.55, 3.90)	1.43 (0.49, 4.18)	1.51 (0.50, 4.59)	6.19 (1.22, 31.56)*	6.11 (1.14, 32.84)*	2.02 (0.61, 6.68)
(1965-1980)	0.02 (0.01, 0.06)***	0.02 (0.01, 0.12)***	0.03 (0.01, 0.13)***	0.04 (0.01, 0.15)***	0.06 (0.01, 0.28)***	0.05 (0.01, 0.26)***
(2000-2016)	0.80 (0.73, 0.83)***	0.80 (0.74, 0.86)***	0.80 (0.75, 0.86)***	0.82 (0.75, 0.89)***	0.84 (0.77, 0.92)***	0.81 (0.75, 0.88)***
Primary education enrolment ratio	0.99 (0.99, 0.99)**		0.99 (0.99, 1.00)	0.99 (0.99, 0.99)***	0.99 (0.99, 0.99)**	0.99 (0.99, 0.99)*
Secondary education enrolment ratio		0.99 (0.99, 0.99)**	0.99 (0.99, 0.99)**		0.99 (0.99, 0.99)***	0.99 (0.99, 0.99)**
Per cent of urban population				0.99 (0.98, 0.99)*	0.99 (0.98, 1.00)	
PCA score for public health campaign						1.01 (0.95, 1.07)
Birth rate (per 1,000 population)						
Production of grain per capita (10,000 tons)						
Hospital bed density (per 10,000 population)						
Length of highways (km)						
Government expenditure adjusted for inflation (100 million yuan)						

Notes: GDP per capita and government expenditure have been adjusted for inflation, i.e. GDP per capita has been divided by the inflation rate. *p<0.05, **p<0.01, ***p<0.001.

Table 6.3: (Cont.)

	Model 17 (N=823, 25.0% missing)	Model 18 (N=823, 25.0% missing)	Model 19 (N=823, 25.0% missing)	**Model 20 (N=781, 28.9% missing)**	Model 21 (N=606, 44.8% missing)
Doctor density (per 10,000 population)					
(1950-1964)	0.92 (0.90, 0.94)***	0.92 (0.90, 0.94)***	0.91 (0.90, 0.93)***	0.91 (0.89, 0.93)***	0.91 (0.89, 0.93)***
(1965-1980)	1.06 (1.03, 1.09)***	1.06 (1.03, 1.09)***	1.06 (1.03, 1.09)***	1.06 (1.03, 1.09)***	1.05 (1.01, 1.08)**
(2000-2016)	1.02 (0.99, 1.06)	1.02 (0.99, 1.06)	1.01 (0.99, 1.04)	1.01 (0.99, 1.04)	1.01 (0.98, 1.03)
Period					
(1950-1964)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)
(1965-1980)	0.28 (0.21, 0.38)***	0.28 (0.21, 0.39)***	0.27 (0.19, 0.37)***	0.28 (0.19, 0.39)***	0.28 (0.20, 0.41)***
(2000-2016)	0.12 (0.06, 0.28)***	0.12 (0.06, 0.27)***	0.13 (0.06, 0.27)***	0.15 (0.07, 0.32)***	0.19 (0.09, 0.39)***
GDP per capita adjusted for inflation (1,000 yuan)					
(1950-1964)	1.91 (0.62, 5.87)	1.94 (0.57, 6.63)	1.54 (0.36, 6.61)	1.66 (0.39, 7.04)	2.41 (0.59, 9.8)
(1965-1980)	0.05 (0.01, 0.23)***	0.05 (0.01, 0.24)***	0.04 (0.01, 0.24)***	0.05 (0.01, 0.25)***	0.11 (0.02, 0.58)**
(2000-2016)	0.81 (0.75, 0.88)***	0.81 (0.75, 0.88)***	0.81 (0.75, 0.88)***	0.82 (0.76, 0.88)***	0.86 (0.77, 0.95)**
Primary education enrolment ratio	0.99 (0.99, 0.99)*	0.99 (0.99, 0.99)*	0.99 (0.99, 0.99)*	0.99 (0.99, 0.99)*	0.99 (0.99, 0.99)**
Secondary education enrolment ratio	0.99 (0.99, 0.99)**	0.99 (0.99, 0.99)***	0.99 (0.99, 0.99)***	0.99 (0.99, 0.99)**	0.99 (0.99, 0.99)***
Per cent of urban population					
PCA score for public health campaign	1.01 (0.95, 1.07)	1.01 (0.95, 1.07)	1.01 (0.95, 1.07)	1.00 (0.94, 1.06)	1.01 (0.95, 1.07)
Birth rate (per 1,000 population)	0.99 (0.99, 1.00)	0.98 (0.99, 1.00)	0.99 (0.99, 1.01)	1.00 (0.99, 1.01)	0.99 (0.99, 1.00)
Production of grain per capita (10,000 tons)		0.98 (0.64, 1.49)	0.96 (0.64, 1.46)	0.97 (0.62, 1.51)	0.56 (0.30, 1.06)
Hospital bed density (per 10,000 population)			1.01 (0.99, 1.02)	1.01 (0.99, 1.02)	1.01 (0.99, 1.02)
Length of highways (km)				0.99 (0.99, 1.00)	1.00 (0.99, 1.00)
Government expenditure adjusted for inflation (100 million yuan)					0.99 (0.98, 0.99)**

Notes: GDP per capita and government expenditure have been adjusted for inflation, i.e. GDP per capita has been divided by the inflation rate.

*p<0.05, **p<0.01, ***p<0.001.

Table 6.4: Unadjusted and adjusted (one covariate at a time) relative risks of the CMR1-4

	Model 0 (N=975, 11.2% missing)	Model 1 (N=926, 15.7% missing)	Model 2 (N=925, 15.8% missing)	Model 3 (N=910, 17.1% missing)	Model 4 (N=962, 12.4% missing)	Model 5 (N=931, 15.2% missing)
Doctor density (per 10,000 population)						
(1950-1964)	0.88 (0.86, 0.91)***	0.89 (0.86, 0.91)***	0.91 (0.88, 0.93)***	0.89 (0.87, 0.92)***	0.91 (0.88, 0.93)***	0.89 (0.87, 0.92)***
(1965-1980)	0.96 (0.89, 1.04)	1.07 (0.99, 1.14)	0.99 (0.93, 1.06)	0.99 (0.95, 1.06)	1.00 (0.94, 1.07)	0.99 (0.92, 1.07)
(2000-2016)	0.96 (0.93, 0.99)*	0.99 (0.95, 1.05)	0.97 (0.93, 1.02)	1.00 (0.97, 1.03)	1.00 (0.98, 1.03)	0.96 (0.93, 0.99)*
Period						
(1950-1964)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)
(1965-1980)	0.17 (0.09, 0.33)***	0.20 (0.14, 0.30)***	0.21 (0.13, 0.36)***	0.17 (0.11, 0.27)***	0.14 (0.08, 0.25)***	0.14 (0.08, 0.25)***
(2000-2016)	0.12 (0.07, 0.22)***	0.08 (0.04, 0.16)***	0.22 (0.11, 0.44)***	0.18 (0.09, 0.37)***	0.15 (0.08, 0.26)***	0.39 (0.08, 1.84)
GDP per capita adjusted for inflation (1,000 yuan)						
(1950-1964)		0.49 (0.11, 2.28)				
(1965-1980)		0.01 (0.00, 0.01)***				
(2000-2016)		0.89 (0.81, 0.98)*				
Primary education enrolment ratio			0.99 (0.99, 0.99)***			
Secondary education enrolment ratio				0.99 (0.98, 0.99)***		
Per cent of urban population					0.98 (0.96, 0.99)**	
PCA score for public health campaign						0.88 (0.78, 1.00)
Birth rate (per 1,000 population)						
Production of grain per capita (10,000 tons)						
Hospital bed density (per 10,000 population)						
Length of highways (km)						
Government expenditure adjusted for inflation (100 million yuan)						

Notes: GDP per capita and government expenditure have been adjusted for inflation, i.e. GDP per capita has been divided by the inflation rate. *$p<0.05$, **$p<0.01$, ***$p<0.001$.

Table 6.4: (Cont.)

	Model 0 (N=975, 11.2% missing)	Model 6 (N=956, 12.9% missing)	Model 7 (N=973, 11.4% missing)	Model 8 (N=931, 15.2% missing)	Model 9 (N=927, 15.6% missing)	Model 10 (N=765, 30.3% missing)
Doctor density (per 10,000 population)						
(1950-1964)	0.88 (0.86, 0.91)***	0.88 (0.85, 0.91)***	0.91 (0.90, 0.93)***	0.90 (0.87, 0.93)***	0.88 (0.86, 0.91)***	0.88 (0.86, 0.91)***
(1965-1980)	0.96 (0.89, 1.04)	0.98 (0.92, 1.04)	0.99 (0.94, 1.03)	0.98 (0.92, 1.04)	0.96 (0.89, 1.04)	0.95 (0.88, 1.03)
(2000-2016)	0.96 (0.93, 0.99)*	0.97 (0.93, 0.99)*	0.94 (0.91, 0.97)***	0.99 (0.96, 1.02)	0.96 (0.92, 1.00)	0.95 (0.88, 1.03)
Period						
(1950-1964)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)
(1965-1980)	0.17 (0.09, 0.33)***	0.16 (0.09, 0.26)***	0.25 (0.17, 0.37)***	0.20 (0.11, 0.37)***	0.18 (0.09, 0.33)***	0.20 (0.11, 0.38)***
(2000-2016)	0.12 (0.07, 0.22)***	0.18 (0.09, 0.36)***	0.15 (0.10, 0.24)***	0.12 (0.07, 0.22)***	0.12 (0.07, 0.21)***	0.17 (0.05, 0.52)**
GDP per capita adjusted for inflation (1,000 yuan)						
(1950-1964)						
(1965-1980)						
(2000-2016)						
Primary education enrolment ratio						
Secondary education enrolment ratio						
Per cent of urban population						
PCA score for public health campaign						
Birth rate (per 1,000 population)		1.03 (1.01, 1.04)***				
Production of grain per capita (10,000 tons)			0.92 (0.57, 1.49)			
Hospital bed density (per 10,000 population)				0.98 (0.96, 0.99)*		
Length of highways (km)					1.00 (0.99, 1.00)	
Government expenditure adjusted for inflation (100 million yuan)						0.99 (0.99, 0.99)**

Notes: GDP per capita and government expenditure have been adjusted for inflation, i.e. GDP per capita has been divided by the inflation rate. *p<0.05, **p<0.01, ***p<0.001.

Table 6.5: Relative risks of the CMR1-4 from multivariable analysis

	Model 11 (N=900, 18.0% missing)	Model 12 (N=886, 19.3% missing)	Model 13 (N=870, 20.8% missing)	Model 14 (N=893, 18.7% missing)	Model 15 (N=864, 21.3% missing)	Model 16 (N=826, 24.8% missing)
Doctor density (per 10,000 population)						
(1950-1964)	0.89 (0.87, 0.92)***	0.89 (0.86, 0.91)***	0.89 (0.87, 0.91)***	0.90 (0.88, 0.92)***	0.90 (0.88, 0.92)***	0.90 (0.87, 0.92)***
(1965-1980)	1.07 (1.00, 1.13)*	1.07 (1.00, 1.14)*	1.07 (1.01, 1.13)*	1.10 (1.04, 1.16)**	1.10 (1.04, 1.15)**	1.07 (1.01, 1.13)*
(2000-2016)	0.99 (0.94, 1.05)	1.00 (0.95, 1.05)	0.99 (0.95, 1.05)	1.00 (0.96, 1.05)	1.01 (0.96, 1.05)	0.99 (0.94, 1.05)
Period						
(1950-1964)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)
(1965-1980)	0.23 (0.16, 0.34)***	0.21 (0.14, 0.30)***	0.22 (0.15, 0.32)***	0.22 (0.15, 0.32)***	0.21 (0.15, 0.31)***	0.20 (0.14, 0.31)***
(2000-2016)	0.13 (0.06, 0.28)***	0.15 (0.07, 0.32)***	0.21 (0.10, 0.46)***	0.26 (0.10, 0.69)**	0.37 (0.14, 0.95)*	0.31 (0.07, 1.30)
GDP per capita adjusted for inflation (1,000 yuan)						
(1950-1964)	1.09 (0.24, 4.95)	1.07 (0.23, 4.90)	1.53 (0.33, 7.02)	18.28 (1.20, 278.43)*	17.37 (1.36, 278.43)*	2.11 (0.38, 11.66)
(1965-1980)	0.01 (0.00, 0.01)***	0.01 (0.00, 0.04)***	0.01 (0.00, 0.08)***	0.01 (0.00, 0.10)***	0.02 (0.00, 0.28)**	0.01 (0.00, 0.13)***
(2000-2016)	0.92 (0.83, 1.02)	0.97 (0.88, 1.08)	0.98 (0.88, 1.09)	1.02 (0.89, 1.16)	1.07 (0.94, 1.22)	0.99 (0.88, 1.11)
Primary education enrolment ratio	0.99 (0.99, 0.99)**		0.99 (0.99, 1.00)	0.99 (0.99, 0.99)***	0.99 (0.99, 0.99)*	0.99 (0.99, 1.00)
Secondary education enrolment ratio		0.99 (0.98, 0.99)***	0.99 (0.99, 0.99)***		0.99 (0.98, 0.99)***	0.99 (0.98, 0.99)***
Per cent of urban population				0.98 (0.96, 0.99)*	0.98 (0.96, 0.99)*	
PCA score for public health campaign						0.97 (0.86, 1.09)
Birth rate (per 1,000 population)						
Production of grain per capita (10,000 tons)						
Hospital bed density (per 10,000 population)						
Length of highways (km)						
Government expenditure adjusted for inflation (100 million yuan)						

Notes: GDP per capita and government expenditure have been adjusted for inflation, i.e. GDP per capita has been divided by the inflation rate.

*p<0.05, **p<0.01, ***p<0.001.

Table 6.5: (Cont.)

	Model 17 (N=820, 25.3% missing)	Model 18 (N=820, 25.3% missing)	Model 19 (N=820, 25.3% missing)	**Model 20 (N=778, 29.1% missing)**	Model 21 (N=603, 45.1% missing)
Doctor density (per 10,000 population)					
(1950-1964)	0.88 (0.86, 0.91)***	0.88 (0.86, 0.91)***	0.88 (0.85, 0.91)***	0.88 (0.86, 0.91)***	0.89 (0.87, 0.92)***
(1965-1980)	1.06 (1.01, 1.12)*	1.06 (1.01, 1.12)*	1.06 (1.00, 1.12)*	1.06 (1.00, 1.12)*	1.06 (1.01, 1.11)*
(2000-2016)	0.99 (0.94, 1.05)	0.99 (0.93, 1.05)	0.98 (0.93, 1.04)	0.99 (0.94, 1.04)	0.95 (0.86, 1.04)
Period					
(1950-1964)	1 (ref)	1 (ref)	1 (ref)	1 (ref)	1 (ref)
(1965-1980)	0.17 (0.11, 0.27)***	0.17 (0.11, 0.27)***	0.17 (0.11, 0.26)***	0.16 (0.10, 0.25)***	0.22 (0.13, 0.34)***
(2000-2016)	0.31 (0.07, 1.35)	0.32 (0.07, 1.44)	0.33 (0.07, 1.45)	0.33 (0.07, 1.56)	0.67 (0.10, 4.40)
GDP per capita adjusted for inflation (1,000 yuan)					
(1950-1964)	2.17 (0.36, 13.11)	1.92 (0.34, 10.76)	1.70 (0.26, 11.16)	1.94 (0.30, 12.45)	2.56 (0.46, 12.20)
(1965-1980)	0.02 (0.00, 0.20)***	0.02 (0.01, 0.19)***	0.02 (0.00, 0.19)**	0.03 (0.00, 0.29)**	0.06 (0.00, 0.75)*
(2000-2016)	0.98 (0.87, 1.10)	0.99 (0.88, 1.10)	0.99 (0.88, 1.10)	0.96 (0.86, 1.06)	1.01 (0.72, 1.43)
Primary education enrolment ratio	0.99 (0.99, 1.00)	0.99 (0.99, 1.00)	0.99 (0.99, 1.00)	0.99 (0.99, 1.00)	0.99 (0.99, 0.99)*
Secondary education enrolment ratio	0.99 (0.98, 0.99)***	0.99 (0.98, 0.99)***	0.99 (0.98, 0.99)***	0.99 (0.98, 0.99)***	0.98 (0.98, 0.99)***
Per cent of urban population					
PCA score for public health campaign	0.96 (0.86, 1.08)	0.96 (0.86, 1.08)	0.96 (0.86, 1.08)	0.94 (0.84, 1.07)	0.98 (0.89, 1.09)
Birth rate (per 1,000 population)	1.01 (0.99, 1.02)	1.01 (0.99, 1.02)	1.01 (0.99, 1.02)	1.01 (0.99, 1.02)	0.99 (0.99, 1.01)
Production of grain per capita (10,000 tons)		1.16 (0.65, 2.08)	1.15 (0.63, 2.08)	1.13 (0.64, 2.01)	0.83 (0.28, 2.45)
Hospital bed density (per 10,000 population)			1.00 (0.99, 1.02)	1.00 (0.99, 1.01)	1.00 (0.98, 1.02)
Length of highways (km)				1.00 (1.00, 1.00)	1.00 (0.99, 1.00)
Government expenditure adjusted for inflation (100 million yuan)					0.99 (0.97, 1.01)

Notes: GDP per capita and government expenditure have been adjusted for inflation, i.e. GDP per capita has been divided by the inflation rate.

*p<0.05, **p<0.01, ***p<0.001.

6.4.4 The confounding effect from GDP per capita

Figure 6.5 shows the confounder triangles by period for the ln(IMR) as the outcome. According to panel a, the confounding effect from GDP per capita is close to zero for the period 1950-1964 (αβ=-0.002, 95% CI: -0.009, 0.005). There is a negligible difference between the unadjusted effect (τ=-0.090, 95% CI: -0.110, -0.070) and the adjusted effect (τ'=-0.089, 95% CI: -0.108, -0.069). For the second period 1965-1980 (panel b), GDP per capita shows very large confounding effect (αβ=-0.068, 95% CI: -0.099, -0.038), which is much bigger than the unadjusted effect (τ= -0.013, 95% CI: -0.059, 0.032). The statistical removal of the confounding effect from GDP per capita changes the sign of the effect of doctor density on the ln(IMR) (τ'= 0.055, 95% CI: 0.018, 0.092; τ= -0.013, 95% CI: -0.059, 0.032). For the last period 2000-2016 (panel c), the magnitude of the confounding effect from GDP per capita (αβ= -0.089, 95% CI: -0.117, -0.060) is bigger than that in the second period. The statistical association between doctor density and the ln(IMR) disappears after adjusting for GDP per capita (τ'= 0.022, 95% CI: -0.009, 0.054).

Figure 6.6 shows the confounder triangles by period for the ln(CMR1-4). The changes in the association between doctor density and the ln(CMR1-4) are very similar to those observed for the ln(IMR).

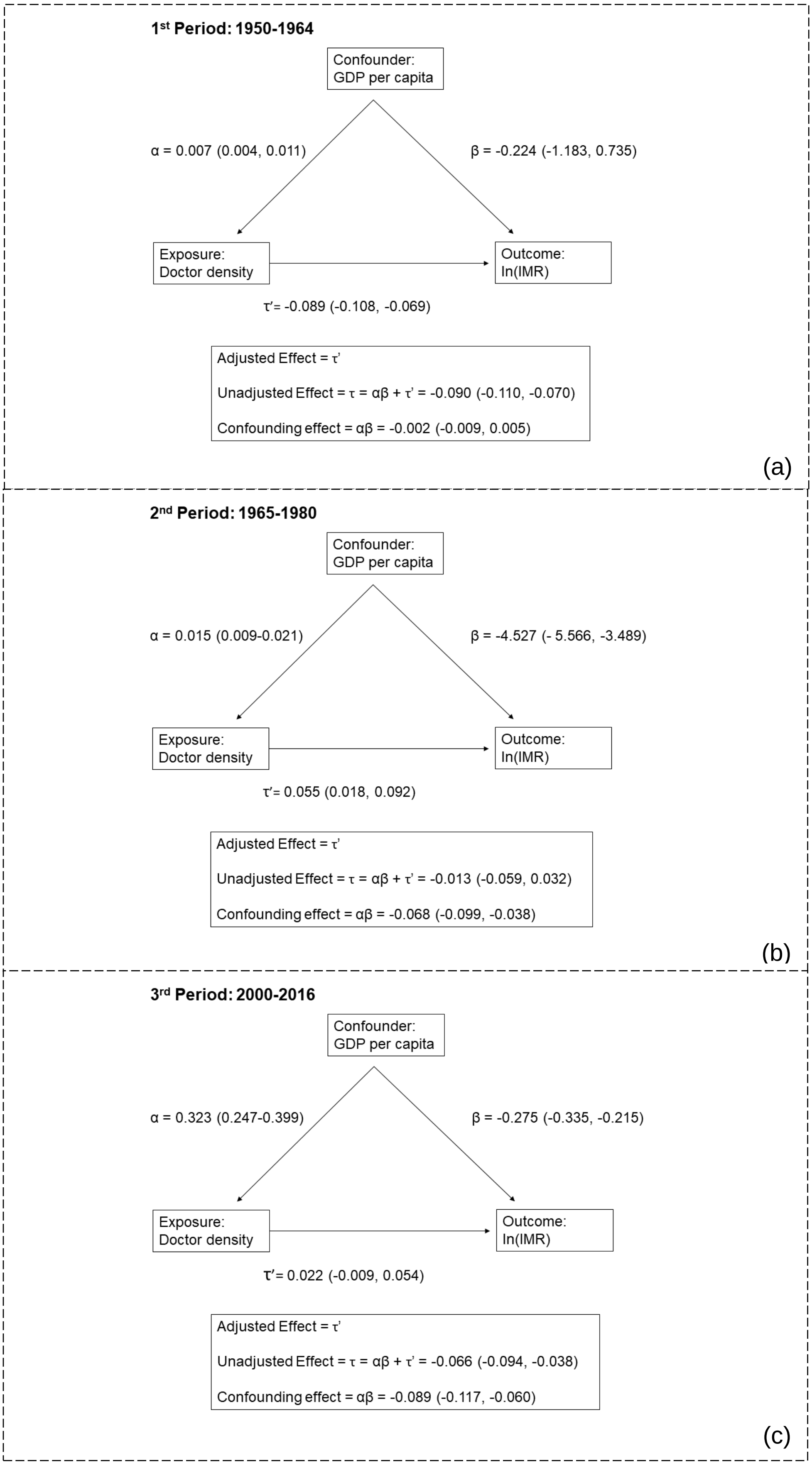


Figure 6.5: The confounding effect from GDP per capita for the ln(IMR) analysis

Note: The estimated coefficients are log risk ratios. The estimates in brackets are 95% confidence intervals.

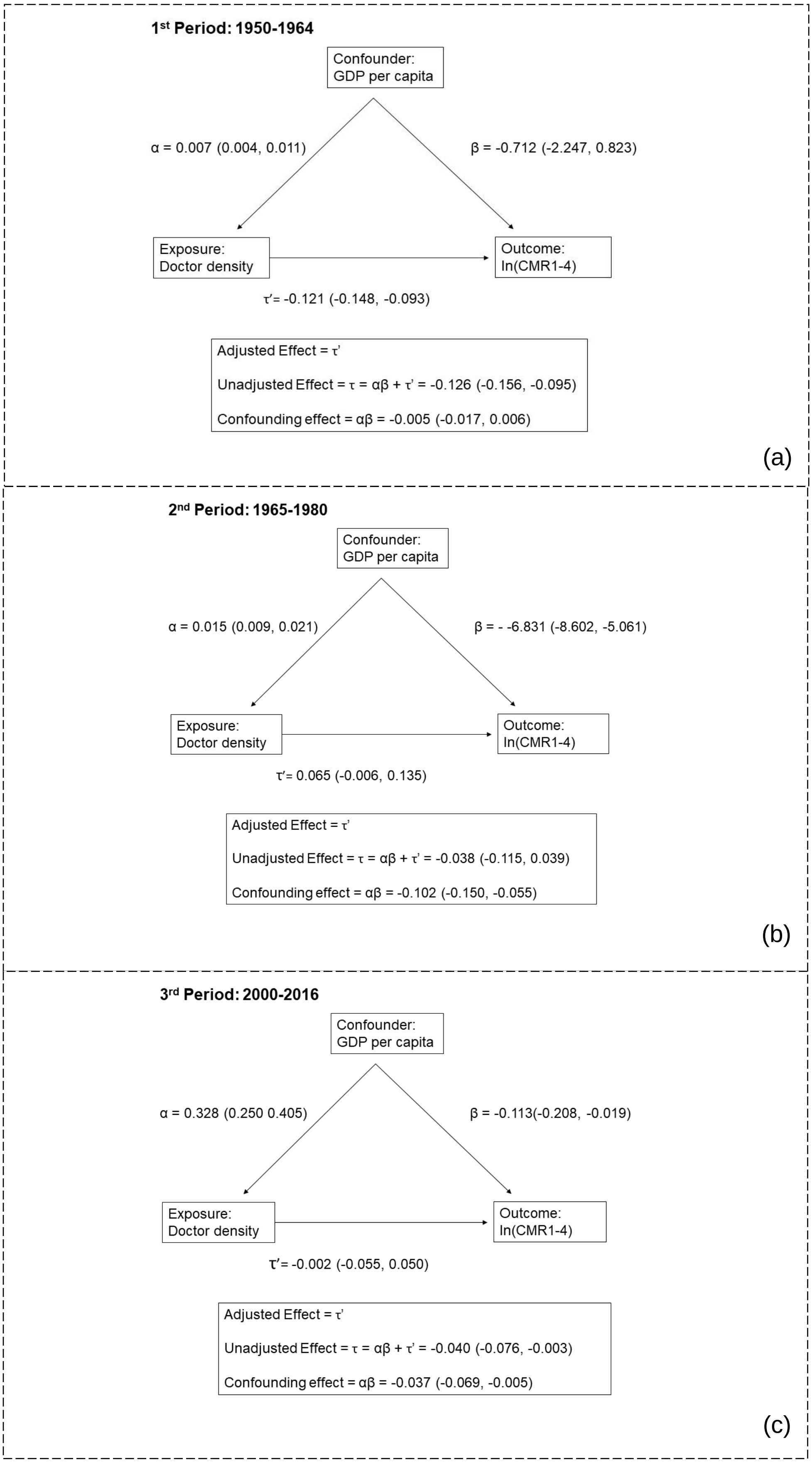


Figure 6.6: The confounding effect from GDP per capita for the ln(CMR1-4) analysis

Note: The estimated coefficients are log risk ratios. The estimates in brackets are 95% confidence intervals.

6.4.5 Sensitivity analysis

The negative association between doctor density and the IMR/CMR1-4 persisted for the period 1950-1964 in the sensitivity analyses after adjusting for the same set of covariates as shown in Model 20 but replacing the education variables by the 9-year lagged gross enrolment ratio of primary education and the 3-year lagged gross enrolment ratio of secondary education and higher education. The positive association between doctor density and the IMR/CMR1-4 for the period 1965-1980 also persisted (Table 6.6). The sensitivity analysis suggested that the lagged effect of education did not have a large effect on my final estimates of the strength of association between doctor density and the mortality outcomes. It should be noted that the replacement of the education variables with the lagged variables meant that either the first 9 or 3 years were missing for the lagged education variables.

Table 6.6: Sensitivity analysis results using lagged education variables

		IMR (N=641, 41.6% missing)	CMR1-4 (N=638, 41.9% missing)
Doctor density (per 10,000 population)			
	(1950-1964)	0.90 (0.86, 0.94)***	0.90 (0.82, 0.98)*
	(1965-1980)	1.06 (1.02, 1.09)**	1.07 (1.01, 1.12)*
	(2000-2016)	1.01 (0.98, 1.03)	0.98 (0.94, 1.03)
Period			
	(1950-1964)	1 (ref)	1 (ref)
	(1965-1980)	0.22 (0.13, 0.37)***	0.18 (0.08, 0.38)***
	(2000-2016)	0.12 (0.05, 0.32)***	0.73 (0.08, 6.67)
GDP per capita adjusted for inflation (1,000 yuan) (1,000 yuan)			
	(1950-1964)	0.97 (0.26, 3.62)	2.41 (0.43, 13.64)
	(1965-1980)	0.05 (0.01, 0.33)**	0.09 (0.01, 1.19)***
	(2000-2016)	0.81 (0.76, 0.87)***	0.94 (0.86, 1.02)
Primary education enrolment ratio (9-year lagged)		0.99 (0.99, 1.00)**	0.99 (0.98, 0.99)**
Secondary education enrolment ratio (3-year lagged)		0.99 (0.98, 0.99)**	0.99 (0.98, 0.99)**
PCA score for public health campaign		1.03 (0.95, 1.12)	0.95 (0.82, 1.11)
Birth rate (per 1,000 population)		1.00 (0.99, 1.01)	1.01 (1.00, 1.02)
Production of grain per capita (10,000 tons)		0.95 (0.63, 1.45)	0.89 (0.58, 1.37)
Hospital bed density (per 10,000 population)		1.01 (0.99, 1.03)	1.01 (0.99, 1.03)
Length of highways (km)		0.99 (0.99, 1.00)	1.00 (1.00, 1.00)

Notes: GDP per capita and government expenditure have been adjusted for inflation. *p<0.05, **p<0.01, ***p<0.001.

6.5 Discussion

To my knowledge, this chapter provides the most comprehensive analysis to date of evidence from China describing the association between doctor density and child mortality over time. Disaggregation by period indicated that the protective effect of doctor density was statistically significant for both the IMR and the CMR1-4 during

1950-1964, but not thereafter. There is good evidence that one unit increase in doctor density is associated with a 9% decline in the IMR and a 12% decline in the CMR1-4 during 1950-1964, after adjusting for the interaction between GDP per capita and period, gross enrolment ratio of primary education, gross enrolment ratio of secondary education and higher education, the PCA score for public health campaign, the crude birth rate, the production of grain per capita, the hospital bed density and the length of highways. But during 1965-1980 increases in doctor density appear to be associated with an increased risk of death. The association disappears in 2000-2016.

By assuming GDP per capita as the single confounder, I was able to compute the confounding effect of GDP per capita and elucidate the confounding effect by period of time. In 1950-1964, GDP per capita did not confound the association between doctor density and the IMR/CMR1-4. In the other two periods 1965-1980 and 2000-2016, GDP per capita confounded the association between doctor density and the IMR/CMR1-4. Through such analysis, I validated my model finding that the negative association between doctor density and the IMR/CMR1-4 in 1950-1964 was independent of GDP per capita. Previous studies examining child mortality trends for specific countries have found that increases in economic resources contribute significantly to infant and child mortality decline, but that the effects are often dependent on the time period[102, 270], supporting my findings.

The importance of doctor density to child mortality reductions in the first period (1950-1964) is perhaps not surprising. Although the specific interventions against child mortality vary, increases in the availability of health workers are essential. Other things being unchanged, as doctor density improves, the coverage of MCH services will increase, potentially leading to child mortality reductions [271]. There is a large body of literature showing an association between primary care (indicated by supply of generalists or primary care physicians) and all-cause mortality, infant mortality and lower birth weight [223, 266, 272]. In the first period, a significant number of doctors in China were generalists focusing on primary health care[210], which may partly explain why the increase in doctor density was associated with lower child mortality. Along with the generalist-led primary health system, the public health campaigns in the 1950s against parasitic and infectious diseases and the free access to public health services, could have been the proximate determinants for the success in child mortality reductions in the first period[260]. But availability of doctors is a more or less exclusive answer to guarantee effective and accessible health services when other conditions are fulfilled.

In the first period, a striking finding is that infant and child mortality reductions were independent of economic development over the period 1950-1964, which corroborate the long-observed fact that initial achievements in child health in China preceded the intensified economic growth after 1978[273]. It would be presumptuous to claim that the most rapid decline in child mortality in China was more health systems than socially determined. The results are nevertheless showing evidence that doctor density increase contributed to infant and child mortality reductions over the period 1950-1964 when poverty and limited education were formidable obstacles to huge mortality decline. The child mortality decline in some western societies, for example the US and Canada, started in the early decades of the 1900s, which was gradual and occurred in response to socio-economic and environmental improvements, better nutrition and personal hygiene after the industrial revolution[244]. Given that socio-economic determinants and the PCA score for public health campaign (capturing environmental improvements, nutrition and hygiene) have been included in my multivariable models, there is little reason to doubt the presence of a negative association between doctor density and child mortality.

The positive association between doctor density and the IMR/CMR1-4 over the period 1965-1980 is complex and difficult to understand. The prolonged Cultural Revolution resulted in de-emphasized professionalization in the health workforce throughout the country [31]. The fact that many doctors were redesignated as barefoot doctors by health authorities throughout the country may have brought unreal decline in doctor density, potentially leading to biased estimates. Furthermore, reverse causality may pose significant threats to the validity of the findings, for example, doctor density could have an effect on the child mortality, but child mortality itself could also have influenced the government’s decision to dispatch more or fewer doctors to a particular province. Using the same data in 1950-1980 and by examining whether changes in the IMR/U5MR affected doctor density, Babiarz and colleagues found evidence showing that increases in doctor density in some provinces were preceded by high infant or under-5 mortality rates, which was aligned with Chairman Mao’s policy (initiated in 1965) emphasis on addressing perceived development imbalance between provinces and posting more doctors in disadvantaged areas [15]. Therefore, the existence of reverse causality threatens causal inference for the period 1965-1980.

I found no association between doctor density and the IMR/CMR1-4 over the period 2000-2016. This is consistent with findings from elsewhere. Based on the latest Global Health Workforce Statistics published by the WHO in 2018, an updated cross-country investigation of the associations between the density of health workers (the density of doctors and the density of nurses and midwives) and multiple child mortality indicators including the NMR, the IMR and the U5MR found evidence of non-linearities in the association between density of health workers and child mortality [274]. A potential explanation for the nonlinearity of the relationship between doctor density and child mortality in China was that an increase in doctor density during 1950-1964 through increasing the number of generalists may be able to address more conditions that put infants and children at higher risk of death compared with an increase in doctor density through increasing the number of specialists during 2000-2016. The finding from the last period also indicates that improving doctor density alone is far from enough to achieve further reductions in child mortality in China.

My analysis underscores the importance of education, which is consistent with other empirical studies[15, 193]. As I reported in the scoping review (Chapter 4), Barbiaz and colleagues found that 55-70 per cent of the declines in the IMR and the U5MR in China during the 1960s and 1970s can be explained by gains in education enrolment and public health campaigns [15]. Banister and Zhang found doctor density and the illiteracy rate among adults were the most important determinants of child mortality across provinces during 1981-1995, after adjusting for GDP per capita, rural-urban inequality, share of education and healthcare expenditure, region and year[193]. In my analysis, the education enrolment remains statistically significant throughout the studied period in the multivariable models and in the sensitivity analyses, which is independent of doctor density, GDP per capita and all the other covariates. The association between education enrolment and child survival indicates a moderately consistent relationship between education and child survival across time and provinces. Even a small reduction of infant/child mortality linked to an additional enrolment ratio of primary or secondary education in relative terms might, in fact, contribute to a substantial number of infants and children saved in absolute terms. The reduction in the RRs of the IMR/CMR1-4 brough by each enrolment ratio observed in this study provides strong evidence to further support universal quality education, as a goal of the SDGs, to further reduce child mortality[275].

The results of this study may be relevant to many LMICs, particularly those who are looking for innovative ways to do more with limited resources. According to the UN[276], the 5-year averaged IMR in 2015-2020 was more than 70 deaths per 1,000 live births in some of the least developed countries in Africa (Somalia, Central Africa Republic, Chad, Sierra Leone, Mali, Equatorial Guinea and the Democratic Republic of the Congo). The 5-year U5MR for these countries over the same period was more than 100 deaths per 1,000 live births. The child mortality burden for these countries is equivalent to that of China in 1960-1965. During the MDG era, several African countries started addressing the health workforce shortages through increasing the number of lower-level cadres of health workers to deliver essential MCH services [277]. The practice has sometimes been challenged by professional bodies worrying that sharing tasks may erode health services and remains controversial as an answer to the shortage of health workforce supply[184]. The shortage of health workers in those countries has often dragged on with policy gaps failing to authorise lower-level cadres of health workers to deliver essential MCH services, such as postnatal care visits and treatment of pneumonia[33].

At the same time, the regions and countries with the highest child mortality burden are facing severe shortages in health workers. In 2019, the global density of doctors was 16.7 per 10,000 population while doctor density in China was 27.2 per 10,000 population[57]. In absolute terms, largest gaps were observed in sub-Saharan Africa (short by 1.9 million doctors) and south Asia (short by 2.6 million doctors), accounting for more than half of the worldwide shortages in doctors. Doctor density was 2.9 per 10,000 population in sub-Saharan Africa and 6.5 per 10,000 population in South Asia in 2019, equivalent to that of China in 1950-1955[57]. Doctors in developed countries receive more or less the same standards of medical training, and their health workforce strategies are unlikely to be feasible in the least developed countries [278]. China is a unique example of an early investment in the health workforce through the use of less qualified health workers and is well positioned to share the lessons to those countries. Given the challenges in sub-Saharan Africa and South Asia, as a result of poverty, poor education, very low economic growth, natural and political crisis, consideration of increasing the availability of health workers through using lower-level cadres of health workers is relevant and timely.

This study has the following strengths. First, the multivariable models include socio-economic, environmental and health system covariates with known associations to child mortality and exploit the associations between doctor density and the IMR/CMR1-4 across time periods. The separation of historical periods and the interpretation of analysis results by period helps mitigate the limitations associated with measurement changes in the estimations of both doctor density and the outcomes. Second, the specification and the models are capable of producing reasonable results. When adding region as a covariate, the model results have negligible differences in the adjusted RRs of doctor density. The results of sensitivity analysis using the lagged education variables are reassuring that the models are robust. Third, many health system reforms and institutional changes take a long time to have their full effect on population health. Thus, the long-term horizon of this study is a strength to give credit to doctor density increase for past success in reducing child mortality.

My understanding of the contribution of health workforce density to infant/child mortality decline has relied mostly on evidence from historical records. The study has the following limitations. First, the inclusion of covariates is strongly influenced by data availability. There could be residual confounding or unmeasured confounders that may affect the results. For example, different to average GDP per capita, income inequalities matter greatly with respect to health outcomes[72]. Income inequalities may confound the association between health workforce density and child mortality. However, no information regarding income inequality was readily available to assess its confounding effects. Second, data are missing for almost all the variables. Adding covariates and modelling lagged education variables with large missing data did not alter the finding, I do not think that missing data introduced bias. Third, any contribution of the health workforce to child mortality may be at least partly through other mechanisms such as the improved medical training leading to better quality of health workers. However, this alternative explanation of the link between the health workforce and child mortality cannot be resolved in this study because no such data are available. Fourth, excluding barefoot doctors and village doctors from official counts results in a substantial underestimation of the size of the health workforce and its potential to reduce child mortality. Fifth, studying the association between doctor density and child mortality at county level rather than at provincial level may have provided better evidence [72]. Anand et al showed that most of this inequality in the distribution of doctors and nurses in China was accounted for by within-province inequalities(82% or more) rather than by between-province inequalities[72]. Ideally data at county level would provide better information. Last, I assessed the ecologic association between doctor density and child mortality among 27 provinces. Causal inference is troublesome in the second period 1965-1980 when child mortality can influence doctor density in provinces (through the impact of posting doctors to provinces with high child mortality rates).

6.6 Conclusion

Using a province-level longitudinal data analysis, I found a strong negative association between doctor density and the IMR/CMR1-4 over the period 1950-1964. China’s experience shows that initiatives to increase the density of doctors contributed to the reductions of infant and child mortality when GDP per capita was very low, but child mortality discontinued decreasing at some point with solely the increase in doctor density. The disappeared association in the last period between doctor density and the IMR/CMR1-4 deserves serious considerations. Improving doctor density alone is unlikely to achieve further progress in reducing child mortality in China. There are still many similarities between China during the period 1950-1964 and contemporary least development countries in terms of access to MCH services. Many parts of less developed countries may also benefit from increasing doctor density and upgrading their skills gradually.

Chapter 7. Discussion

7.1 Overview of thesis

The overall aim of the thesis was to examine the progress in child mortality declines in China and to understand how the health workforce contributes to that progress. My thesis consists of four main themes. First, the systematic review provided insights into the education, certification and density of MCH workers in China in 1949-2020. Second, a scoping review assessed China's progress in reducing infant and under-5 mortality and the determinants that underpinned the achievement in 1949-2019. Third, the provincial data analysis presented the speed of decline in infant and child mortality and the trends of the health systems and socio-demographic status in 1950-2017. Fourth, the investigation of the association between doctor density and child mortality by period of time (1950-1964, 1965-1980, 2000-2016) in China provided opportunities for shared lessons about if and how an increased density of doctors may contribute to mortality decline.

7.2 Summary of main findings

7.2.1 MCH workforce profile and density in China in 1949-2020

I undertook a systematic review of the literature reporting on the profile (education level, health-related discipline, certification) and density of MCH workers in China published between 1 October 1949 and 20 July 2020. I included a total of 50 studies: 35 reporting on MCH workforce profiles, 18 reporting on the MCH workforce density and three covering both. Most of the included studies (94%) were done after 1990.

I found that professional labels such as "obstetricians" or "obstetric nurses" represent a wide range of educational backgrounds in China. Meta analysis of 35 studies found that only two thirds of obstetricians and paediatricians (67%, 95% CI: 59.6%-74.3%) had a bachelor or higher degree. This proportion was lower in primary level facilities (28% (95% CI: 1.5%-53.9%)). For nurses involved in MCH care the proportions with a bachelor or higher degree were lower (20.0% (95% CI: 12.0%-30.0%) in any health facility and 1% (95% CI: 0.0%-5.0%) in primary care facilities).

Unlike previous studies which examine the density of doctors per population - without specifying any discipline - I specifically report the MCH workforce density by cadre and by total population and births. The average density of MCH doctors and nurses was 11.9 (95% CI: 7.5-16.2) and 11.4 (95% CI: 7.6-15.2) per 100,000 population respectively in 2010-2017. The average density of obstetricians was 9.0 (95% CI: 7.9-10.2) per 1,000 births and that of obstetric nurses 16.0 (95% CI: 14.8-17.2) per 1,000 births in 2007-2014. These estimates were equivalent to 32 doctors and 57 obstetric nurses per 3600 births per year, much higher than what has been recommended internationally in 2005 (3 part-time doctors with obstetric skills or 20 midwives per 3,600 births per year)[122], suggesting that there may be a substantial excess of maternal health workers in China. The ratio of obstetric nurses to obstetricians (1.4:1 to 1.7:1) and the ratios of paediatric nurses to paediatricians (1.1:1 to 1.7:1) were lower than the 2:1 nurse-to-doctor ratio recommended by the WHO[28].

China achieved a high density of MCH workers through a mix of workers with high and low educational profiles. Many workers labelled as “obstetricians” or “paediatrician” have lower qualifications than what is internationally recognised, but China compensates for these low educational levels through task-shifting, in-service training and supervision.

7.2.2 Levels, trends and determinants of child mortality in China in 1949-2019

My scoping review of published and unpublished data documented a wealth of data sources reporting on the levels of child mortality in China, including household registration, censuses and micro-censuses, retrospective surveys, national surveillance and report systems, and international reports of infant and under-5 mortality. There are well-known concerns about the quality of household registration data in China due to massive migration without registration updates and under-registration of illegal births and child deaths. Censuses and retrospective surveys, notably the National Survey of Fertility, were the main sources on rates of child mortality before 1990 and are affected by known biases and errors[96]. There has been reasonable progress in data availability after 1990[199, 212]. Comprehensive surveillance (the MCHSS) and death report systems (the Annual Report System) are able to generate timely and reliable estimates of infant and under-5 mortality routinely. These systems have become the main sources for estimating the rates of infant and child mortality in recent years. The reliability of data from the MCHSS and the Annual Report System was much improved in the later 1990s when rigorous quality control measures were introduced[22, 109]. International monitoring of infant and child mortality based on modelling are also important sources of data, but knowledge about their quality is scarce because of the lack of transparency in data inclusion and adjustment.

The IMR and the U5MR declined substantially between 1949 and 2019, except during the Great Leap Forward famine (1959-1961) when mortality increased. Unlike most western countries, where child mortality declined steadily from the late nineteenth century into the 1950s[243], China still had extremely high levels of infant and child mortality in 1950. The IMR at the national level declined from 200 deaths per 1,000 live births in 1950 to 5.6 deaths per 1,000 live births in 2019. The U5MR at the national level declined from 308.5 deaths per 1,000 live births in 1950 to 7.8 deaths per 1,000 live births in 2019. In 1965-1969, China reached the global mean of the U5MR, around 140 per 1,000 live births and continued to be lower than the global mean thereafter[12]. Few studies have compared the speed of decline for the IMR and the CMR1-4 by province throughout the study period.

The cause-of-death composition of under-five deaths changed massively over the study period. Existing evidence showed that communicable diseases, such as tetanus, pneumonia, tuberculosis, and diarrhoea were the major threat to children’s health before 1990. Premature birth and congenital anomalies became increasingly important issues after 1990. The epidemiological transition in causes of deaths suggests that the determinants of infant and child mortality between 1949 and 2019 may have changed over time.

Geographic variation in infant and under-5 mortality has been well documented between regions, provinces, counties, and between urban and rural areas over the studied period, which is closely related to socioeconomic circumstances. Multiple determinants have been shown important in explaining geographic variation, including GDP per capita, increased educational length, health worker density, hospital bed density, public health interventions, decreased fertility rates, rural or urban residence, and availability of public services (including transportation and tele-communication) [15, 72].

As the prerequisite for healthcare, the density of health workers has been examined for its effect on infant or under-5 mortality. Other investments in health systems, such as hospital bed density, have not been examined as primary exposures in the statistical analyses[15, 72, 221, 222]. Evidence on the effect of health worker density on infant or child mortality in China has not been fully conclusive. Ecological studies have shown that populations with a higher density of doctors have lower infant and under-5 mortality[72, 221, 222]. However, using province-level data in 1950-1980, Babiarz et al found no evidence of the effect of health worker density on rates of infant or child mortality, and postulated the hypothesis that there were feed-back loop between doctor density and child mortality [15]. Many questions remain regarding the strength of association, especially when the confounding effects of other determinants of child mortality are taken into account in each period.

7.2.3 Child mortality by province in 1950-2017: levels, trends and speed of decline

I updated a longitudinal dataset on China's infant and child mortality across 27 provinces in Chinses mainland (excluding municipalities and special regions) between 1950 and 1980 to 2017, along with socio-economic and health systems determinants. I updated all the socio-economic and health systems variables from the same data sources as those used by Babiarz and colleagues[15], ensuring the updated dataset was directly comparable to the previous dataset. I also added 17 variables (3 health system input variables and 14 socio-demographic variables) into the dataset. One important limitation to the data is the large amount of missing data for the IMR and the CMR1-4 in 1981-1999 and for the U5MR in 1981-1989, restricting my ability to examine the decline in infant and child mortality for the 1980s and the 1990s.

Better-off regions and provinces have comparatively lower infant and child mortality burden than their counterparts over the period studied (1950-2017). In 1950, all provinces had very high IMRs, ranging from 120.0 deaths per 1,000 livebirths in Fujian to 368.4 deaths per 1,000 live births in Guangxi. By 2016, all the provinces had IMRs below 20 deaths per 1,000 live births, ranging from 2.0 in Guangzhou to 19.4 deaths per 1,000 live births in Xinjiang. In 1950, the CMR1-4 ranged from 19.2 in Jilin to 269.2 deaths children surviving to age one in Yunnan. By 2016, all the provinces had the CMR1-4 below 20 deaths per 1,000 children surviving to age one, ranging from 2.4 deaths in Liaoning to 16.5 deaths per 1,000 children surviving to age one in Gansu. In 2017, several provinces in east China (Liaoning, Jiangsu, Zhejiang, Fujian, Guangdong) had the lowest U5MR (7.0 deaths per 1,000 live births), which was equivalent to the estimates in north America (6.3) but higher than the estimates in Western Europe (3.8) in 2019[258]. In contrast, Tibet had the highest U5MR (36.0) in 2017, equivalent to the level of under-5 mortality in South Asia (40.2) in 2019[258]. As long as there are regional and provincial variation in child survival, the potential for further improvement in China's child mortality rates exists.

There is a generally increasing ratio of infant mortality to 1-4 mortality between 1950 and 1980 and a decreasing trend from 2000 afterwards. The public health programs and interventions China adopted in 2000, for example the Eliminating Neonatal Tetanus Program, could have explained the greater-than-expected progress in infant mortality reductions after 2000.

The analysis of speed of mortality decline using Fractional Polynomials revealed that the declines in the IMR and the CMR1-4 were greatest in 1950-1955 across all the provinces and slowed down thereafter. Between 1950 and 1951 the predicted yearly absolute change across all provinces was -26.7 (95% CI: -29.8, -23.5) deaths per 1,000 live births for the IMR, and -8.4 (95% CI: -9.9, -6.9) deaths per 1,000 children surviving to age one for the CMR1-4. From 1985 onwards all yearly absolute changes were below 2 deaths per 1000 live births (or per 1,000 children surviving to age one). There were marked differences in the speed of decline between provinces and socio-economic regions. The SDI-low category and provinces with the highest burden of mortality made the greatest absolute progress.

Descriptive analysis of the longitudinal data showed that the density of health institutions increased quite a lot in the initial years under Chairman Mao (1950-1964), with little increase thereafter (relative to population increases) except after 2010. The rapid expansion of doctor density—three-fold increase between 1950 (3.1 doctors per 10,000 population) and 1964 (10.3 doctors per 10,000 population)—occurred through the expansion of secondary technical schools (3 years of study or less). The rapid expansion of health institution density and doctor density, which kept up with a growing population size, means that medical care can be expanded rapidly following a national ideology of universal health coverage and government imperatives[72, 210]. In 2017, the mean of doctor density across provinces reached 23.9 per 10,000 population, which is quantitatively comparable to high-income countries (US's 26 per 10,000 population in 2018). In LMICs today, in contrast, the density of doctors is only 2.9 per 10,000 population in sub-Saharan Africa and 6.5 per 10,000 population in South Asia, equivalent to that of China in 1950-1955[57].

Descriptive analysis of the longitudinal data also showed that the largest reductions in infant and child mortality happened when China was extremely poor before economic reforms were introduced in 1978. In the absence of major economic changes, rapid expansion in the health workforce, public health campaigns and expansion of education enrolment made rapid decline in infant and child mortality possible. By contrast, the transportation (e.g. length of highways and possession of civil vehicles) and communications infrastructure (e.g. ownership of telephone and television coverage rate) developed more rapidly after the economic reforms in 1978, providing further support for separate analysis of the determinants of infant/child mortality declines by periods of time.

7.2.4 The contribution of doctor density to child mortality in 1950-2016

By dividing the longitudinal data into discrete groups (1950-1964, 1965-1980, 2000-2016), I have gained insights into the contribution of doctor density to child mortality reductions. The effects vary by period, both in magnitude and direction. There appears to be a beneficial effect of increasing doctor density on child mortality between 1950 and 1964, a harmful effect between 1965 and 1980, and no effect between 2000 and 2016. The definitions of doctors may have changed over time, and caution is required in the interpretation of the strength of association between doctor density and child mortality.

The protective effect of doctor density was statistically significant for both the IMR (adjusted RR=0.91, 95% CI: 0.89-0.93, p<0.001) and the CMR1-4 (adjusted RR=0.88, 95% CI: 0.86-0.91, p<0.001) during 1950-1964, after adjusting for the interaction between GDP per capita and period, gross enrolment ratio of primary education, gross enrolment ratio of secondary education and higher education, the PCA score for public health campaign, the crude birth rate, the production of grain per capita, the hospital bed density and the length of highways. This finding suggests that the substantial increase in doctor density between 1950 and 1964, when the population was extremely poor and educational levels were low, may have contributed to infant and child mortality reductions.

The positive association between doctor density and the IMR (adjusted RR=1.06, 95% CI: 1.03-1.09, p<0.001) and the CMR1-4 (adjusted RR=1.06, 95% CI: 1.00-1.12, p=0.048) over the period 1965-1980 is surprising. This effect seems to be related to the large confounding effect of GDP per capita in this period, since the statistical removal of the confounding effect from GDP per capita changes the sign of the effect of doctor density on the IMR/CMR1-4. The positive association between doctor density and the IMR/CMR1-4 in 1965-1980 may also be due to reverse causality, i.e. the number of doctors was increased more in high mortality provinces, as suggested by Babiaz and colleagues[15]. The presence of reverse causality was consistent with Chairman Mao’s policy emphasis on mobilising health resources to address the perceived imbalance between advantaged and disadvantaged areas in 1965-1980[67].

The public health impact of increasing doctor density on infant and child mortality is likely to be small in China in the future because doctor density is similar as in the UK and the US and because there is evidence that the association between doctor density and child mortality decline disappears after 2000 (adjusted RR=1.01, 95% CI: 0.99-1.04, p=0.32 for the IMR analysis; adjusted RR=0.99, 95% CI: 0.94-1.04, p=0.80 for the CMR1-4 analysis). A potential explanation for the disappeared association is that an increase in doctor density during 2000-2016 through increasing the number of specialists may not help in addressing the conditions that put infants and children at higher risk of death. Possibly there is no more gain above a certain threshold in doctor density.

7.3 Recommendations

7.3.1 Public health recommendations

There are various lessons to be drawn from this research. Some apply to other LMICs whilst others apply to China itself.

Reducing child mortality is still a tough challenge for many LMICs, most evidently in sub-Saharan African countries where the number of health workers continues to fall short of international standards[57]. The shortages of health workers in LMICs are generally worse in rural areas and in disadvantaged populations[279]. China has addressed its human resource challenges for MCH through a form of task-shifting – i.e. workers with lower levels of education can become qualified MCH workers (including doctors) by being assigned specific tasks (e.g. immunisation or antenatal care) and through an elaborate system of certification and supervision. Many LMICs may learn from this. A practical option is to train community health workers like China’s barefoot doctors or nurse practitioners with shorter medical training. But there are precautions when sharing China’s health workforce strategy to other LMICs. China is unique in its strong government, which is the main reason for the rapid production of doctors in a short space of time. China’s doctor density in rural area also expanded rapidly before economic liberalization, owing to its political stability and the government’s emphasis on universal access to health[210]. The uniqueness might affect the acceptability and transferability of its lessons in other countries. Implementation of similar workforce strategies need to be piloted and evaluated before implementing nationwide.

A substantial reduction in overall mortality must involve a decline in mortality from the causes. Due to the changed epidemiology of child mortality, comprehensive interventions focusing on specific causes of deaths should be promoted in China and in other similar settings, including improving care for preterm infants and those with congenital malformations, and raising safety awareness of child injuries. In responding to the new set of child mortality burden, particularly to manage the preterm birth complications and intrapartum-related events, increasing the accessibility and utilization of key interventions (such as skilled care for child birth, neonatal resuscitation, initiation of kangaroo mother care for low birth weight infants) is important. Specific attention to the health workforce for newborns is more recent and relatively neglected[45, 279]. Evidence from multiple countries reveals that neonatal care content is often lacking in training of relevant cadres of health workers[280]. The means of fast-track training in neonatal care has not been addressed in the literature.

In China, obstetricians, paediatricians and other MCH worker cadres are much less educated at the primary level than at the tertiary level. The capacity of MCH workers in primary health facilities should be fostered, which can be realized through implementing upgrading training programmes and more timely and routine supervision from higher-level institutions. The lower capacity of MCH workers in primary health facilities is also seen in other LMICs. Certification of MCH workers is an important strategy to ensure that particular tasks in primary health facilities are only performed by those skilled and equipped to do so.

Despite massive progress, there are still regional inequalities in infant and child survival in China. Barriers to health-care access have been well documented in the literature. The main challenge for China's MCH services is to maintain the gains already made for the majority and prioritize resources to the population living in underserved areas. The focus now is more needed on implementation and evaluation of targeted interventions that may benefit the underserved population residing in rural and remote areas.

7.3.2 Research recommendations

Research on the contribution of health workforce to child mortality can be strengthened in the following aspects.

Researchers and policy-makers in China should explicitly define health workers by cadre who work in MCH area. Base on the published data from the Ministry of Health, the cadres counted in the numerator of doctor density in this thesis do not necessarily refer to those specialized in MCH care. Moreover, it is clear that even within a single cadre, problems of comparability exist due to changing medical education. In the future, a clear standard definition should be adopted, counting MCH workers with different training and certification into different cadres. Such definition can also bolster further studies regarding the relative contribution of different cadres of MCH workers to the reduction of child mortality and reduce measurement errors.

Global work is needed to assess the MCH workforce density in relation to the number of births or the number of children in certain age groups, which could yield more precise health workforce targets by taking into account the size of the targeted population. Information on the obstetrician density in relation to annual live births could help societies prepare to care for pregnancies and births. Understanding the densities of paediatricians, neonatologists and other paediatric professionals could facilitate efforts to address the pressing issues in child health, e.g. pre-term births and congenital malformation. Examining the MCH workforce density per births makes sense for China given its low birth weight, but the comparison between China's density of maternal health workers (32 doctors or 57 obstetric nurses per 3,600 births per year) and the international benchmarks (3 doctors or 20 midwives per 3,600 births per year) is puzzled. The international benchmark could have been much too low, which need further exploration. It is also plausible that the studies included my systematic review in estimating the MCH workforce density is not representative enough of the entire country, which requires more studies to precisely count the number of MCH workers in relation to the number of live births at national level. In addition, previous work has highlighted how health workers (including MCH workers) tend to concentrate in urban areas and in tertiary-level facilities, leaving shortfalls in rural areas and in primary-level facilities. More granular research is needed to look at subnational disparities in the MCH workforce density.

For the purpose of consistent analysis, it is useful to divide the health workforce into three cadres: doctors, nurses (including midwives) and other health workers (e.g. community health workers). However, subnational data on the densities of nurses and community health workers were not available for the whole studied period, yielding an incomplete picture of the effects of health workforce on child mortality. The training of nurses has long been neglected in China, and there are many reasons to expect that the effects of nurse density on child mortality is different to that observed in doctor density. Ideally separate analyses are required for each cadre of MCH workers. Understanding the contributions of each cadre, such as obstetricians and paediatricians, is an important avenue for future research. Moreover, further research is needed in China and in settings outside of China to characterize the optimal ratios of different cadres of MCH workers, including doctors, nurses/midwives and community health workers, in the attainment of lower infant and child mortality.

It is plausible that provinces with fewer doctors had more robust community health worker programs, i.e. barefoot doctor programs, to conduct public health campaigns that reach a large number of infants and children. The WHO also endorsed relying on community health workers with lower-level training where there are shortages of higher-level health workers[281]. Community health workers are frequently an important part of the health system in LMICs and may play an important role in lowering child mortality where doctors are not enough. Given the small number of studies on barefoot doctors included in the systematic review and the obviation of barefoot doctors from the numerator of doctor density, it would be interesting to further investigate the impact of having barefoot doctors on infant and child survival in China.

Newborns and children under five are the most vulnerable population in the world that they have specific needs and are sensitive to the quality of care. The WHO did an online survey in 2011 to identify priorities for perinatal care based on responses from the regional and country offices in 2012 and suggested that improvement in quality of care was the most important domain to reduce all-cause perinatal mortality[282]. I relied on the education level of MCH workers as a proxy for their competency in China. However, how the MCH workers with lower-level training will translate into quality of care has not been explored in the thesis. Internationally, proven strategies to improve quality of care include continued education, regular monitoring and supportive supervision[33]. China has launched the standardised residency training system as a national strategy in 2013 to promote quality of care[65], which need to be monitored and evaluated systematically and repeatedly.

The methodology adopted in examining the association between doctor density and child mortality can be enhanced in multiple ways. First, the results over the period 1965-1980 offered some empirical support to the theories postulated to describe the feed-back loop between doctor density and child mortality. Further longitudinal study is needed to capture event-timings precisely and test the reverse causality that doctor density and child mortality may affect each other over time. Second, a potential strategy for reducing ecologic fallacy is to use smaller units in ecologic studies. Studying the association between doctor density and child mortality at county level rather than at provincial level may have provided better evidence. But such investigation is only possible for the time period after 1990 when child mortality data at county level from the surveillance system and the health workforce data at county level from the Ministry of Health can be accessed and linked. Third, conceptually a model with interactions between each potential covariate and the “period” is appealing but is not supported by the data due to multicollinearity. In many circumstances the different determinants of child mortality are likely to be of different importance by period of time and therefore analytical efforts dealing with the interaction between other determinant (e.g. education) and time periods are needed in the future. Last, the assessment of the effect by period of time is based on the assumption that the association between health worker density and child mortality is non-linear. But it is not known whether a threshold in doctor density exists and whether the threshold is constant across populations with varying levels of socio-economic development. Thus it may be relevant to test the nonlinearity of the association between health worker density and child mortality in different populations.

7.3.3 Data quality recommendations

Existing data on the health workforce in China has its limitations and was not designed with the intention of tracking human resources by functional categories, such as MCH.

Available data for specific cadres of MCH workers, such as obstetricians and paediatricians, rarely provided information beyond national level, precluding subnational investigation of the MCH workforce. Problems of completeness and timeliness of data are barriers to the overall usefulness of existing sources. Improved data-gathering efforts might possibly act as a catalyst for improving the availability and quality of data for the health workforce. There is ongoing demand from the international community for health workforce benchmarks or minimum density thresholds to achieve health system goals[28, 57]. Despite this attention, gaps in the health workforce data and lack of methodological standardisation across sources undermine the utilization of data worldwide. More precise data on the profile and density of health workforce in each country could yield more precise estimates of health workforce shortages.

The monitoring scope of child mortality in China should be advanced through focusing on mortality indicators that are largely neglected, in particular the NMR. The neonatal period (the first 28 days of life) is the most vulnerable period of child survival. More data are needed in this area for future sets of estimates. The continued efforts to strengthen child death registration and surveillance will hopefully improve the precision of age-specific mortality rates by reducing the dependency on statistical modelling. Along with continued surveillance and monitoring efforts, high-quality cause of death data can assist decision making about what interventions are needed and where they are needed most. Data sharing need to be improved across sectors to link population databases (household registration, censuses and nationally representative surveys) and health-related databases to improve the accuracy of child mortality data.

References

1. Victora, C.G.P.D., et al., *Countdown to 2015: a decade of tracking progress for maternal, newborn, and child survival.* The Lancet (British edition), 2015. **387**(10032): p. 2049-2059.
2. World Health Organization, *Children: improving survival and well-being*. 2020: Geneva, Switzerland.
3. Perin, J., et al., *Global, regional, and national causes of under-5 mortality in 2000-2019: an updated systematic analysis with implications for the Sustainable Development Goals.* The Lancet Child & Adolescent Health, 2022. **6**(2): p. 106-115.
4. *Tracking progress in child survival : the 2005 report*. Countdown to 2015 : Child survival. 2005, New York, NY: UNICEF.
5. Black, R.E., S.S. Morris, and J. Bryce, *Where and why are 10 million children dying every year?* The Lancet, 2003. **361**(9376): p. 2226-2234.
6. Burstein, R., et al., *Mapping 123 million neonatal, infant and child deaths between 2000 and 2017.* Nature, 2019. **574**(7778): p. 353-8.
7. Bhutta, Z.A. and R.E. Black, *Global Maternal, Newborn, and Child Health — So Near and Yet So Far.* New England Journal of Medicine, 2013. **369**(23): p. 2226-2235.
8. Lozano, R.P., et al., *Progress towards Millennium Development Goals 4 and 5 on maternal and child mortality: an updated systematic analysis.* The Lancet (British edition), 2011. **378**(9797): p. 1139-1165.
9. UN General Assembly, *Transforming our world : the 2030 Agenda for Sustainable Development*. 2015.
10. Paulson, K.R., et al., *Global, regional, and national progress towards Sustainable Development Goal 3.2 for neonatal and child health: all-cause and cause-specific mortality findings from the Global Burden of Disease Study 2019.* The Lancet, 2021. **6736**(21): p. 1-36.
11. *Global, regional, and national under-5 mortality, adult mortality, age-specific mortality, and life expectancy, 1970-2016: a systematic analysis for the Global Burden of Disease Study 2016.* Lancet (London, England), 2017. **390**(10100): p. 1084-1150.
12. Ahmad, O.B., A.D. Lopez, and M. Inoue, *The decline in child mortality: a reappraisal.* Bulletin of the World Health Organization, 2000. **78**(10): p. 1175-1191.
13. Wang, Y., et al., *Under-5 mortality in 2851 Chinese counties, 1996–2012: a subnational assessment of achieving MDG 4 goals in China.* Lancet, 2016. **387**(10015): p. 273-83.
14. Information Office of the State Council of the People's Republic of China, *The Situation of Children in China*, Information office of the state council, Editor. 1996: Beijing, China.
15. Babiarz, K.S., et al., *An exploration of China's mortality decline under Mao: A provincial analysis, 1950–80.* Population studies, 2015. **69**(1): p. 39-56.
16. The partnership for Maternal, N.C.H., WHO, and A.f.H.P.a.S.R. The World Bank, *Success factors for women's and children's health policy and programme highlights from 10 fast-track countries.* 2014: Geneva: World Health Organization,.
17. Qiao, J., et al., *A Lancet Commission on 70 years of women's reproductive, maternal, newborn, child, and adolescent health in China.* The Lancet, 2021.
18. Guo, Y., J. Bai, and H. Na. *The history of China's maternal and child health care development*. in *Seminars in Fetal and Neonatal Medicine*. 2015.
19. Feng, X.L., et al., *China's facility-based birth strategy and neonatal mortality: a population-based epidemiological study.* The Lancet, 2011. **378**(9801): p. 1493-1500.
20. UNICEF. *Neonatal mortality*. 2021 [cited 2022 Feb 2]; Available from: https://data.unicef.org/resources/dataset/child-mortality/.

21. He, C., et al., *National and subnational all-cause and cause-specific child mortality in China, 1996–2015: a systematic analysis with implications for the Sustainable Development Goals.* Lancet Glob Health, 2017. **5**(2): p. e186-97.
22. Feng, X.L., et al., *Social, economic, political and health system and program determinants of child mortality reduction in China between 1990 and 2006: a systematic analysis.* Journal of global health, 2012. **2**(1).
23. Zhang, D. and P.U. Unschuld, *China's barefoot doctor: past, present, and future.* The Lancet, 2008. **372**(9653): p. 1865-1867.
24. Halstead, S.B., J.A. Walsh, and K.S. Warren, *Good health at low cost.* 1985.
25. National Health Commision of the People’s Republic of China, *China Health Statistics Yearbook 2021*. 2021: Beijing, China.
26. Organization, W.H., *Closing the gap in a generation*. 2008: Geneva, Switzerland.
27. WHO, *A Health Policy and Systems Research Reader on Human Resources for Health*. 2017, World Health Organization: Geneva.
28. WHO, *The world health report 2006: working together for health*. 2006: World Health Organization.
29. Chen, L., et al., *Human resources for health: overcoming the crisis.* The Lancet, 2004. **364**(9449): p. 1984-1990.
30. Gan, X.L., et al., *Provincial Maternal Mortality Surveillance Systems in China. LID - 187896.* (2314-6133 (Print)).
31. Youlong, G., A. Wilkes, and G. Bloom, *Health Human Resource Development in Rural China.* Health policy and planning, 1997. **12**(4): p. 320-328.
32. Rennie, T., et al., *Global Supply of Health Professionals.* The New England journal of medicine, 2014. **370**(23): p. 2246-2248.
33. Haley, C.A., et al., *Impact of a critical health workforce shortage on child health in Zimbabwe: a country case study on progress in child survival, 2000-2013.* Health policy and planning, 2017. **32**(5): p. 613-624.
34. Blumenthal, D. and W. Hsiao, *Lessons from the East — China's Rapidly Evolving Health Care System.* The New England journal of medicine, 2015. **372**(14): p. 1281-1285.
35. Eggleston, K., et al., *Health service delivery in China: a literature review.* Health economics, 2008. **17**(2): p. 149-165.
36. WHO, *People's Republic of China health system review*. 2015, Manila: WHO Regional Office for the Western Pacific.
37. Hsiao, W.C., *The Chinese health care system: lessons for other nations.* Social science & medicine, 1995. **41**(8): p. 1047-1055.
38. Yip, W. and W.C. Hsiao, *What drove the cycles of Chinese health system reforms?* Health Systems & Reform, 2015. **1**(1): p. 52-61.
39. The State Council of the People's Republic of China, *Measures for Implementation of the Law of the People's Republic of China on Maternal and Infant Health Care* 2001: Beijing, China.
40. Raven, J., et al., *The quality of childbirth care in China: women’s voices: a qualitative study.* BMC pregnancy and childbirth, 2015. **15**(1): p. 113.
41. Ren, Z., et al., *China’s human resources for maternal and child health: a national sampling survey.* BMC health services research, 2015. **15**(1): p. 561.
42. Liu, Y., et al., *Health care in China: The role of non-government providers.* Health Policy, 2006. **77**(2): p. 212-220.
43. Flexer, A., *Medical education in the United States and Canada*. 1910: Boston.
44. Narasimhan, V., et al., *Responding to the global human resources crisis.* The Lancet, 2004. **363**(9419): p. 1469-1472.
45. Bolan, N., et al., *Human Resources for Health-Related Challenges to Ensuring Quality Newborn Care in Low- and Middle-Income Countries: A Scoping Review.* Glob Health Sci Pract, 2021. **9**.
46. WHO, *The world health report 2000: health systems: improving performance*. 2000: World Health Organization.

47. Frenk, J., et al., *Health professionals for a new century: transforming education to strengthen health systems in an interdependent world.* Lancet (London, England), 2010. **376**(9756): p. 1923-1958.
48. Ten Cate, O., et al., *Time-Variable Training in Medicine: Theoretical Considerations.* Acad Med, 2018. **93**(3S Competency-Based, Time-Variable Education in the Health Professions): p. S6-s11.
49. Organization, W.H. *Global Health Workforce Statistics*. 2018; Available from: https://apps.who.int/gho/data/node.main.HWFGRP?lang=en.
50. Diallo, K., et al., *Monitoring and evaluation of human resources for health: an international perspective.* Hum Resour Health, 2003. **1**(1): p. 3.
51. Organization, W.H., *Strengtening the performance of community health workers in primary health care. Report of a WHO Study Group.* 1989, World Health Organization: Geneva.
52. Mukherjee, J.S., *Community Health Workers*, in *An Introduction to Global Health Delivery*. 2017, Oxford University Press: New York.
53. Organization, W.H., *Community health workers: a strategy to ensure access to primary health care services*. 2016, World Health Organization: Geneva.
54. UNFPA and ICM, *WHO: The state of the world's midwifery 2014: A universal pathway. A women's right to health.* United Nations Population Fund, New York, 2014.
55. Anand, S. and T. Bärnighausen, *Health workers at the core of the health system: framework and research issues.* Health policy (Amsterdam, Netherlands), 2012. **105**(2-3): p. 185-191.
56. Anand, S. and T. Barnighausen, *Human resources and health outcomes: cross-country econometric study.* The Lancet, 2004. **364**(9445): p. 1603-1609.
57. Haakenstad, A., et al., *Measuring the availability of human resources for health and its relationship to universal health coverage for 204 countries and territories from 1990 to 2019: a systematic analysis for the Global Burden of Disease Study 2019.* The Lancet, 2022.
58. WHO, *Global strategy on human resources for health: workforce 2030*, in *Global strategy on human resources for health: workforce 2030*. 2016.
59. Division, U.N.S. *Metadata for the Proposed Global Indicators for the Review of the 2030 Agenda for Sustainable Development: Metadata for Goal 3*. 2016; Available from: https://unstats.un.org/sdgs/files/metadata-compilation/Metadata-Goal-3.pdf.
60. *Human resources for health : overcoming the crisis*. 2004, Cambridge, Mass.: Joint Learning Initiative.
61. Organization, W.H., *Health workforce requirements for universal health coverage and the sustainable development goals*, in *Human Resources for Health Observer Series No 17*. 2016: Geneva, Switzerland.
62. Hou, J., et al., *Transformation of the education of health professionals in China: progress and challenges.* The Lancet, 2014. **384**(9945): p. 819-827.
63. Hillier, S., *The politics of medicine in China: by David M. Lampton, Wm Dawson, Kent, 1977. 301 pp. £12.* Social Science & Medicine. Part C: Medical Economics, 1979. **13**(4): p. 239-241.
64. Nutter, D.O., *Medical education in the People's Republic of China.* Academic Medicine, 1983. **58**(7).
65. Zhu, J., W. Li, and L. Chen, *Doctors in China: improving quality through modernisation of residency education.* The Lancet, 2016. **388**(10054): p. 1922-1929.
66. Song, F., T.O.M. Rathwell, and D. Clayden, *Doctors in China from 1949 to 1988.* Health policy and planning, 1991. **6**(1): p. 64-70.
67. Li，Decheng, *Review on the study of the barefoot doctor.* Chinese Primary Health Care, 2007. **21**(1): p. 6-8.
68. Volker Scheid, B.H.S., E. Roy Weintraub, *Chinese Medicine in Contemporary China: Plurality and Synthesis.* 2002: p. 76.

69. Hesketh, T. and X.Z. Wei, *Health in China. From Mao to market reform.* BMJ (Clinical research ed.), 1997. **314**(7093): p. 1543-1545.
70. Gross, M., *Between Party, People, and Profession: The Many Faces of the 'Doctor' during the Cultural Revolution.* Medical history, 2018. **62**(3): p. 333-359.
71. Gao, T., et al., *Medical education in China for the 21st century.* Medical Education, 1999. **33**(10): p. 768-773.
72. Anand, S., et al., *China's human resources for health: quantity, quality, and distribution.* The Lancet, 2008. **372**(9651): p. 1774-1781.
73. Chen, Z., et al., *The origin, development and status quo of rural doctors in China.* Chinese Primary Health Care, 2009. **23**(9): p. 1-3.
74. Xu, J., M. Gorsky, and A. Mills, *A path dependence analysis of hospital dominance in China (1949-2018): lessons for primary care strengthening.* Health policy and planning, 2020. **35**(2): p. 167-179.
75. Wang, W., *Medical education in china : progress in the past 70 years and a vision for the future.* 2021: p. 4-9.
76. Ministry of Education of the People's Republic of China. *Blueprint for Medical Education Reform and Development* 2001 [cited 2018 June 19]; Available from: http://old.moe.gov.cn/publicfiles/business/htmlfiles/moe/moe_19/200107/295.html.
77. Bank, W. *World Health Organization's Global Health Workforce Statistics*. 2021 [cited 2022 Feb 18]; Available from: https://data.worldbank.org/indicator/SH.MED.NUMW.P3.
78. Bhutta, Z.A., et al., *Countdown to 2015 decade report (2000–10): taking stock of maternal, newborn, and child survival.* The Lancet, 2010. **375**(9730): p. 2032-2044.
79. Beverley Chalmers, et al., *Family-centred maternity and newborn care in Canada: Underlying philosophy and principles*. 2017, Public Health Agency of Canada: Ottawa.
80. Hoope‐Bender, P.t., J. Liljestrand, and S. MacDonagh, *Human resources and access to maternal health care.* International Journal of Gynecology & Obstetrics, 2006. **94**(3): p. 226-233.
81. WHO, *Making pregnancy safer: the critical role of the skilled attendant: a joint statement by WHO, ICM and FIGO.* 2004.
82. Gabrysch, S., et al., *Tracking progress towards safe motherhood: meeting the benchmark yet missing the goal? An appeal for better use of health‐system output indicators with evidence from Zambia and Sri Lanka.* Tropical medicine & international health, 2011. **16**(5): p. 627-639.
83. WHO and UNFPA, *Conducting a Sexual, Reproductive, Maternal, Newborn and Adolescent Health Workforce Assessment: A Handbook*. 2015.
84. WHO, *Monitoring the building blocks of health systems: a handbook of indicators and their measurement strategies*. 2010: World Health Organization.
85. WHO, *Monitoring emergency obstetric care: a handbook. 2009.* Geneva: World Health Organization Google Scholar, 2014.
86. World Health, O., *WHO recommendations: optimizing health worker roles to improve access to key maternal and newborn health interventions through task shifting*. 2012, Geneva: World Health Organization.
87. Chen, L.C., *Striking the right balance: health workforce retention in remote and rural areas.* Bulletin of the World Health Organization, 2010. **88**(5): p. 323, A.
88. Harper, B.D., et al., *Where are the paediatricians? An international survey to understand the global paediatric workforce.* BMJ paediatrics open, 2019. **3**(1): p. e000397.
89. Filippi, V., et al., *Maternal health in poor countries: the broader context and a call for action.* The Lancet, 2006. **368**(9546): p. 1535-1541.
90. UN，, *Indicators for monitoring the Millennium Development Goals: definitions, rationale, concepts and sources*. Vol. 95. 2003: United Nations Publications.

91. Black, R.E., et al., *Global, regional, and national causes of child mortality in 2008: a systematic analysis.* The Lancet, 2010. **375**(9730): p. 1969-1987.
92. Reidpath, D.D. and P. Allotey, *Infant mortality rate as an indicator of population health.* Journal of Epidemiology and Community Health, 2003. **57**(5): p. 344.
93. Rajaratnam, J.K., et al., *Neonatal, postneonatal, childhood, and under-5 mortality for 187 countries, 1970–2010: a systematic analysis of progress towards Millennium Development Goal 4.* The Lancet, 2010. **375**(9730): p. 1988-2008.
94. Preston, S.H., P. Heuveline, and M. Guillot, *Demography: measuring and modeling population processes.* Pop. Dev. Rev, 2001. **27**: p. 365.
95. Morris, S.S., R.E. Black, and L. Tomaskovic, *Predicting the distribution of under-five deaths by cause in countries without adequate vital registration systems.* International Journal of Epidemiology, 2003. **32**(6): p. 1041-1051.
96. Hill, K., et al., *Child Mortality Estimation: Accelerated Progress in Reducing Global Child Mortality, 1990–2010.* PLOS Medicine, 2012. **9**(8): p. e1001303.
97. Alkema, L. and D. You, *Child Mortality Estimation: A Comparison of UN IGME and IHME Estimates of Levels and Trends in Under-Five Mortality Rates and Deaths.* PLOS Medicine, 2012. **9**(8): p. e1001288.
98. Liu, L., et al., *Global, regional, and national causes of under-5 mortality in 2000–15: an updated systematic analysis with implications for the Sustainable Development Goals.* Lancet, 2016. **388**(10063): p. 3027-35.
99. Organization, W.H. *International Classification of Diseases 11th Revision*. 2021; Available from: https://icd.who.int/en.
100. McGovern, L., G. Miller, and P. Hughes-Cromwick, *The Relative Contribution of Multiple Determinants to Health Outcomes.* Health Affairs, 2014. **August 21**: p. 1-9.
101. WHO, *A policy guide for implementing essential interventions for reproductive, maternal, newborn and child health (RMNCH): a multisectoral policy compendium for RMNCH.* 2014.
102. Pamuk, E.R., R. Fuchs, and W. Lutz, *Comparing relative effects of education and economic resources on infant mortality in developing countries.* Population and development review, 2011. **37**(4): p. 637-664.
103. Houweling, T.A., et al., *Determinants of under-5 mortality among the poor and the rich: a cross-national analysis of 43 developing countries.* Int J Epidemiol, 2005. **34**(6): p. 1257-65.
104. Filmer, D. and L. Pritchett, *The impact of public spending on health: does money matter?* Social Science & Medicine, 1999. **49**(10): p. 1309-1323.
105. Gakidou, E., et al., *Increased educational attainment and its effect on child mortality in 175 countries between 1970 and 2009: a systematic analysis.* The Lancet, 2010. **376**(9745): p. 959-974.
106. Mosley, W.H. and L.C. Chen, *An analytical framework for the study of child survival in developing countries. .* Bull World Health Organ, 1984. **81**(2): p. 140-5.
107. UN, *World Population Prospects, the 2010 Revision*. 2011: New York, US.
108. National Health and Family Planning Commission. *The 2019 statistical report on the development of medical and health services in China*. 2020 [cited 2020 July 2]; Available from: http://www.nhc.gov.cn/guihuaxxs/s10748/202006/ebfe31f24cc145b198dd730603ec4442.shtml.
109. Gao, Y., et al., *Progress and challenges in maternal health in western China: a Countdown to 2015 national case study.* Lancet Glob Health, 2017. **5**(5): p. e523-e536.
110. Balabanova, D., et al., *Good Health at Low Cost 25 years on: lessons for the future of health systems strengthening.* The Lancet, 2013. **381**(9883): p. 2118-2133.

111. Kerber, K.J., et al., *Continuum of care for maternal, newborn, and child health: from slogan to service delivery.* The Lancet, 2007. **370**(9595): p. 1358-1369.
112. Bernis, L., et al., *Skilled attendants for pregnancy, childbirth and postnatal care.* British medical bulletin, 2003. **67**(1): p. 39-57.
113. Harvey, S.A., et al., *Are skilled birth attendants really skilled? A measurement method, some disturbing results and a potential way forward.* Bulletin of the World Health Organization, 2007. **85**: p. 783-790.
114. Hobbs, A.J., et al., *Scoping review to identify and map the health personnel considered skilled birth attendants in low-and-middle income countries from 2000–2015.* PloS one, 2019. **14**(2): p. e0211576.
115. Adegoke, A., et al., *Skilled Birth Attendants: who is who? A descriptive study of definitions and roles from nine Sub Saharan African countries.* PloS one, 2012. **7**(7): p. e40220.
116. Carlough, M. and M. McCall, *Skilled birth attendance: what does it mean and how can it be measured? A clinical skills assessment of maternal and child health workers in Nepal.* International journal of gynecology & obstetrics, 2005. **89**(2): p. 200-208.
117. Ariff, S., et al., *Evaluation of health workforce competence in maternal and neonatal issues in public health sector of Pakistan: an assessment of their training needs.* BMC health services research, 2010. **10**(1): p. 319.
118. WHO, *Definition of skilled health personnel providing care during childbirth: the 2018 joint statement by WHO, UNFPA, UNICEF, ICM, ICN, FIGO and IPA.* 2018, World Health Organization: Geneva.
119. Standing Committee of the Eighth National People's Congress, *Law of the People's Republic of China on Maternal and Infant Health Care*. 1994: Beijing, China.
120. Collender, G., S. Gabrysch, and O.M. Campbell, *Reducing maternal mortality: better monitoring, indicators and benchmarks needed to improve emergency obstetric care. Research summary for policymakers.* Tropical medicine & international health, 2012. **17**(6): p. 694-696.
121. National Bureau of Statistics, *China Statistical Yearbook 2019*. 2019, Beijing: China Statistics Press.
122. WHO, *The World Health Report 2005: Make every mother and child count*. 2005: World Health Organization.
123. Higgins, J.P. and S. Green, *Cochrane handbook for systematic reviews of interventions.* 2008.
124. Liao, X.P., et al., *Advanced neonatal medicine in China: A national baseline database.* PLoS ONE, 2017. **12**(1): p. e0169970.
125. Fu, J., *Research on the distribution and equity of human resources in autonomous prefecture of Chuxiong, Yunnan province*. 2012, Kunming Medical University.
126. Chen, D., *Structure analysis of human resources for health in Fujian maternal and child health center, 2010-2015.* Strait Journal of Preventive Medicine 2016. **22**(06): p. 75-77.
127. Zhu, X., *The talent strategy of maternal and child health hospital in Zunyi*. 2009, Guizhou University.
128. Xiao, Y., *Research on the current status and equality of health manpower resources of minority regions in Sichuan province*. 2011, Chengdu University of Traditional Chinese Medicine.
129. Wang, X., et al., *Study on the current situation and the equity of health human resource allocation in maternal and child health care hospitals of poor counties in Guangxi.* Maternal and Child Health Care of China 2014. **29**(27): p. 4365-4367.
130. Ding, L., et al., *Analysis of maternal and child healthcare in Lanzhou city, 2010-2014.* Maternal and Child Health Care of China 2016. **31**(21): p. 4345-4348.

131. Huang, Z., *The current status of maternal and child health workforce of township hospitals in remote ethnic area.* Maternal and Child Health Care of China, 2009. **24**(28): p. 3920-3922.
132. Feng, J., et al., *The status quo analysis of maternal and child health workforce in remote ethnic area, Guangxi province.* Maternal and Child Health Care of China, 2012. **3**(04): p. 491-493.
133. Lu, B. and H. xiao, *Analysis of obstetric workforce in Nanchang* Chinese Community Doctors, 2010. **12**(240): p. 243.
134. Yao, H., et al., *Analysis of the obstetric departments at different levels of health facilities in Guangxi.* Maternal and Child Health Care of China 2015. **30**(32): p. 5523-5526.
135. Zhu, L., et al., *The status quo analysis of obstetric health workers in Shanghai and policy implications.* Maternal and Child Health Care of China 2008. **23**(06): p. 736-738.
136. Guo, Y., et al., *Effect of paediatric human resource on regional infant mortality rate.* Maternal and Child Health Care of China 2015. **30**(21): p. 3551-3553.
137. Liu, Y., *Study on human resource development strategy of paediatric in Guangdong province*. 2010, Huazhong University of Science & Technology.
138. Shao, Y., *The current situation of paediatric health resources in Zhejiang province under the two-child policy.* Soft Science of Health, 2016(05): p. 295-298.
139. Yang, T., *Research on evaluation of pediatric medical service ability of maternal and child health hospital in district level in Guangzhou city*. 2017, Guangzhou University of Chinese Medicine.
140. Liu, D., *Study on the job burnout situation and its influence factors of clinical nurses in maternal and child health hospital of Hunan province*. 2013, Central South University.
141. Sun, X., et al., *Investigation on the allocation status of neonatology nursing human resources in China's economically developed areas.* Chinese Journal of Practical Nursing 2014. **30**(17): p. 26-30.
142. Zheng, F., *Fuzhou three level hospital pediatric clinical nursing human resource status and development countermeasure research*. 2015, Fujian Medical University.
143. Wu, X., et al., *Analysis on the personnel structure and inlfuencing factors of wage of nurses in a children's hospital.* Chinese Health Resources, 2017. **20**(3): p. 230-233.
144. Li, L., H. Jiang, and Q. Dan, *Status quo analysis of midwifery staff in Leshan.* Guide of China Medicine, 2014. **12**(36): p. 398-399.
145. Ge, W., et al., *The investigation of midwife professionals in one province.* Chinese Health Quality Management 2010. **17**(04): p. 28-31.
146. Wang, J., *The Study on Core Competency of Midwives in Changchun*. 2012, Jilin University.
147. Yu, F., et al., *Two round surveys on child healthcare staff in community health centres, Xiaoshan district, Hangzhou.* Chinese Journal of Preventive Medicine, 2015. **16**(12): p. 978-980.
148. He, Y. and C. Gao, *The current status of maternal and child health workers in townships, Jiangsu.* Jiangsu Healthcare Administration, 1997(06): p. 57-59.
149. Liao, W., *Investigation and evaluation on maternal and children health care network and their working status in a certain main district of Chongqing*. 2008, Chongqing Medical University.
150. Lu, Y., J. Tang, and M. Xue, *Research on maternal and child health workers in community health centres in Huzhou city.* Zhejiang Journal of Preventive Medicine, 2013. **15**(10): p. 81-82.
151. Guo, L., et al., *Analysis of maternal and child healthcare staff in community health centres.* Zhejiang Journal of Preventive Medicine 2015. **27**(11): p. 1165-70.

152. Chen, Y., *A survey on maternal and child health workers in Hengshan, Hunan.* Maternal and Child Health Care of China 1988. **3**(01): p. 8-9.
153. Shen, Y., *Investigation of the capacity of vaccinators in rural area, Anhui province.* Chinese Rural Health Service Administration, 1991(04): p. 20-21.
154. Zan, B., et al., *Human resource status of child and adult vaccination clinics in Yinzhou District of Ningbo City.* Chinese Rural Health Service Administration, 2016(06): p. 716-719.
155. Liu, W., et al., *Analysis of maternal and child health information human resources in Jilin province.* Maternal and Child Health Care of China 2012(17): p. 2568-2570.
156. Ye, J., *A comprehensive analysis of female village doctors who are responsible for maternal and child health and the quality of care.* Maternal and Child Health Care of China, 1992(03): p. 41-42.
157. Cheung, N.F., et al., *Proposed continuing professional education programme for midwives in China: new mothers' and midwives' views.* Nurse Education Today, 2011. **31**(5): p. 434-8.
158. Zhao, J., *Analysis of maternal and child health workforce in Xinyuan county.* Maternal and Child Health Care of China 2007. **22**(01): p. 8-9.
159. Wang, V.L., *Training of the barefoot doctor in the People's Republic of China: from prevention to curative service.* International Journal of Health Services, 1975. **5**(3): p. 475-488.
160. Li, X., *Survey on the present situations of the technical service of mother and infant healthcare in Chongqing city*. 2014, Chongqing Medical University.
161. Ren, Z., et al., *Inequality of obstetric and gynaecological workforce distribution in China.* International journal for equity in health, 2018. **17**(1): p. 3.
162. Xue, M., S. Tang, and J. Gao, *Equity analysis on the distribution of obstetrician and pediatrician in rural China.* Chinese Health Resources, 2003. **6**(04): p. 184-186.
163. Tao, F., et al., *Low postnatal care rates in two rural counties in Anhui Province, China: Perceptions of key stakeholders.* Midwifery, 2011. **27**(5): p. 707-715.
164. Chen, J., X. Ge, and W. Liu, *The current status of obstetric and paediatric resources in Nantong city.* Jiangsu Healthcare Administration 2017. **28**(02): p. 17-19.
165. Hu, Y., et al., *Cross-sectional study on the obstetric service in Hangzhou.* Maternal and Child Health Care of China, 2010. **25**(05): p. 589-591.
166. Ji, G., et al., *Report of delivery resources in Anhui province, China.* Anhui Journal of Preventive Medicine, 2017. **23**(02): p. 82-86.
167. Zhu, L., et al., *Investigation on current situation of obstetrical service in Shanghai city.* Maternal and Child Health Care of China, 2013. **5**(05): p. 817-819.
168. Yang, H., et al., *Current situation and countermeasures of obstetric service in Kunming.* Maternal and Child Health Care of China 2016. **31**(06): p. 1127-1130.
169. Wang, X., *Study on status of prenatal care and influencing factors in rural counties of Southern Xinjiang*. 2015, Lanzhou University.
170. Song, P., et al., *Inequality of Paediatric workforce distribution in China.* International journal of environmental research and public health, 2016. **13**(7): p. 703.
171. Zou, X., et al., *Analysis on change trend and difference of community maternal and child health human resource equity in Guangzhou.* Maternal and Child Health Care of China, 2016. **31**(22): p. 4612-4614.
172. Chen, J., et al., *Comparison of the situation of vaccination clinics in Guangzhou city in 2009 and 2003.* Journal of tropical medicine, 2010. **10**(06): p. 727-729.
173. Jin, X., *A study on the supply and demand of paediatric services in E'shan county*. 2016, Yunnan University.
174. Zhang, Y., et al., *Characteristics and Workload of Pediatricians in China.* Pediatrics, 2019. **144**(1): p. e20183532-e20183532.

175. Hu, Y., et al., *Public health workers and vaccination coverage in eastern China: A health economic analysis.* International Journal of Environmental Research and Public Health, 2014. **11**(5): p. 5555-5566.
176. Wang, H., M.K. Gusmano, and Q. Cao, *An evaluation of the policy on community health organizations in China: will the priority of new healthcare reform in China be a success?* Health Policy, 2011. **99**(1): p. 37-43.
177. Meng, Q., et al., *Mobility of primary health care workers in China.* Human resources for health, 2009. **7**(1): p. 24.
178. Fang, H., et al., *Enhancing financial protection under China's social health insurance to achieve universal health coverage.* BMJ 2019. **365**: p. l2378.
179. Supratikto, G., et al., *A District-based audit of the causes and circumstances of maternal deaths in South Kalimantan, Indonesia.* Bulletin of the World Health Organization, 2002. **80**(3): p. 228-234.
180. Rooney, A.L. and P.R. Van Ostenberg, *Licensure, accreditation, and certification: approaches to health services quality*. 1999: Center for Human Services, Quality Assurance Project.
181. Alkhenizan, A. and C. Shaw, *Impact of accreditation on the quality of healthcare services: a systematic review of the literature.* Annals of Saudi medicine, 2011. **31**(4): p. 407-416.
182. WHO Regional Office for Europe, *Obstetricians and gynaecologists, per 100 000*. 2020: UN city.
183. Hu, K.-j., et al., *Shortage of paediatricians in China.* The Lancet, 2014. **383**(9921): p. 954.
184. Dawson, A.J., et al., *Task shifting and sharing in maternal and reproductive health in low-income countries: a narrative synthesis of current evidence.* Health policy and planning, 2014. **29**(3): p. 396-408.
185. Castro Lopes, S., et al., *A descriptive analysis of midwifery education, regulation and association in 73 countries: the baseline for a post-2015 pathway.* Human Resources for Health, 2016. **14**(1): p. 37-37.
186. Liangming, L., et al., *The levels and trends of infant and under-5 mortality in China from 1991 to 1993.* Population Research, 1996(04): p. 50-56.
187. Feng, X.L., et al., *Regional disparities in child mortality within China 1996–2004: epidemiological profile and health care coverage.* Environ Health Prev Med, 2011. **16**(4): p. 209-16.
188. Zhang, G. and Z. Zhao, *Reexamining China's fertility puzzle: Data collection and quality over the last two decades.* Population and Development Review, 2006. **32**(2): p. 293-321.
189. Banister, J. and K. Hill, *Mortality in China 1964-2000.* Population studies, 2004. **58**(1): p. 55-75.
190. Zhu, W., L. Lu, and T. Hesketh, *China's excess males, sex selective abortion, and one child policy: Analysis of data from 2005 national intercensus survey.* BMJ (Clinical research ed.), 2009. **338**: p. b1211.
191. Menghan, Z. and Y. Fan, *Infant mortality and under-5 mortality rate in China's 2010 census: an assessment.* Population Research, 2013. **37**(05): p. 68-80.
192. Shuzhuo, L., *Analysis of the changing demography in China in the 1980s using adjusted mortality data from the 1990 census.* Population research, 1994(02): p. 37-44.
193. Banister, J. and X. Zhang, *China, economic development and mortality decline.* World Development, 2005. **33**(1): p. 21-41.
194. Zou, X.N., et al., *Epidemiological Characteristics of Cancer in Elderly Chinese.* ISRN Oncology, 2012. **2012**: p. 381849.
195. Yang, G., et al., *Mortality registration and surveillance in China: History, current situation and challenges.* Population health metrics, 2005. **3**(1): p. 3-3.
196. Coale., A.J. and C. ShengLi., *Basic data on fertility in the provinces of China, 1940-82*. 1987, East-West Center: Honolulu Hawaii.

197. Honggui, L., *An assessment of the effectiveness of China's family planning policy on population control based on fertility surveys.* Population Research, 1990(03): p. 8-12.
198. Chen, J., Z. Xie, and H. Liu, *Son preference, use of maternal health care, and infant mortality in rural China, 1989–2000.* Population studies, 2007. **61**(2): p. 161-183.
199. The monitoring group of under-5 child deaths from the Ministry of Health, *Monitoring of the under-5 mortality rate in China during 1991-1995.* Chinese Journal of Healthy Birth & Child Care, 2000(01): p. 27-31.
200. Zhou, M., et al., *Mortality, morbidity, and risk factors in China and its provinces, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017.* The Lancet, 2019. **394**(10204): p. 1145-1158.
201. Ma, Y., et al., *Cause of death among infants in rural western China: a community-based study using verbal autopsy.* The Journal of pediatrics, 2014. **165**(3): p. 577-584.
202. Li, Y., et al., *Analysis of inequality in maternal and child health outcomes and mortality from 2000 to 2013 in China.* International journal for equity in health, 2017. **16**(1): p. 66-66.
203. Zhou, M., et al., *Cause-specific mortality for 240 causes in China during 1990-2013: a systematic subnational analysis for the Global Burden of Disease Study 2013.* The Lancet, 2016. **387**(10015): p. 251-272.
204. Liu, S., et al., *An integrated national mortality surveillance system for death registration and mortality surveillance, China.* Bulletin of the World Health Organization, 2016. **94**(1): p. 46-57.
205. Guo, K., et al., *Propensity score weighting for addressing under-reporting in mortality surveillance: a proof-of-concept study using the nationally representative mortality data in China.* Population Health Metrics, 2015. **13**(1): p. 16.
206. Zhou, M., et al., *Mortality, morbidity, and risk factors in China and its provinces, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017.* Lancet, 2019. **394**(10204): p. 1145-58.
207. Almond, D., et al. *Long-Term Effects of Early-Life Development: Evidence from the 1959 to 1961 China Famine*. 2010.
208. UNICEF, *Joint Review of Maternal and Child Survival Strategies in China*. 2006: Beijing, China. p. 93.
209. UN Inter-agency Group for Child Mortality Estimates, *Levels & Trends in Child Mortality*. 2020.
210. Andrews, B. and M.B. Bullock, *Medical transitions in twentieth-century China*. 2014: Indiana University Press.
211. Ren, X.S., *Infant and child survival in Shaanxi, China.* Social Science and Medicine, 1994. **38**(4): p. 609-621.
212. Yan, M., *The changing trends and the regional differences of infant mortality in China.* Population Research, 2009. **33**(05): p. 77-87.
213. Yang, G., et al., *Rapid health transition in China, 1990-2010: Findings from the Global Burden of disease study 2010.* The Lancet, 2013. **381**(9882): p. 1987-2015.
214. Rudan, I., et al., *Causes of deaths in children younger than 5 years in China in 2008.* The Lancet, 2010. **375**(9720): p. 1083-1089.
215. Wang, Y., et al., *Geographical disparities of infant mortality in rural China.* Archives of Disease in Childhood: Fetal and Neonatal Edition, 2012. **97**(4): p. F285-F290.
216. Wang, Y.P., et al., *Mortality rate for children under 5 years of age in China from 1996 to 2006.* Public health, 2011. **125**(5): p. 301-307.
217. Yimin, S., *Selected findings from recent fertility surveys in three regions of China.* International Family Planning Perspectives, 1987. **13**(3): p. 80-85.

218. Li, J., C. Luo, and N. de Klerk, *Trends in infant/child mortality and life expectancy in Indigenous populations in Yunnan Province, China.* Australian and New Zealand journal of public health, 2008. **32**(3): p. 216-223.
219. Huang, Y., et al., *Ethnicity and maternal and child health outcomes and service coverage in western China: a systematic review and meta-analysis.* The Lancet. Global health, 2018. **6**(1): p. e39-e56.
220. Zhao, Z.L., et al., *All-cause child mortality in minority and non-minority areas in Sichuan Province in Western China, 2008-2017.* Scientific reports, 2019. **9**(1).
221. Sufang, G., W. Linhong, and Z. Wenkun, *Cross-County Analysis on Infant Mortality in Remote and Poverty-Stricken Areas in China.* China Public Health, 2001(06): p. 78-80.
222. Liang, S., et al., *The impact of the health care workforce on under-five mortality in rural China.* Human resources for health, 2019. **17**(1).
223. Luo, Z., et al., *The association between the supply and utilization of community-based primary care and child health in a context of hospital-oriented healthcare system in urban districts of Guangdong, China: a panel dataset, 2014-2016.* BMC health services research, 2020. **20**(1).
224. Song, S. and S.A. Burgard, *Dynamics of inequality: mother's education and infant mortality in China, 1970-2001.* J Health Soc Behav, 2011. **52**(3): p. 349-64.
225. Shusheng, L., et al., *Study on infant mortality rate and related factors in China in 1998-2003.* Maternal & Child Health Care of China, 2006. **21**(13): p. 1841-1845.
226. Chen, Y. and G.Z. Jin, *Does health insurance coverage lead to better health and educational outcomes? Evidence from rural China.* Journal of Health Economics, 2012. **31**(1): p. 1-14.
227. Foggin, P., et al., *Risk factors and child mortality among the Miao in Yunnan, Southwest China.* Social Science and Medicine, 2001. **53**(12): p. 1683-1696.
228. Huang, W., et al., *Infant mortality among various nationalities in the middle part of Guizhou, China.* Social Science and Medicine, 1997. **45**(7): p. 1031-1040.
229. Ross, J., et al., *Effects of malnutrition on child survival in China as estimated by PROFILES.* Biomedical & Environmental Sciences, 2003. **16**(2): p. 187-93.
230. Liu, L., et al., *Global, regional, and national causes of child mortality: An updated systematic analysis for 2010 with time trends since 2000.* The Lancet, 2012. **379**(9832): p. 2151-2161.
231. Chan, E.Y.Y., et al., *Addressing disparities in children’s health in China.* Archives of Disease in Childhood, 2008. **93**(4): p. 346.
232. Chengchao, Z., et al., *China’s Left-Behind Children: Impact Of Parental Migration On Health, Nutrition, And Educational Outcomes.* Health Affairs, 2015. **34**(11): p. 1964-1971.
233. Gillespie, D., *Knowledge into action for child survival.* The Lancet (British edition), 2003. **362**(9380): p. 323-327.
234. Tang, S., et al., *Tackling the challenges to health equity in China.* Lancet (London, England), 2008. **372**(9648): p. 1493-1501.
235. Hsiao, W.C., *Transformation of health care in China.* N Engl J Med, 1984. **310**(14): p. 932-6.
236. Hardee-Cleaveland, K. and J. Banister, *Fertility policy and implementation in China, 1986-88.* Population and Development Review, 1988: p. 245-286.
237. *Communique of the National Sample Survey of Fertility and Birth Control (abstract).* China population newsletter, 1989. **6**(2).
238. National Bureau of Statistics of the People's Republic of China. *National Data*. 2018 [cited 2018 Feb 23]; Available from: http://data.stats.gov.cn/easyquery.htm?cn=C01.
239. UNESCO, U., *Education: Gross enrolment ratio by the level of education.* Education: Gross enrolment ratio by the level of education. Accessed October, 2017. **20**.

240. Evaluation, I.f.H.M.a. *IHME Measuring what matters*. [cited 2021 Nov 13]; Available from: https://www.healthdata.org/.
241. Wang, Y. and G. Yang, *Public health in China*. 2011, Beijing: Zhongguo xiehe yike daxue chubanshe.
242. United Nations Development Programme, *Human development report 2015.* 2016: Geneva: United Nations, .
243. Gwatkin, D.R., *Indications of Change in Developing Country Mortality Trends: The End of an Era?* Population and Development Review, 1980. **6**(4): p. 615-644.
244. Omran, A.R., *The epidemiologic transition theory revisited thirty years later.* World Health Statistics Quarterly, 1998. **53**(2, 3, 4): p. 99-119.
245. Lim, K., *Obstetrics and Gynecology in the Past Ten Years.* Chinese Medical Journal, 1959. **79**(5): p. 375-383.
246. Ashton, B., et al., *Famine in China, 1958-61.* Population and Development Review, 1984. **10**(4): p. 613-645.
247. Bernstein, T.P., *Stalinism, famine, and Chinese peasants.* Theory and Society, 1984. **13**(3): p. 339-377.
248. Sen, A., *Poverty and Famines: An Essay on Entitlement and Deprivation*. 1983, New York: Oxford University Press.
249. London, M. and I.D. London, *The Other China Hunger: Part I: The Three Red Flags of Death.* Worldview, 2018. **19**(5): p. 4-11.
250. Smil, V., *China's great famine: 40 years later.* BMJ (Clinical research ed.), 1999. **319**(7225): p. 1619-1621.
251. Zhu, X., *Understanding China's Growth: Past, Present, and Future.* Journal of Economic Perspectives, 2012. **26**(4): p. 103-24.
252. Preston, S.H., *The changing relation between mortality and level of economic development.* Popul Stud (Camb), 1975. **29**: p. 231-48.
253. Schell, C.O., et al., *Socioeconomic determinants of infant mortality: a worldwide study of 152 low-, middle-, and high-income countries.* Scand J Public Health, 2007. **35**(3): p. 288-97.
254. James J. Heckman and J. Yi, *Human capital, economic growth, and inequality in China*. 2012, National Bureau of Economic Research: Cambridge.
255. Chen, L.C., *Good health at low cost: from slogan to wicked problem.* The Lancet, 2012. **379**(9815): p. 509-510.
256. Moak, K. and M.W.N. Lee, *History of Chinese Economic Development 1949–78*, in *China’s Economic Rise and Its Global Impact*, K. Moak and M.W.N. Lee, Editors. 2015, Palgrave Macmillan US: New York. p. 77-90.
257. S, A., A.J. Coale, and E.M. Hoover, *Population Growth and Economic Development in Low-Income Countries. A Case Study of India's Prospects.* Population (France), 1959. **14**(1): p. 160.
258. Sharrow, D., et al., *Global, regional, and national trends in under-5 mortality between 1990 and 2019 with scenario-based projections until 2030: a systematic analysis by the UN Inter-agency Group for Child Mortality Estimation.* The Lancet Global Health, 2022. **10**(2): p. e195-e206.
259. Rosano, A., et al., *Infant mortality and congenital anomalies from 1950 to 1994: an international perspective.* Journal of Epidemiology and Community Health, 2000. **54**(9): p. 660.
260. Hipgrave, D., *Communicable disease control in China: From Mao to now.* Journal of global health, 2011. **1**(2): p. 224-238.
261. UNICEF, *State of the world's children 2003*. UNICEF: New York.
262. Moucheraud, C., et al., *Consequences of maternal mortality on infant and child survival: a 25-year longitudinal analysis in Butajira Ethiopia (1987-2011).* Reproductive health, 2015. **12 Suppl 1**(Suppl 1): p. S4-S4.
263. Ronsmans, C.P., et al., *Effect of parent's death on child survival in rural Bangladesh: a cohort study.* The Lancet (British edition), 2010. **375**(9730): p. 2024-2031.

264. Sear, R., et al., *The effects of kin on child mortality in rural Gambia.* Demography, 2002. **39**(1): p. 43-63.
265. Fraser, A.M., J.E. Brockert, and R.H. Ward, *Association of young maternal age with adverse reproductive outcomes.* New England journal of medicine, 1995. **332**(17): p. 1113-1118.
266. Nikoloski, Z., et al., *The impact of primary health care and specialist physician supply on amenable mortality in Mexico (2000–2015): Panel data analysis using system-Generalized Method of Moments.* Social Science and Medicine, 2021. **278**(April): p. 113937-113937.
267. Organization, W.H. *The Global Health Observatory*. 2022 [cited 2022 March 18]; Available from: https://www.who.int/data/gho.
268. Mickey, R.M. and S. Greenland, *The impact of confounder selection criteria on effect estimation.* American journal of epidemiology, 1989. **129**(1): p. 125-137.
269. MacKinnon, D.P., J.L. Krull, and C.M. Lockwood, *Equivalence of the mediation, confounding and suppression effect.* Prev Sci, 2000. **1**(4): p. 173-81.
270. DaVanzo, J. and J.-P. Habicht, *Infant mortality decline in Malaysia, 1946–1975: The roles of changes in variables and changes in the structure of relationships.* Demography, 1986. **23**(2): p. 143-160.
271. Anand, S. and T. Bärnighausen, *Health workers and vaccination coverage in developing countries: an econometric analysis.* The Lancet, 2007. **369**(9569): p. 1277-1285.
272. Basu, S., et al., *Association of Primary Care Physician Supply With Population Mortality in the United States, 2005-2015.* JAMA internal medicine, 2019. **179**(4): p. 506-514.
273. Mason, E., M. Mathai, and M.A. Silvestre, *Time of transition: lessons from China's progress in reproductive, maternal, newborn, child, and adolescent health.* The Lancet, 2021.
274. Liu, J. and K. Eggleston, *The Association between Health Workforce and Health Outcomes: A Cross-Country Econometric Study.* Social Indicators Research, 2022.
275. Balaj, M., et al., *Parental education and inequalities in child mortality: a global systematic review and meta-analysis.* The Lancet, 2021. **398**(10300): p. 608-620.
276. UN. *World Population Prospects 2019*. 2019 [cited 2022 Apr 24]; Available from: https://population.un.org/wpp/Download/Standard/Mortality/.
277. Haines, A., et al., *Achieving child survival goals: potential contribution of community health workers.* The Lancet, 2007. **369**(9579): p. 2121-2131.
278. Cochrane, A.L., A.S. St Leger, and F. Moore, *Health service 'input' and mortality 'output' in developed countries.* Journal of Epidemiology and Community Health, 1978. **32**(3): p. 200-205.
279. World Health, O., *Roadmap on human resource strategies to improve newborn care in health facilities in low- and middle-income countries*. 2020, Geneva: World Health Organization.
280. Sharma, G., et al., *Analysis of maternal and newborn training curricula and approaches to inform future trainings for routine care, basic and comprehensive emergency obstetric and newborn care in the low- and middle-income countries: Lessons from Ethiopia and Nepal.* PLOS ONE, 2021. **16**(10): p. e0258624.
281. Lewin, S., et al., *Optimizing health worker roles to improve access to key maternal and newborn health interventions through task shifting. WHO recommendations.* 2012.
282. Coltart, C.E., J.P. Souza, and A.M. Gülmezoglu, *Prioritizing WHO normative work on maternal and perinatal health: a multicountry survey.* Reprod Health, 2011. **8**: p. 30.

Appendix A. Systematic review

A.1 Search strategy for English and Chinese literature on China’s MCH workforce

A1.1 English database search

Embase: 1517

Medline: 941

Cochrane: 71

Econlit: 5

Web of Science: 1357

Global Health: 1108

6 databases in total: 4999

Duplicated references：delete 1429 duplicates

Final dataset: 3570

Embase Classic+Embase@Ovid

No.	Classification	Term	Results
1	Human resources for health	exp medical profession/ or exp paramedical personnel/ or exp medical education/ or exp medical student/ or exp Medical Staff/ or exp Health Care Manpower/ or exp Health Personnel/ or exp health practitioner/ or exp residency education/ or exp health student/ or exp medical personnel/ or 'health worker*'.tw. or 'health workforce*'.tw. or 'health personnel'.tw. or HRH.tw. or HHR.tw. or 'health human resource*'.tw. or 'medical staff'.tw. or 'health*care provider*'.tw. or 'health*care worker*'.tw. or 'health professional*'.tw. or 'health*care professional*'.tw. or 'health*care workforce*'.tw. or 'health provider*'.tw. or 'medical staff'.tw. or 'medical workforce*'.tw. or 'health*care personnel'.tw. or 'health personnel'.tw. 'Health*care Practitioner*'.tw. or 'health practitioner*'.tw. or 'medical student*'.tw. or 'med student*'.tw. or 'health student*'.tw. or 'medical graduate*'.tw. or physician*.tw. or doctor*.tw. or surgeon*.tw. or internist*.tw.or 'general practitioner*'.tw. or nurse*.tw. or 'skilled birth attendant*'.tw. or 'family planning personnel'.tw. or 'medical technician*'.tw. or 'midwifery workforce*'.tw. or midwi?e*.tw. or 'nursing staff'.tw. or 'nursing personnel'.tw. or 'nursing workforce*'.tw. or 'nursing professional*'.tw. or pharmacist.tw. or pharmacists.tw. or 'health care practitioner*'.tw. or 'health care personnel'.tw. or 'health care workforce*'.tw. or 'health care professional*'.tw. or 'health care worker*'.tw. or 'health care provider*'.tw. or paediatrician*.tw. or pediatrician*.tw. or obstetrist*.tw. or obstetrician*.tw. or tocologist*.tw. or gynaecologist*.tw. or gynecologist*.tw. or(human resource* adj4 health).tw. or 'obstetric*	2256760

		workforce*'.tw. or 'paediatric* workforce*'.tw. or 'pediatric* workforce*'.tw. or 'vaccination staff'.tw. or vaccinator*.tw. or 'vaccination personnel'.tw. or 'obstetric* personnel'.tw. or 'paediatric* personnel'.tw. or 'paediatric* personnel'.tw.	
2	MCH services	exp Child Health Services/ or exp Maternal Health Services/ or exp Cesarean Section/ or exp Maternal-Child Nursing/ or exp Obstetric Nursing/ or exp Prenatal Care/ or exp Prenatal Diagnosis/ or exp Home Childbirth/ exp Pediatric Nursing/ or exp Maternal Health Services/ or exp Maternal Health/ or exp Child Care/ or exp Child Health Services/ or exp Intensive Care, Neonatal/ or exp Child Health/ or exp Vaccination/ or exp Immunization/ or exp BCG Vaccine/ or exp Measles Vaccine/ or exp Diphtheria-Tetanus-Pertussis Vaccine/ exp Hepatitis B Vaccines/ or maternal health*.tw. or child health*.tw. or neonat* health*.tw. or MCH.tw. or MNH.tw. or MDG4.tw. or MDG5.tw. or millennium development goal*.tw. or safe motherhood.tw. or prenatal.tw. or pre-natal.tw. or antenatal.tw. or ante-natal.tw. or postnatal.tw. or post-natal.tw. or c-section*.tw. or caesarean section*.tw. or cesarean section*.tw. or facility deliver*.tw. or facility-based deliver*.tw. or home birth.tw. or homebirth.tw. or child birth.tw. or childbirth.tw. or home deliver*.tw. or skilled deliver*.tw. or institutional* deliver*.tw. or vaccin*.tw. or immuniz*.tw. or immunis*.tw. or EPI.tw.	1272246
3	China	exp China/ or China.tw. or Chinese.tw.	391966
4		#1 AND #2 AND #3	1517

Medline@Ovid

No.	Classification	Term	Results
1	Human resources for health	exp medical profession/ or exp paramedical personnel/ or exp medical education/ or exp medical student/ or exp Medical Staff/ or exp Health Manpower/ or exp Health Personnel/ or exp Nurse Practitioners/ exp Internship and Residency/ or 'health worker*'.tw. or 'health workforce*'.tw. or 'health personnel'.tw. or HRH.tw. or HHR.tw. or 'health human resource*'.tw. or 'medical staff'.tw. or 'health*care provider*'.tw. or 'health*care worker*'.tw. or 'health professional*'.tw. or 'health*care professional*'.tw. or 'health*care workforce*'.tw. or 'health provider*'.tw. or 'medical staff'.tw. or 'medical workforce*'.tw. or 'health*care personnel'.tw. or 'health personnel'.tw. or 'Health*care Practitioner*'.tw. or 'health practitioner*'.tw. or 'medical student*'.tw. or 'med student*'.tw. or 'health student*'.tw. or 'medical graduate*'.tw. or Physician*.tw. or doctor*.tw. or surgeon*.tw. or or internist*.tw. or general practitioner*.tw. or nurse*.tw. or 'skilled birth attendant*'.tw. or 'family planning personnel'.tw. or 'medical technician*'.tw. or 'midwifery workforce*'.tw. or midwi?e*.tw. or 'nursing staff'.tw. or 'nursing personnel'.tw. or 'nursing workforce*'.tw. or 'nursing professional*'.tw. or pharmacist.tw. or pharmacists.tw. or 'health care practitioner*'.tw. or 'health care personnel'.tw. or 'health care workforce*'.tw. or 'health care professional*'.tw. or 'health care worker*'.tw. or 'health care provider*'.tw. or paediatrician*.tw. or pediatrician*.tw. or obstetrist*.tw. or obstetrician*.tw. or tocologist*.tw. or gynaecologist*.tw. or gynecologist*.tw. or(human resource* adj4 health).tw. or 'obstetric* workforce*'.tw. or 'paediatric* workforce*'.tw. or 'pediatric* workforce*'.tw. or 'vaccination staff'.tw. or vaccinator*.tw. or 'vaccination personnel'.tw. or 'obstetric* personnel'.tw. or 'paediatric* personnel'.tw. or 'paediatric* personnel'.tw.	1328681

2	MCH services	exp Child Health Services/ or exp Maternal Health Services/ or exp Cesarean Section/ or exp Maternal-Child Nursing/ or exp Obstetric Nursing/ or exp Prenatal Care/ or exp Prenatal Diagnosis/ or exp Home Childbirth/ or exp Obstetric Nursing/ or exp Pediatric Nursing/ or exp Maternal Health/ or exp Child Care/ or exp Child Health Services/ or exp Intensive Care, Neonatal/ or exp Child Health/ or exp Vaccination/ or exp Immunization/ or exp BCG Vaccine/ or exp Measles Vaccine/ or exp Diphtheria-Tetanus-Pertussis Vaccine/ or exp Hepatitis B Vaccines/ or 'maternal health*'.tw. or 'child health*'.tw. or 'neonat* health*'.tw. or MCH.tw. or MNH.tw. or MDG4.tw. or MDG5.tw. or 'millennium development goal*'.tw. or 'safe motherhood'.tw. or prenatal.tw. or pre-natal.tw. or antenatal.tw. or ante-natal.tw. or postnatal.tw. or post-natal.tw. or c-section*.tw. or 'caesarean section*'.tw. or 'cesarean section*'.tw. or 'facility deliver*'.tw. or 'facility-based deliver*'.tw. or 'home birth'.tw. or homebirth.tw. or 'child birth'.tw. or childbirth.tw. or 'home deliver*'.tw. or 'skilled deliver*'.tw. or 'institutional* deliver*'.tw. or EPI.tw. or vaccin*.tw. or immuniz*.tw. or immunis*.tw.	850849
3	China	exp China/ or China.tw. or Chinese.tw.	285572
4		#1 AND #2 AND #3	941

Cochrane Library

No.	Classification	Term	Results
1	Human resources for health	MeSH descriptor: [Health Manpower] explode all trees or MeSH descriptor: [Medical Staff] explode all trees or MeSH descriptor: [Allied Health Personnel] explode all trees or MeSH descriptor: [Health Personnel] explode all trees or MeSH descriptor: [Community Health Workers] explode all trees or MeSH descriptor: [Allied Health Occupations] explode all trees or MeSH descriptor: [Education, Medical] explode all trees or MeSH descriptor: [Students, Medical] explode all trees or ‘health worker*’:ti,ab,kw or ‘health workforce*’:ti,ab,kw or ‘health personnel’:ti,ab,kw or HRH:ti,ab,kw or HHR:ti,ab,kw or ‘health human resource*’:ti,ab,kw or ‘medical staff’:ti,ab,kw or ‘health*care provider*’:ti,ab,kw or ‘health care provider*’:ti,ab,kw or ‘health care worker*’:ti,ab,kw or ‘health*care worker*’:ti,ab,kw or ‘health professional*’:ti,ab,kw or ‘health care professional*’:ti,ab,kw or ‘health*care professional*’:ti,ab,kw or ‘health*care workforce*’:ti,ab,kw or ‘health care workforce*’:ti,ab,kw or ‘health provider*’:ti,ab,kw or ‘health practitioner*’:ti,ab,kw or ‘medical workforce*’:ti,ab,kw or ‘medical personnel’:ti,ab,kw or ‘medical practitioner*’:ti,ab,kw or ‘health care personnel’:ti,ab,kw or ‘health*care personnel’:ti,ab,kw or ‘health care practitioner*’:ti,ab,kw or ‘health*care practitioner*’:ti,ab,kw or ‘human resource*’ near/4 health or ‘medical student*’:ti,ab,kw or ‘med student*’:ti,ab,kw or ‘health student*’:ti,ab,kw or ‘medical graduate*’:ti,ab,kw or physician*:ti,ab,kw or doctor*:ti,ab,kw or surgeon*:ti,ab,kw or internist*:ti,ab,kw or ‘general practitioner*’:ti,ab,kw or nurse*:ti,ab,kw or ‘skilled birth attendant*’:ti,ab,kw or ‘family planning personnel’:ti,ab,kw or ‘midwifery workforce’:ti,ab,kw or midwi?e*:ti,ab,kw or	75398

		‘nursing staff’:ti,ab,kw or ‘nursing personnel’:ti,ab,kw or ‘nursing workforce’:ti,ab,kw or ‘nursing professional*’:ti,ab,kw or dentist*:ti,ab,kw or pharmacist*:ti,ab,kw or ‘medical technician*’:ti,ab,kw	
2	MCH services	MeSH descriptor: [Maternal Health] explode all trees or MeSH descriptor: [Maternal Health Services] explode all trees or MeSH descriptor: [Child Health] explode all trees or MeSH descriptor: [Intensive Care, Neonatal] explode all trees or MeSH descriptor: [Child Health Services] explode all trees or MeSH descriptor: [Infant Health] explode all trees or MeSH descriptor: [Perinatal Care] explode all trees or MeSH descriptor: [Neonatal Nursing] explode all trees or MeSH descriptor: [Prenatal Care] explode all trees or MeSH descriptor: [Postnatal Care] explode all trees or MeSH descriptor: [Cesarean Section] explode all trees or MeSH descriptor: [Delivery, Obstetric] explode all trees or MeSH descriptor: [Parturition] explode all trees or MeSH descriptor: [Pregnancy] explode all trees or MeSH descriptor: [Immunization] explode all trees or MeSH descriptor: [Vaccination] explode all trees or ‘maternal health*’:ti,ab,kw or ‘child health*’:ti,ab,kw or ‘neonat* health*’:ti,ab,kw or MCH:ti,ab,kw or MNH:ti,ab,kw or MDG4:ti,ab,kw or MDG5:ti,ab,kw or millennium development goal*:ti,ab,kw or safe motherhood:ti,ab,kw or prenatal:ti,ab,kw or pre-natal:ti,ab,kw or antenatal:ti,ab,kw or ante-natal:ti,ab,kw or postnatal:ti,ab,kw or post-natal:ti,ab,kw or c-section*:ti,ab,kw or caesarean section*:ti,ab,kw or cesarean section*:ti,ab,kw or facility deliver*:ti,ab,kw or facility-based deliver*:ti,ab,kw or ‘home birth’:ti,ab,kw or homebirth:ti,ab,kw or ‘child birth’:ti,ab,kw or childbirth:ti,ab,kw or ‘home deliver*’:ti,ab,kw or ‘skilled deliver*’:ti,ab,kw or ‘institutional* deliver*’:ti,ab,kw or vaccin*:ti,ab,kw or immuniz*:ti,ab,kw or immunis*:ti,ab,kw or EPI:ti,ab,kw or	42671
3	China	MeSH descriptor: [China] explode all trees or ‘china’:ti,ab,kw or ‘Chinese’:ti,ab,kw	22427
4		#1 AND #2 AND #3	71

Econlit@Ovid

No.	Classification	Term	Results
1	Human resources for health	'health worker*'.tw. or 'health workforce*'.tw. or 'health personnel'.tw. or HRH.tw. or HHR.tw. or 'health human resource*'.tw. or 'medical staff'.tw. or 'health$care provider$'.tw. or 'health$care worker$'.tw. or 'health professional*'.tw. or 'health$care professional*'.tw. or 'health$care workforce*'.tw. or 'health provider$'.tw. or 'medical staff'.tw. or 'medical workforce*'.tw. or 'health$care personnel'.tw. or 'health personnel'.tw. or 'Health$care or practitioner*'.tw. or 'health practitioner*'.tw. or 'medical student*'.tw. or 'med student*'.tw. or 'health student*'.tw. or 'medical graduate*'.tw. or Physician*.tw. or doctor*.tw. or surgeon*.tw. or internist*.tw. or general practitioner*.tw. or nurse*.tw. or 'skilled birth attendant*'.tw. or 'family planning personnel'.tw. or 'medical technician*'.tw. or 'midwifery workforce*'.tw. or midwi?e*.tw. or 'nursing staff'.tw. or 'nursing personnel'.tw. or 'nursing workforce*'.tw. or 'nursing	7142

		professional*’.tw. or pharmacist.tw. or pharmacists.tw. or ‘health care practitioner*’.tw. or ‘health care personnel’.tw. or ‘health care workforce*’.tw. or ‘health care professional*’.tw. or ‘health care worker*’.tw. or ‘health care provider*’.tw. or paediatrician*.tw. or pediatrician*.tw. or obstetrist*.tw. or obstetrician*.tw. or tocologist*.tw. or gynaecologist*.tw. or gynecologist*.tw. or(human resource* adj4 health).tw. or ‘obstetric* workforce*’.tw. or ‘paediatric* workforce*’.tw. or ‘pediatric* workforce*’.tw. or resident*.tw. or ‘vaccination staff’.tw. or vaccinator*.tw. or ‘vaccination personnel’.tw. or ‘obstetric* personnel’.tw. or ‘paediatric* personnel’.tw. or ‘paediatric* personnel’.tw.	
2	MCH services	maternal health*.tw. or child health*.tw. or neonat* health*.tw. or MCH.tw. or MNH.tw. or MDG4.tw. or MDG5.tw. or millennium development goal*.tw. or safe motherhood.tw. or prenatal.tw. or pre-natal.tw. or antenatal.tw. or ante-natal.tw. or postnatal.tw. or post-natal.tw. or c-section*.tw. or caesarean section*.tw. or cesarean section*.tw. or facility deliver*.tw. or facility-based deliver*.tw. or home birth.tw. or homebirth.tw. or child birth.tw.	3777
3	China	China.tw. or Chinese.tw.	38851
4		#1 AND #2 AND #3	5

Web of Science

No.	Classification	Term	Results
1	Human resources for health	ts=(‘medical professional*’ or ‘medical personnel’ or ‘health personnel’ or ‘health human resource*’ or ‘health workforce*’ or ‘medical staff’ or ‘healthcare provider*’ or ‘health-care provider*’ or ‘health care worker*’ or surgeon* or internist* or ‘healthcare worker*’ or ‘health professional*’ or ‘health care professional*’ or ‘health worker*’ or practitioner* or physician* or doctor* or nurse* or pharmacist* or physician* or ‘skilled birth attendant*’ or midwife* or ‘midwifery workforce*’ or midwives or ‘health manpower’ or HRH or HHR or paediatrician* or pediatrician* or obstetrist* or obstetrician* or tocologist* or gynaecologist* or gynecologist* or ‘human resource* adj4 health’ or ‘obstetric* workforce*’ or ‘paediatric* workforce*’ or ‘pediatric* workforce*’ or ‘vaccination staff’ or vaccinator* or ‘vaccination personnel’ or ‘obstetric* personnel’ or ‘paediatric* personnel’ or ‘pediatric* personnel’)	887960
2	MCH services	ts=(maternal health* or child health* or neonat* health* or infant health* or MCH or MNH or MDG4 or MDG5 or millennium development goal* or safe motherhood or prenatal or pre-natal or antenatal or ante-natal or postnatal or post-natal or c-section* or caesarean section* or cesarean section* or facility deliver* or facility-based deliver* or hospital* deliver* or hospital-based deliver* or home birth or home birth or home deliver* or skilled deliver* or institutional* deliver* or vaccin* or immuniz* or immunis* or EPI)	928149
3	China	ts=(China or Chinese)	699607
4		#1 AND #2 AND #3	1357

Global Health

No.	Classification	Term	Results
1	Human resources for health	exp health care workers/ or exp medical education/ or exp medical student/ or 'health worker*'.tw. or 'health workforce*'.tw. or 'health personnel'.tw. or HRH.tw. or HHR.tw. or 'health human resource*'.tw. or 'medical staff'.tw. or 'health$care provider$'.tw. or 'health$care worker$'.tw. or 'health professional*'.tw. or 'health$care professional*'.tw. or 'health$care workforce*'.tw. or 'health provider$'.tw. or 'medical staff'.tw. or 'medical workforce*'.tw. or 'health$care personnel'.tw. or 'health personnel'.tw. or 'Health$care Practitioner*'.tw. or 'health practitioner*'.tw. or 'medical student*'.tw. or 'med student*'.tw. or 'health student*'.tw. or 'medical graduate*'.tw. or Physician*.tw. or doctor*.tw. or surgeon*.tw. or internist*.tw. or general practitioner*.tw. or nurse*.tw. or 'skilled birth attendant*'.tw. or 'family planning personnel'.tw. or 'medical technician*'.tw. or 'midwifery workforce*'.tw. or midwi?e*.tw. or 'nursing staff'.tw. or 'nursing personnel'.tw. or 'nursing workforce*'.tw. or 'nursing professional*'.tw. or pharmacist.tw. or pharmacists.tw. or ‘health care practitioner*’.tw. or ‘health care personnel’.tw. or ‘health care workforce*’.tw. or ‘health care professional*’.tw. or ‘health care worker*’.tw. or ‘health care provider*’.tw. or paediatrician*.tw. or pediatrician*.tw. or obstetrist*.tw. or obstetrician*.tw. or tocologist*.tw. or gynaecologist*.tw. or gynecologist*.tw. or(human resource* adj4 health).tw. or ‘obstetric* workforce*’.tw. or ‘paediatric* workforce*’.tw. or ‘pediatric* workforce*’.tw. or resident*.tw. or ‘vaccination staff’.tw. or vaccinator*.tw. or ‘vaccination personnel’.tw. or ‘obstetric* personnel’.tw. or ‘paediatric* personnel’.tw. or ‘paediatric* personnel’.tw.	187811
2	MCH services	exp Prenatal Care/ or exp Prenatal Education/ or exp Prenatal Diagnosis/ or exp Child Care/ or exp Child Health/ or exp Vaccination/ or exp Immunization/ or exp BCG Vaccine/ or maternal health*.tw. or child health*.tw. or neonat* health*.tw. or MCH.tw. or MNH.tw. or MDG4.tw. or MDG5.tw. or millennium development goal*.tw. or safe motherhood.tw. or prenatal.tw. or pre-natal.tw. or antenatal.tw. or ante-natal.tw. or postnatal.tw. or post-natal.tw. or c-section*.tw. or caesarean section*.tw. or cesarean section*.tw. or facility deliver*.tw. or facility-based deliver*.tw. or home birth.tw. or homebirth.tw. or child birth.tw. or childbirth.tw. home deliver*.tw. or skilled deliver*.tw. or institutional* deliver*.tw. or vaccin*.tw. or immuniz*.tw. or immunis*.tw. or EPI.tw.	221331
3	China	exp China/ or China.tw. or Chinese.tw.	194448
4		#1 AND #2 AND #3	1108

A1.2 Chinese database search

CNKI: 20792

Wanfang: 6464

Two databases in total: 27256

Duplicated references：delete 927 duplicates

Final Chinese database: 26329

China National Knowledge Infrastructure(CNKI)

No.	Classification	Searching terms	Results
1	Human resources for health	SU=卫生人力+卫生人才+卫生人员+医学人力+医学人才+医院人力+医务人员+医务工作者+卫生服务者+护理人力+护理人才+护理人员+药学人力+药学人才+药剂师+医技人才+医技人员+助产士+产科人力+产科人才+产科专家+儿科人力+儿科人才+儿科专家+接种人员+疫苗接种者+接生人员+接生人力+接生者+接生婆+医生+护士+大夫 Translation: SU= health manpower + health talents + health staff + medical manpower + medical talents + hospital staff+ medical staff+ medical workers+ nursing workforce + nursing talents + nursing staff + pharmaceutical talents + pharmaceutical workforce +pharmacists + technical talents + technical talents + midwives +obstetric manpower +obstetric talents + obstetric professionals+ paediatric personnel + paediatric talents + paediatric professionals + vaccination personnel + vaccination staff + midwifery personnel + midwifery workforce +midwifery workers + howdie + doctor + nurse + physician	606345
2	MCH services	SU=妇幼保健+妇幼服务+妇幼健康+妇幼卫生+孕期卫生服务+孕产期保健+孕产妇+围产期保健+围生保健+剖腹产+剖宫产+分娩方式+产科护理+住院分娩+孕期保健+孕前保健+产前保健+孕前护理+产前护理+产前检查+儿童健康+儿科护理+儿童保健+婴儿卫生服务+新生儿保健+新生儿护理+新生儿健康+接种+疫苗+计划免疫+免疫规划 Translation: SU= maternal and child service + maternal and child healthcare + maternal and child health + maternal and child hygiene + pregnancy health care + perinatal health care + pregnant women+ perinatal health care+ perinatal care+ caesarean section+ cesarean section+ delivery + obstetric care+ hospital delivery+ pregnancy care+ pre-pregnancy health care+ prenatal health care+ pre-pregnancy care+ prenatal care+ prenatal test+ health care card+ child health+ pediatric care+ child health care+ infant health care+ neonatal care + neonatal health + vaccination+ vaccine+ planned immunization + immunization programme	450129
3		1 AND 2	20792

SU means searching for title, keyword and abstract.

Wanfang database

No.	Classification	Searching terms	Results
1	Human resources for health	题名或关键词:(卫生人力+卫生人才+卫生人员+医学人力+医学人才+医院人力+医务人员+医务工作者+卫生服务者+护理人力+护理人才+护理人员+助产士+产科人力+产科人才+产科专家+儿科人力+儿科人才+儿科专家+接种人员+疫苗接种者+接生人员+接生人力+接生者+接生婆+医生+护士+大夫) Translation: Topic OR Key words= health manpower + health talents + health staff + medical manpower + medical talents + hospital staff+ medical staff+ medical workers+ nursing workforce + nursing talents + nursing staff + pharmaceutical talents + pharmaceutical workforce +pharmacists + technical talents + technical talents + midwives +obstetric manpower +obstetric talents + obstetric professionals+ paediatric personnel + paediatric talents + paediatric professionals + vaccination personnel + vaccination staff + midwifery personnel + midwifery workforce +midwifery workers + howdie + doctor + nurse + physician	230185
2	MCH services	题名或关键词:(妇幼保健+妇幼服务+妇幼健康+妇幼卫生+孕期卫生服务+孕产期保健+孕产妇+围产期保健+围生保健+剖腹产+剖宫产+分娩方式+产科护理+住院分娩+孕期保健+孕前保健+产前保健+孕前护理+产前护理+产前检查+儿童健康+儿科护理+儿童保健+婴儿卫生服务+新生儿保健+新生儿护理+新生儿健康+接种+疫苗+计划免疫+免疫规划) Translation: Topic OR Key words= maternal and child service + maternal and child healthcare + maternal and child health + maternal and child hygiene + pregnancy health care + perinatal health care + pregnant women+ perinatal health care+ perinatal care+ caesarean section+ cesarean section+ delivery + obstetric care+ hospital delivery+ pregnancy care+ pre-pregnancy health care+ prenatal health care+ pre-pregnancy care+ prenatal care+ prenatal test+ health care card+ child health+ pediatric care+ child health care+ infant health care+ neonatal care + neonatal health + vaccination+ vaccine+ planned immunization + immunization programme	160883
3		1 AND 2	6464

A.2 Quality assessment of included studies

A2.1 Quality assessment for studies reporting on the MCH workforce profile

	Definition of health workers	Study design	Completeness of data
Liao et al, 2017 (E)	Health workers who practiced at a single hospital and held certificates issued by the Ministry of Health	Non-random sampling, data source clearly stated	Not given
Risk	Low risk	High risk	Unclear risk
Fu, 2012 (C)	Not defined	Health bureau data, data source not clearly stated	Not given
Risk	Unclear risk	High risk	Unclear risk
Chen, 2016 (C)	Not defined	Non-random sampling, data source not clearly stated	Not given
Risk	Unclear risk	High risk	Unclear risk
Xiao, 2011 (C Thesis)	Not defined	Census, data source clearly stated	100%
Risk	Unclear risk	Low risk	Low risk
Wang et al, 2014 (C)	Not defined	Census, data source clearly stated	100%
Risk	Unclear risk	Low risk	Low risk
Huang, 2009 (C)	Health workers who worked in the clinical departments	Census, data source clearly stated	100%
Risk	Low risk	Low risk	Low risk
Feng, et al, 2012 (C)	Health workers who worked in the clinical departments	Census, data source clearly stated	100%
Risk	Low risk	Low risk	Low risk
Lu et al, 2010 (C)	Health workers who provided outpatient, inpatient, emergent or ambulatory obstetric services	Census, data source clearly stated	100%
Risk	Low risk	Low risk	Low risk
Zhu et al, 2008 (C)	Not defined	Census, data source clearly stated	100%
Risk	Unclear risk	Low risk	Low risk
Guo et al, 2015 (C)	Not defined	Data from previous survey, but methods not stated	Not given

	Definition of health workers	Study design	Completeness of data
Risk	Unclear risk	High risk	Unclear risk
Liu, 2010 (C Thesis)	Not defined	Non-random sampling, data source clearly stated	Not given
Risk	Unclear risk	High risk	Unclear risk
Shao, 2016 (C)	Health workers who worked in internal wards	Online survey to health workers, but methods not stated	Not given
Risk	Low risk	High risk	Unclear risk
Yang, 2017 (C Thesis)	Not defined	Cross-sectional survey, but sampling methods not clearly stated	Not given
Risk	Unclear risk	High risk	Unclear risk
Liu, 2013 (C Thesis)	Health workers who provided clinical services at the frontline	Cross-sectional survey, but sampling methods not clearly stated	68.75%, no comparison of persons in the study to those not in the study
Risk	Low risk	High risk	High risk
Sun et al, 2014 (C)	Not defined	Multistage sampling, but methods not clearly stated	Not given
Risk	Unclear risk	High risk	Unclear risk
Zheng, 2015 (C Thesis)	Health workers who provided child health care	Non-random sampling, data source clearly stated	Not given
Risk	Low risk	High risk	Unclear risk
Wu et al, 2017 (C)	Paediatric nurse, but no definition	Census, data reported by hospital administrator	100%
Risk	High risk	Low risk	Low risk
Li et al, 2014 (C)	Health workers who held midwifery qualifications, either full-time or part-time	Census, data source clearly stated	100%
Risk	Low risk	Low risk	Low risk
Ge et al, 2010 (C)	Full-time midwife staff	Non-random sampling, data source clearly stated	Not given

	Definition of health workers	Study design	Completeness of data
Risk	Low risk	High risk	Unclear risk
Wang, 2012 (C Thesis)	Health workers who(1) held nursing certificate and qualification for MCH care;(b) working in obstetric department in the past one year;(c) midwifery working experience was more than half a year	Census, data source clearly stated	88.3%
Risk	Low risk	Low risk	Low risk
Yu et al, 2015 (C)	Health workers who provided primary health care for children	Census, data source clearly stated	100%
Risk	Low risk	Low risk	Low risk
He et al, 1997 (C)	Health workers who provided child healthcare and practiced full-time	Census, data source clearly stated	80.4%
Risk	Low risk	Low risk	Low risk
Liao, 2008 (C)	Not defined	Census, data source clearly stated	100%
Risk	Unclear risk	Low risk	Low risk
Lu et al, 2013 (C)	Not defined	Census, data source clearly stated	100%
Risk	Unclear risk	Low risk	Low risk
Guo et al, 2015 (C)	Not defined	Multi-stage cluster sampling, but methods not clearly stated	Not given
	Unclear risk	Unclear risk	Unclear risk
Chen, 1988 (C)	Not defined	Census, data source clearly stated	100%
Risk	Unclear risk	Low risk	Low risk
Shen, 1991 (C)	Not defined	Cross-sectional survey, but sampling methods not clearly stated	Not given
Risk	Unclear risk	High risk	Unclear risk
Zan et al, 2016 (C)	Not defined	Census, data reported by hospital administrator	100%
Risk	Unclear risk	Low risk	Low risk

	Definition of health workers	Study design	Completeness of data
Chen, 2016 (C)	Not defined	Non-random sampling, data reported by hospital administrator	Not given
Risk	Unclear risk	High risk	Unclear risk
Wang et al, 2014 (C)	Not defined	Census, data source clearly stated	100%
Risk	Unclear risk	Low risk	Low risk
Liu et al, 2012 (C)	Health workers who worked in MCH information monitoring and statistics	Census, data source clearly stated	100%
Risk	Low risk	Low risk	Low risk
Ye, 1992 (C)	Health workers who provided maternal healthcare in the villages	Cross-sectional survey, but sampling methods not clearly stated	90%
Risk	Low risk	High risk	Low risk
Wang, 1975 (E)	Health workers who were selected by the people in the communes and were trained in their locale	Non-random sampling, data source clearly stated	Not given
Risk	Low risk	High risk	Unclear risk
Cheung et al, 2011 (E)	Health workers who offered midwifery services including all midwives, nurses, doctors, doulas	Non-random sampling, data source clearly stated	95.3%
Risk	Low risk	High risk	Low risk
Ren et al, 2015 (E)	Health workers who provided curative and preventive healthcare services and held at least one legal health qualification certificate	Clustered random sampling of health facilities and census of health workers, data source clearly stated	Not given
Risk	Low risk	Low risk	Unclear risk

A2.2 Quality assessment for studies reporting on the MCH workforce density

	Definition of health workers	Study design	Completeness of data
Ren et al, 2018 (E)	MCH workers who held professional certificates and worked in clinical departments	Nominator from structured questionnaire to health facilities, denominator from local government	Not given
	Low risk	Low risk	Unclear risk
Xue et al, 2003 (C)	Not given	Numerator and denominator both from National bureau of statistics	Not given
	Unclear risk	Low risk	Unclear risk
Tao et al, 2011 (E)	Midwives with three-year midwifery training	Numerator and denominator both from local health bureau	Not given
	Low risk	Low risk	Unclear risk
Hu et al, 2010 (C)	Not given	Numerator from structured questionnaire to health facilities, denominator source not given	Not given
	Unclear risk	Unclear risk	Unclear risk
Zhu, 2013 (C)	Not given	Nominator from structured questionnaire to health facilities, denominator from record review of Statistics Yearbook	Not given
	Unclear risk	Low risk	Unclear risk
Yang et al, 2016 (C)	Not given	Nominator from structured questionnaire to health facilities, denominator from record review of local health report	Not given
	Unclear risk	Low risk	Unclear risk
Wang, 2015 (C Thesis)	Not given	Nominator from structured questionnaire to health facilities, denominator from record review of local health report	Not given
	Unclear risk	Low risk	Unclear risk
Song et al, 2016 (E)	Not given	Nominator from structured questionnaire to health facilities, denominator source not given	Not given
	Unclear risk	Unclear risk	Unclear risk
Chen et al, 2017 (C)	Not given	Numerator from health bureau data, denominator from census	Not given
	Unclear risk	Low risk	Unclear risk

	Definition of health workers	Study design	Completeness of data
Jin, 2016 (C Thesis)	Not given	Numerator and denominator both from local health bureau	Not given
	Unclear risk	Low risk	Unclear risk
Zhang et al, 2019 (E)	Doctors certified by the National Health Commission and licensed as specializing in medical care for children	Nominator from structured questionnaire to health facilities, denominator source not given	The complete rate for the numerator is 91.8%, unclear for denominator
	Low risk	Unclear risk	Unclear risk
Ji et al, 2017 (C)	Not given	Numerator from health bureau data, denominator from statistics yearbook	Not given
	Unclear risk	Low risk	Unclear risk
Hu et al, 2014 (E)	Full-time vaccination personnel and part-time public health workers who work in childhood immunization	Numerator from health bureau data, denominator source not given	Not given
	Low risk	Unclear risk	Unclear risk
Guo et al, 2015 (C)	Public health workers who provided MCH services	Numerator from structured questionnaire to health facilities, denominator from local health bureau	Not given
	Low risk	Low risk	Unclear risk
Zou et al, 2016 (C)	Public health workers who provided maternal care or child care	Numerator from record review of local health report, denominator source not given	Not given
	Low risk	Unclear risk	Unclear risk
Chen et al, 2010 (C)	Vaccinators who provided outpatient immunization services for children	Numerator from health bureau data, denominator source not given	Not given
	Low risk	Unclear risk	Unclear risk
Wang, 1975 (E)	Traditional birth attendants or barefoot doctors who worked on prenatal check-ups, postnatal care or child care in the communes	Numerator from structured interviews of health workers, denominator source not given	Not given
	Low risk	Unclear risk	Unclear risk

Appendix B. Scoping review

B.1 Literature search in Embase (Classic+Embase1947-2021 April 02) and Medline (1946 to March Week 4 2021) through Ovid. 2021/04/04 13:00

No.	Classification	Term	Results
1	Infant/Child mortality	[tw=(MDG4 or ‘millennium development goal 4’ or ‘under-five mortality’ or ‘under five mortality’ or ‘under-5 mortality’ or 'child mortality' or 'infant death' or 'infant mortality' or 'childhood mortality' or IMR or U5MR or ‘child death’ or ‘live birth’)]or(exp childhood mortality/ or exp infant mortality/ or exp child death/ or exp infant death)	153255
2	China	exp China/ or tw=China or tw=Chinese	1041814
3	Objective specific term(trend)	[tw=(‘declin*’ or ‘reduction’ or ‘reduce’ or ‘reducing’ or ‘decrease’ or ‘decreasing’)]	7672447
4	Objective specific term(determinant)	[tw=(‘determinant’ or ‘associat*’ or ‘correlat*’ or ‘relationship’ or ‘relation’ or ‘relate’)]	17028284
5	Final search	#1 AND #2 AND (#3 OR #4)	1545

B.2 China National Knowledge Infrastructure (CNKI) database, 2021/04/04 20:30

No.	Classification	Searching terms
1	Infant/Child mortality	SU=(婴儿死亡率+儿童死亡率+MDG4+千年发展目标 4) Translation: SU=(infant mortality rate+ child mortality rate+ MDG4 + Millennium Development Goal 4)
2	China	SU=(我国+全国+中国+国家) Translation: Topic OR Key words= Country+ Nation+ China+ State

No.	Classification	Searching terms
3	Objective specific term(trend)	SU=(下降+减少+降低) Translation: SU = (decline + reduce + decrease)
4	Objective specific term(determinant)	SU=(决定因素+关联+相关) Translation: SU = (determinant + association + correlation)
5	Final search	#1 AND #2 AND (#3 OR #4)

SU means searching for title, keyword and abstract.

B.3 Wanfang database 2021/04/04 22:00

No.	Classification	Searching terms
1	Infant/Child mortality	题名或关键词:(婴儿死亡率+儿童死亡率+MDG4+千年发展目标 4) Translation: Topic OR Key words= infant mortality rate+ child mortality rate+ MDG4 + Millennium Development Goal 4
2	China	题名或关键词:(我国+全国+中国+国家) Translation: Topic OR Key words= Country+ Nation+ China+ State
3	Objective specific term(trend)	题名或关键词:(下降+减少+降低) Translation:

No.	Classification	Searching terms
		Topic OR Key words= decline + reduce + decrease
4	Objective specific term(determinant)	题名或关键词:(决定因素+关联+相关) Translation: Topic OR Key words= determinant + association + correlation
5	Final search	#1 AND #2 AND (#3 OR #4)

Appendix C. Definition of variables in the longitudinal dataset (1950-2017)

Table C.1 Definitions and data sources of outcome variables

Variable	Definition (1950-80)	Data source (1950-80)	Definition (1981-2017)	Data source for updating (1981-2017)
Infant Mortality Rate	Deaths per 1,000 live births	"Using the maternal fertility histories of the June 1988 National Survey of Fertility and Contraception conducted by State Family Planning Commission, authors created cohort life tables and calculated age-specific death rates experienced by each birth cohort."	Deaths of infants younger than 1 year per 1,000 livebirths	(1) Health statistics yearbook 2001-population census 1981/1990;(2) Annual reports on maternal and child health based on National Maternal and Child Mortality Surveillance System 2000/2002/2004/2006/2008/2010/2012/2013/2014/2015/2016
Under 5 Mortality Rate	Deaths per 1,000 live births	*Same as above*	Deaths of children younger than 5 years per 1,000 livebirths	(1) Annual reports on maternal and child health - National Maternal and Child Mortality Surveillance System 2000/2002/2004/2006/2008/2010/2012/2013/2014/ 2015/2016;(2) Zhou, M. et al.(2019)-Disease Surveillance Point system, the Maternal and Child Surveillance System, the Chinese Center for Disease Control and Prevention cause-of-death reporting system 1990-2017

Table C.2 Definitions and data sources of demographic variables

Variable	**Definition (1950-80)**	**Data source (1950-80)**	**Definition (1981-2017)**	**Data source for updating (1981-2017)**
Total Population	Year-end total population (10000 persons)	(1) Official provincial yearbooks produced by the National Bureau of Statistics;(2) Supplemental records from “China Statistical Data Compilation, 1949-2003 ”.	The population number at 24:00, 31st December.	Same as 1950-80 data source
Per cent of population over 60	Per cent of population over aged 60	Laonian Renkou Ditu Ji (Collection of Maps of the Elderly Population)	Same as 1950-80 dataset	Derived using census data (year 1964, 1982, 1990, 2000, 2010)
Per cent of population under 5	Per cent of population under age 5	Laonian Renkou Ditu Ji (Collection of Maps of the Elderly Population)	Same as 1950-80 dataset	Derived using census data (year 1964, 1982, 1990, 2000, 2010)
Per cent of population who are male	Per cent of population who are male	(1) Official provincial yearbooks produced by the National Bureau of Statistics;(2) Supplemental records from “China Statistical Data Compilation, 1949-2003”.	The number of male population divided by total population.	Same as 1950-80 data source
Per cent of urban population	Per cent of urban population	*Same as above*	The number of population residing in urban areas divided by resident population(year-end)	*Same as above*
Crude death Rate	Deaths per 1,000 population	*Same as above*	The ratio of the number of deaths to the average population (or mid-period population) during a year.	*Same as above*
Crude birth Rate	Births per 1,000 population	*Same as above*	The ratio of the number of births to the average population (or mid-period population) during a year.	*Same as above*
Natural growth rate*	N/A	N/A	The ratio of natural increase in population (number of births minus number of deaths) in a year to the average population of the same year	*Same as above*

Table C.3 Definitions and data sources of education variables

Variable	**Definition (1950-80)**	**Data source (1950-80)**	**Definition (1981-2017)**	**Data source for updating (1981-2017)**
Gross enrolment ratio of primary education	The number enrolled in primary education divided by the number of population aged 6-11.	The numerator was from provincial yearbooks. The denominator was interpolated from the age-group population counts in the 1953, 1964, and 1982 censuses.	Same as 1950-80 dataset. Institutions of Higher Education recruit graduates from senior secondary schools. They include full-time universities, colleges, institutions of higher professional education, institutions of higher vocational education, institutions of higher vocational education and others(non-university tertiary, branch schools and undergraduate classes)	The numerator was from:(1) Official provincial yearbooks;(2) "China Statistical Data Compilation, 1949-2003" for supplemental early records. The denominator was interpolated from the age-group population counts in the 1964, 1982, 1990, 2000 and 2010 censuses.
Gross enrolment ratio of secondary and higher education	The number enrolled in secondary and higher education divided by the number of population aged 12-18	*Same as above*	Same as 1950-80 dataset. Secondary school includes junior secondary school and senior secondary school. Primary education refers to the people who accept the highest level of education, whether they are in school, graduated, educated or dropouts.	*Same as above*

Table C.4 Definitions and data sources of health system input variables

Variable	**Definition (1950-80)**	**Data source (1950-80)**	**Definition (1981-2017)**	**Data source for updating (1950-2017)**
Doctor density	Number of doctors for every 10,000 members of the population	(1) Official provincial yearbooks;(2) "China Statistical Data Compilation, 1949-2003".	Number of doctors in Health Care Institutions per 10,000 persons. Before 2002, the numerator counts the number of licensed doctors, licensed assistant doctors and intern doctors who are practising in medical treatment, disease prevention or health institutions. Since 2002, the numerator only counts the number of licensed(assistant) doctors, referring to the medical workers who have obtained the licenses of qualified assistant doctors and are employed in medical treatment, disease prevention or health institutions. The numerator excludes the licensed assistant doctors engaged in management job. The denominator is the population figure of household registration from the Ministry of Public Security.	Same as 1950-80 data source
Hospital bed density*	Number of hospital beds for every 10,000 members of the population.	*Same as above*	Number of beds in health care institutions per 10,000 population. The numerator is the fixed sum of beds in health care institutions at the end of the year, including formal beds, simple beds, care beds, beds being disinfected and repaired, disabled beds due to expansion or overhaul, excluding obstetric neonatal beds, expectant beds of confinements room, inventory beds, observation beds, extra beds and escort beds of the patient's family. Health care institutions include hospitals, health care institutions at grass-root level, specialized public health institutions, and other medical and health care institutions. Same denominator as the above variable.	(1) Official provincial yearbooks;(2) "China Statistical Data Compilation, 1949-2003".
Health professional density*	N/A	N/A	Number of health professionals per 10,000 population. Before 2002, the numerator counts the number of licensed doctors, licensed assistant doctors, registered nurses, pharmacists, technicians and interns (doctors, pharmacists, nurses, and technical personnel), excluding the medical technical personnel engaged in managerial job. Since 2002, the numerator excludes the interns. Same denominator as the above variable.	*Same as above*
Health institution density*	N/A	N/A	Number of health institutions per 10,000 population. The numerator counts the number of medical and health care institutions, including: hospitals, health care institutions at grass-root level and specialized public health institutions. Same denominator as the above variable.	*Same as above*

Notes: The variable "hospital bed density" has much missing data from the original data source. The information on "number of beds in health care institutions" is more complete. I generated a new variable "Number of beds in health care institutions per 10,000 persons" using the same denominator as that of "doctor density".

Table C.5 Definitions and data sources of socio-economic development variables

Variable	**Definition (1950-80)**	**Data source (1950-80)**	**Definition (1981-2017)**	**Data source for updating (1981-2017)**
Gross domestic product (100 million yuan)	Not defined	(1) Official provincial yearbooks;(2) “China Statistical Data Compilation, 1949-2003” for supplemental early records.	Gross Domestic Product (GDP) refers to the final products at market prices produced by all resident units in a country per year. For a region, it is called as Gross Regional Product (GRP) or regional GDP.	Same as 1950-80 data source
Investment in fixed assets (current price) per capita	Not defined	*Same as above*	Total investment in fixed assets divided by year-end population. Total investment in fixed assets refers to the volume of activities in construction and purchases of fixed assets and related fees, expressed in monetary terms (RMB) during the reference period.	*Same as above*
General retail price index (preceding year=100)	Not defined	*Same as above*	Retail Price Indices reflect the trend and degree of change in retail prices of commodities during a given period. The change in retail prices of commodities is related to government revenue, the equilibrium of market supply and demand, and the ratio of consumption to accumulation.	*Same as above*
Local revenue per capita (1 million yuan)	Not defined	*Same as above*	Local governments general budgetary revenue divided by year-end population. The revenue includes total tax revenue and total non-tax revenue, excluding the receipts of domestic and foreign debts.	*Same as above*
Total agricultural production per capita (10,000 tons)	Not defined (After comparison with data source, this variable is actually “Local governments expenditure, agriculture, forestry and water conservancy”. This could be an error in dataset)	*Same as above*	Agricultural expenditure items of local general budget expenditure. It refers to the government's agriculture, forestry and water affairs expenditures, including spending on agriculture, forestry expenditures, water expenditures, poverty alleviation expenditures and agricultural comprehensive development expenditures.	*Same as above*
Production of grain per capita (10,000 tons)	Not defined	*Same as above*	Output of grain crops divided by year-end population. Output of grain crops refers to the total output of grain by agricultural production operator in calendar year. According to the harvest season, it includes summer grain, early rice and autumn grain. According to crop varieties, it includes cereals, potatoes and	*Same as above*

			beans.	
Production of fruit per capita (10,000 tons)	Not defined	*Same as above*	Output of fruits divided by year-end population. Output of fruits refer to fruits of trees and vines produced by agricultural producer within the calendar year.	*Same as above*

Table C.6 Definitions and data sources of sanitary campaign variables

Variable	Definition (1950-80)	Data source (1950-80)	Definition (1981-2017)	Data source for updating (1981-2017)
Monitoring-water quality	Not defined	The authors obtained, coded, and digitized annual data contained in the *Weishengzhi*, which comprise compilations of historic public health records.	Same as 1950-80 definition	"Public health in China: implementation (national report)". Surveillance system for specific infectious diseases was established in 1978. The functions include monitoring infectious disease epidemic, food and water monitoring and disease control effort. So this variable was coded "1" in all provinces since 1980.
Monitoring-disease prevention	Not defined	*Same as above*	*Same as above*	*Same as above*
Monitoring-food quality	Not defined	*Same as above*	*Same as above*	*Same as above*
Provision of clean drinking water	Not defined	*Same as above*	*Same as above*	*Same as above*
Sanitary campaigns-against dysentery	Not defined	*Same as above*	*Same as above*	*Same as above*
Sanitary campaigns-against typhoid	Not defined	*Same as above*	*Same as above*	*Same as above*
Sanitary campaigns-against diarrhoea	"Combined intensive environmental management, including indoor residual insecticide spraying and the control of larval breeding sites, with mass chemoprophylaxis and treatment for infected individuals"	*Same as above*	*Same as above*	*Same as above*
Patriotic Public	"Focusing on sanitation; refuse removal; latrine construction; the composting of human excrement ('night soil') to reduce the	*Same as above*	*Same as*	*Same as above*

Hygiene	concentration of intestinal parasites before its use as fertilizer; and the eradication of the ‘four pests’ of rats, flies, mosquitoes, and bedbugs.”	*above*

Table C.7 Definitions and data sources of vaccination variables

Variable	Definition (1950-80)	Data source (1950-80)	Definition (1981-2017)	Data source for updating (1981-2017)
Pertussis Vaccination	"Systematic efforts to vaccinate the population against pertussis"	The authors obtained, coded, and digitized annual data contained in the *Weishengzhi*, which comprise compilations of historic public health records.	Same as 1950-80 definition	The Expanded Program on Immunization was launched in 1978. Diphtheria-tetanus-pertussis vaccine (DTwP) vaccine has been routinely administered to all infants. So this variable was coded "1" in all provinces since 1980.
Diphtheria Vaccination	"Systematic efforts to vaccinate the population against diphtheria"	*Same as above*	*Same as above*	*Same as above*
Smallpox Vaccination	"Systematic efforts to vaccinate the population against smallpox"	*Same as above*	*Same as above*	The eradication of smallpox in China was achieved in the 1950s. This variable was coded "0" since 1980.
Typhoid Vaccination	"Systematic efforts to vaccinate the population against typhoid"	*Same as above*	*Same as above*	National Immunization Program was implemented in 1982, setting out population prevention and immunization covering typhoid. So this variable coded "1" from 1982 onwards. There was no relevant intervention in 1981 based on the yearbook database searching results. So this variable was coded "0" in 1981.
Meningitis Vaccination	"Systematic efforts to vaccinate the population against meningitis"	*Same as above*	*Same as above*	National Immunization Program was implemented in 1982, setting out population prevention and immunization covering meningitis. So this variable coded "1" from 1982 onwards. There was no relevant intervention in 1981 based on the yearbook database searching results. So this variable was coded "0" in 1981.
Cholera Vaccination	"Systematic efforts to vaccinate the population against cholera"	*Same as above*	*Same as above*	In 1987 "Frontier health and quarantine law of the People's Republic of China" was formulated in order to prevent infectious disease including cholera. So this variable was coded "1" from 1987 afterwards. According to yearbook database searching results, between 1981 and 1986, this variable was coded "1" in Liaoning province in year 1985 and 1986. The remaining was coded "0".
Measles	"Systematic efforts to vaccinate the	*Same as above*	*Same as*	The Expanded Program on Immunization was launched in 1978. Measles vaccine

Vaccination	population against measles”		*above*	has been routinely administered to all infants. So this variable was coded “1” in all provinces since 1980.
Tuberculosis Vaccination	“Systematic efforts to vaccinate the population against tuberculosis”	*Same as above*	*Same as above*	The Expanded Program on Immunization was launched in 1978. Bacillus Calmette-Guerin vaccine has been routinely administered to all infants. So this variable was coded “1” in all provinces since 1980.

Table C.8 Definitions and data sources of mosquito vector control variables and other infectious disease control variables

Variable	Definition (1950-80)	Data source (1950-80)	Definition (1981-2017)	Data source for updating (1981-2017)
Mosquito vector control				
Dengue prevention	Not defined	The authors obtained, coded, and digitized annual data contained in the *Weishengzhi*, which comprise compilations of historic public health records.	Same as 1950-80 definition	"Law of the People's Republic of China on the prevention and treatment of infectious diseases" was enacted in 1989, strengthening disease surveillance. Dengue fever was covered. This variable was coded "1" since 1989. Between year 1981 and 1988, no relevant intervention was recorded in the provincial yearbooks. So this variable was coded "0" from 1981 to 1988
Campaign against malaria	"Combined intensive environmental management, including indoor residual insecticide spraying and the control of larval breeding sites, with mass chemoprophylaxis and treatment for infected individuals."	*Same as above*	*Same as above*	Surveillance system for specific infectious diseases was established in 1978. The functions include monitoring infectious disease epidemic, food and water monitoring and disease control effort. So this variable was coded "1" in all provinces since 1980.
Malaria prevention	Not defined	*Same as above*	*Same as above*	*Same as above*
Other infectious disease control				
Influenza	Not defined	*Same as above*	*Same as above*	*Same as above*
Meningitis	Not defined	*Same as above*	*Same as above*	*Same as above*
Tuberculosis	"Widespread vaccination and incorporated drug treatment regimens and case management"	*Same as above*	*Same as above*	*Same as above*

Typhus	Not defined	*Same as above*	*Same as above*	*Same as above*
Pertussis	Not defined	*Same as above*	*Same as above*	*Same as above*
Polio	Not defined	*Same as above*	*Same as above*	The Expanded Program on Immunization was launched in 1978. Oral poliovirus vaccine has been routinely administered to all infants. So this variable was coded “1” in all provinces since 1980.

Table C.9 Definitions and data sources of reproductive health variables and malnutrition variables

Variable	Definition (1950-80)	Data source (1950-80)	Definition (1981-2017)	Data source for updating (1981-2017)
Reproductive health				
Contraception	Not defined	The authors obtained, coded, and digitized annual data contained in the *Weishengzhi*, which comprise compilations of historic public health records.	Same as 1950-80 definition	One-child policy was introduced in 1979. The policy was enforced by methods ranging from offering financial perks for families in compliance and providing contraceptives to implementing forced sterilizations and forced abortions. So this variable was coded "1" throughout the later years.
Midwifery	"Modern midwifery campaigns, which involves short but intensive training, emphasizing sanitary childbirth."	*Same as above*	*Same as above*	China encouraged aseptic delivery from 1981. From 1995, the government started encouraging facility-based delivery. So this variable was coded "1" from 1981.
Malnutrition				
Malnutrition	Large-scale nutrition programmes	*Same as above*	*Same as above*	China promoted systematic management of child healthcare throughout the country from 1986 based on a regulation "Requirements for urban and rural children's health work", focusing on malnutrition caused by poor feeding. The variable malnutrition was coded "1" from 1986 onwards. According to yearbook database searching results, between 1981 and 1985, this variable was coded "1" in Anhui province in 1985. The remaining was coded "0".

Table C.10 Definitions and data sources of newly-added economic variables in 1950-2017 dataset

Variable	**Definition**	**Data source**
Gross domestic product per capita(yuan) *	Ratio of the absolute value of GDP to the average population in that year, which is a measurement of each resident's economic contribution or value creation of his country or region.	(1) Official provincial yearbooks;(2) “China Statistical Data Compilation, 1949-2003” for supplemental early records. Both sources were produced by the National Bureau of Statistics.
Consumer price index *	The degree of changes in prices of consumer goods and services purchased by urban and rural households during a given period.	*Same as above*
General budgetary expenditure (100 million yuan)*	Local governments’ expenditures on general public services, national defence, public security, education, science and technology, culture, sport and media, social safety net and employment effort, health care, environmental protection, urban and rural community affairs, agriculture, forestry and water conservancy, transportation and other expenditures.	*Same as above*
Subset of general budgetary expenditure-culture, education, science and health care combined expenditure (100 million yuan)*	Expenditure on culture, education, health care, science affair disbursed by local governments. Culture item includes culture, heritage, sports, radio and television, journalism, publishing. Education item includes educational administrative management, preschool education, primary education, secondary education, high school education, general education, elementary vocational education, secondary education, technical education, vocational high school education, vocational education, radio and television education, students education, special education, continuing education of cadres and educational institutions services, Related matters were listed not exhaustively for science and health care.(*Notes:* Data for the four items were reported separately from 2007.)	*Same as above*
Subset of general budgetary expenditure-general public service expenditure (100 million yuan)*	Expenditure on general public service disbursed by local governments. Related matters were not clear (*Notes:* This variable was termed “Administration expenditure” before 2006.)	*Same as above*
Subset of general budgetary expenditure-social safety net and employment effort(100 million	Expenditure on social security and employment disbursed by local governments. Related matters include social security and employment management services, civil administration affairs, fiscal subsidies to social insurance funds to supplement the national social security fund, retired administrative institutions, enterprise reform subsidies,	*Same as above*

yuan)*	employment subsidies, pension, retirement resettlement, social welfare, disability human undertakings, urban minimum living security, social assistance to other towns and rural social relief, natural disasters living allowance and the Red Cross affairs	

Notes: a) The data in value terms in the table are calculated at current prices;

b) The indices and growth rates of the follow indicators are calculated at comparable prices: Gross domestic product per capita, price index.

Table C.11 Definitions and data sources of newly-added social development variables in 1950-2017 dataset

Variable	**Definition**	***Data source***
Length of railways in operation(km)*	Total length of the trunk line for passenger and freight transportation in full operation or temporary operation calculated the actual length of the period between the two stations. Any full or partial lane and above lines, are calculated in the actual length of the first line; tracks, station lines, segments, branch lines and special purpose lines and does not calculate shipping connecting lines of business mileage	(1) Official provincial yearbooks;(2) "China Statistical Data Compilation, 1949-2003" for supplemental early records. Both sources were produced by the National Bureau of Statistics.
Length of navigable inland waterway(km)*	Actual length of waterways at the end of reference period that are open to navigation for ships and rafts at different water levels in the water areas of the natural rivers, lakes, reservoirs, canals, and ditches. It is calculated according to the actual length of central line of the main channels. If two provinces share one river as the border, the length of waterways will be half divided for each province. (*Notes:* Since 2004, inland waterways refers to navigable inland waterways.)	*Same as above*
Length of highways(km)*	Actual length of highways at the end of reference period. It covers public roads running vehicles among cities, city and rural areas, township(villages), highways passing through streets at small cities and towns, length of bridges and tunnels, width of ferry piers. It does not include the length of streets in cities, dead end highways, the length of streets built for agricultural(forest) production and inside factories(mines). It can only be calculated with the actual mileage having been completed, checked and accepted or put into operation. If two or more highways go the same section of the way, the length of the section is only calculated for once.(*Notes:* Length of highways include the village road since 2005.)	*Same as above*
Possession of civil vehicles (10,000 units)*	Total numbers of vehicles that are registered under the department of public security at the end of the reference period.	*Same as above*
Ownership of telephone (including mobile telephone) (set/100 persons)*	Average number of telephones per hundred possess in the total population of the administrative area during the reporting period.	*Same as above*

Radio Coverage Rate of the Population (%)*	The percentage of population, which can receive central, provincial, city, prefecture, and county radio programs relayed by wireless, cable, satellite and other technical means, in the surveying area, to national total population	*Same as above*
Television Coverage Rate of Population (%)*	The percentage of population, which can receive central, provincial, city, prefecture, and county television programs relayed by wireless, cable, satellite and other technical means, in the surveying area, to national total population	*Same as above*

Appendix D. Completeness of data in the longitudinal dataset (1950-2017)

Table D.1 Availability of outcome data by province, 1950-2017

Region	Province	Infant mortality rate	1-4 mortality rate	Under-five mortality rate
East	Hebei	1950-81; 1990; 2000; 2002; 2004; 2006; 2008; 2010; 2012-16	1950-80; 1990; 2000; 2002; 2004; 2006; 2008; 2010; 2012-16	1950-80; 1990-2017
	Liaoning			
	Jiangsu	1950-81; 2000; 2002; 2004; 2006; 2008; 2010; 2012-16	1950-80; 2000; 2002; 2004; 2006; 2008; 2010; 2012-16	
	Zhejiang	1950-81; 1990; 2000; 2002; 2004; 2006; 2008; 2010; 2012-16	1950-80; 1990; 2000; 2002; 2004; 2006; 2008; 2010; 2012-16	
	Fujian			
	Shandong			
	Guangdong			
	Hainan	1950-80; 1990; 2000-10; 2012-2016	1950-80; 1990; 2000-10; 2012-2016	
Central	Shanxi	1950-81; 1990; 2000; 2002; 2004; 2006; 2008; 2010; 2012-16	1950-80; 1990; 2000; 2002; 2004; 2006; 2008; 2010; 2012-16	1950-80; 1990-2017
	Jilin			
	Heilongjiang			
	Anhui	1950-81; 1990; 2000; 2002; 2004-08; 2010; 2012-16	1950-80; 1990; 2000; 2002; 2004-08; 2010; 2012-16	
	Jiangxi	1950-81; 1990; 2000; 2002; 2004; 2006; 2008; 2010; 2012-16	1950-80; 1990; 2000; 2002; 2004; 2006; 2008; 2010; 2012-16	
	Henan			
	Hubei			
	Hunan			
Western	Inner Mongolia	1950-81; 1990; 2000; 2002; 2004; 2006; 2008; 2010; 2012-16	1950-80; 1990; 2000; 2002; 2004; 2006; 2008; 2010; 2012-16	1950-80; 1990-2017
	Guangxi			
	Guizhou			
	Yunnan			
	Shaanxi			
	Gansu			
	Qinghai			
	Ningxia			
	Xinjiang	1950-81; 1990; 2004; 2006; 2008; 2010; 2012-16	1950-80; 1990; 2004; 2006; 2008; 2010; 2012-16	
	Sichuan	1950-81; 1990; 2002; 2004; 2006; 2008; 2010; 2012-16	1950-80; 1990; 2002; 2004; 2006; 2008; 2010; 2012-16	
	Tibet	1990; 2008; 2010; 2013	1990; 2008; 2010; 2013	-

Table D.2 Availability of demographic data by province, 1950-2017

Region	**Province**	**Total population**	**Per cent of male population**	**Per cent urban population**	**Death rate**	**Birth rate**	**Natural growth rate**
East	**Hebei**	1950-2017	1950-2017	1950-2017	1950-2017	1950-2017	1950-2017
	Liaoning						
	Jiangsu						
	Zhejiang						
	Fujian	1952-2017		1952-2017			
	Shandong	1950-2017		1950-2017			
	Guangdong		1950-89; 2000; 2005-17				1950; 1952; 1957; 1962; 1965; 1970; 1975; 1978-2017
	Hainan		1950-2017		1957; 1961-65; 1970-2017		
Central	**Shanxi**	1950-2017		1950-2017	1950-2017		
	Jilin						
	Heilongjiang				1954-2017	1950-2017	1954-2017
	Anhui			1952-2017	1950-2017		
	Jiangxi			1950-2017			
	Henan				1954-2017		
	Hubei				1950-2017		1950; 1952; 1954-2017
	Hunan						1950-2017
Western	**Inner Mongolia**	1950-2017		1952; 1957; 1965; 1970-2017	1954-2017		
	Guangxi			1950-2017			
	Guizhou						
	Yunnan						
	Shaanxi			1950-2017	1954-99; 2001-17	1953-2017	1954-2017
	Gansu			1956-58; 1961-2017	1950-2017		
	Qinghai			1950-2017	1952-2017		1981-2017
	Ningxia				1950-2017		
	Xinjiang						
	Sichuan			1957; 1962; 1965; 1970; 1975; 1978-2017			
	Tibet	1959-80; 2000-17	1959-2017		1965-2017		

Table D.3 Availability of education and public health campaign data by province, 1950-2017

Region	**Province**	**Primary education enrolment ratio**	**Secondary education enrolment ratio**	**PCA score for public health campaign**
East	**Hebei**	1950-2017	1950-2017	1950-2017
	Liaoning		1980-2017	
	Jiangsu		1950-2017	
	Zhejiang			
	Fujian			
	Shandong		1950-69; 1971-2004; 2009-17	
	Guangdong		1950-53; 1957-66; 1970; 1973-2017	
	Hainan	1983-2017	1984; 1988-2017	
Central	**Shanxi**	1950-2017	1950-2017	1950-2017
	Jilin		1950-68; 1971-2017	
	Heilongjiang		1950-2017	
	Anhui			
	Jiangxi			
	Henan	1950-65; 1970-2017		
	Hubei	1950-2017		
	Hunan			
Western	**Inner Mongolia**	1950-2017	1952; 1957; 1965; 1975; 1978-2017	1950-2017
	Guangxi		1950-2017	
	Guizhou			No record
	Yunnan		1950-69; 1971-2017	1950-2017
	Shaanxi		1950-2017	
	Gansu			
	Qinghai	1952-2017	1956-2017	
	Ningxia	1954-2017	1958-2017	
	Xinjiang	1950-2017		
	Sichuan	1952; 1957; 1965-66; 1970-2017	1972-2017	
	Tibet	1982-2017		No record

Notes: public health campaigns include six indices: sanitary campaigns, early vaccination campaigns, reproductive health programme, efforts to control mosquito-borne diseases, campaigns against other infectious diseases and malnutrition intervention.

Table D.4 Availability of health system input data by province, 1950-2017

Region	**Province**	**Hospital bed density**	**Doctor density**	**Health professional density**	**Hospital density**
East	**Hebei**	1950-2017			
	Liaoning	1950; 1952; 1957; 1965; 1970; 1975; 1970-2017			
	Jiangsu	1950-2017			
	Zhejiang	1950-65; 1970-2017	1950-2017	1950-65; 1970-2017	
	Fujian	1950-2017			
	Shandong	1950-60; 1962; 1965; 1970; 1972-2017			
	Guangdong	1950; 1952; 1957; 1962; 1965; 1970; 1975; 1978-2017			
	Hainan	1950-66; 1972-2017			
Central	**Shanxi**	1950-2017	1950-2017		
	Jilin				
	Heilongjiang	1952; 1957; 1962; 1965; 1970; 1978-2017	1950-60; 1962-67; 1970; 1971; 1978-2017	1952; 1957; 1962; 1965; 1970; 1978-2017	
	Anhui	1950-2017	1950-2017		
	Jiangxi				
	Henan	1952-99; 2001-2004; 2008-17	1950-99; 2001-2004; 2008-17	1952-99; 2001-2004; 2008-17	
	Hubei	1950-2017	1950-2017		
	Hunan				
Western	**Inner Mongolia**	1952; 1957; 1965; 1970; 1975; 1978-2017			
	Guangxi	1950-65; 1969; 1970; 1972-2017			
	Guizhou	1950-2017			
	Yunnan				
	Shaanxi	1952-2017			
	Gansu	1950-2017			
	Qinghai	1952; 1957-2017			
	Ningxia	1958-2017			
	Xinjiang	1950-2017			
	Sichuan	1978-2017	1952; 1957; 1962; 1965; 1970; 1975; 1978-2017	1978-2017	
	Tibet	1959-2000; 2004; 2008-17			

Table D.5 Availability of socioeconomic data by province, 1950-2017

<table>
<tr><th>Region</th><th>Province</th><th>Gross Domestic Product</th><th>Investment in fixed assets per head</th><th>General Retail Price Index</th><th>Local governments general budgetary revenue</th><th>Local Revenue per head</th></tr>
<tr><td rowspan="8">East</td><td>Hebei</td><td rowspan="7">1952-2017</td><td rowspan="4">1950-2017</td><td rowspan="3">1951-2017</td><td>1950-2017</td><td>1950-2017</td></tr>
<tr><td>Liaoning</td><td colspan="2">1952-2017</td></tr>
<tr><td>Jiangsu</td><td rowspan="2">1950-2017</td><td rowspan="3">1950-2017</td></tr>
<tr><td>Zhejiang</td><td>1953-2017</td></tr>
<tr><td>Fujian</td><td>1952-2017</td><td rowspan="3">1951-2017</td><td>1995-2017</td></tr>
<tr><td>Shandong</td><td rowspan="2">1950-2017</td><td colspan="2">1950-2017</td></tr>
<tr><td>Guangdong</td><td>1952; 1957; 1962; 1965; 1970; 1975; 1978-2017</td><td>1950-2017</td></tr>
<tr><td>Hainan</td><td>1978-2017</td><td>1952-2017</td><td>1979-2017</td><td colspan="2">1952-2017</td></tr>
<tr><td rowspan="8">Central</td><td>Shanxi</td><td rowspan="8">1952-2017</td><td rowspan="8">1950-2017</td><td rowspan="3">1951-2017</td><td colspan="2">1950-2017</td></tr>
<tr><td>Jilin</td><td colspan="2">1952-2017</td></tr>
<tr><td>Heilongjiang</td><td colspan="2">1952-2017</td></tr>
<tr><td>Anhui</td><td>1960-66; 1971-2017</td><td>1950-2017</td><td>1952-2017</td></tr>
<tr><td>Jiangxi</td><td>1951-67; 1971-2017</td><td colspan="2" rowspan="2">1950-2017</td></tr>
<tr><td>Henan</td><td>1957-2017</td></tr>
<tr><td>Hubei</td><td rowspan="2">1951-2017</td><td colspan="2">1953-2017</td></tr>
<tr><td>Hunan</td><td colspan="2">1950-2017</td></tr>
<tr><td rowspan="11">Western</td><td>Inner Mongolia</td><td rowspan="10">1952-2017</td><td>1951-2017</td><td>1952-2017</td><td colspan="2" rowspan="6">1950-2017</td></tr>
<tr><td>Guangxi</td><td rowspan="8">1950-2017</td><td>1952; 1957; 1962; 1965; 1970; 1975; 1978-2017</td></tr>
<tr><td>Guizhou</td><td rowspan="3">1951-2017</td></tr>
<tr><td>Yunnan</td></tr>
<tr><td>Shaanxi</td></tr>
<tr><td>Gansu</td><td>1951-65; 1972-2017</td></tr>
<tr><td>Qinghai</td><td colspan="3">1951-2017</td></tr>
<tr><td>Ningxia</td><td>1958-2017</td><td colspan="2">1950-2017</td></tr>
<tr><td>Xinjiang</td><td>1951-2017</td><td colspan="2">1950-2017</td></tr>
<tr><td>Sichuan</td><td colspan="2">1952; 1957; 1962; 1965; 1970; 1975; 1978-2017</td><td>1985-2017</td><td>1978-2017</td></tr>
<tr><td>Tibet</td><td>1951-80; 1993-2017</td><td>1959-80; 2000-17</td><td>1990-2017</td><td>1952-2017</td><td>1959-80; 2000-17</td></tr>
</table>

Table D.5 (continued) Availability of socioeconomic data by province, 1950-2017

Region	**Province**	**Total agricultural production per head**	**Production of grain per head**	**Production of fruit per head**	**Gross Domestic Product per capita**
East	**Hebei**	1950-2017		1952-80; 1996-2017	1952-2017
	Liaoning	1952-2017	1950-2017	1950-80; 1996-2017	
	Jiangsu	1950-2017			
	Zhejiang	1951-2017		1971-80; 1996-2017	1950-2017
	Fujian		1952-2017	1952-80; 1996-2017	1952-2017
	Shandong	1950-2017		1950-80; 1996-2017	
	Guangdong	1979; 1980; 1994-2017	1950-2017	1952-80; 1996-2017	1950-2017
	Hainan	1965-2017		1952; 1957; 1962; 1965; 1970-80; 1996-2017	1978-2017
Central	**Shanxi**	1950-2017		1950-80; 1996-2017	1952-2017
	Jilin	1952-2017	1950-2017	1954-63; 1965-1980; 1996-2017	
	Heilongjiang	1952-80; 1998-2017		1952-61; 1970-80; 1996-2017	
	Anhui	1978-80; 1990-2017		1950-80; 1996-2017	
	Jiangxi	1950-2017			1950-2017
	Henan			1952-80; 1996-2017	
	Hubei	1953-2017		1950-80; 1996-2017	1952-2017
	Hunan	1950-2017			
Western	**Inner Mongolia**	1950-2017		1980; 1996-2017	1952-2017
	Guangxi			1952-80; 1996-2017	1950-2017
	Guizhou	1952-2017	1950-2017		
	Yunnan	1950-2017		1953-58; 1963; 1970-80; 1996-2017	
	Shaanxi			1950-80; 1996-2017	1952-2017
	Gansu	1979; 1980; 1987-2017		1950-65; 1970-80; 1996-2017	
	Qinghai	1950-2017		1950-63; 1967; 1971-1980; 1996-2017	1950-2017
	Ningxia	1958-2017		1950-65; 1971-1980; 1996-2017	1952-2017
	Xinjiang	1950-2017		1950-80; 1996-2017	
	Sichuan	1978-80; 1994-2017	1952; 1957; 1962; 1965; 1970; 1975; 1978-2017	1952; 1957; 1962; 1965; 1970; 1975; 1978-80; 1996-2017	
	Tibet	1952-2017	1959-80; 2000-17	1978-80; 2000-2017	1951-2017

Table D.5 (continued) Availability of socioeconomic data by province, 1950-2017

Region	Province	General budgetary expenditure	Culture, education, science and health expenditure combined	General public service) expenditure	Subsidies to social security programs
East	**Hebei**	1950-2017	1950-2008	1950-2008	1998-2017
	Liaoning	1952-2017		1952-2008	
	Jiangsu	1950-2017		1950-2008	
	Zhejiang				1986-2017
	Fujian				2000-17
	Shandong		1979-2008		1998-2017
	Guangdong	1952; 1957; 1962; 1965; 1970; 1975; 1978-2017	1988-2008		
	Hainan	1952-2017	1952-2008		
Central	**Shanxi**	1950-2017	1950-2008		1998-2017
	Jilin	1952-2017	1952-2008		
	Heilongjiang				1952-2017
	Anhui	1950-2017			1990-2017
	Jiangxi		1950-2008		1998-2017
	Henan				
	Hubei	1953-2017	1953-2008		2001-2017
	Hunan	1950-2017	1950-2008		1998-2017
Western	**Inner Mongolia**	1950-2017	1950-2008		1995-2017
	Guangxi		1950-2006		1998-2017
	Guizhou		1950-2008		1951-2017
	Yunnan				1998-2017
	Shaanxi				
	Gansu				1987-2017
	Qinghai		1951-2008	1950-2008	1998-2017
	Ningxia		1950-2008		
	Xinjiang				2000-17
	Sichuan	1985-2017	1994-2008	1985-2008	1998-2017
	Tibet	1952-2017	1952-2008		1991-2017

Table D.5 (continued) Availability of socioeconomic data by province, 1950-2017

<table>
<tr><th>Region</th><th>Province</th><th>Length of railways in operation</th><th>Length of navigable inland waterway</th><th>Length of highways</th><th>Number of civil vehicles owned</th></tr>
<tr><td rowspan="8">East</td><td>Hebei</td><td>1952-2017</td><td>1978-1985;
1990-2008</td><td colspan="2">1952-2017</td></tr>
<tr><td>Liaoning</td><td>1952; 1956-1961; 1963-2017</td><td colspan="3">1950-2017</td></tr>
<tr><td>Jiangsu</td><td>1952-2017</td><td>1952; 1953; 1957; 1962; 1965; 1970; 1974-2017</td><td>1952-2017</td><td>1961-2017</td></tr>
<tr><td>Zhejiang</td><td colspan="3">1952; 1957; 1962; 1965; 1970; 1975; 1978-2017</td><td rowspan="2">1979-2017</td></tr>
<tr><td>Fujian</td><td>1956-2015</td><td colspan="2">1950-2015</td></tr>
<tr><td>Shandong</td><td rowspan="2">1950-2017</td><td rowspan="2">1950-2017</td><td colspan="2">1950-2017</td></tr>
<tr><td>Guangdong</td><td>1950-2017</td><td>1952; 1957; 1962; 1965; 1970; 1975; 1978-2017</td></tr>
<tr><td>Hainan</td><td>1958-2017</td><td>1965; 1970; 1975; 1978-80; 1985; 1987; 1990-2017</td><td colspan="2">1950-2017</td></tr>
<tr><td rowspan="8">Central</td><td>Shanxi</td><td rowspan="2">1950-2017</td><td>2007-17</td><td colspan="2" rowspan="2">1950-2017</td></tr>
<tr><td>Jilin</td><td>1978-2017</td></tr>
<tr><td>Heilongjiang</td><td>1952-2017</td><td>1950-2017</td><td>1950-2017</td><td>1979-1998; 2000-17</td></tr>
<tr><td>Anhui</td><td colspan="2">1950-2015</td><td>1950-2015</td><td>1950-2017</td></tr>
<tr><td>Jiangxi</td><td colspan="2">1978; 1980; 1985-2017</td><td>1950-2017</td><td>1978-2017</td></tr>
<tr><td>Henan</td><td colspan="4">1950-2017</td></tr>
<tr><td>Hubei</td><td colspan="4">1952; 1957; 1962; 1965; 1970; 1975; 1978-2017</td></tr>
<tr><td>Hunan</td><td colspan="4">1950-2017</td></tr>
<tr><td rowspan="11">Western</td><td>Inner Mongolia</td><td rowspan="2">1950-2017</td><td>1987-2017</td><td rowspan="3">1950-2017</td><td>1953-2017</td></tr>
<tr><td>Guangxi</td><td>1978-2017</td><td rowspan="2">1978-2017</td></tr>
<tr><td>Guizhou</td><td colspan="2">1957-2017</td></tr>
<tr><td>Yunnan</td><td colspan="4" rowspan="2">1950-2017</td></tr>
<tr><td>Shaanxi</td></tr>
<tr><td>Gansu</td><td>1950-2015</td><td>1999-2015</td><td rowspan="4">1950-2015</td><td>1950-2017</td></tr>
<tr><td>Qinghai</td><td>1959-2017</td><td>2009-17</td><td>1951-2017</td></tr>
<tr><td>Ningxia</td><td rowspan="2">1958-2017</td><td>1950-2017</td><td rowspan="2">1950-2017</td></tr>
<tr><td>Xinjiang</td><td>_</td></tr>
<tr><td>Sichuan</td><td>1950-2017</td><td>1952; 1957; 1963-2017</td><td>1952; 1957-2017</td><td>1979-2017</td></tr>
<tr><td>Tibet</td><td>2007-17</td><td>_</td><td colspan="2">1954-2017</td></tr>
</table>

Table D.5 (continued) Availability of socioeconomic data by province, 1950-2017

<table>
<tr><th>Region</th><th>Province</th><th>Ownership of telephone</th><th>Radio coverage rate of the population</th><th>Television coverage rate of the population</th></tr>
<tr><td rowspan="8">East</td><td>Hebei</td><td>1952-1994; 1996-2008; 2010-17</td><td rowspan="2">1980-2008; 2010-17</td><td>1980-2008; 2010-17</td></tr>
<tr><td>Liaoning</td><td>2000-08; 2010-17</td><td>1978; 1980-2008; 2010-17</td></tr>
<tr><td>Jiangsu</td><td>1978-2008; 2010-17</td><td>1981-2008; 2010-17</td><td>1960-2008; 2010-17</td></tr>
<tr><td>Zhejiang</td><td>1952; 1962; 1965; 1970; 1975; 1980; 1985; 1988; 1990-2008; 2010-17</td><td colspan="2">2000-08; 2010-17</td></tr>
<tr><td>Fujian</td><td>2000-17</td><td>1980-2008; 2010-17</td><td>1978; 1980-2008; 2010-17</td></tr>
<tr><td>Shandong</td><td>2002-08; 2010-17</td><td>1958-2008; 2010-17</td><td>1960-1962; 1969-2008; 2010-17</td></tr>
<tr><td>Guangdong</td><td>1965; 1975; 1978-2008; 2010-17</td><td colspan="2">1980-2008; 2010-17</td></tr>
<tr><td>Hainan</td><td>1953-2008; 2010-17</td><td>1991-2008; 2010-17</td><td>1985-2008; 2010-17</td></tr>
<tr><td rowspan="8">Central</td><td>Shanxi</td><td>1954-2008; 2010-17</td><td colspan="2">1978-2008; 2010-17</td></tr>
<tr><td>Jilin</td><td>1950-1998; 2001-17</td><td colspan="2">1980-2008; 2010-17</td></tr>
<tr><td>Heilongjiang</td><td>1985; 1990; 1995-2008; 2010-17</td><td>1952; 1957; 1962; 1965; 1978-2008; 2010-17</td><td>1958-2008; 2010-17</td></tr>
<tr><td>Anhui</td><td rowspan="2">1950-2008; 2010-17</td><td>1950; 1952; 1954; 1955; 1959; 1960; 1965-67; 1970; 1975; 1978-2008; 2010-17</td><td>1960; 1965; 1970; 1975; 1978-2008; 2010-17</td></tr>
<tr><td>Jiangxi</td><td colspan="2">1980-2008; 2010-17</td></tr>
<tr><td>Henan</td><td>1960-2008; 2010-17</td><td>1950-2008; 2010-17</td><td>1969-2008; 2010-17</td></tr>
<tr><td>Hubei</td><td>1997-99; 2001-08; 2010-17</td><td>1952; 1957; 1962; 1965; 1970; 1975; 1978-2008; 2010-17</td><td>1965; 1970; 1975; 1978-2008; 2010-17</td></tr>
<tr><td>Hunan</td><td>1999-2008; 2010-17</td><td colspan="2">1985-2008; 2010-17</td></tr>
<tr><td rowspan="11">Western</td><td>Inner Mongolia</td><td>1952; 1957; 1958; 1965; 1970; 1975; 1978-2008; 2010-17</td><td colspan="2">1980-2008; 2010-17</td></tr>
<tr><td>Guangxi</td><td>1978; 1980; 1985-2008; 2010-17</td><td rowspan="2">1950-2008; 2010-17</td><td>1970-2008; 2010-17</td></tr>
<tr><td>Guizhou</td><td>1978-2008; 2010-17</td><td>1968-2008; 2010-17</td></tr>
<tr><td>Yunnan</td><td rowspan="2">1950-2008; 2010-17</td><td>1965-2008; 2010-17</td><td>1969-2008; 2010-17</td></tr>
<tr><td>Shaanxi</td><td colspan="2">1985-2008; 2010-17</td></tr>
<tr><td>Gansu</td><td>1995-2018; 2010-17</td><td>1952; 1953; 1956; 1962; 1965; 1976; 1978; 1980-2008; 2010-17</td><td>1970-73; 1980-2008; 2010-17</td></tr>
<tr><td>Qinghai</td><td>1990; 1995; 2000-08; 2010-17</td><td colspan="2">1978; 1980; 1985-2008; 2010-17</td></tr>
<tr><td>Ningxia</td><td>1975; 1978; 1980; 1985-2004; 2010-17</td><td>1978, 1980-2008; 2010-17</td><td>1978-2008; 2010-17</td></tr>
<tr><td>Xinjiang</td><td>1993-2008; 2010-17</td><td colspan="2">1995-2008; 2010-17</td></tr>
<tr><td>Sichuan</td><td>1990-2008; 2010-17</td><td>1950-2008; 2010-17</td><td>1960-2008; 2010-17</td></tr>
<tr><td>Tibet</td><td>2008; 2010-17</td><td colspan="2">1985; 1987-2008; 2010-17</td></tr>
</table>

Appendix E. Comparison of mortality data from different sources

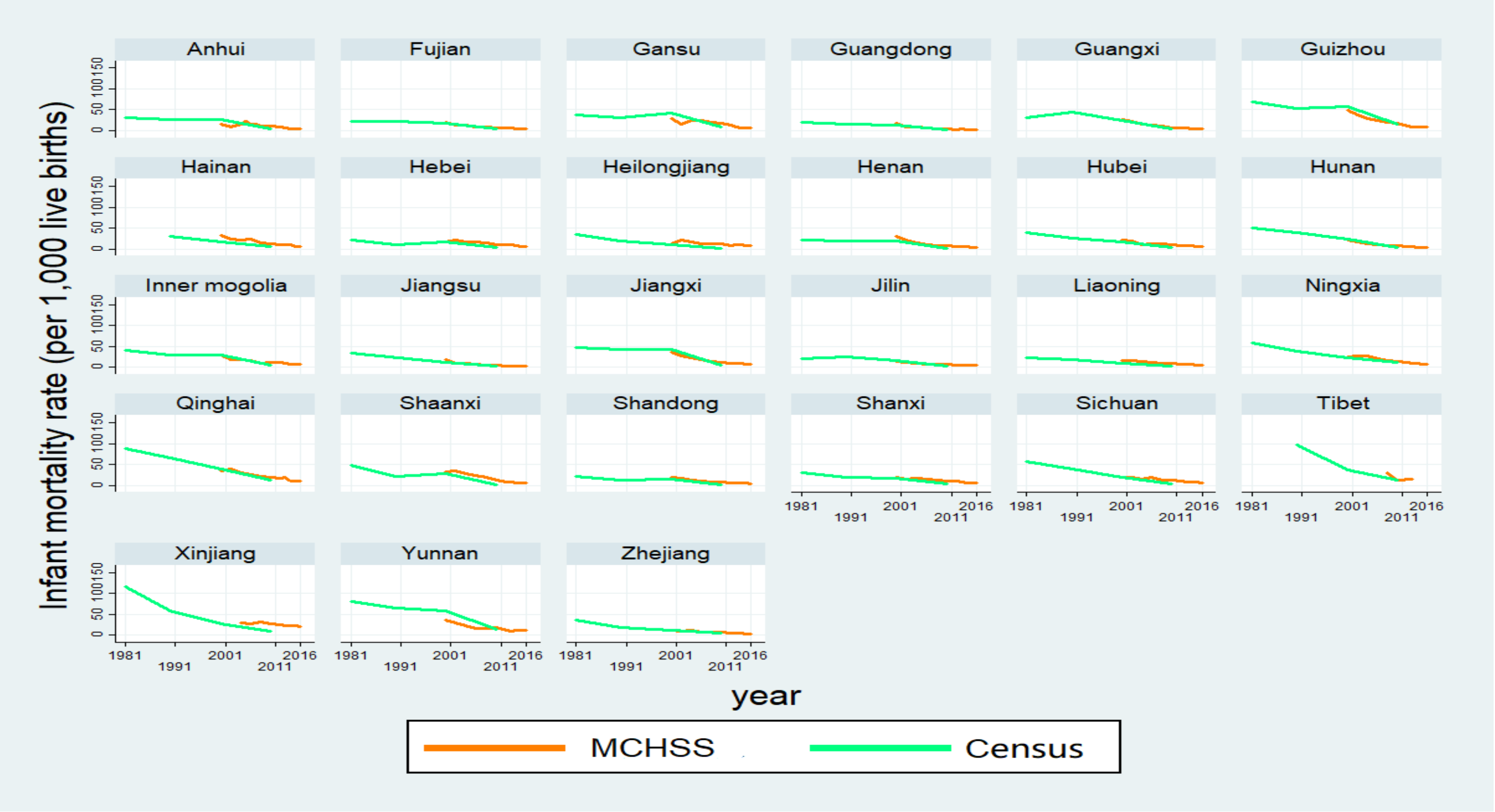


Figure E.1 The infant mortality rate from 1981 onward

Notes: MCHSS is short for Maternal and Child Health Surveillance System.

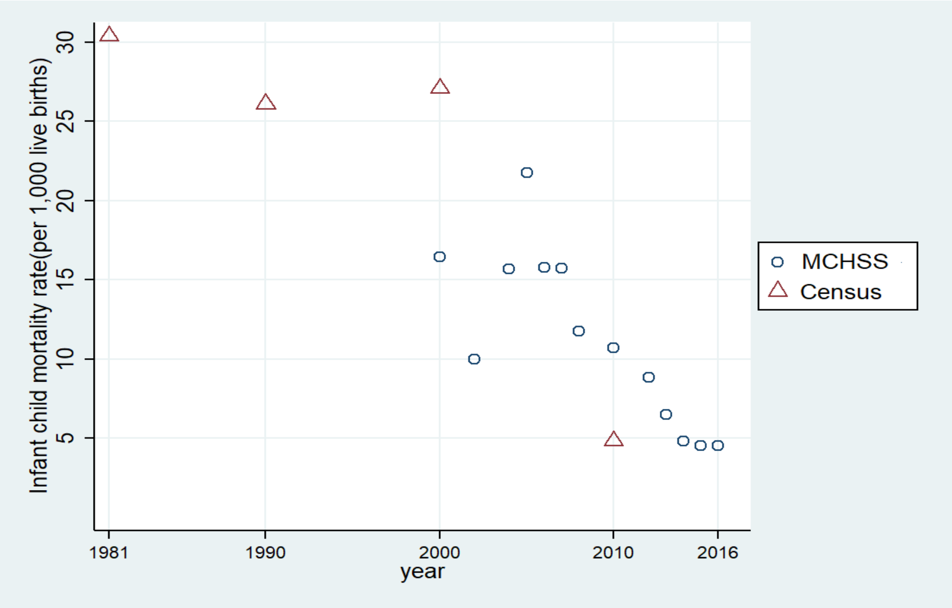


Figure E.2 Data of the infant mortality rate for Anhui from 1981 onwards

Notes: Observations from the same data series joined by lines and each colour identifying different data sources. MCHSS is short for Maternal and Child Health Surveillance System.

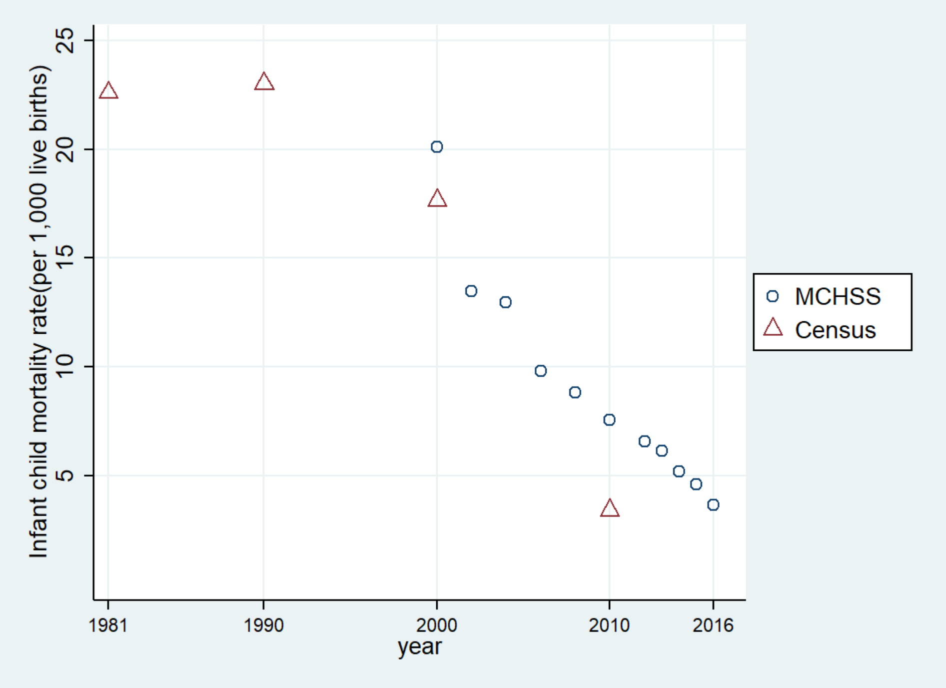


Figure E.3 Data of the infant mortality rate for Fujian from 1981 onwards

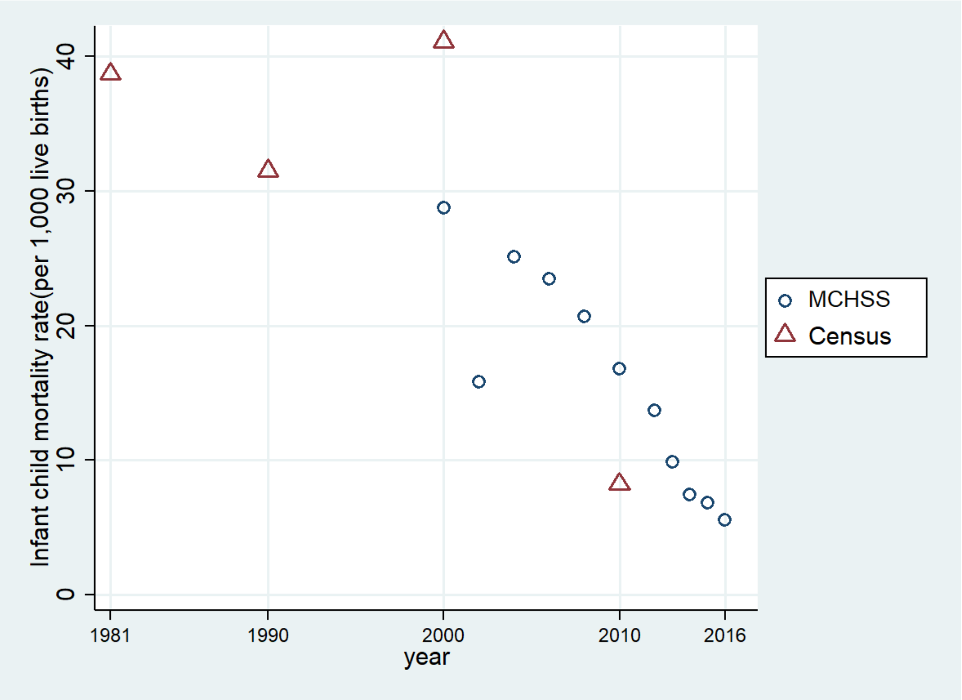


Figure E.4 Data of the infant mortality rate for Gansu from 1981 onwards

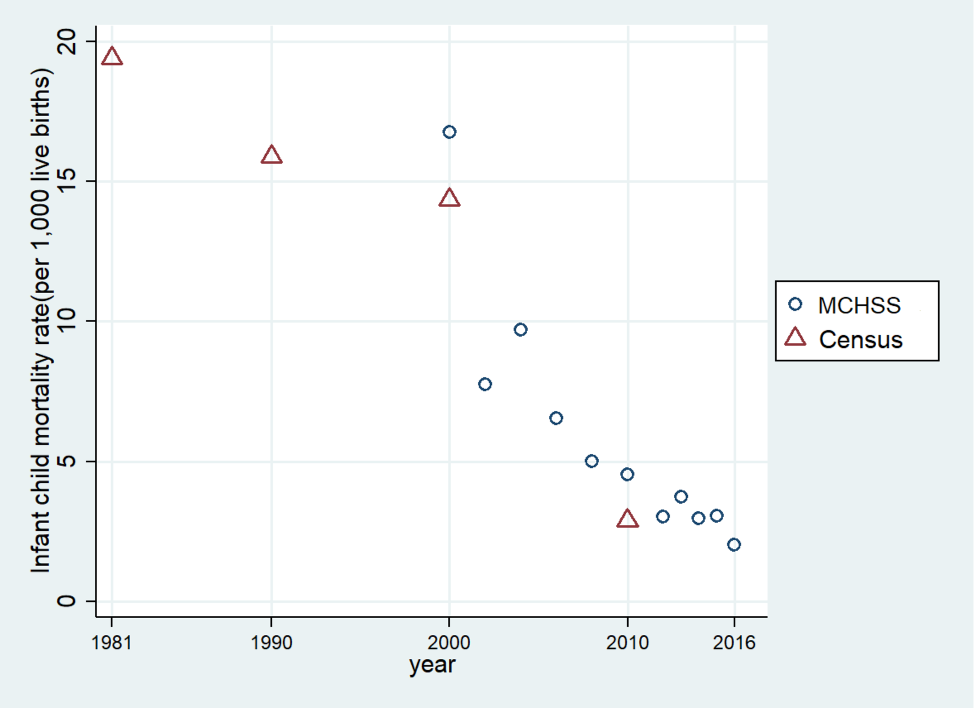


Figure E.5 Data of the infant mortality rate for Guangdong from 1981 onwards

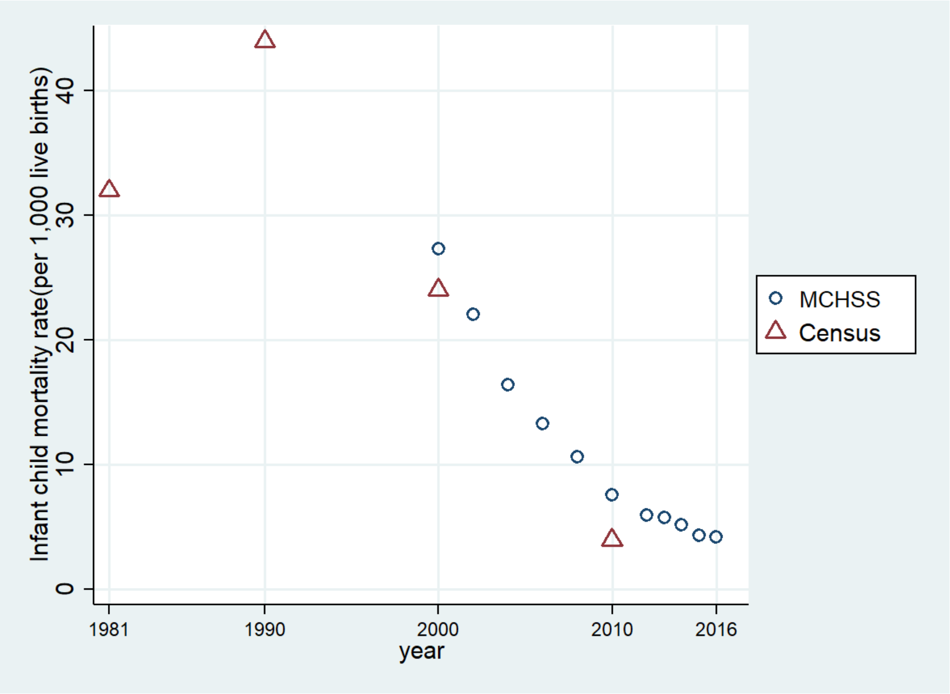


Figure E.6 Data of the infant mortality rate for Guangxi from 1981 onwards

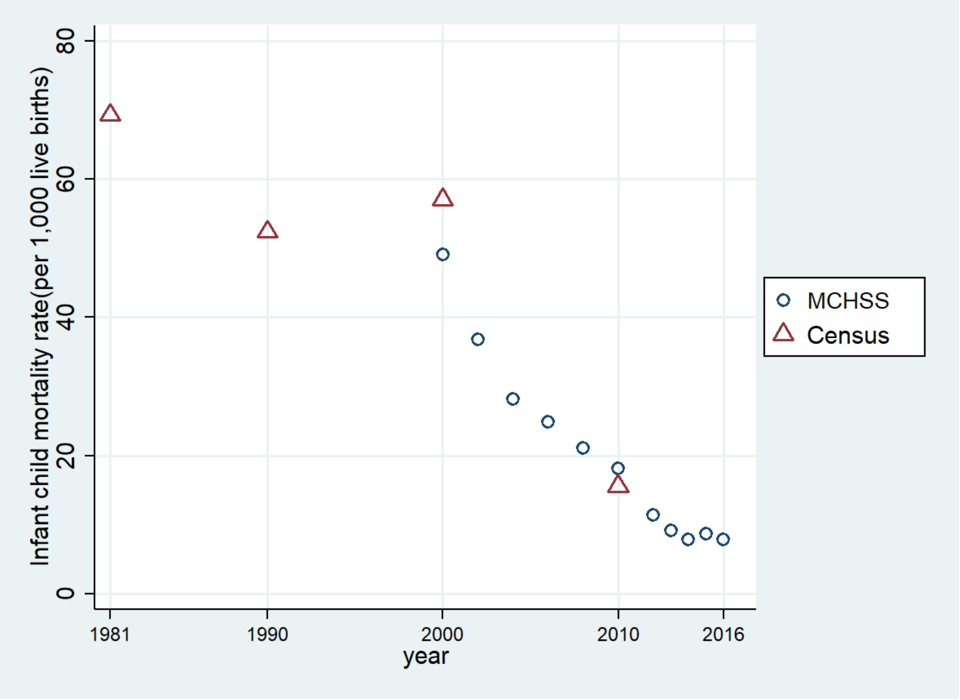


Figure E.7 Data of the infant mortality rate for Guizhou from 1981 onwards

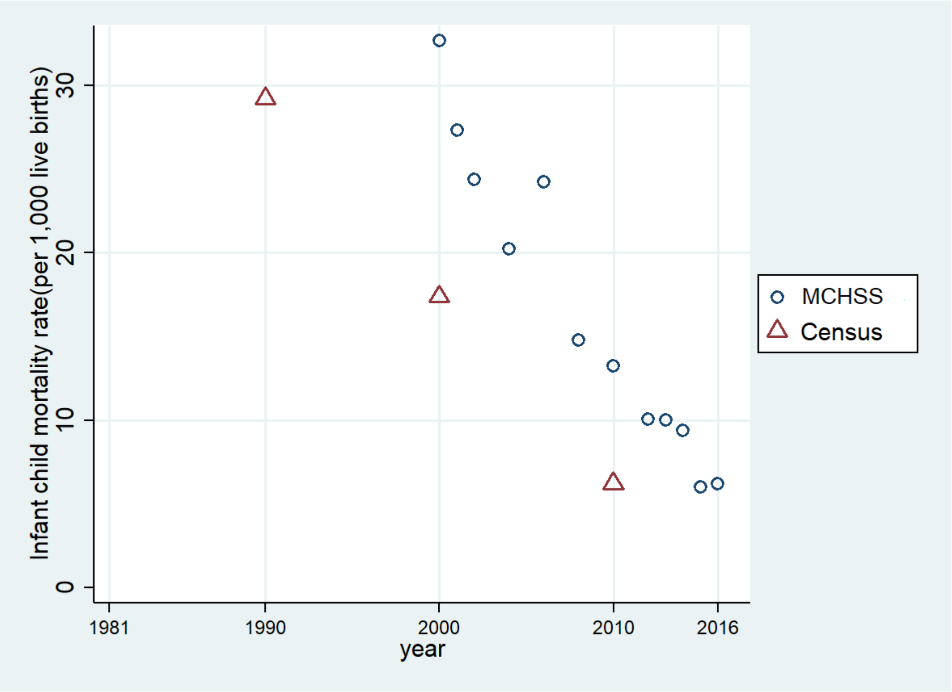


Figure E.8 Data of the infant mortality rate for Hainan from 1981 onwards

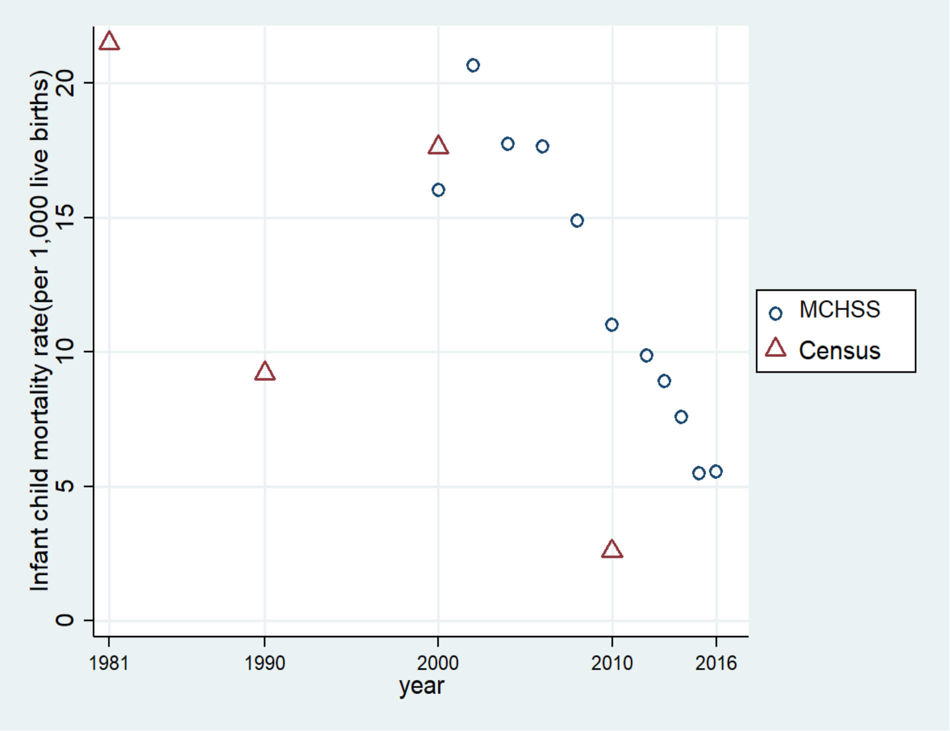


Figure E.9. Data of the infant mortality rate for Hebei from 1981 onwards

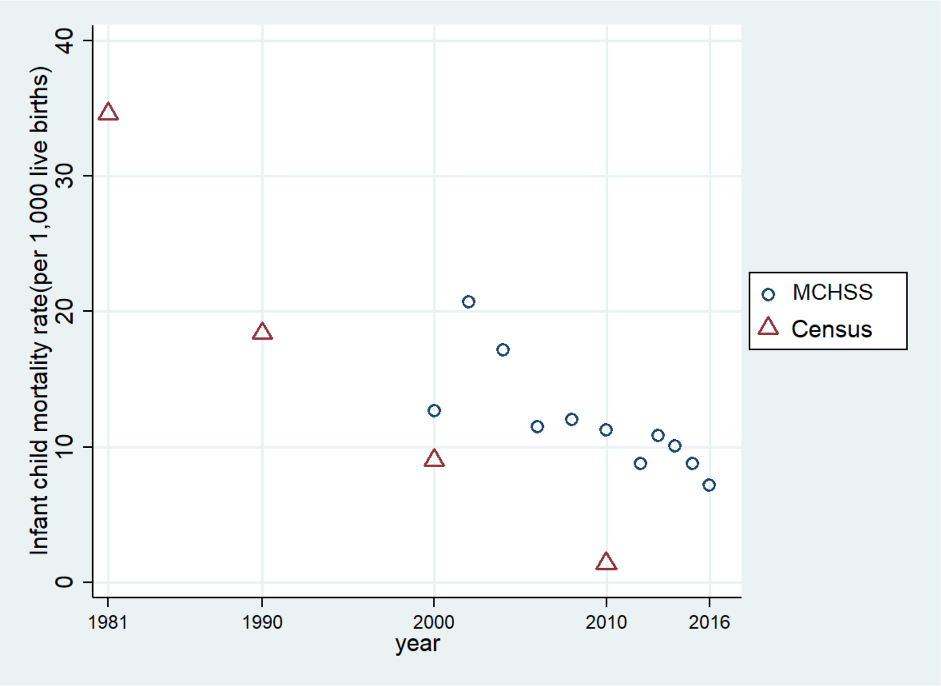


Figure E.10 Data of the infant mortality rate for Heilongjiang from 1981 onwards

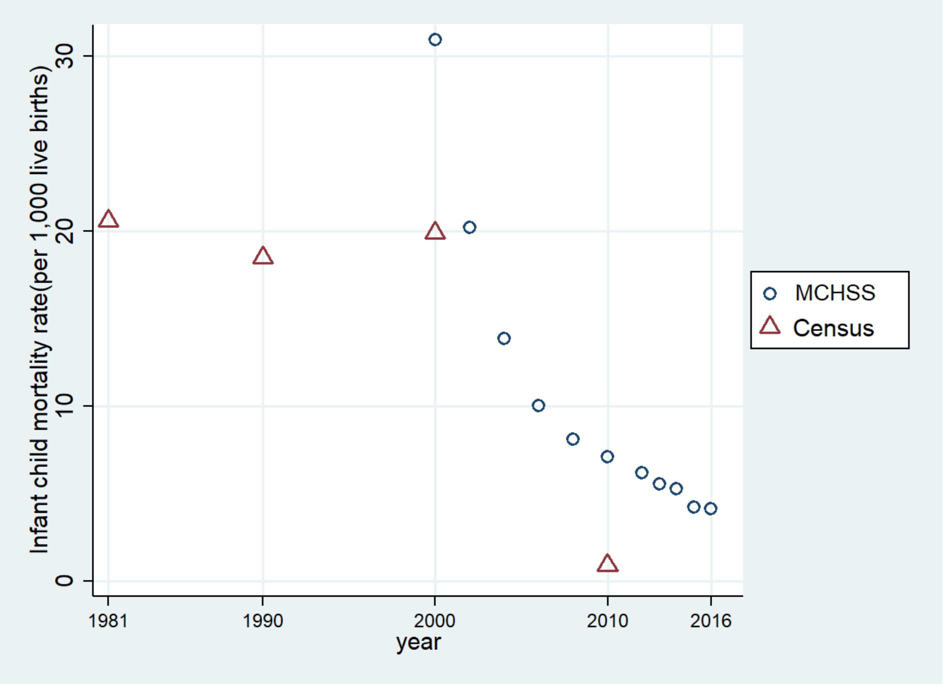


Figure E.11 Data of the infant mortality rate for Henan from 1981 onwards

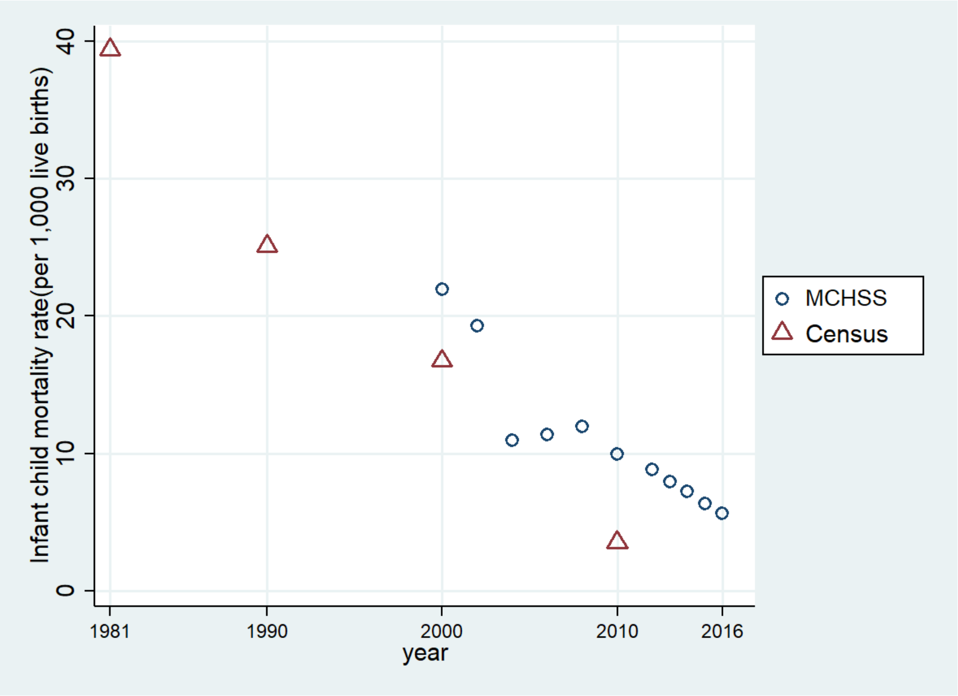


Figure E.12 Data of the infant mortality rate for Hubei from 1981 onwards

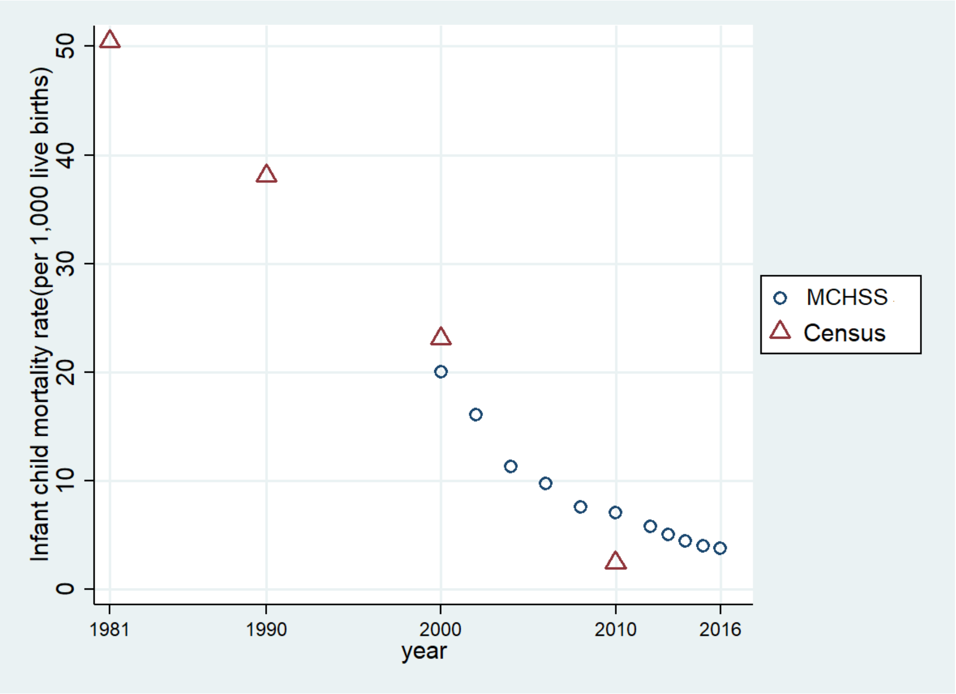


Figure E.13 Data of the infant mortality rate for Hunan from 1981 onwards

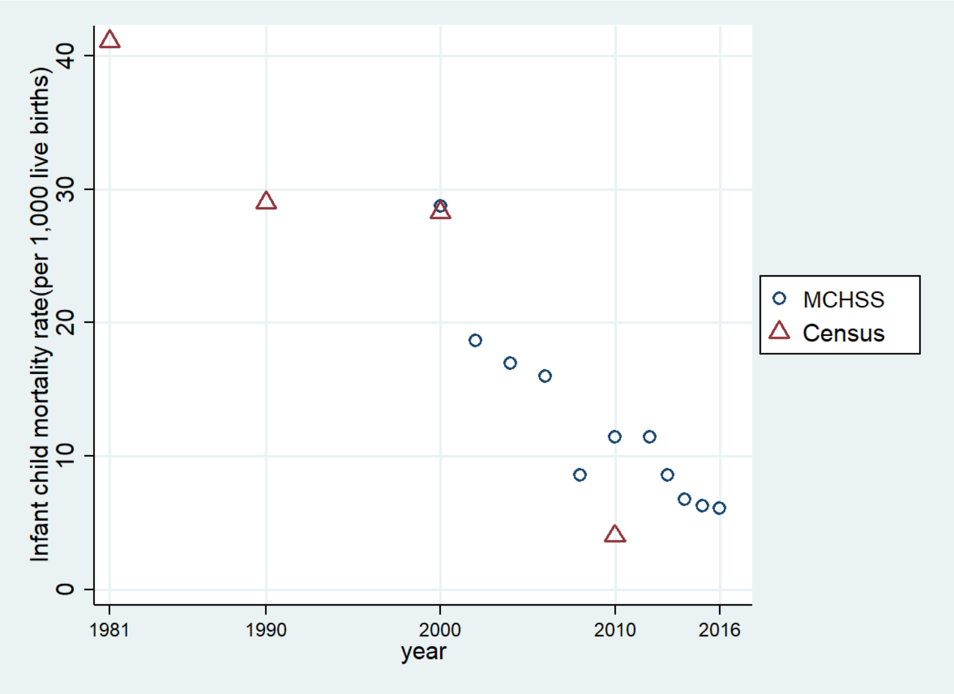


Figure E.14 Data of the infant mortality rate for Inner mongolia from 1981 onwards

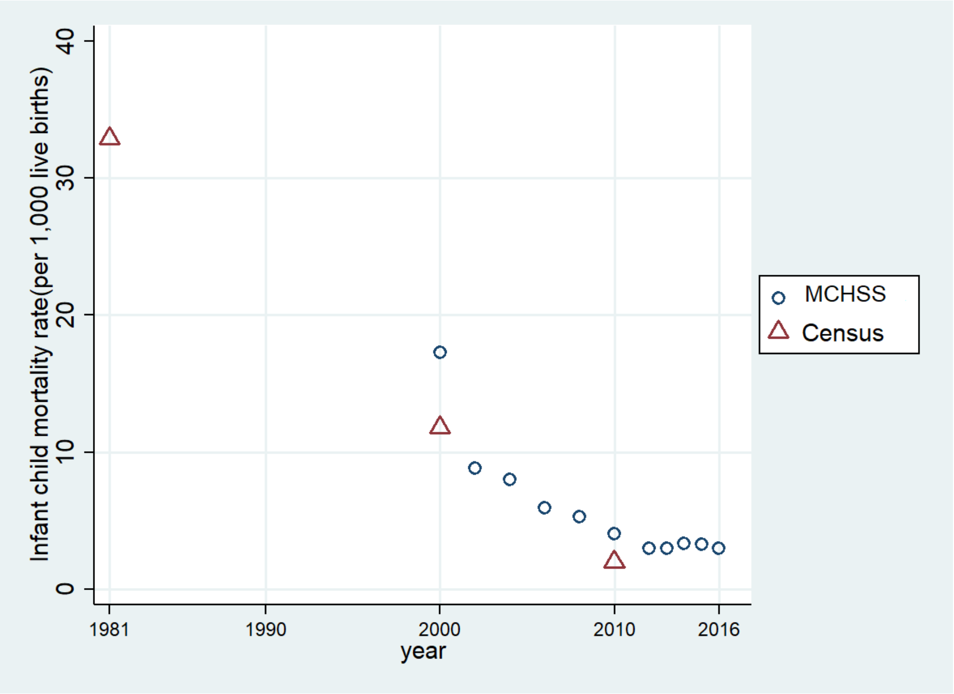


Figure E.15 Data of the infant mortality rate for Jiangsu from 1981 onwards

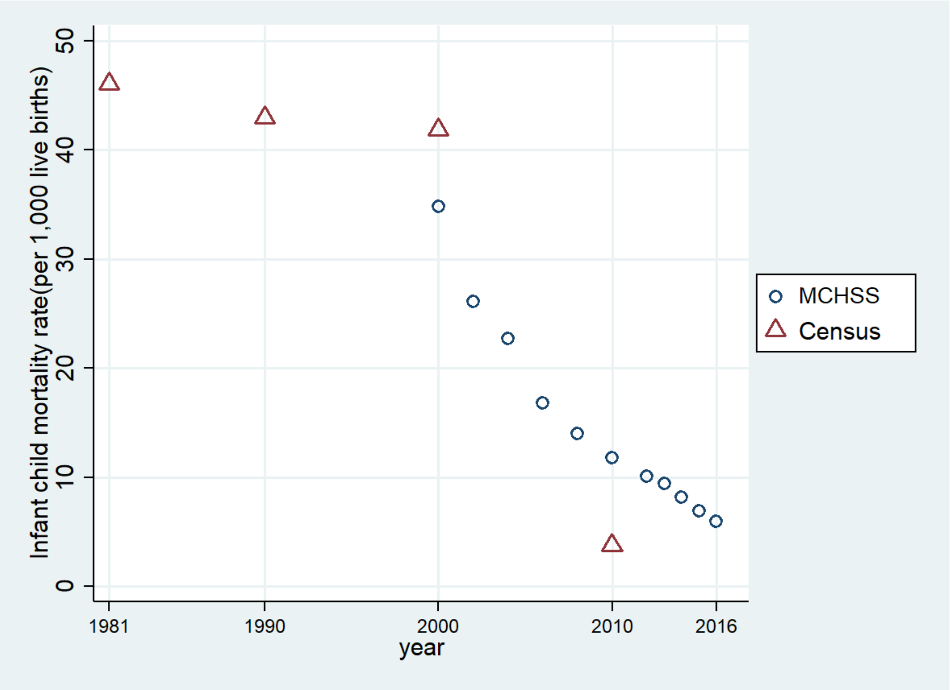


Figure E.16 Data of the infant mortality rate for Jiangxi from 1981 onwards

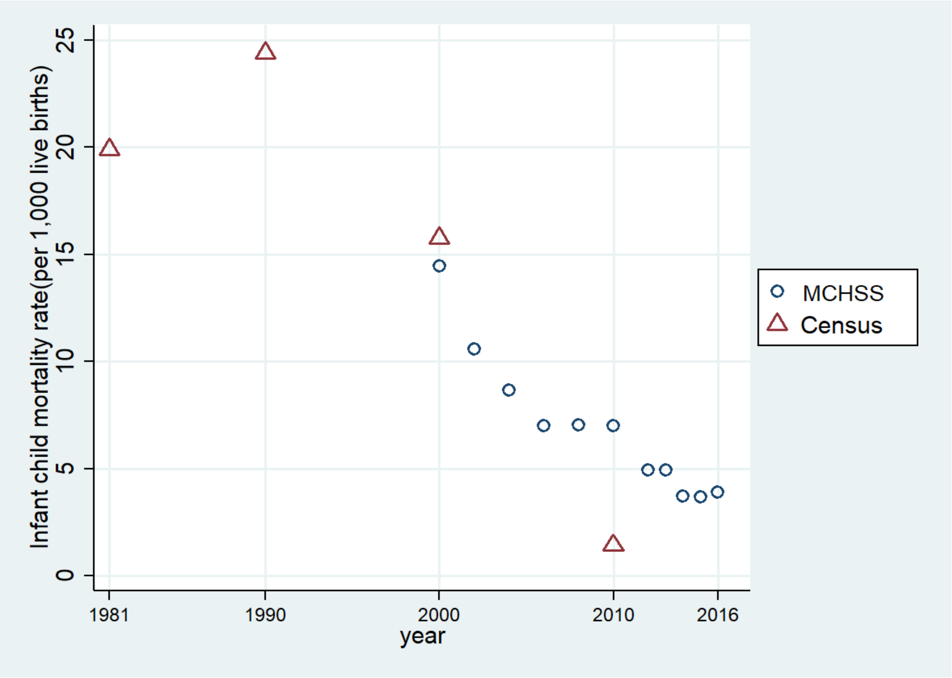


Figure E.17 Data of the infant mortality rate for Jilin from 1981 onwards

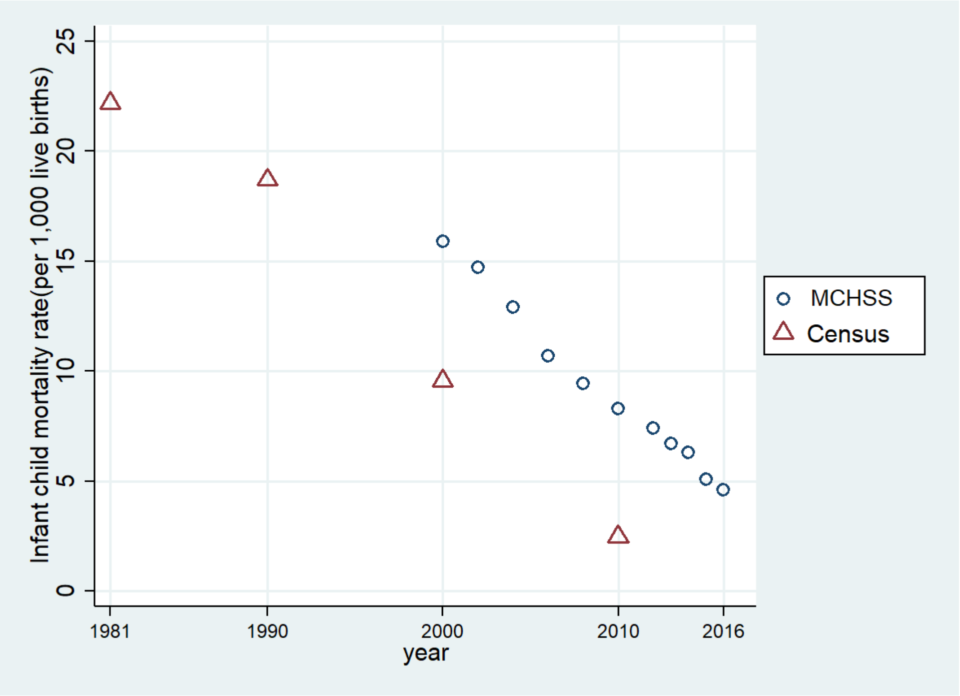


Figure E.18 Data of the infant mortality rate for Liaoning from 1981 onwards

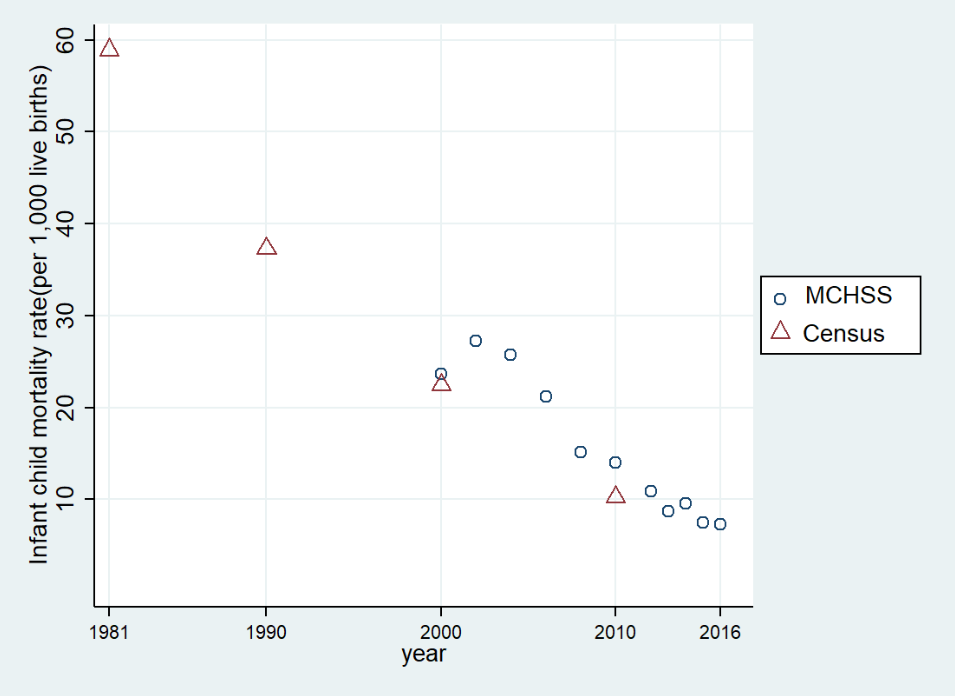


Figure E.19 Data of the infant mortality rate for Ningxia from 1981 onwards

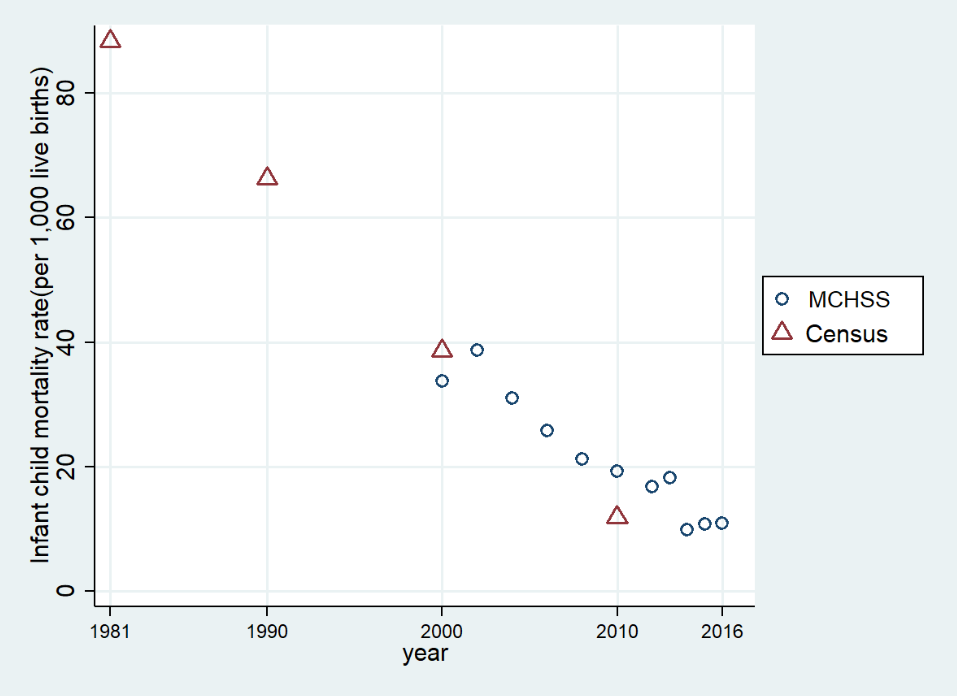


Figure E.20 Data of the infant mortality rate for Qinghai from 1981 onwards

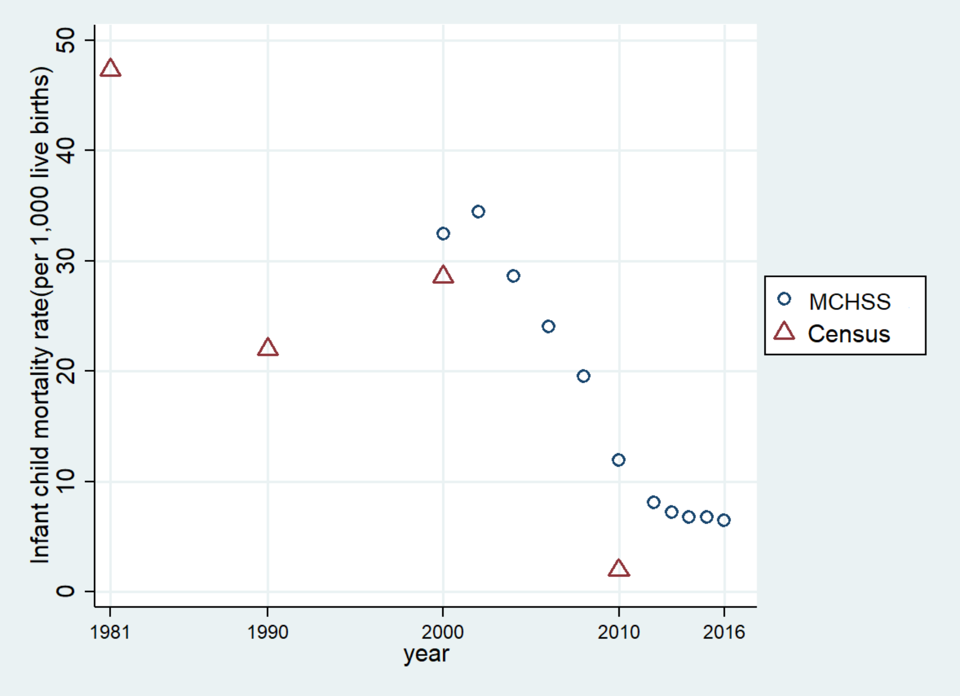


Figure E.21 Data of the infant mortality rate for Shaanxi from 1981 onwards

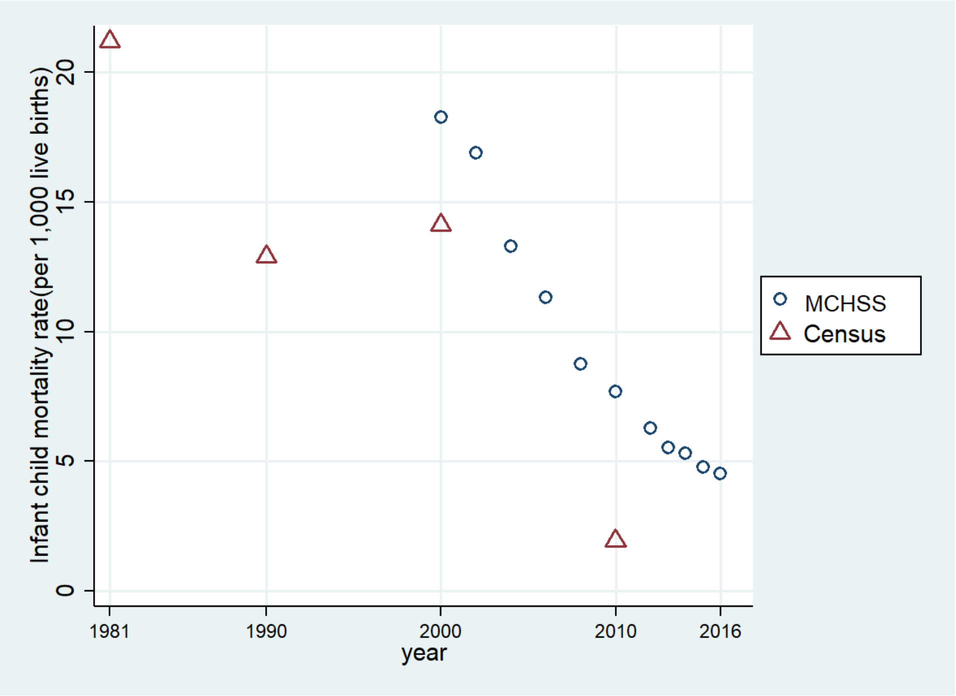


Figure E.22 Data of the infant mortality rate for Shandong from 1981 onwards

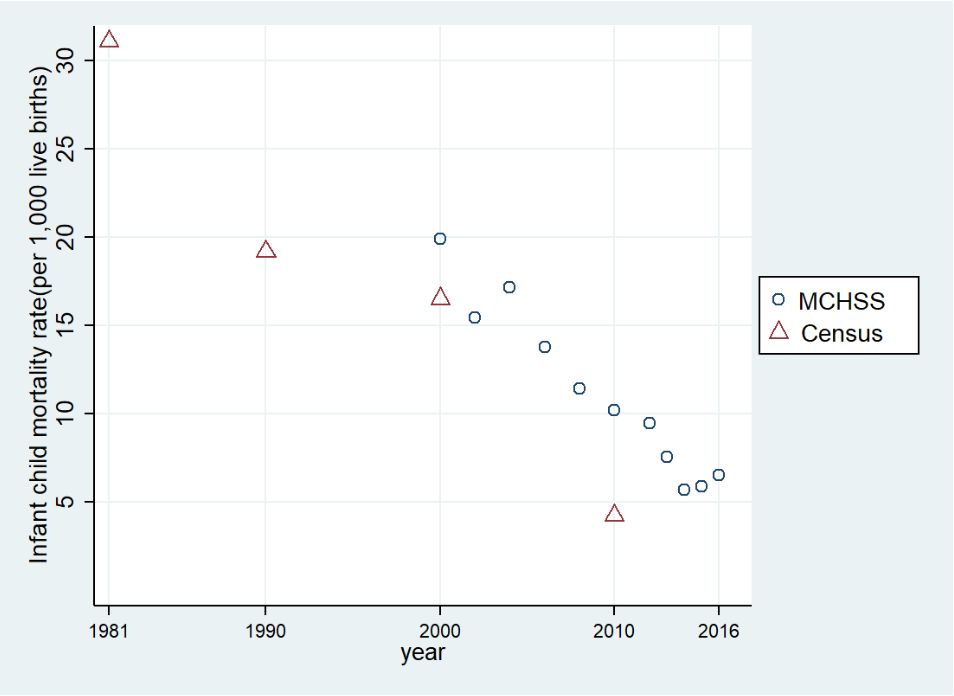


Figure E.23 Data of the infant mortality rate for Shanxi from 1981 onwards

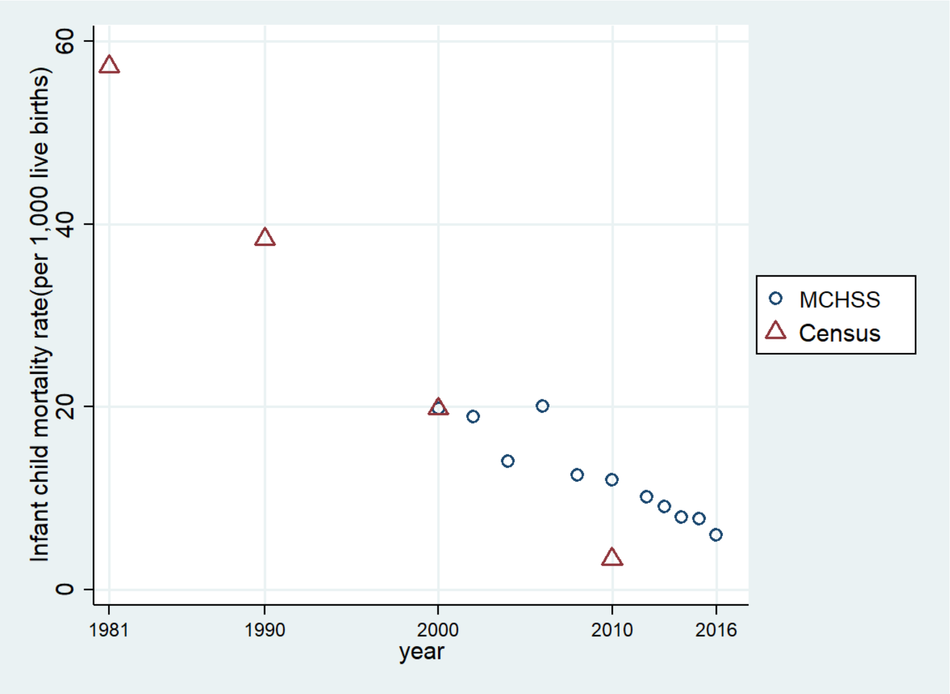


Figure E.24 Data of the infant mortality rate for Sichuan from 1981 onwards

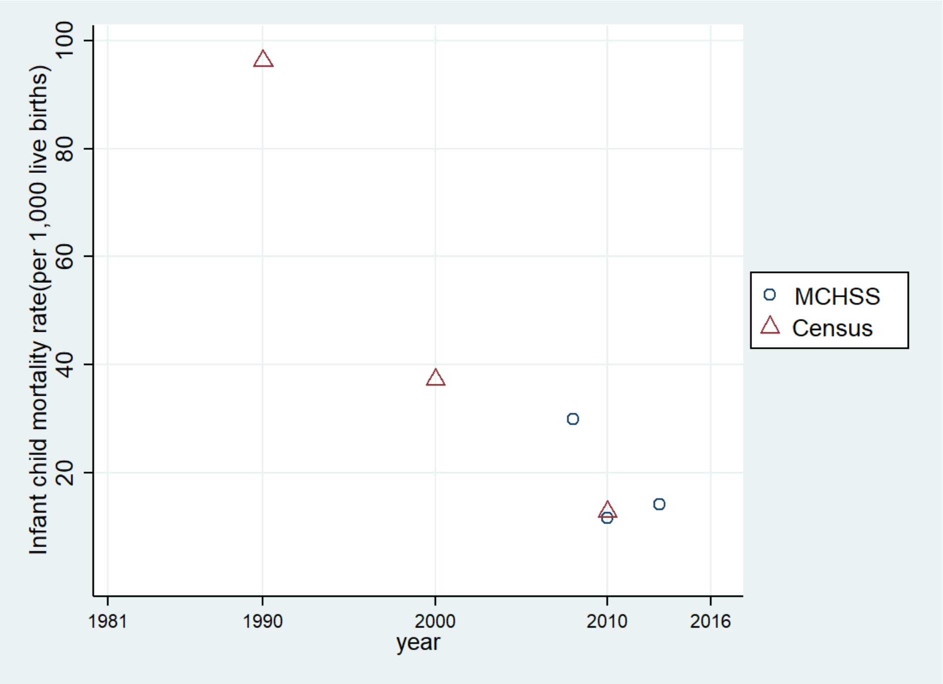


Figure E.25 Data of the infant mortality rate for Tibet from 1981 onwards

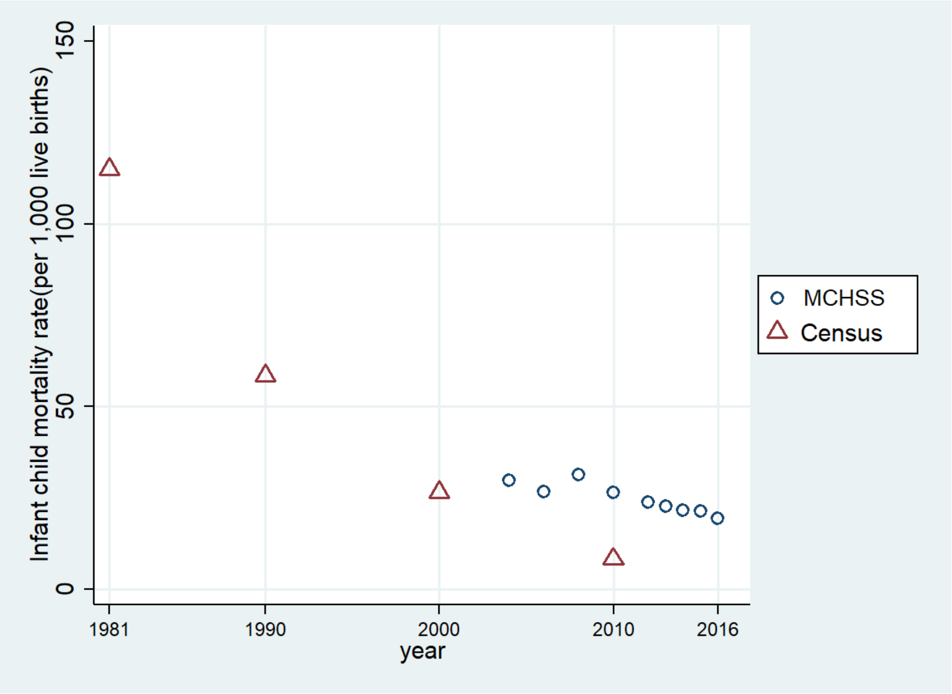


Figure E.26 Data of the infant mortality rate for Xinjiang from 1981 onwards

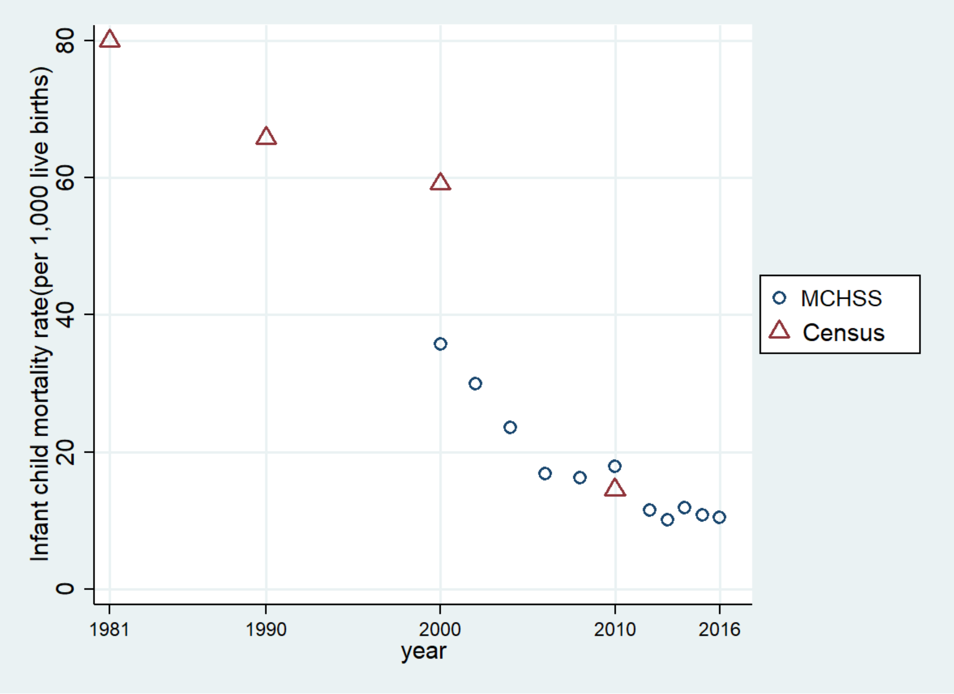


Figure E.27 Data of the infant mortality rate for Yunnan from 1981 onwards

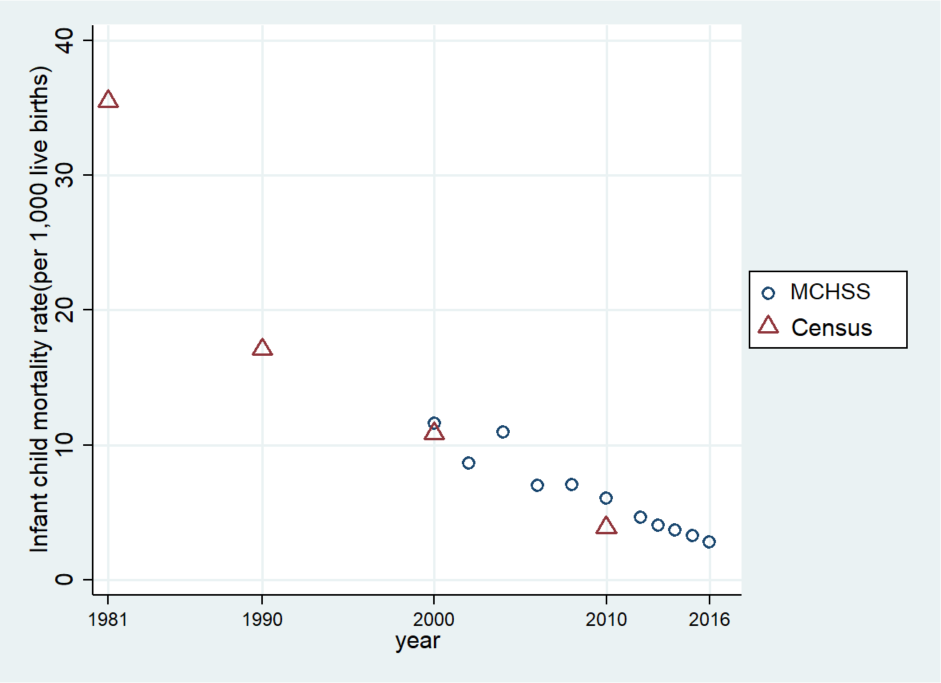


Figure E.28 Data of the infant mortality rate for Zhejiang from 1981 onwards

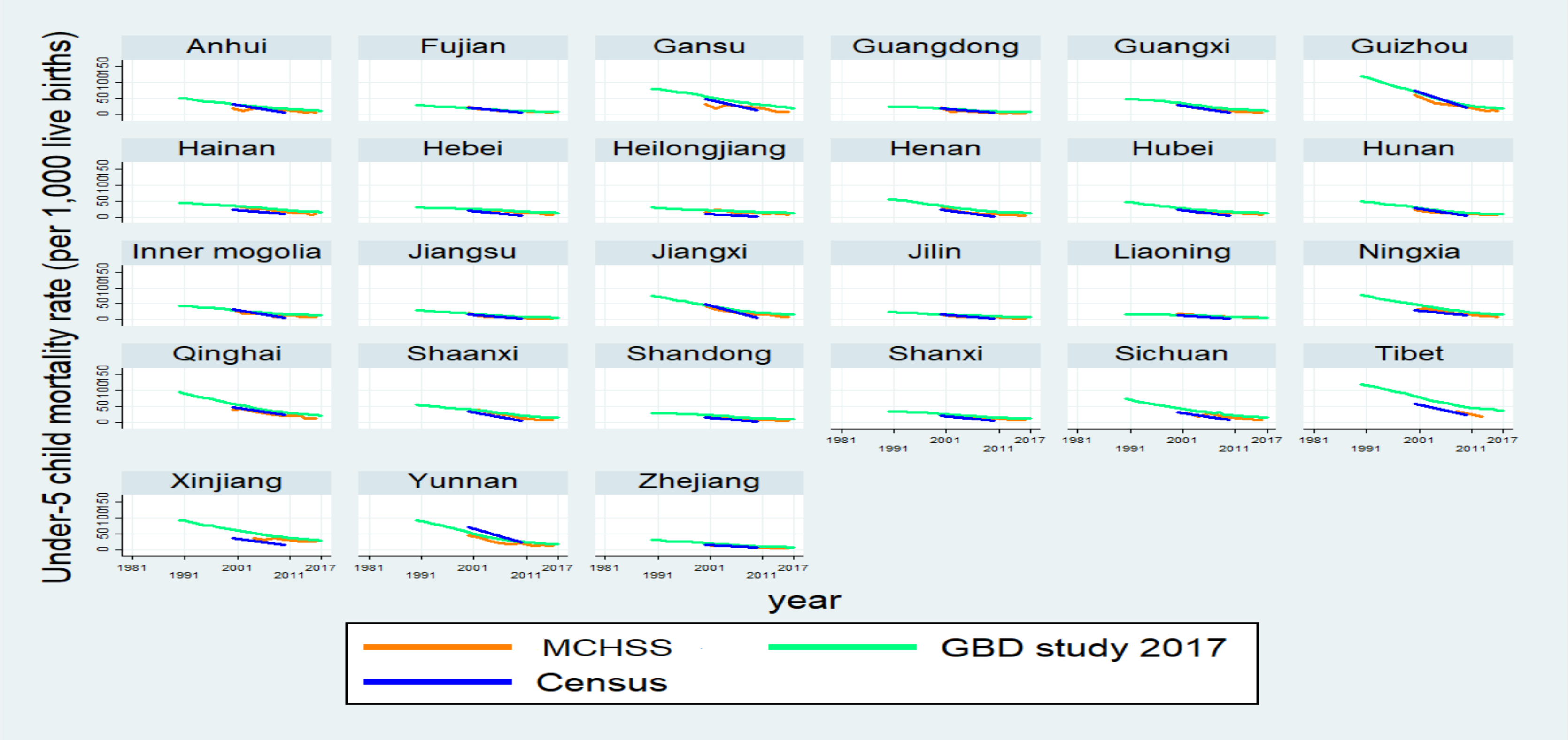


Figure E.29 The under-5 child mortality rate from 1981 onwards

Notes: Observations from the same data series joined by lines and each colour identifying different data sources. MCHSS is short for Maternal and Child Health Surveillance System. GBD is short for global burden disease.

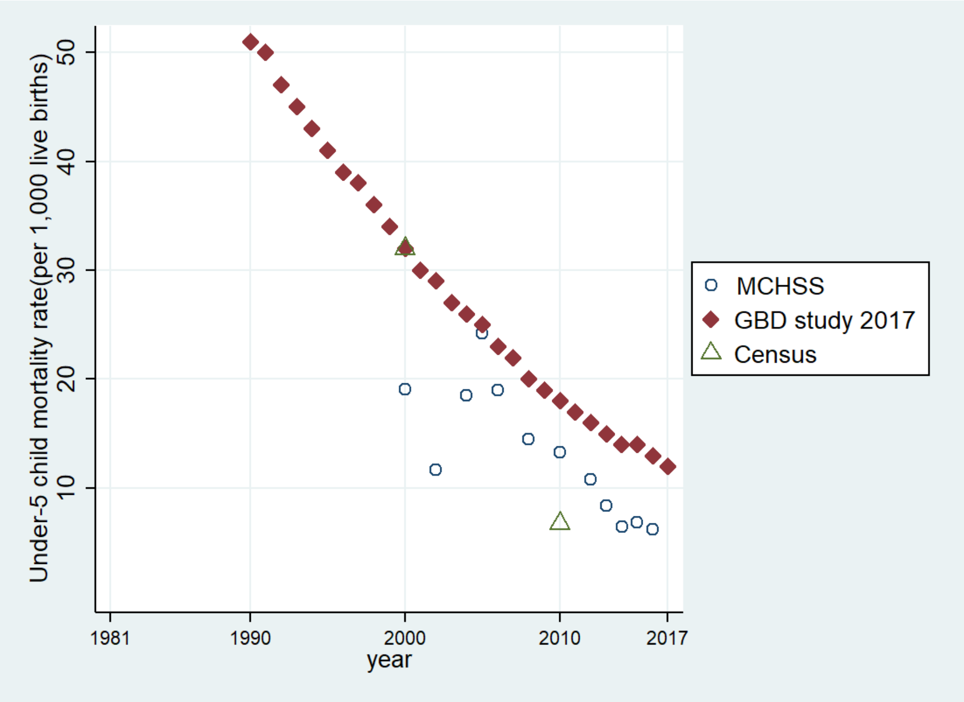


Figure E.30 Data of the under-5 child mortality rate for Anhui from 1981 onwards

Notes: GBD is short for global burden disease.

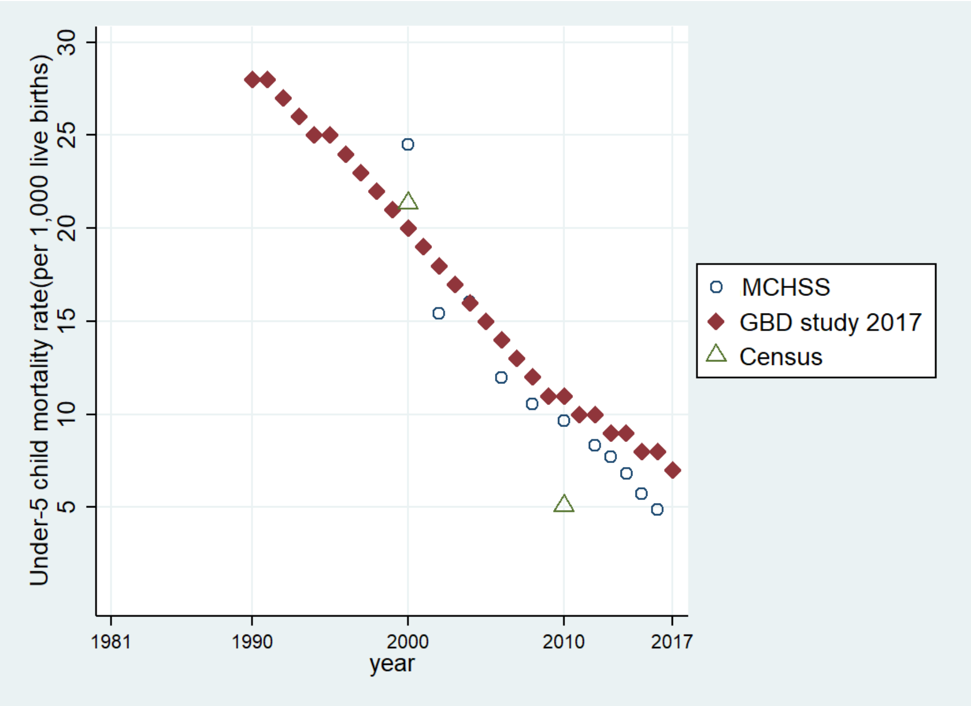


Figure E.31 Data of the under-5 child mortality rate for Fujian from 1981 onwards

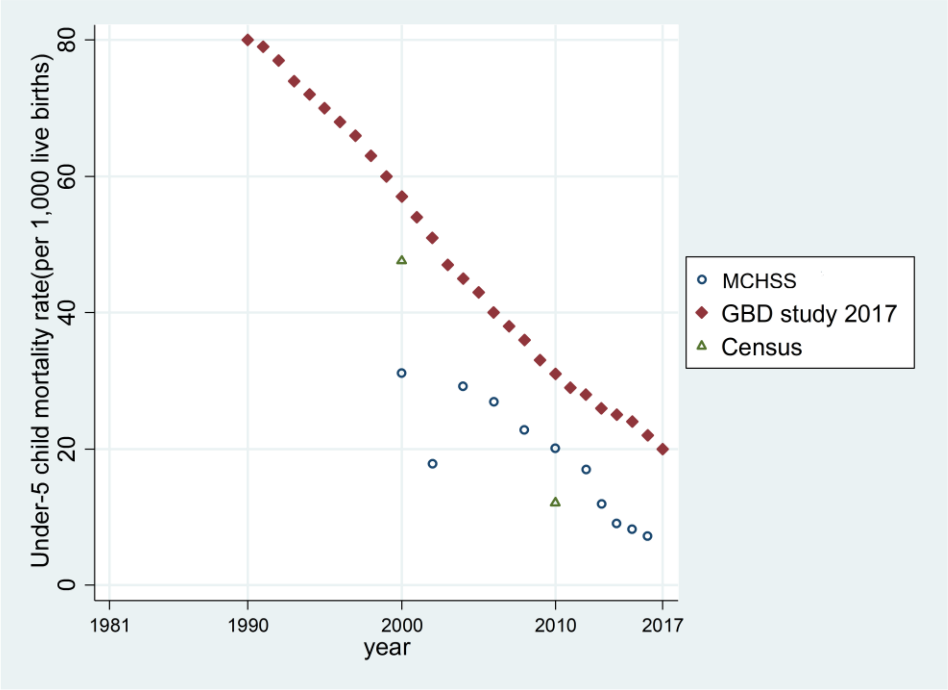


Figure E.32 Data of the under-5 child mortality rate for Gansu from 1981 onwards

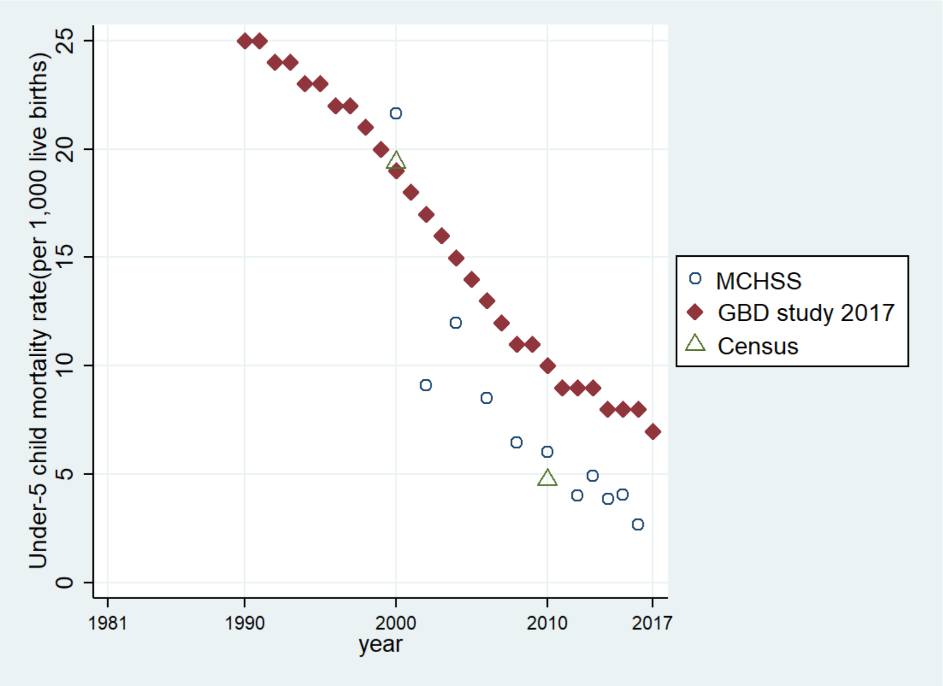


Figure E.33 Data of the under-5 child mortality rate for Guangdong from 1981 onwards

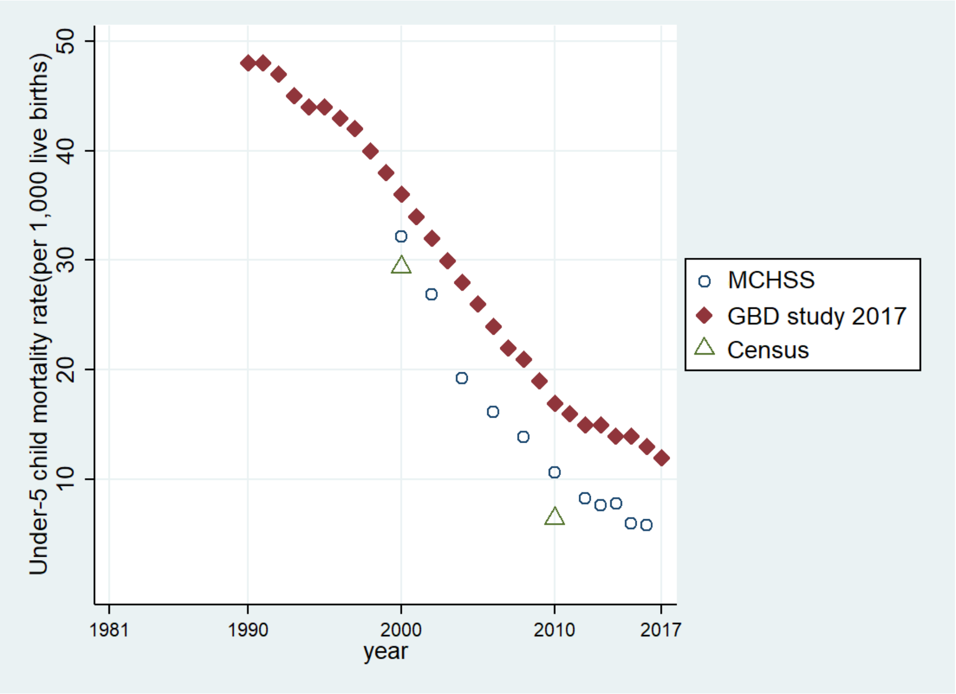


Figure E.34 Data of the under-5 child mortality rate for Guangxi from 1981 onwards

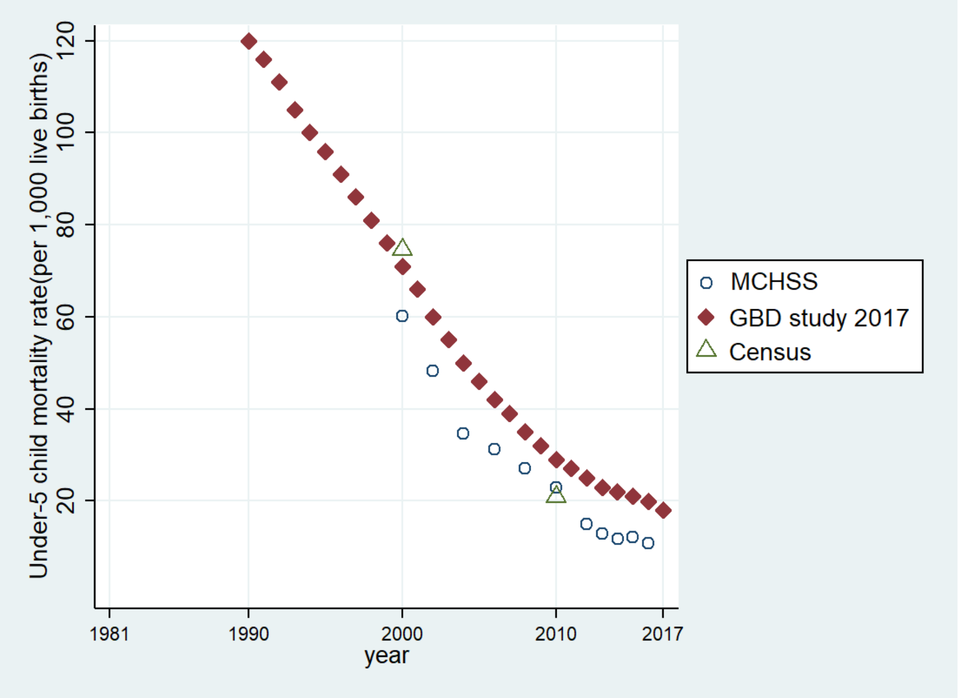


Figure E.35 Data of the under-5 child mortality rate for Guizhou from 1981 onwards

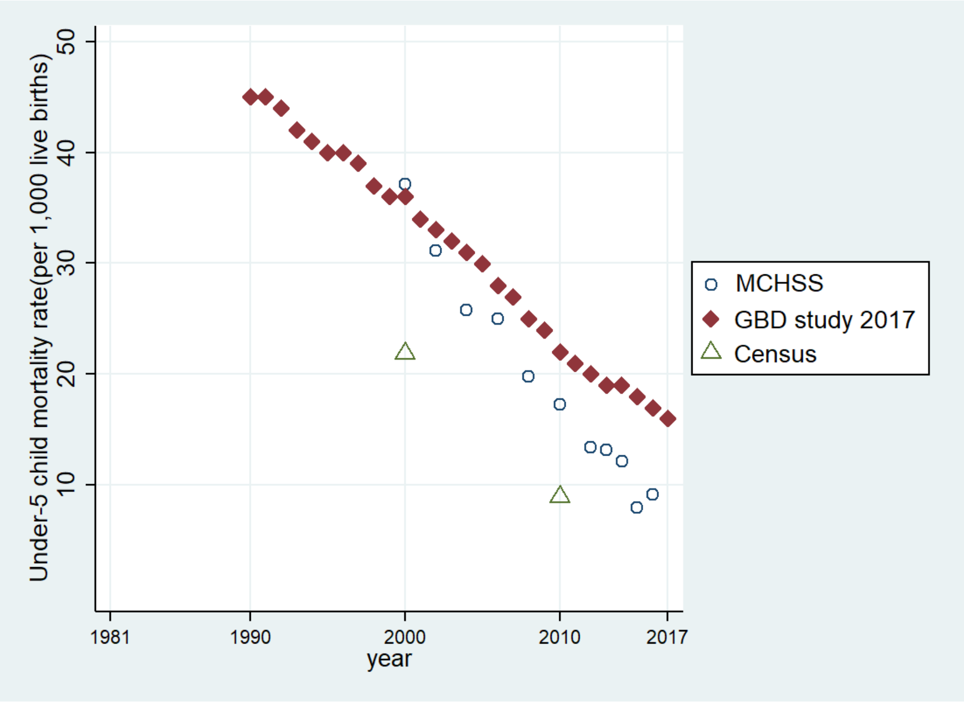


Figure E.36 Data of the under-5 child mortality rate for Hainan from 1981 onwards

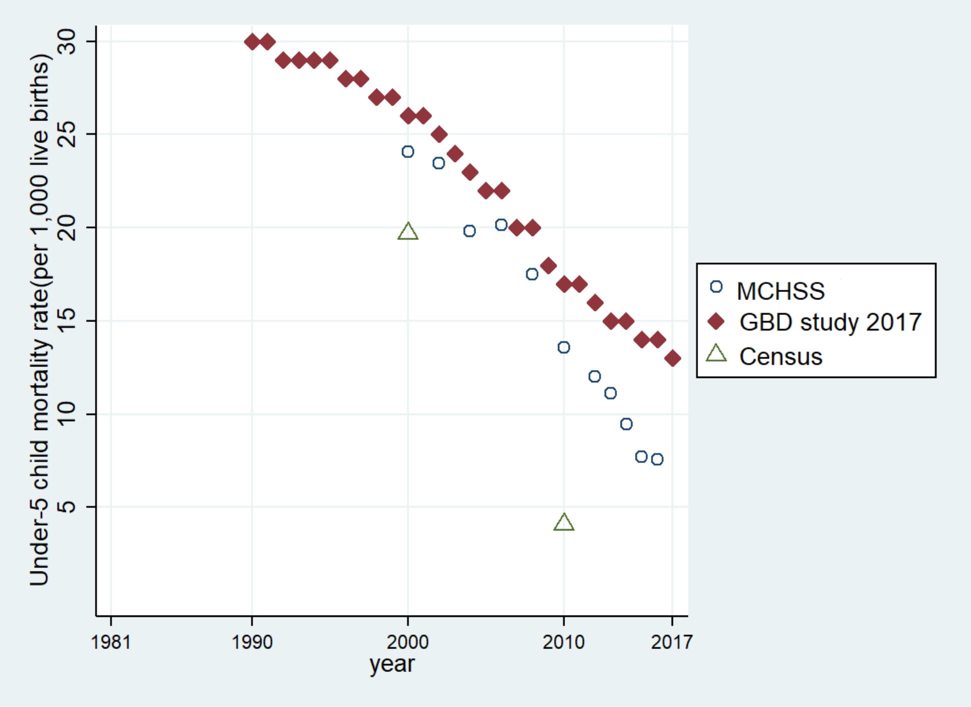


Figure E.37 Data of the under-5 child mortality rate for Hebei from 1981 onwards

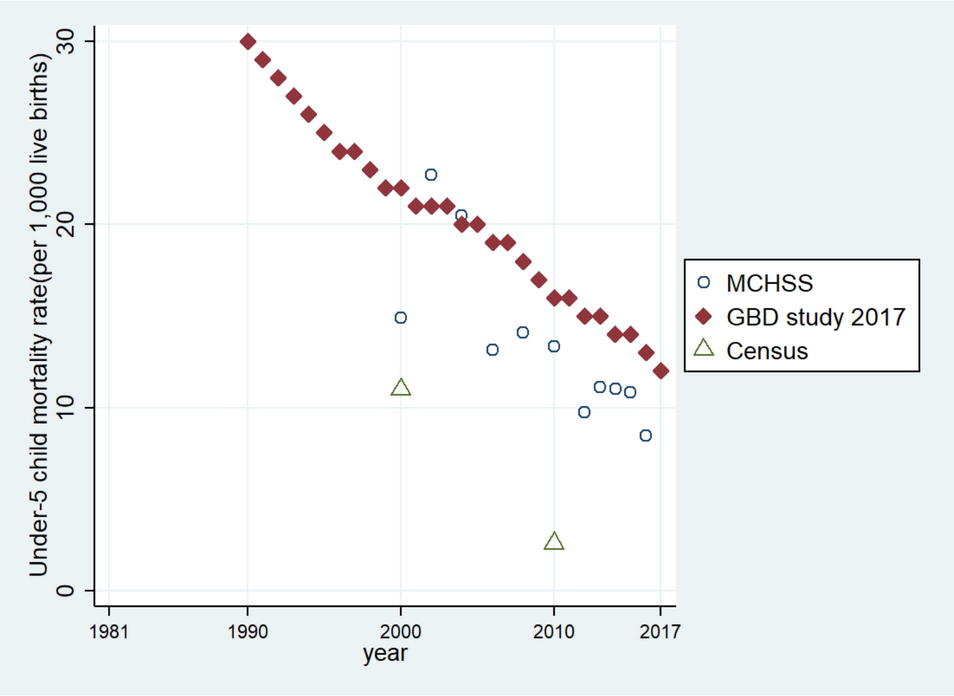


Figure E.38 Data of the under-5 child mortality rate for Heilongjiang from 1981 onwards

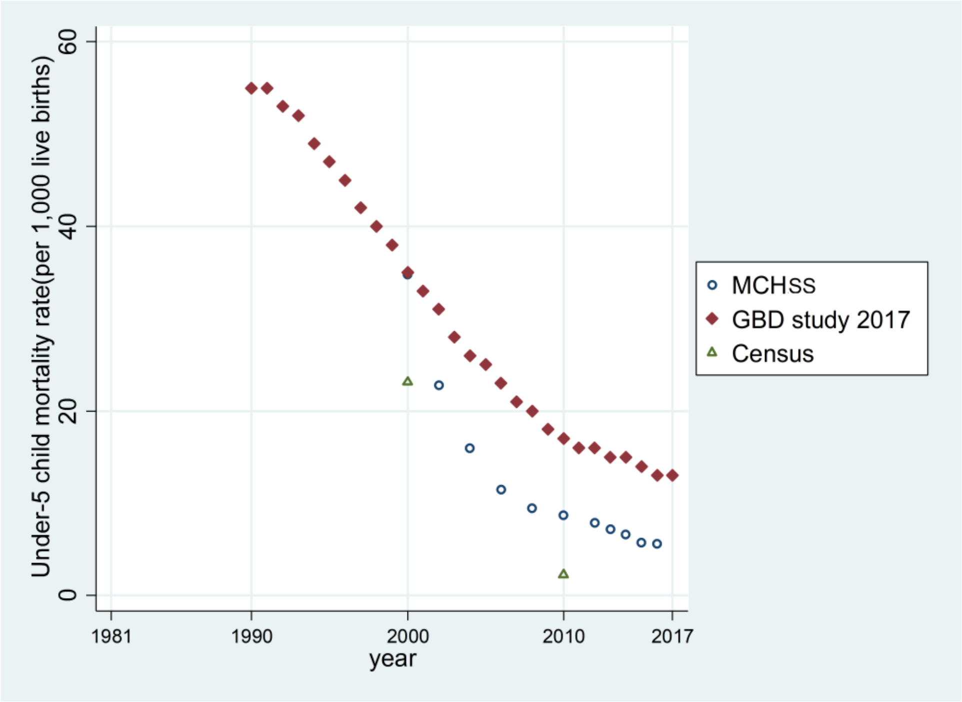


Figure E.39 Data of the under-5 child mortality rate for Henan from 1981 onwards

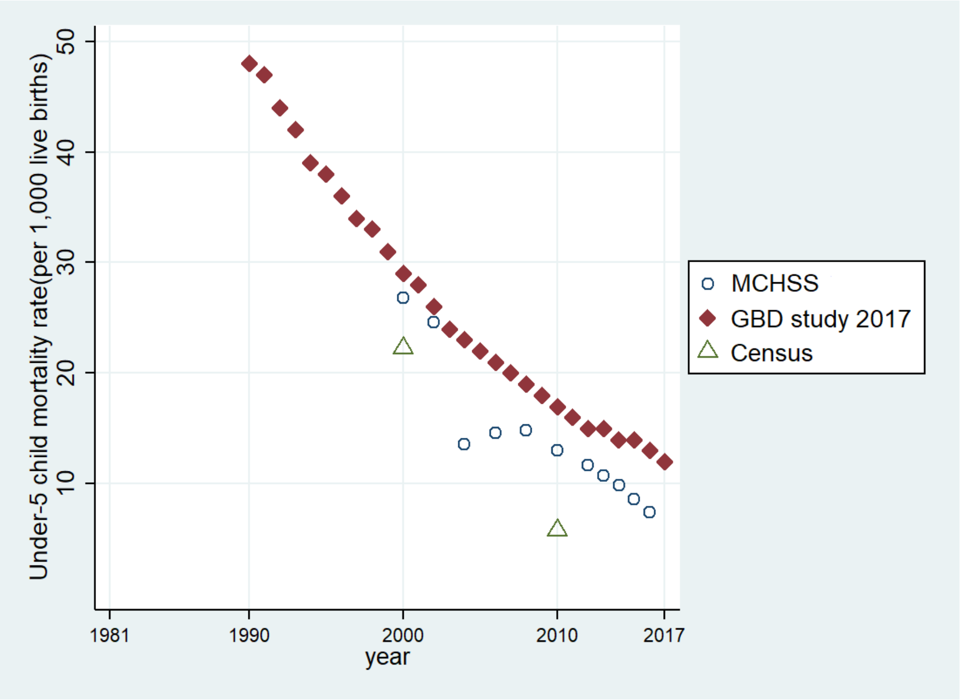


Figure E.40 Data of the under-5 child mortality rate for Hubei from 1981 onwards

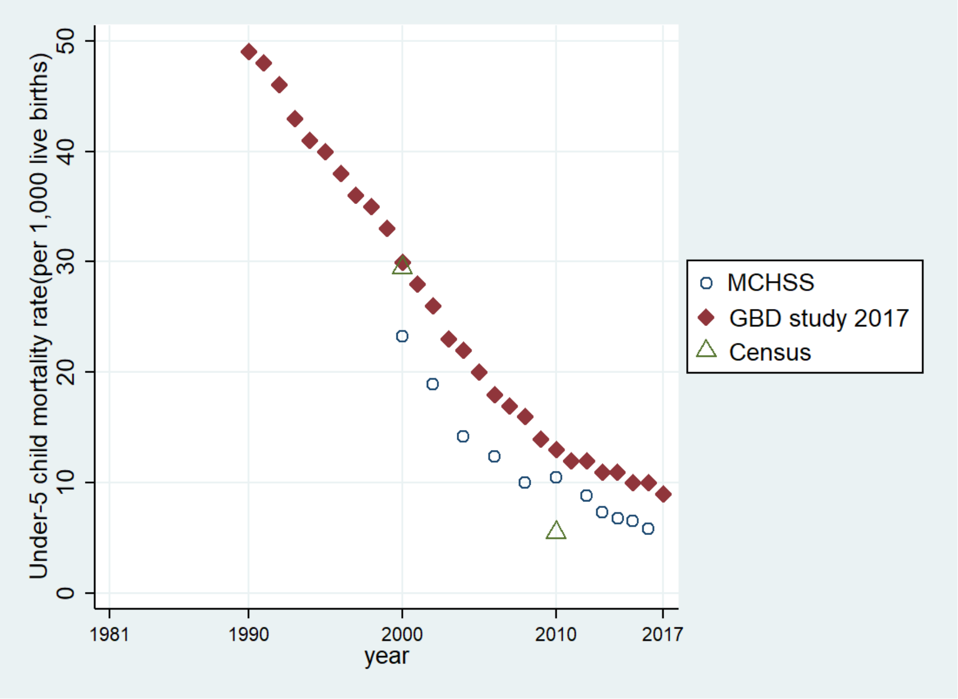


Figure E.41 Data of the under-5 child mortality rate for Hunan from 1981 onwards

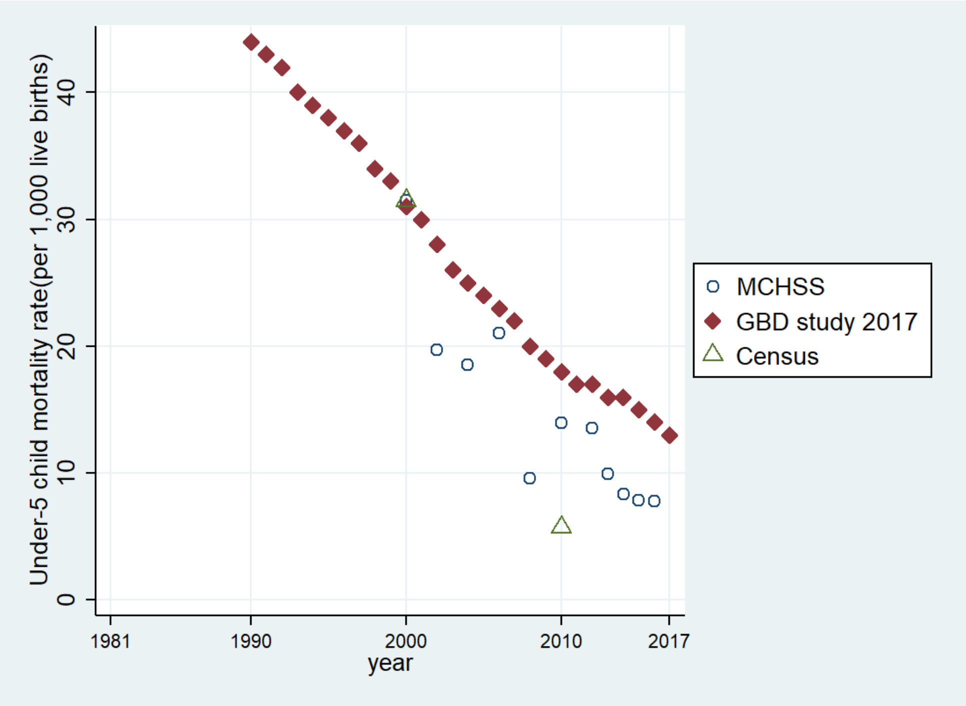


Figure E.42 Data of the under-5 child mortality rate for Inner mongolia from 1981 onwards

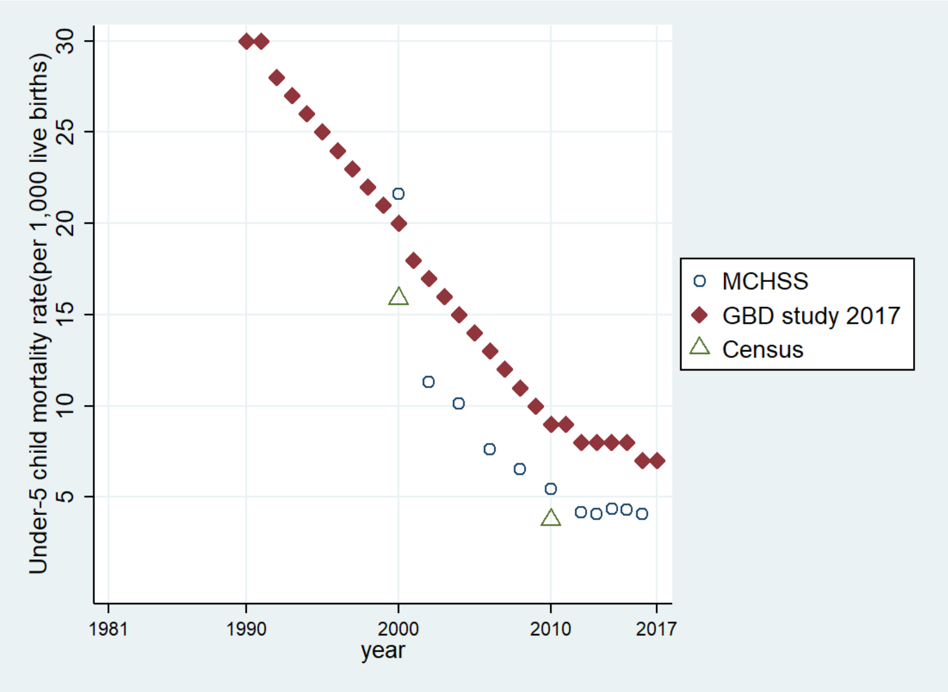


Figure E.43 Data of the under-5 child mortality rate for Jiangsu from 1981 onwards

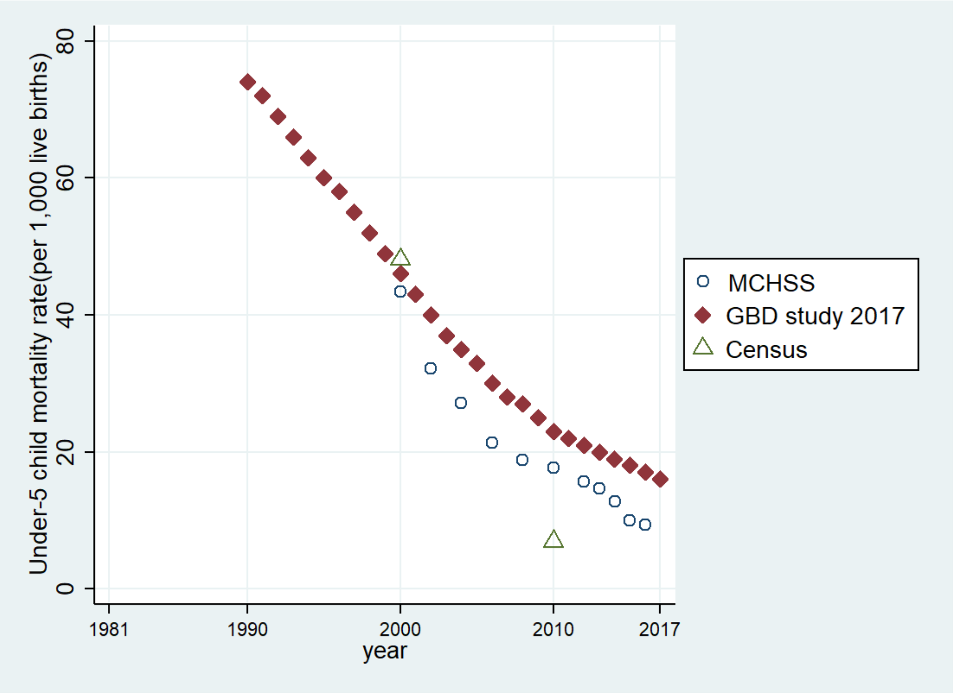


Figure E.44 Data of the under-5 child mortality rate for Jiangxi from 1981 onwards

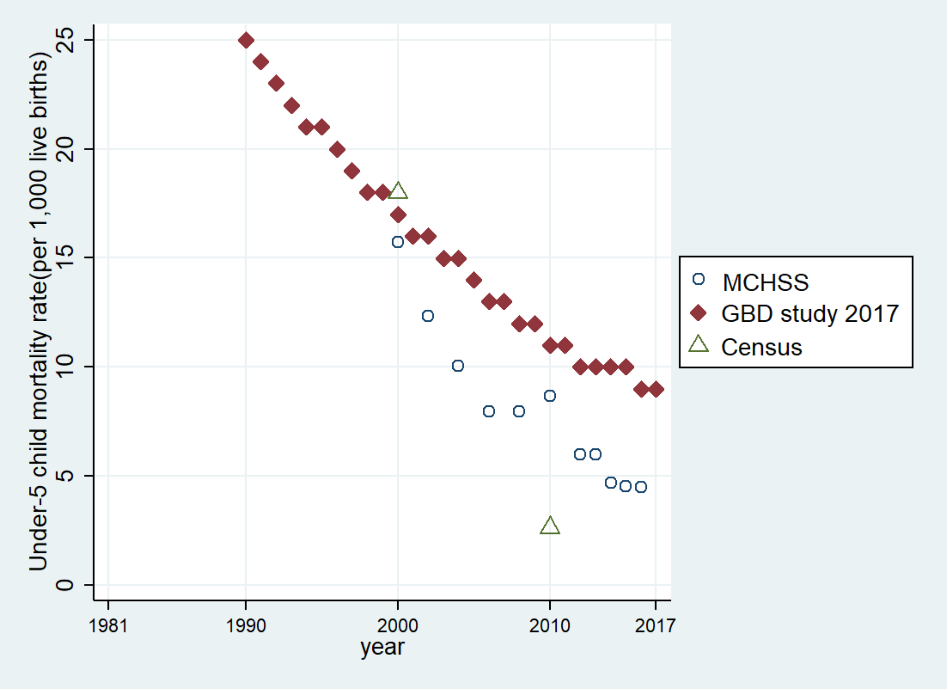


Figure E.45 Data of the under-5 child mortality rate for Jilin from 1981 onwards

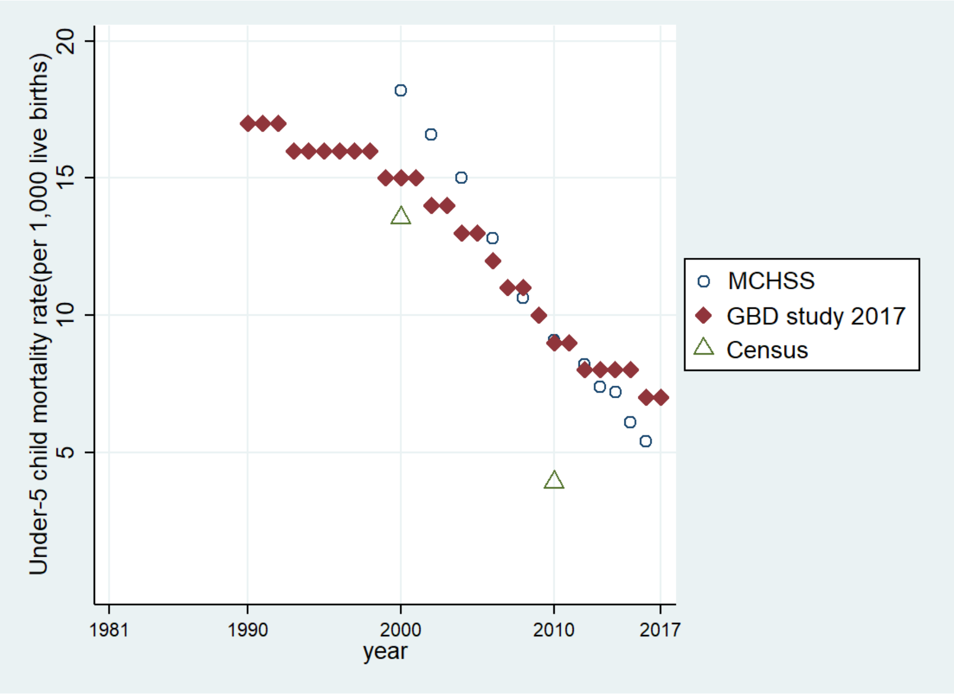


Figure E.46 Data of the under-5 child mortality rate for Liaoning from 1981 onwards

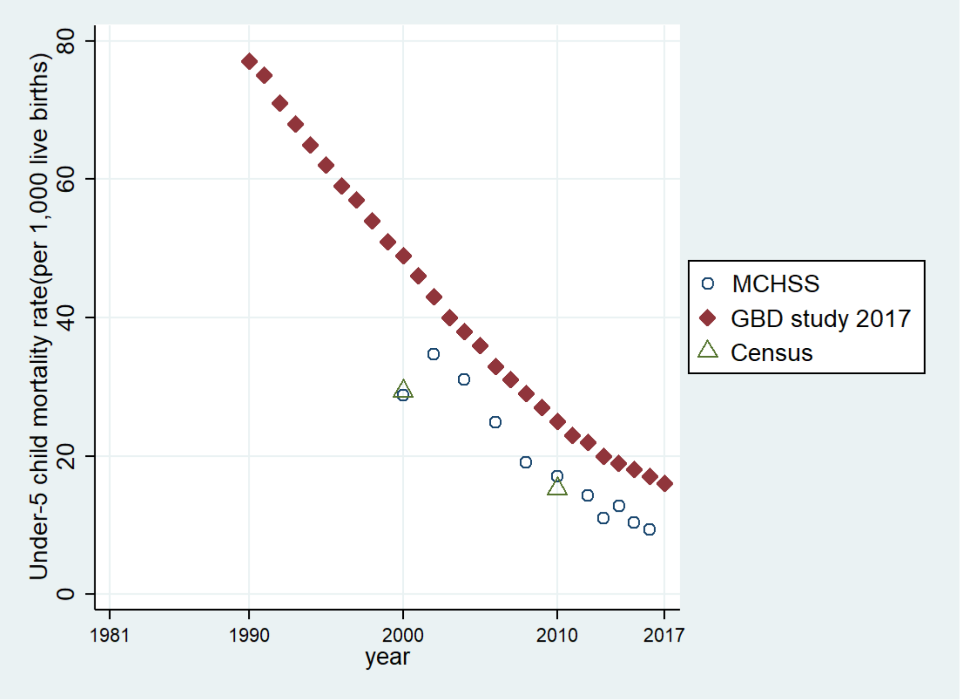


Figure E.47 Data of the under-5 child mortality rate for Ningxia from 1981 onwards

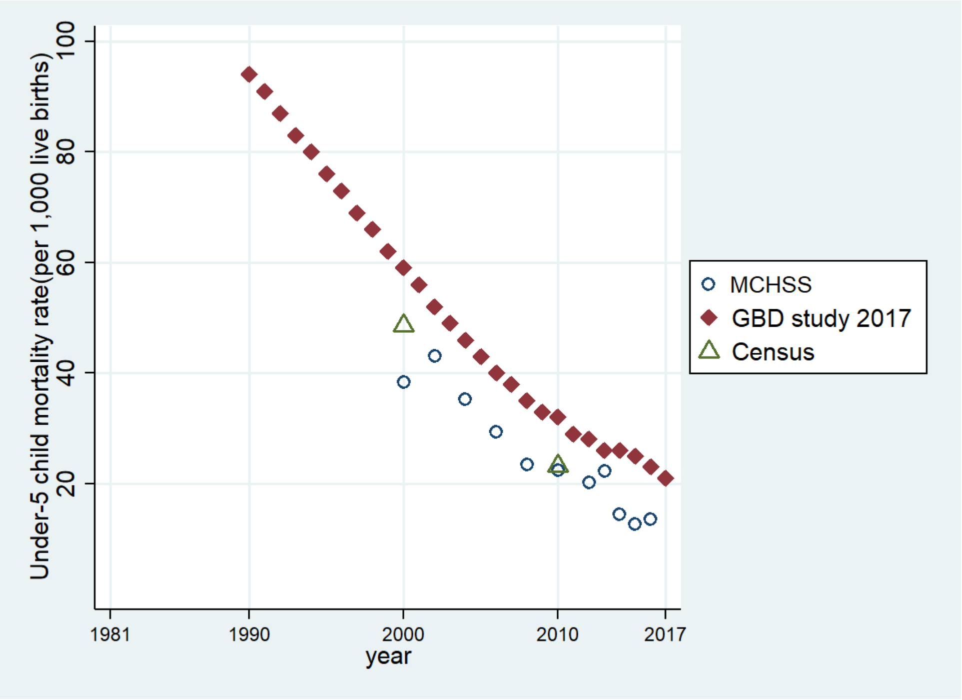


Figure E.48 Data of the under-5 child mortality rate for Qinghai from 1981 onwards

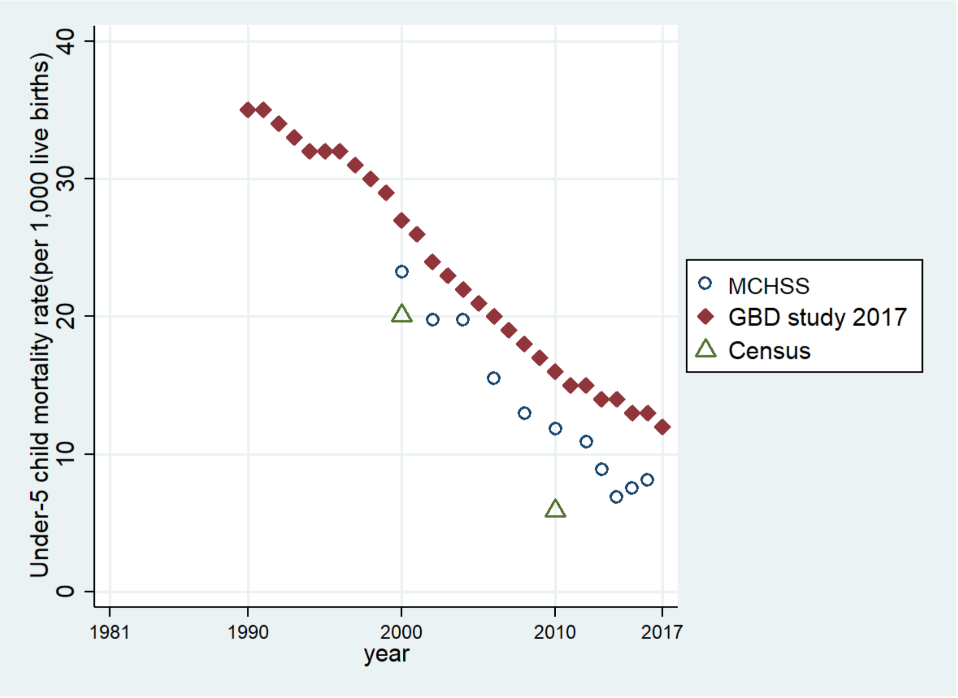


Figure E.49 Data of the under-5 child mortality rate for Shaanxi from 1981 onwards

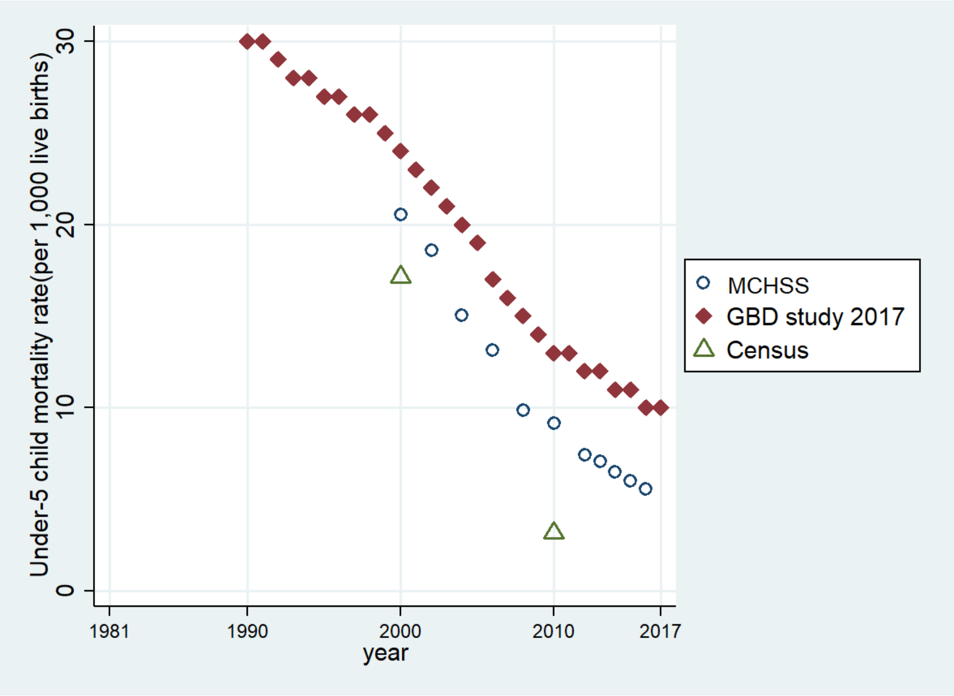


Figure E.50 Data of the under-5 child mortality rate for Shandong from 1981 onwards

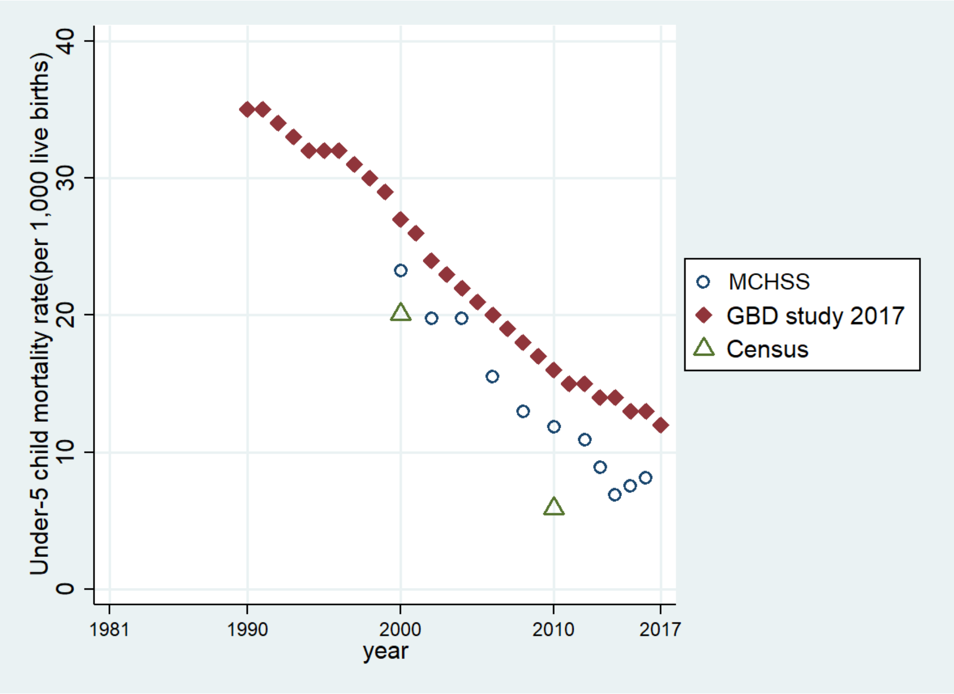


Figure E.51 Data of the under-5 child mortality rate for Shanxi from 1981 onwards

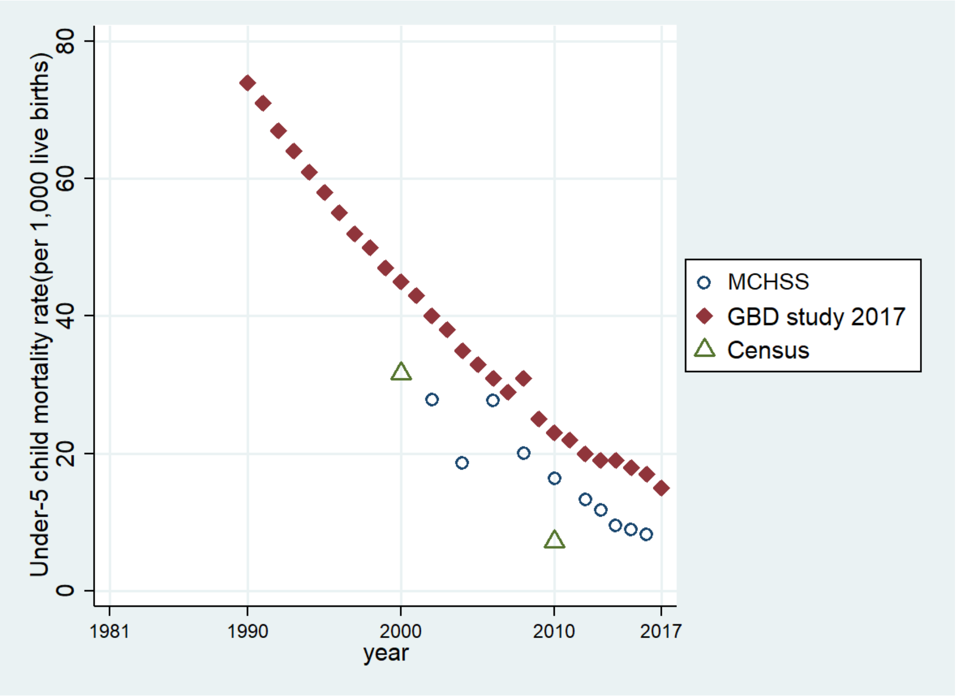


Figure E.52 Data of the under-5 child mortality rate for Sichuan from 1981 onwards

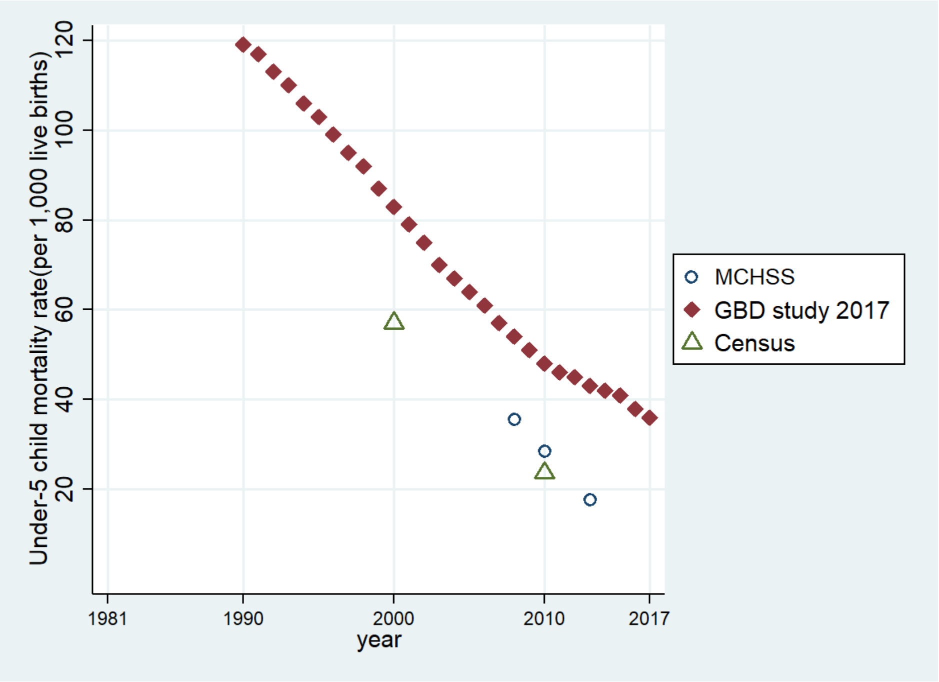


Figure E.53 Data of the under-5 child mortality rate for Tibet from 1981 onwards

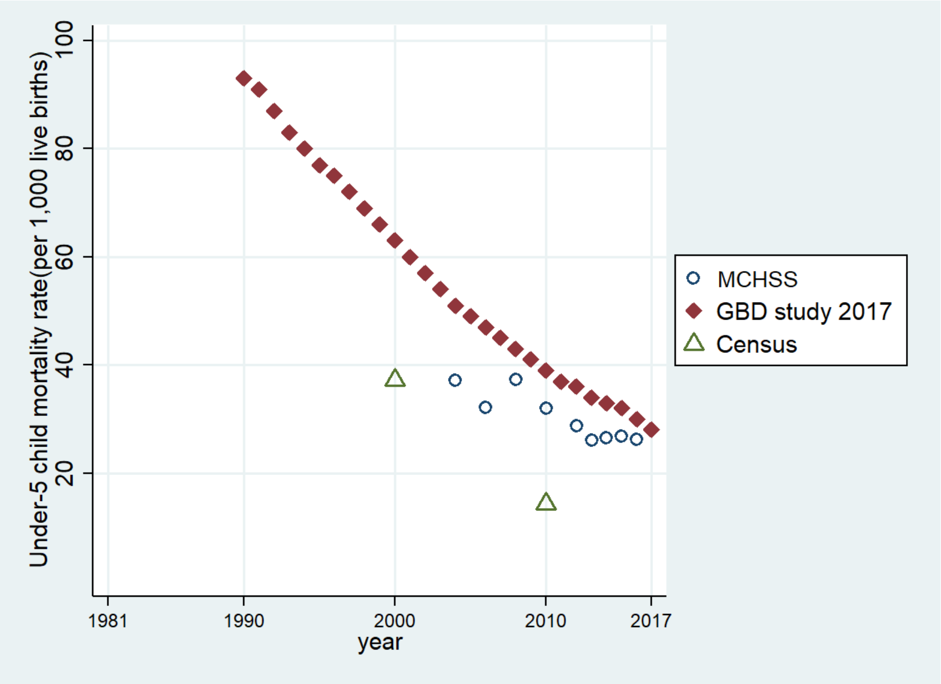


Figure E.54 Data of the under-5 child mortality rate for Xinjiang from 1981 onwards

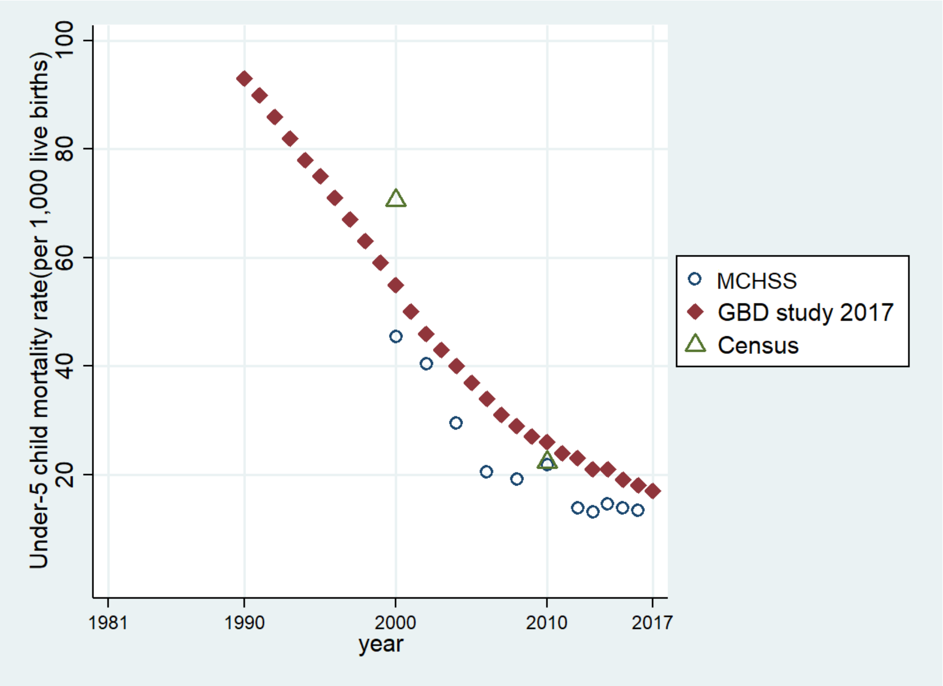


Figure E.55 Data of the under-5 child mortality rate for Yunnan from 1981 onwards

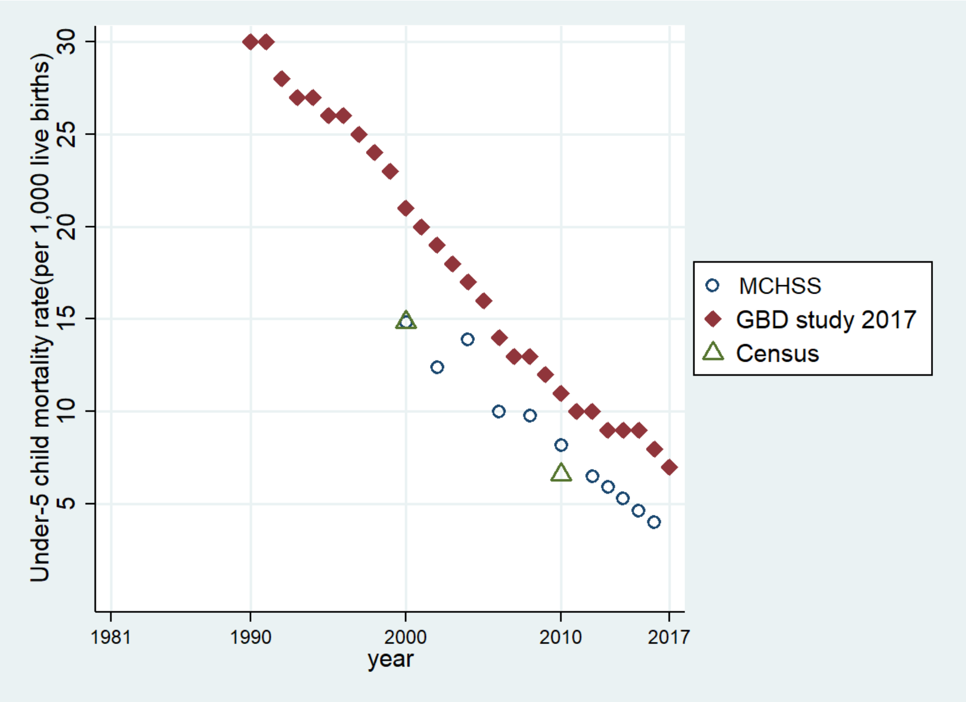


Figure E.56 Data of the under-5 child mortality rate for Zhejiang from 1981 onwards

Appendix F. Descriptive analysis of all the variables in the longitudinal dataset 1950-2017

Table F.1 Summary statistics of the outcome variables at the start (1950) and the end (2016/2017) of the study period

Region	Province	IMR (1950)	IMR (2016)	Proportion of reduction in the IMR from 1950 to 2016 (%)	Proportion of years with data available for the IMR	U5MR (1950)	U5MR (2017)	Proportion of reduction in the U5MR from 1950 to 2017 (%)	Proportion of years with data available for the U5MR
East	Hebei	153.9	5.6	96.4	100%	200.0	13.0	93.5	100%
	Liaoning	155.8	4.6	97.0	100%	194.8	7.0	96.4	100%
	Jiangsu	164.4	3.0	98.2	100%	246.6	7.0	97.2	100%
	Zhejiang	196.7	2.8	98.6	100%	270.5	7.0	97.4	100%
	Fujian	120.0	3.7	96.9	100%	180.0	7.0	96.1	100%
	Shandong	236.8	4.5	98.1	100%	263.2	10.0	96.2	100%
	Guangdong	189.2	2.0	98.9	100%	270.3	7.0	97.4	100%
	Hainan	200.0	6.2	96.9	100%	400.0	16.0	96.0	100%
Central	Shanxi	197.7	6.5	96.7	100%	244.2	12.0	95.1	100%
	Jilin	200.0	3.9	98.1	100%	215.4	9.0	95.8	100%
	Heilongjiang	184.6	7.2	96.1	100%	292.3	12.0	95.9	100%
	Anhui	250.0	4.5	98.2	100%	333.3	12.0	96.4	100%
	Jiangxi	213.1	6.0	97.2	100%	360.7	16.0	95.6	100%
	Henan	180.6	4.1	97.7	100%	263.9	13.0	95.1	100%
	Hubei	231.9	5.6	97.6	100%	333.3	12.0	96.4	100%
	Hunan	226.4	3.8	98.3	100%	330.2	9.0	97.3	100%
Western	Inner Mongolia	195.4	6.1	96.9	100%	298.9	13.0	95.7	100%
	Guangxi	368.4	4.2	98.9	100%	500.0	12.0	97.6	100%
	Guizhou	260.9	7.9	97.0	100%	369.6	18.0	95.1	100%
	Yunnan	277.8	10.5	96.2	100%	472.2	17.0	96.4	100%
	Shaanxi	302.3	6.5	97.8	100%	395.4	15.0	96.2	100%
	Gansu	215.9	5.6	97.4	100%	340.9	20.0	94.1	100%
	Qinghai	228.6	11.0	95.2	100%	285.7	20.0	93.0	100%
	Ningxia	197.5	7.3	96.3	100%	234.6	21.0	91.0	100%
	Xinjiang	244.9	19.4	92.1	98%	387.8	28.0	92.8	100%
	Sichuan	256.8	6.0	97.7	98%	337.8	15.0	95.6	100%
	Tibet	-	-	-	7%	-	36.0	-	48%

Table F.1 (Continued)

Region	Province	CMR1-4 (1950)	CMR1-4 (2016)	Proportion of reduction in the CMR1-4 from 1950 to 2016 (%)	Proportion of years with data available for the CMR1-4
East	Hebei	54.5	8.5	84.4	100%
	Liaoning	46.2	2.4	94.8	100%
	Jiangsu	98.4	4.0	95.9	100%
	Zhejiang	91.8	5.2	94.3	100%
	Fujian	68.2	4.4	93.5	100%
	Shandong	34.5	5.5	84.1	100%
	Guangdong	100.0	6.0	94.0	100%
	Hainan	250.0	10.8	95.7	100%
Central	Shanxi	58.0	6.5	88.8	100%
	Jilin	19.2	5.1	73.4	100%
	Heilongjiang	132.1	5.8	95.6	100%
	Anhui	111.1	8.5	92.3	100%
	Jiangxi	187.5	11.1	94.1	100%
	Henan	101.7	8.9	91.2	100%
	Hubei	132.1	7.4	94.4	100%
	Hunan	134.1	6.3	95.3	100%
Western	Inner Mongolia	128.6	7.9	93.9	100%
	Guangxi	208.3	8.9	95.7	100%
	Guizhou	147.1	12.2	91.7	100%
	Yunnan	269.2	7.6	97.2	100%
	Shaanxi	133.3	9.6	92.8	100%
	Gansu	159.4	16.5	89.6	100%
	Qinghai	74.1	12.2	83.5	100%
	Ningxia	46.2	9.8	78.8	100%
	Xinjiang	189.2	10.8	94.3	98%
	Sichuan	109.1	11.1	89.8	98%
	Tibet	-	-	-	7%

Table F.2 Summary statistics of all the variables in the longitudinal dataset 1950-2017

Variable	1950		1960		1970		1980		1990		2000		2010		2017	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Outcome variables																
Infant mortality rate	217.3	51.1	118.3	53.2	52.0	17.5	44.9	21.8	33.9	20.3	23.5	9.2	11.3	5.1	-	-
Mortality rate aged 1-4	118.6	64.1	53.9	34.7	21.9	13.6	13.4	10.4	23.6	16.5	13.2	12.2	8.9	6.5	-	-
Under-5 child mortality rate	308.5	81.7	164.6	74.0	72.6	28.5	57.5	30.8	55.5	29.4	37.4	17.9	20.1	9.5	14.1	6.6
Demographic variables																
Total Population	1968.5	1333.4	2274.2	1469.8	2880.8	1820.4	3437.4	2098.3	4129.3	2349.1	4416.7	2668.5	4627.3	2814.8	4800.5	2933.1
Per cent of population over 60	-	-	6.2	1.0	6.2	1.0	7.0	1.1	7.9	1.3	9.8	1.4	12.5	2.2	14.4	3.0
Per cent of population under 5	-	-	13.0	1.2	16.0	1.7	9.9	1.9	10.6	1.2	6.0	1.6	5.9	1.3	5.8	1.6
Per cent of male	51.5	1.4	52.0	2.1	51.3	1.0	51.2	0.7	51.4	0.7	51.4	1.0	51.3	0.6	51.1	1.0
Per cent of urban	12.1	5.4	21.2	10.1	15.2	7.3	17.6	8.0	21.7	9.0	33.1	9.5	47.1	10.0	55.8	8.5
Crude death Rate	15.7	3.4	24.9	16.0	7.3	1.4	6.2	1.0	6.8	0.8	6.1	0.7	5.9	0.6	6.2	0.8
Birth Rate	33.6	4.5	21.7	6.6	33.1	4.7	18.8	3.7	22.0	3.1	13.6	3.4	11.8	2.5	12.6	2.9
Natural growth rate	17.5	4.1	-2.4	21.6	25.6	4.4	12.5	3.9	15.1	2.9	7.3	3.4	5.9	2.6	6.4	3.2
Education variables																
Primary education enrolment ratio	0.4	0.4	0.6	0.2	0.6	0.2	1.0	0.1	1.0	0.1	1.1	0.2	1.1	0.1	2.1	1.9
Secondary education enrolment ratio	0.02	0.01	0.2	0.1	0.2	0.1	0.3	0.1	0.3	0.1	0.5	0.2	0.9	0.1	1.1	0.5
Health system input variables																
Hospital bed density	2.2	1.5	19.6	9.7	16.2	6.9	23.8	8.0	26.9	8.3	25.4	6.6	35.5	6.7	57.3	7.4
Doctor density	3.1	2.5	8.2	2.0	9.2	2.5	12.7	3.6	16.2	3.8	16.7	3.9	17.9	4.1	24.0	3.1
Health professional density	4.8	4.0	22.0	6.4	18.6	4.9	29.7	8.5	35.7	9.3	35.6	8.4	43.3	9.1	63.9	8.0
Health institution density	0.1	0.1	5.8	3.2	1.7	0.8	2.1	1.1	2.1	0.9	2.8	0.9	7.3	2.1	7.5	2.2

Note: SD means standard deviation. The most recent estimates of infant mortality rate for the included provinces are from 2016. The mean of infant mortality in 2016 is 6.1 deaths per 1,000 live births (SD 3.4). The mean of child mortality aged 1-4 in 2016 is 8.2 deaths per 1,000 children surviving to age one (SD 3.1).

Table F.2 (continued) Summary statistics of all the variables in the longitudinal dataset 1950-2017

	1950		1960		1970		1980		1990		2000		2010		2017	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Socio-economic development variables																
Gross domestic product (100 million yuan)	-	-	48.6	32.8	66.0	40.3	139.0	92.5	644.4	427.3	3232.1	2698.4	14393.1	12130.9	27797.0	23705.6
Investment in fixed assets (current price) per capita	0.0002	0.0003	0.007	0.004	0.004	0.002	0.008	0.004	0.04	0.02	0.2	0.1	2.0	0.7	4.6	1.4
Local revenue per capita (100 million yuan)	0.0007	0.0003	0.006	0.004	0.004	0.002	0.006	0.005	0.02	0.005	0.04	0.02	0.3	0.1	0.6	0.2
Total agricultural production per capita (10,000 tons)	0.03	0.04	1.2	0.6	0.5	0.3	2.7	1.2	5.9	3.1	21.6	12.1	264.1	105.3	613.0	213.4
Production of grain per capita (10,000 tons)	0.3	0.1	0.2	0.05	0.3	0.1	0.3	0.1	0.4	0.1	0.4	0.1	0.4	0.3	0.5	0.4
Production of fruit per capita (10000 tons)	0.01	0.01	0.01	0.01	0.01	0.005	0.01	0.01	-	-	0.05	0.04	0.2	0.1	0.2	0.1
General budgetary expenditure (100 million yuan)	0.5	0.3	12.5	5.7	9.1	4.3	18.5	8.3	79.4	34.5	334.7	211.7	2399.2	1255.0	5601.4	3026.7
Culture, education, science and health care combined expenditure (100 million yuan)	0.05	0.04	1.4	0.9	1.2	0.7	4.5	2.2	17.8	8.9	78.6	51.3	-	-	-	-
General public service expenditure (100 million yuan)	0.2	0.1	0.9	0.4	0.8	0.4	2.1	1.0	7.5	3.1	34.4	19.7	-	-	-	-
Social safety net and employment effort (100 million yuan)	-	-	0.9	1.2	0.6	0.7	1.6	1.6	2.9	4.1	16.8	14.0	284.0	140.1	762.7	379.6
Gross domestic product per capita(yuan)	70.0	19.2	227.5	117.4	234.2	78.0	411.6	125.0	1537.3	453.5	6939.3	2864.2	29012.7	11177.9	53648.7	18662.9
Length of railways (1,000 km)	0.8	0.6	1.3	1.0	1.5	1.1	1.9	1.2	2.2	1.4	2.6	1.5	3.2	1.7	4.5	2.3
Length of navigable inland waterway (1,000 km)	4.4	4.4	6.1	5.4	7.1	6.8	5.0	5.6	4.9	5.5	4.8	5.6	4.9	5.6	5.0	5.6
Length of highways (1,000 km)	3.6	2.3	16.9	7.0	22.5	9.2	31.8	15.0	36.9	17.8	52.7	31.5	142.3	63.5	169.5	73.4
Possession of civil vehicles (10,000 units)	0.1	0.1	0.7	0.4	1.3	0.7	5.9	3.0	18.4	11.2	51.4	37.5	255.7	202.0	715.7	531.2
Ownership of telephone (set/100 persons)	0.03	0.04	0.2	0.08	0.2	0.1	0.2	0.1	0.7	0.6	16.9	9.7	84.2	21.5	113.2	17.9
Radio Coverage Rate (%)	11.7	11.7	24.6	12.9	34.0	11.2	46.0	16.4	69.5	15.5	89.8	8.1	95.8	3.2	98.4	1.3
Television Coverage Rate (%)	-	-	3.5	3.5	7.7	7.0	38.3	16.8	75.7	11.7	91.8	5.5	97.0	2.1	98.9	0.8

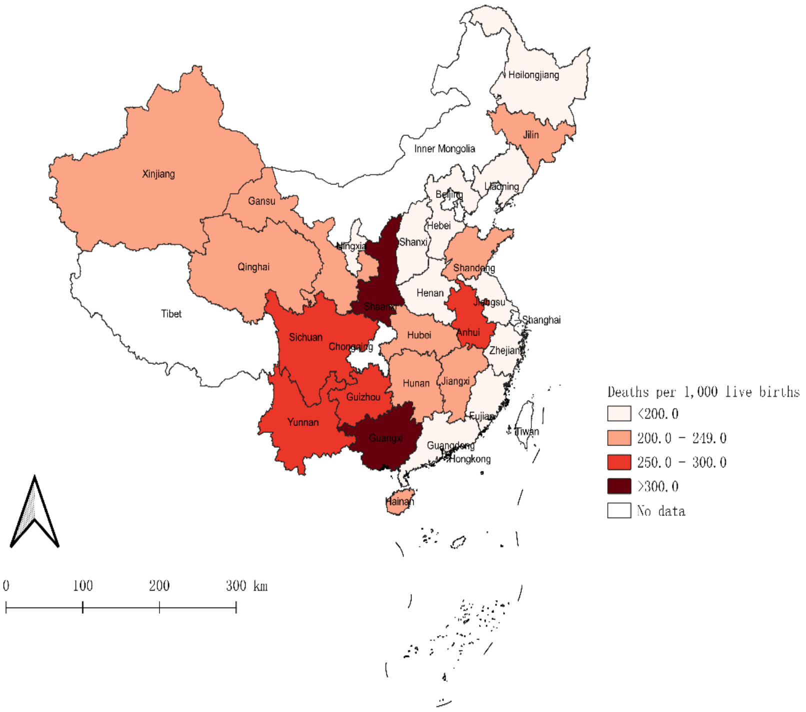


Figure F.1 Spatial distribution of infant mortality rate across provinces in1950

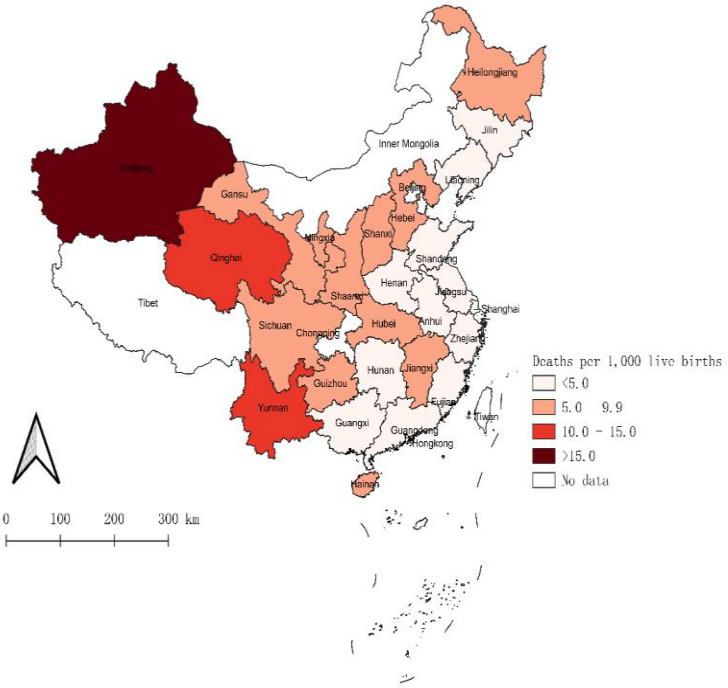


Figure F.2 Spatial distribution of infant mortality rate across provinces in 2016

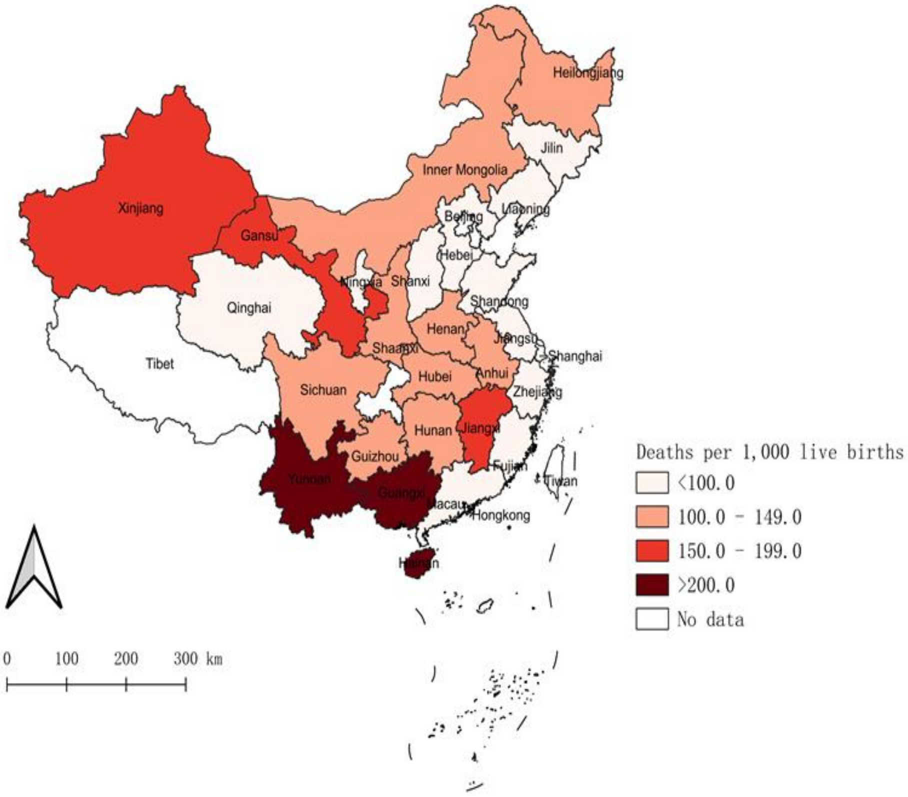


Figure F.3 Spatial distribution of mortality rate aged 1-4 across provinces in 1950

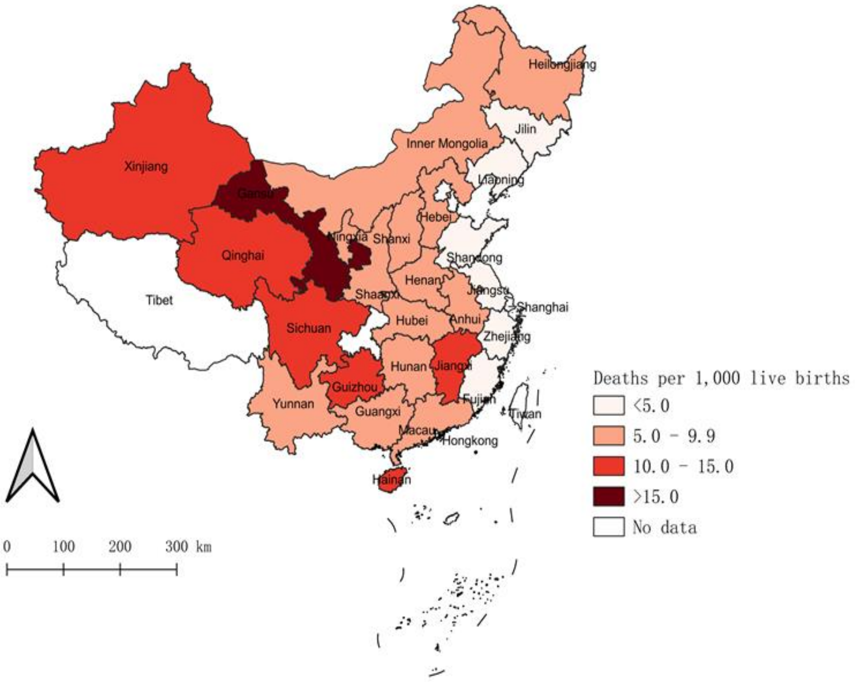


Figure F.4 Spatial distribution of mortality rate aged 1-4 across provinces in 2016

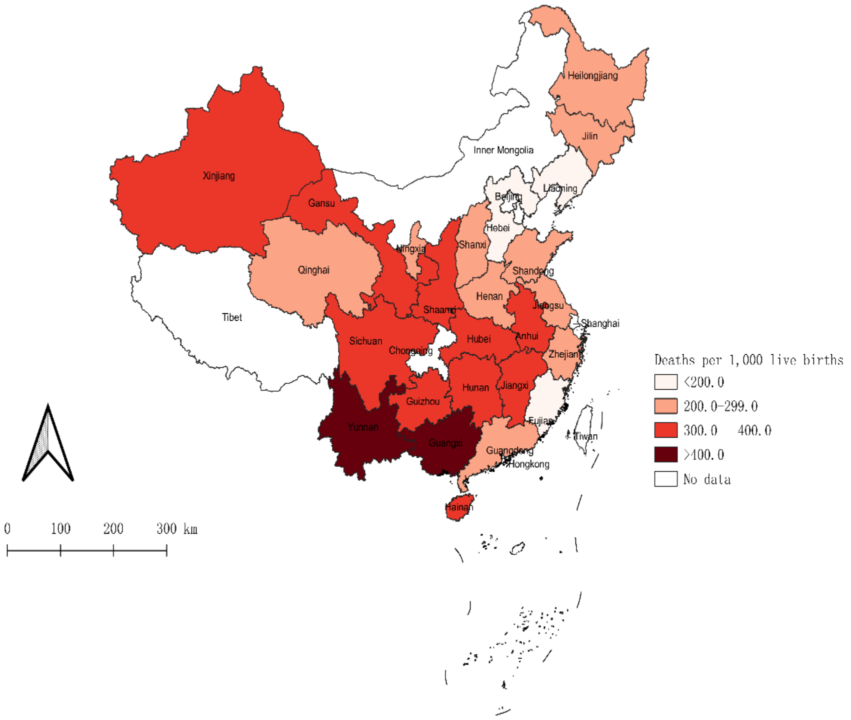


Figure F.5 Spatial distribution of under-5 child mortality across provinces in 1950

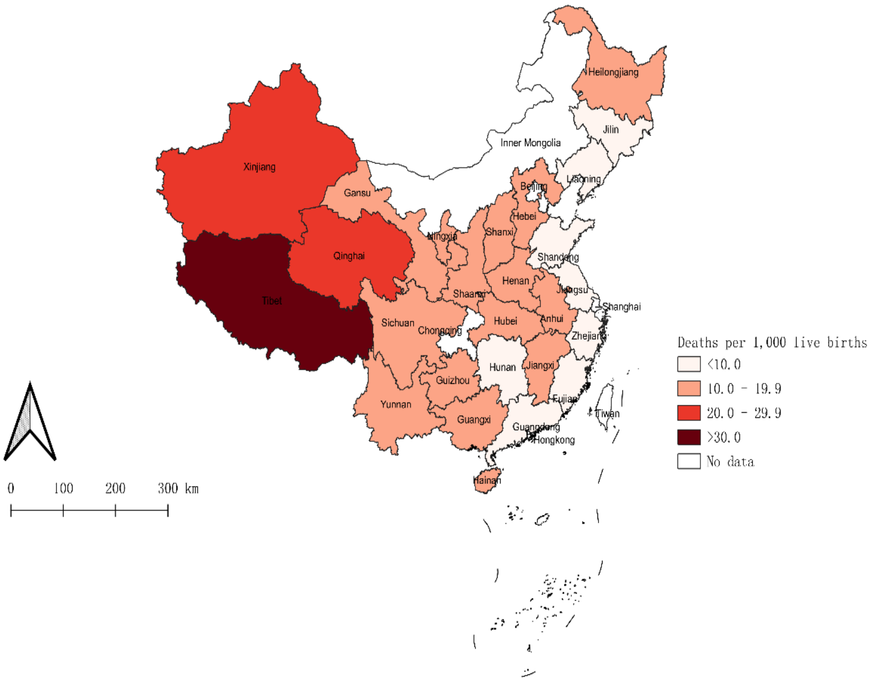


Figure F.6 Spatial distribution of under-5 child mortality across provinces in 2017

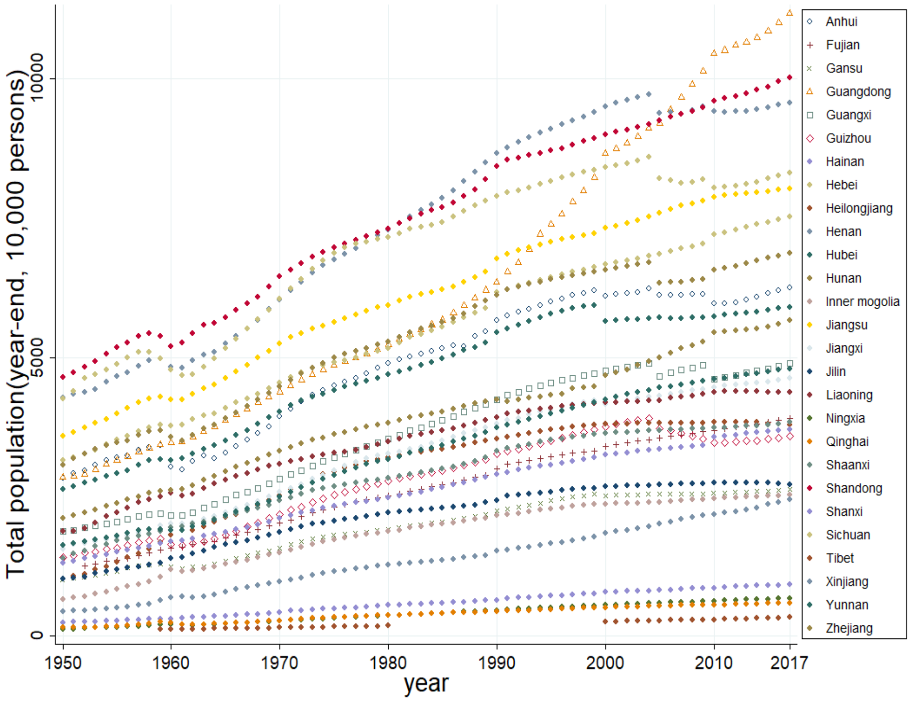


Figure F.7 Total population (year-end, 10,000 persons) by province, 1950-2017

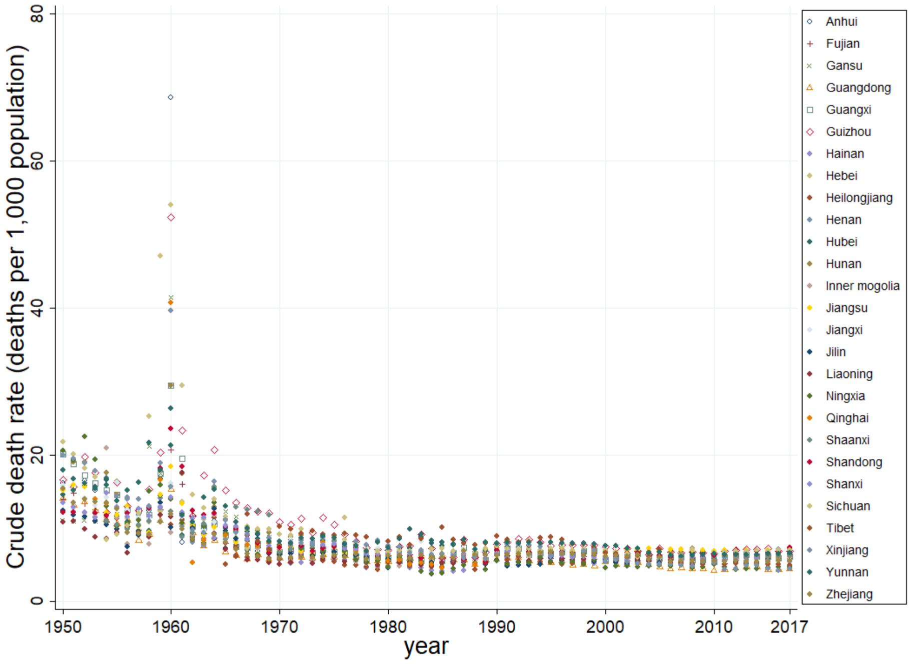


Figure F.8 Crude death rate (deaths per 1,000 population) by province, 1950-2017

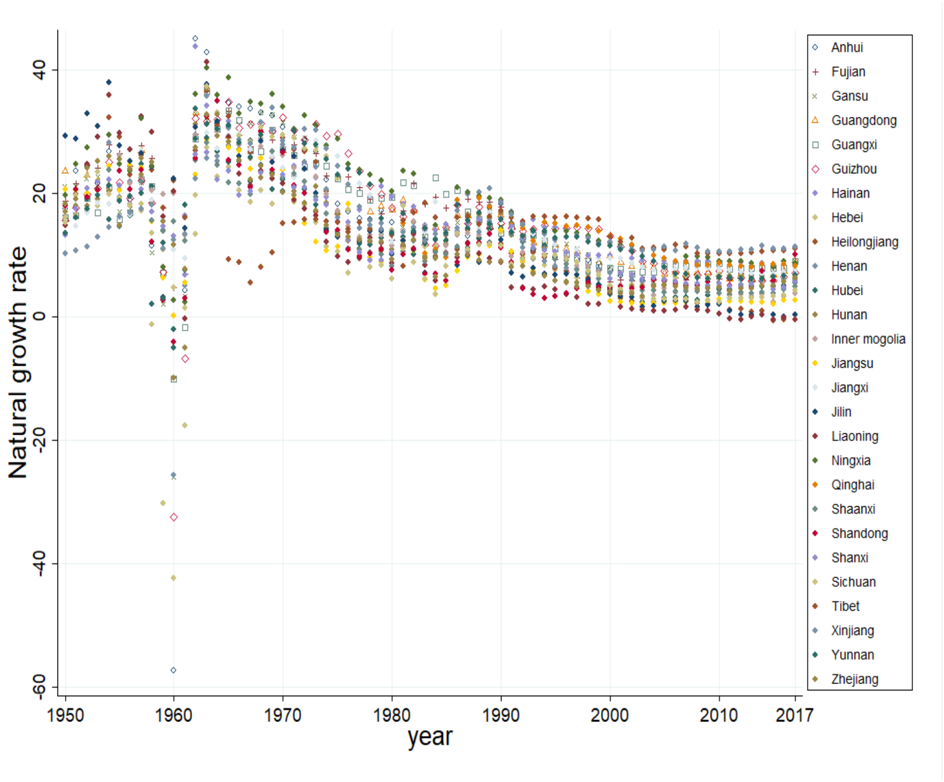


Figure F.9 Natural growth rate by province, 1950-2017

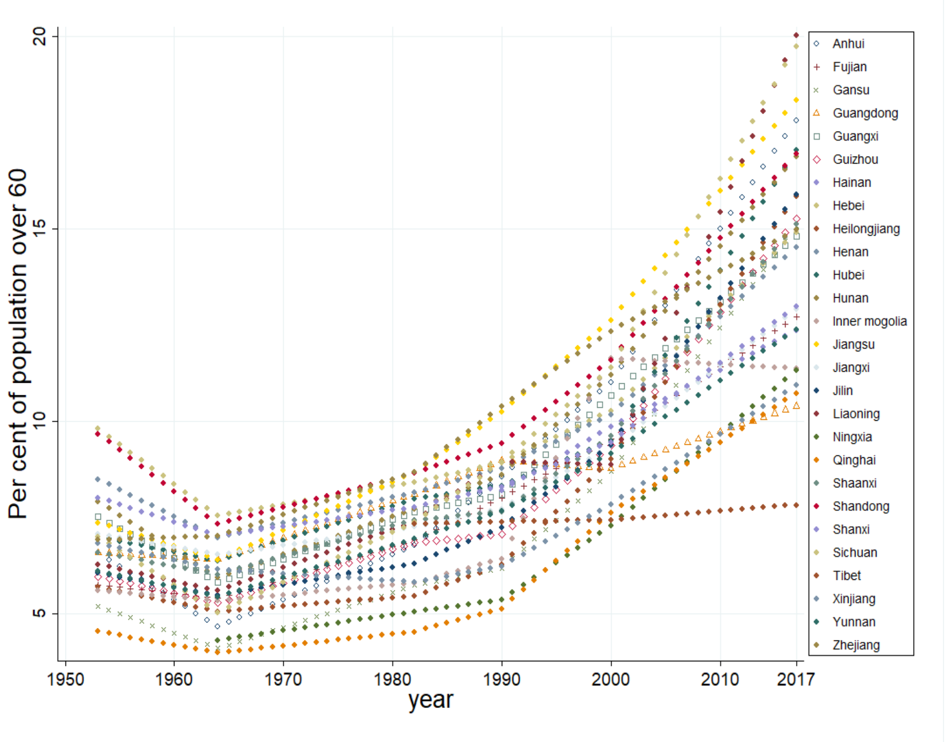


Figure F.10 Per cent of population over 60 by province, 1950-2017

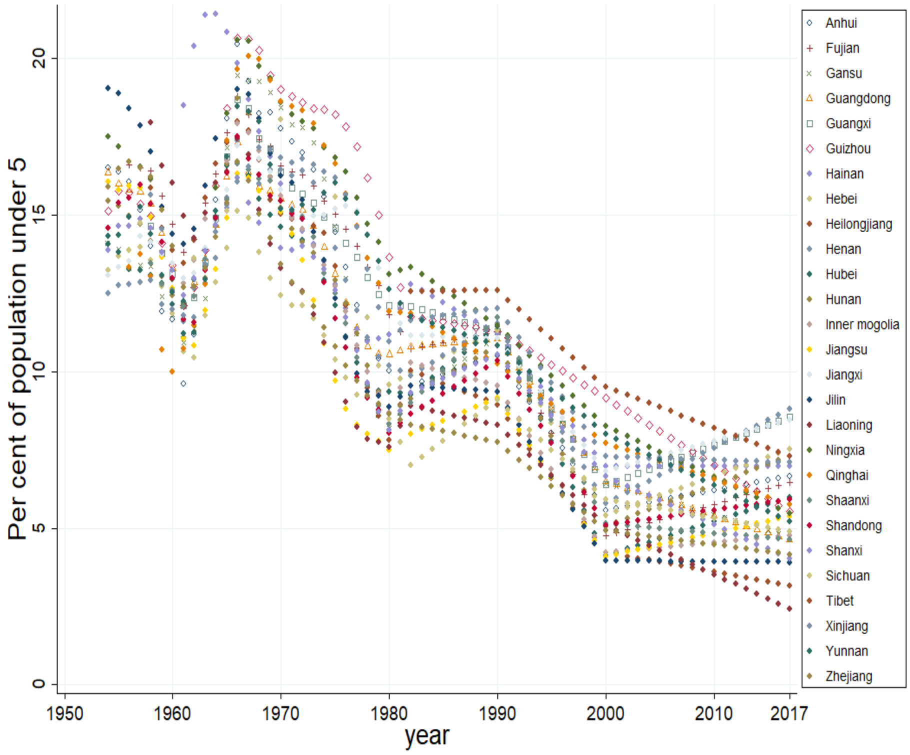


Figure F.11 Per cent of population under 5 by province, 1950-2017

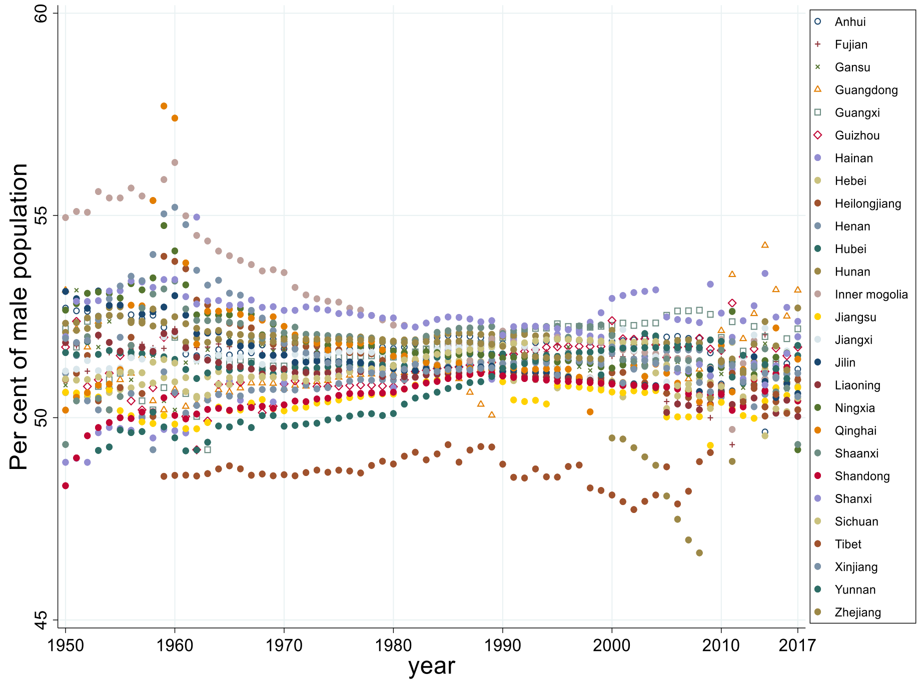


Figure F.12 Per cent of male population by province, 1950-2017

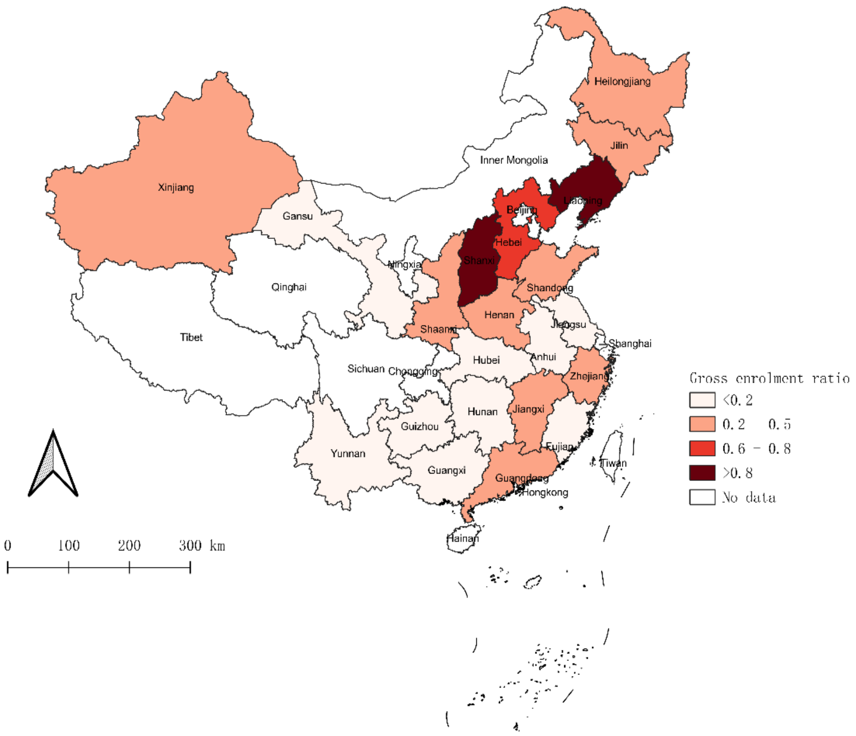


Figure F.13 Spatial distribution of gross enrolment ratio of primary education across provinces in 1950

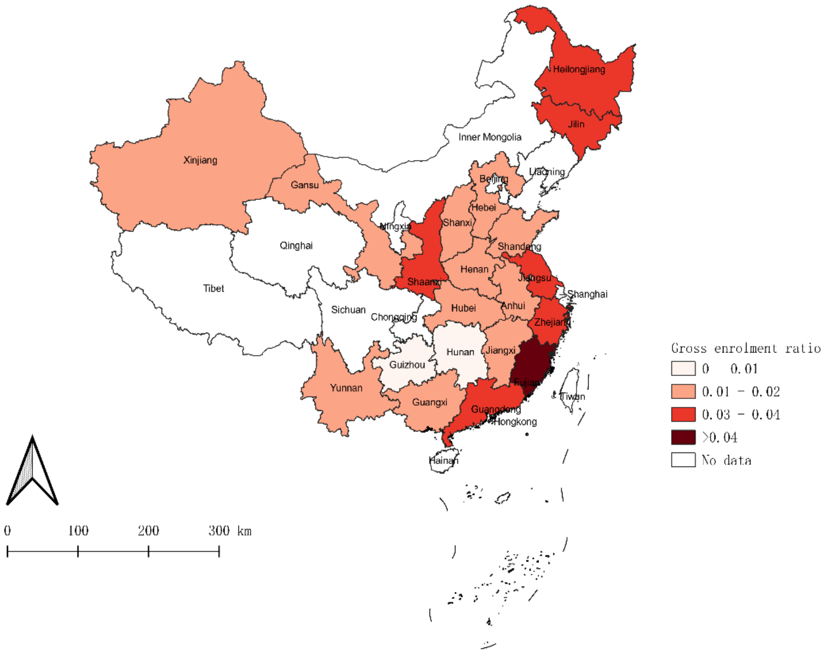


Figure F.14 Spatial distribution of gross enrolment ratio of secondary and higher education across provinces in 1950

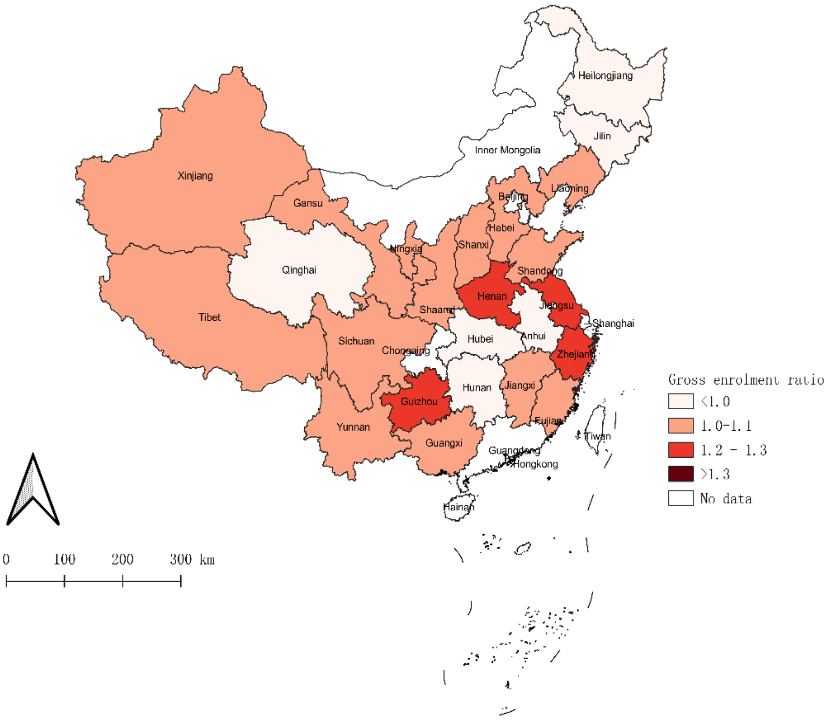


Figure F.15 Spatial distribution of gross enrolment ratio of primary education across provinces in 2017

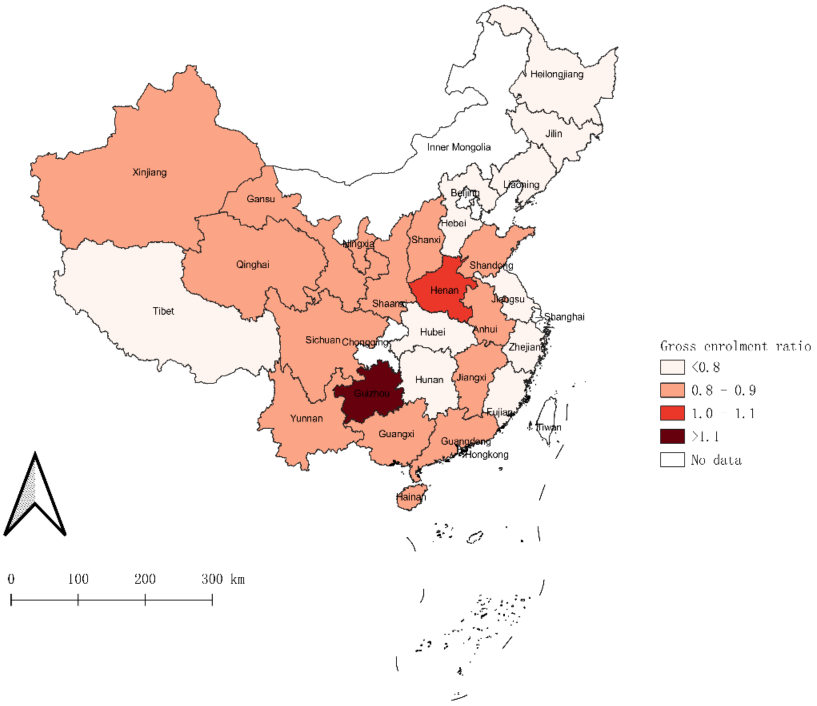


Figure F.16 Spatial distribution of gross enrolment ratio of secondary and higher education across provinces in 2017

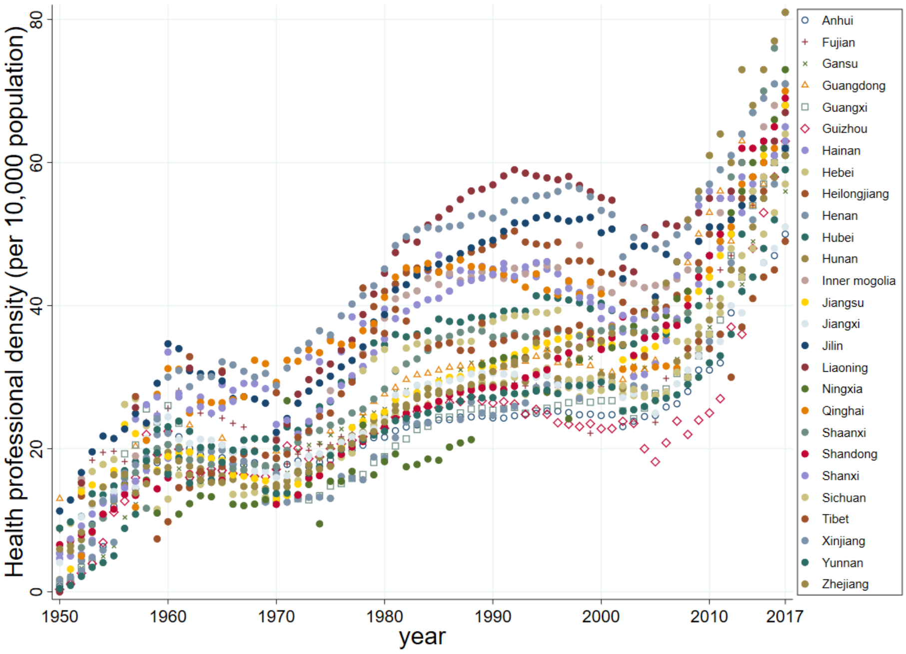


Figure F.17 Health professional density (per 10,000 population) by province, 1950-2017

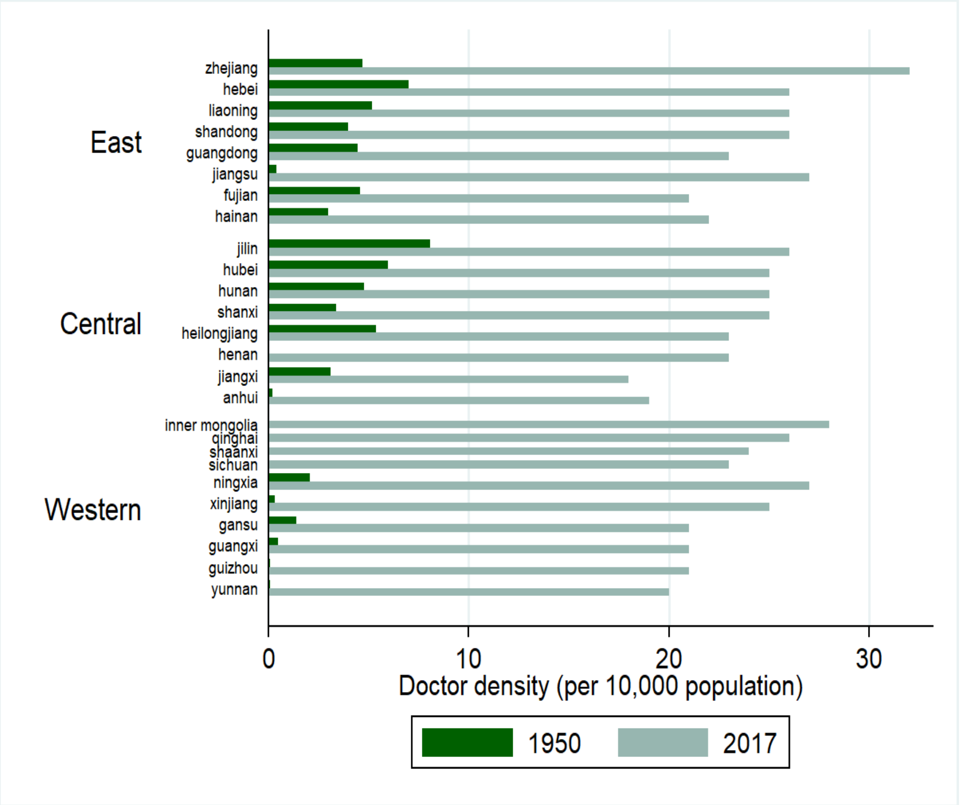


Figure F.18 Doctor density by regions, 1950 and 2017

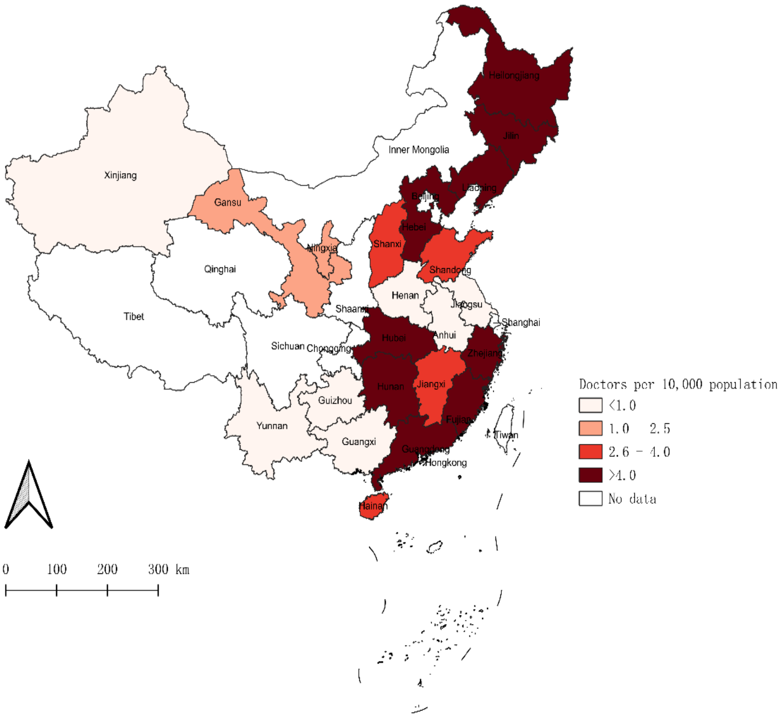


Figure F.19 Spatial distribution of doctor density across provinces in 1950

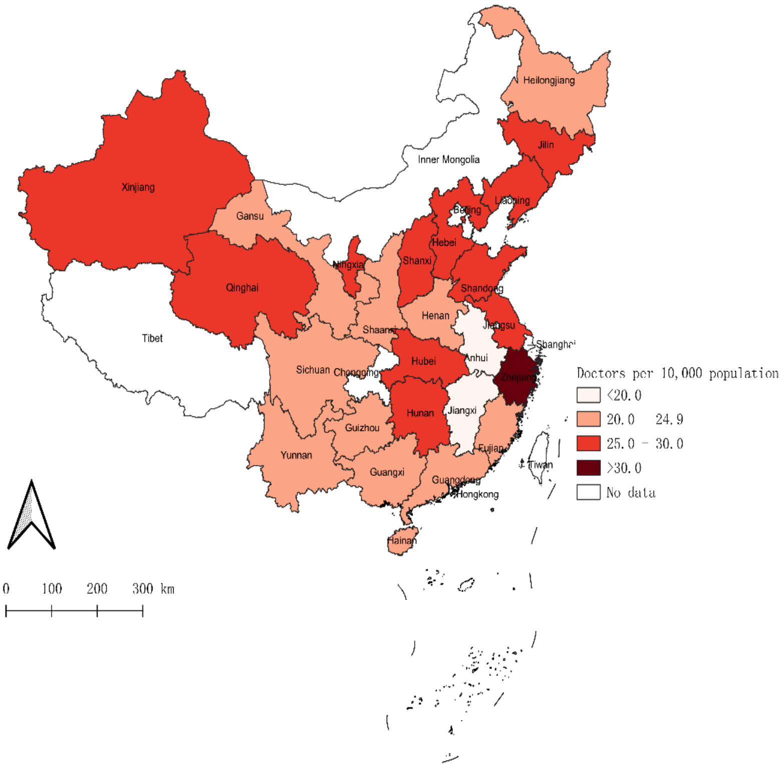


Figure F.20 Spatial distribution of doctor density across provinces in 2017

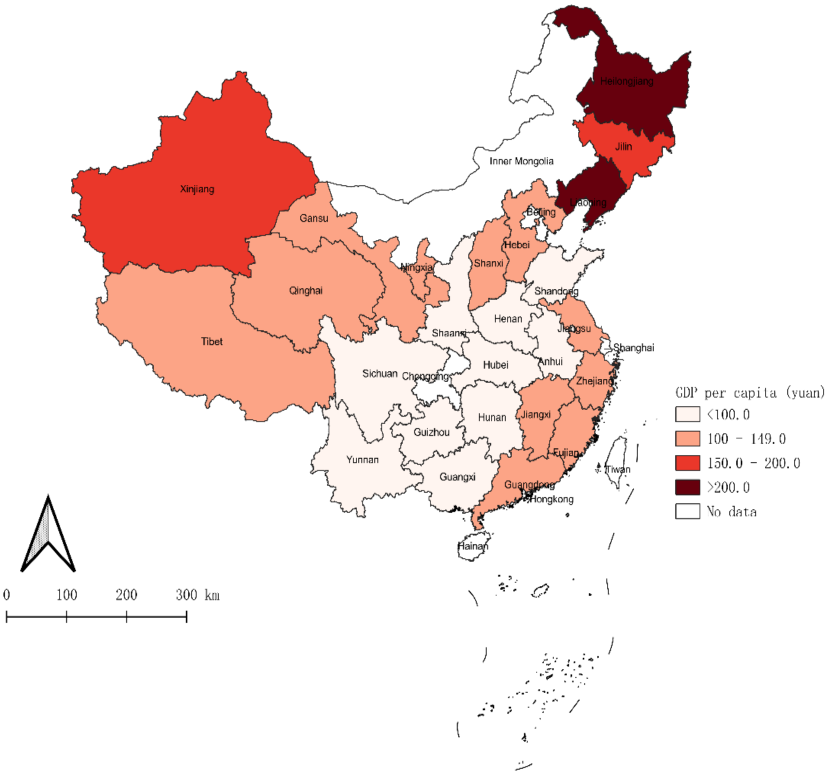


Figure F.21 Spatial distribution of gross domestic product per capita across provinces in 1952

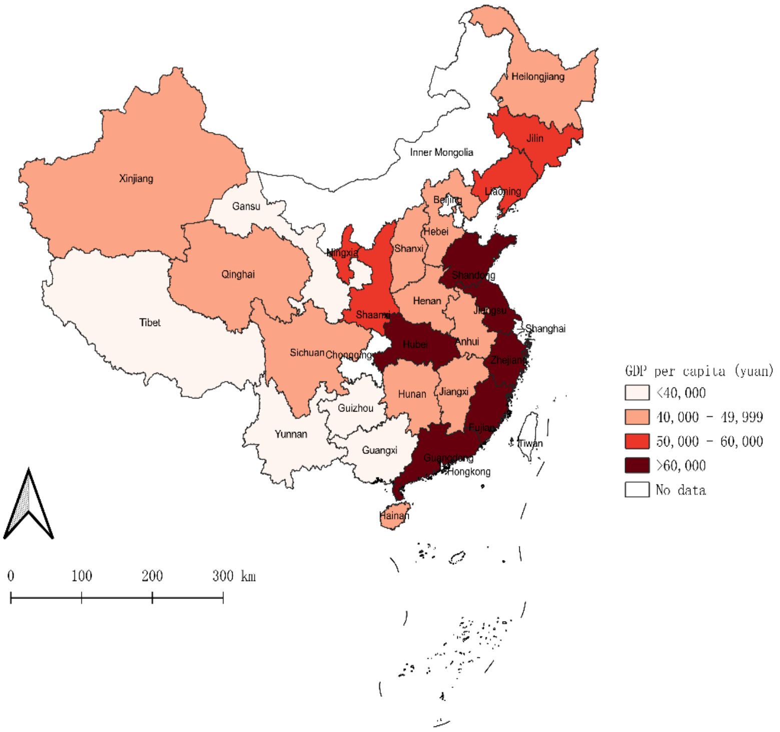


Figure F.22 Spatial distribution of gross domestic product per capita across provinces in 2017

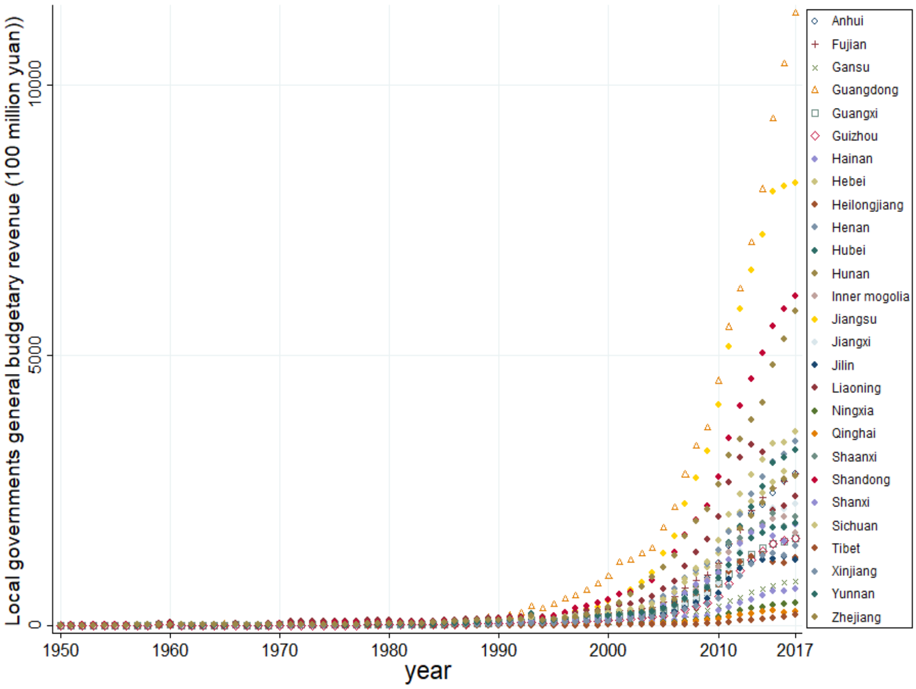


Figure F.23 Local governments general budgetary revenue (100 million yuan) by province, 1950-2017

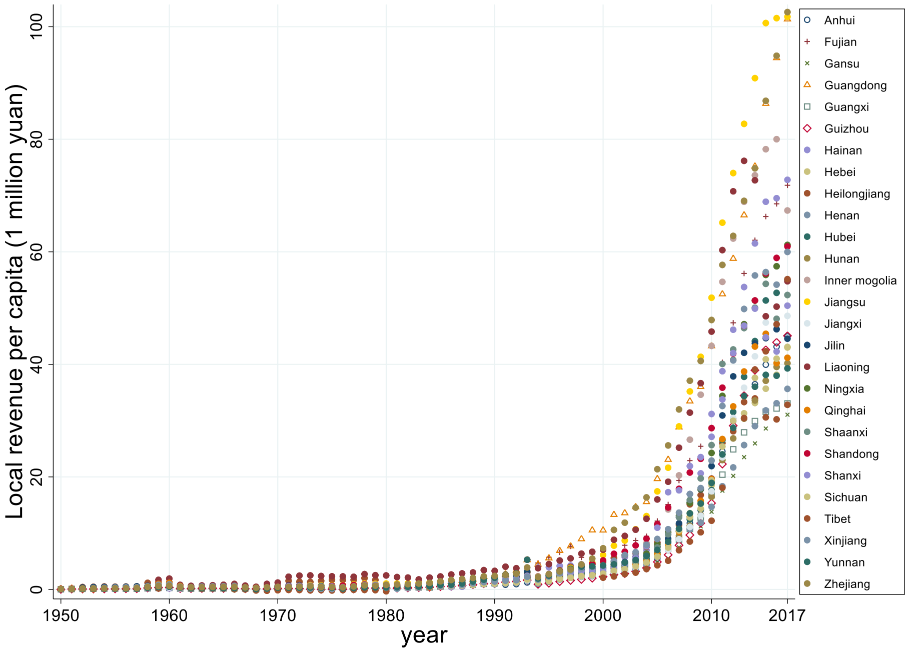


Figure F.24 Local revenue per capita (1 million yuan) by province, 1950-2017

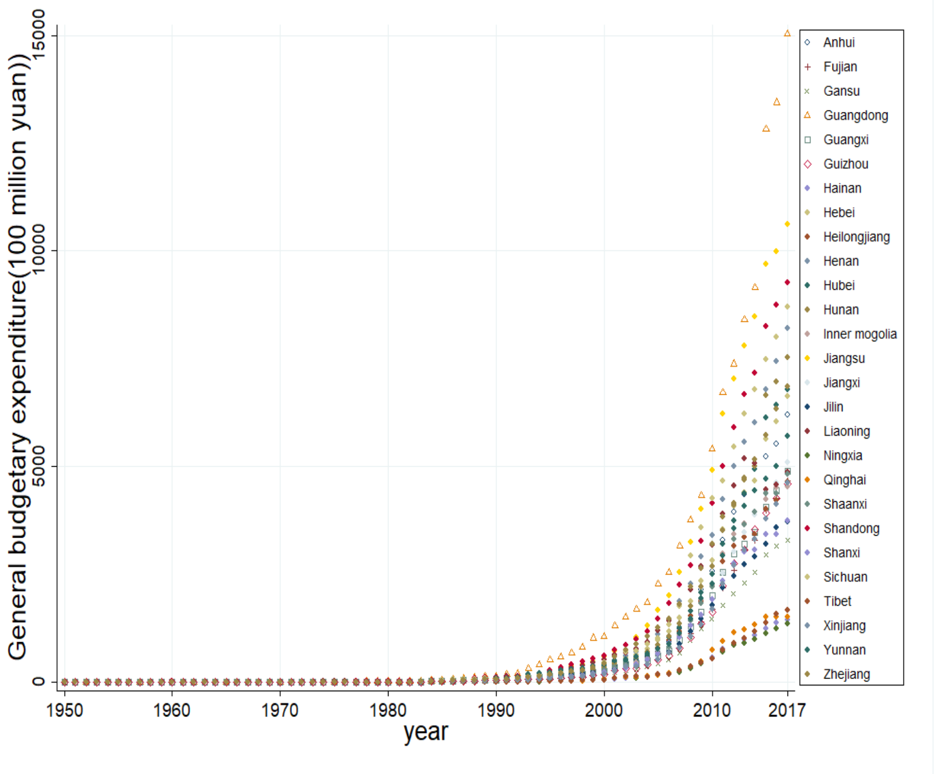


Figure F.25 General budgetary expenditure (100 million yuan) by province, 1950-2017

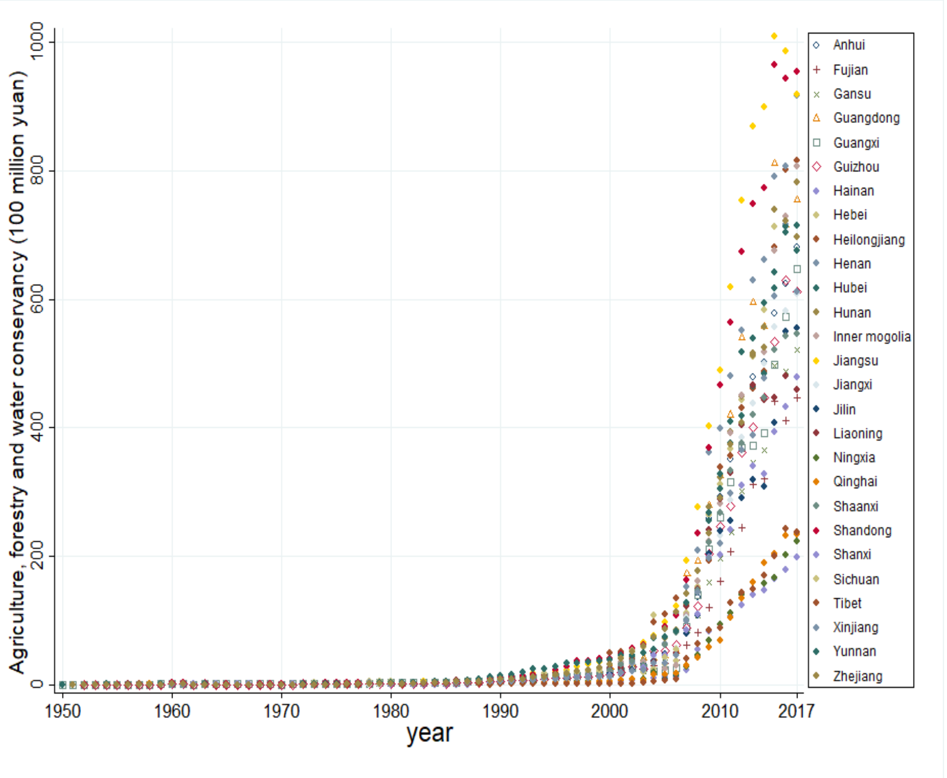


Figure F.26 Local government expenditure-agriculture, forestry and water conservancy (100 million yuan) by province, 1950-2017

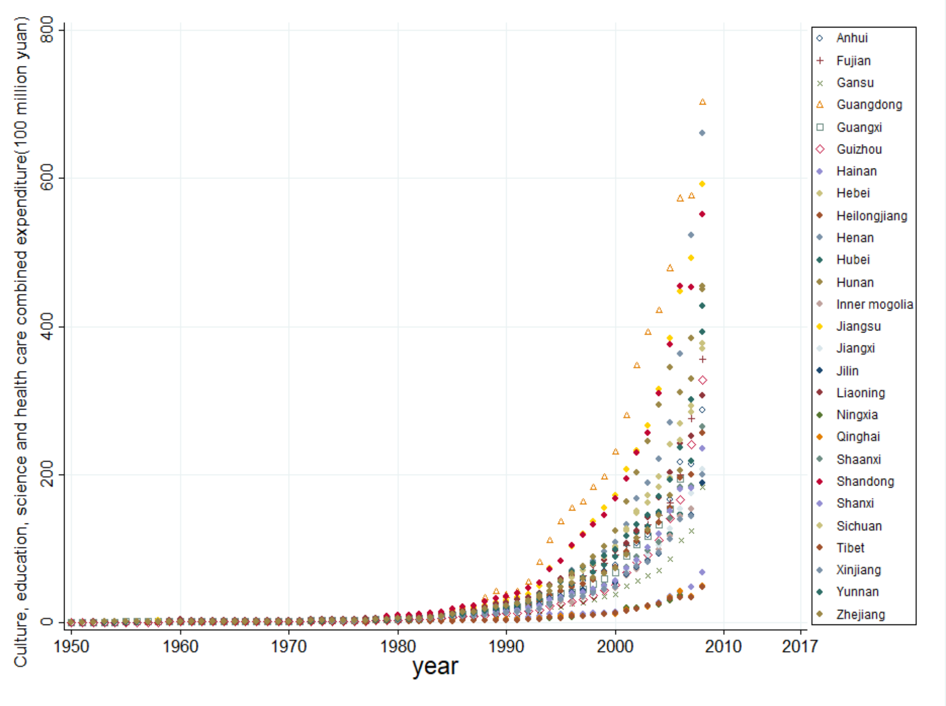


Figure F.27 Local government expenditure-culture, education, science and health care combined expenditure (100 million yuan) by province, 1950-2017

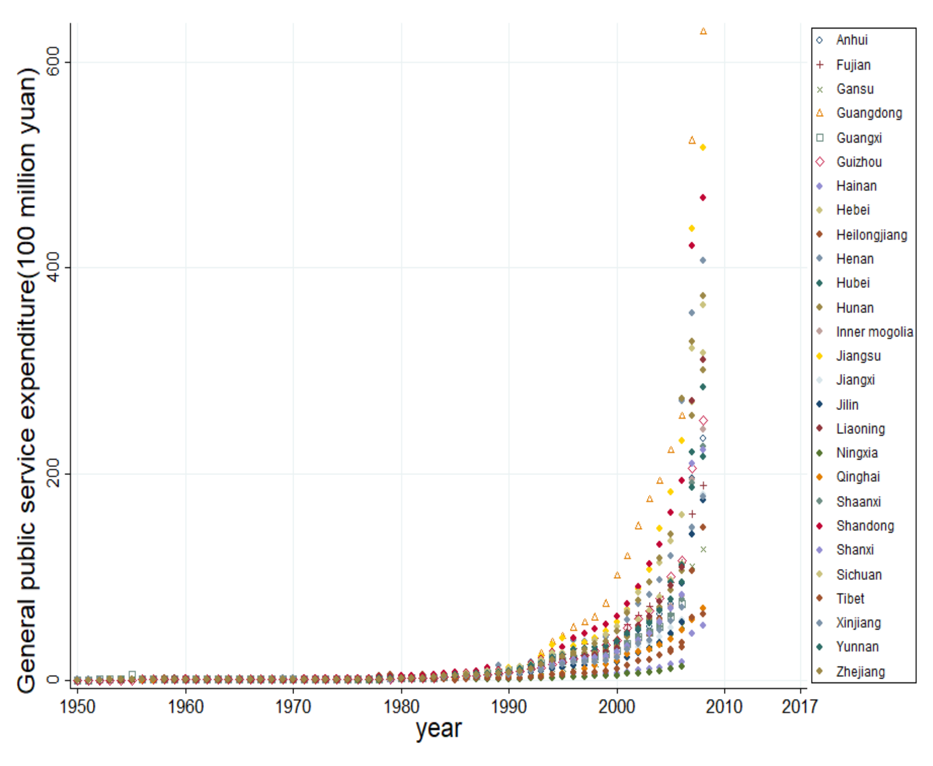


Figure F.28 Local government expenditure-general public service expenditure (100 million yuan) by province, 1950-2017

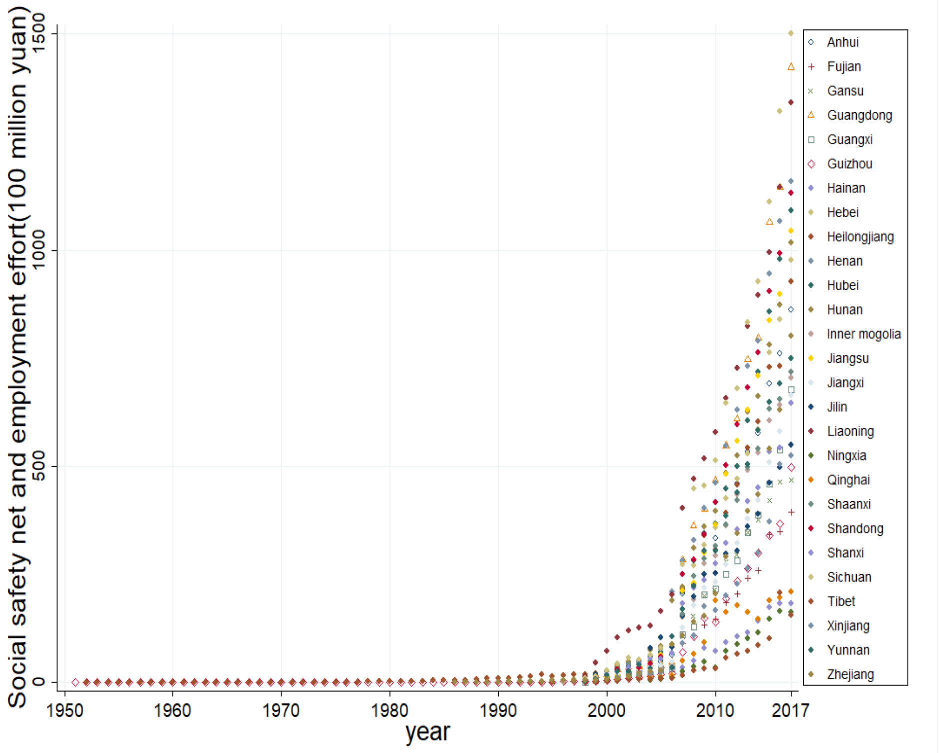


Figure F.29 Local government expenditure-social safety net and employment effort (100 million yuan) by province, 1950-2017

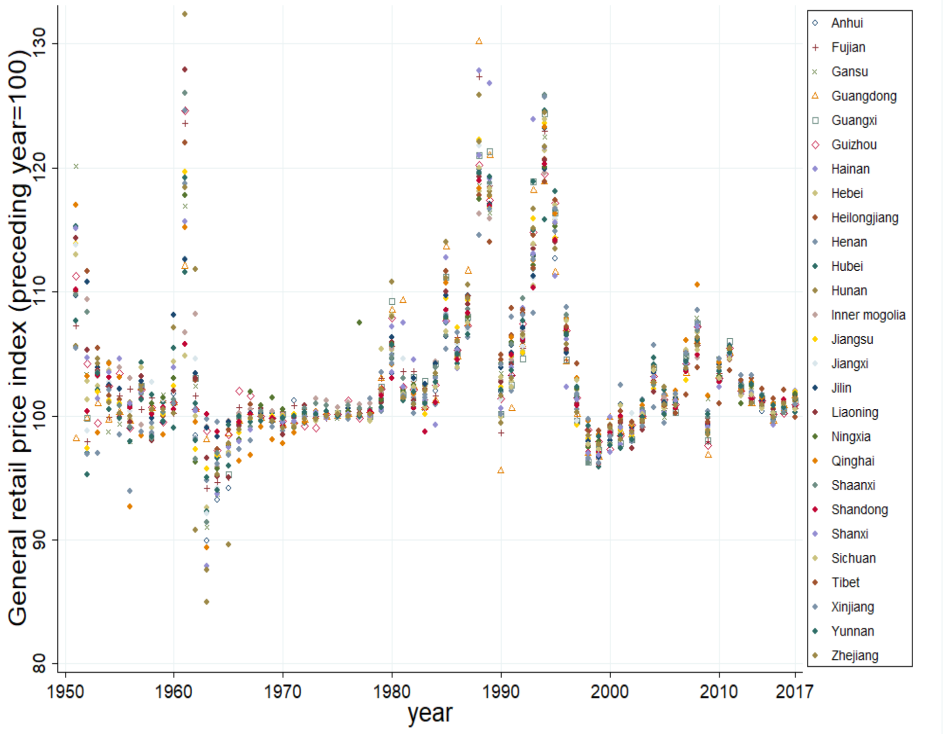


Figure F.30 General retail price index by province, 1950-2017

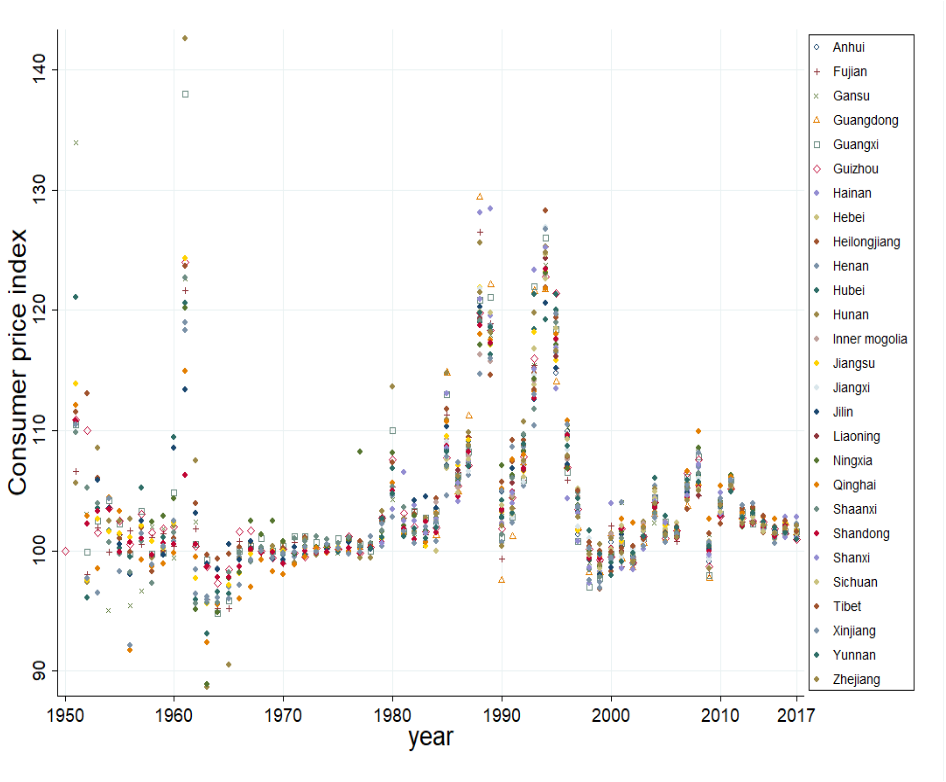


Figure F.31 Consumer price index by province, 1950-2017

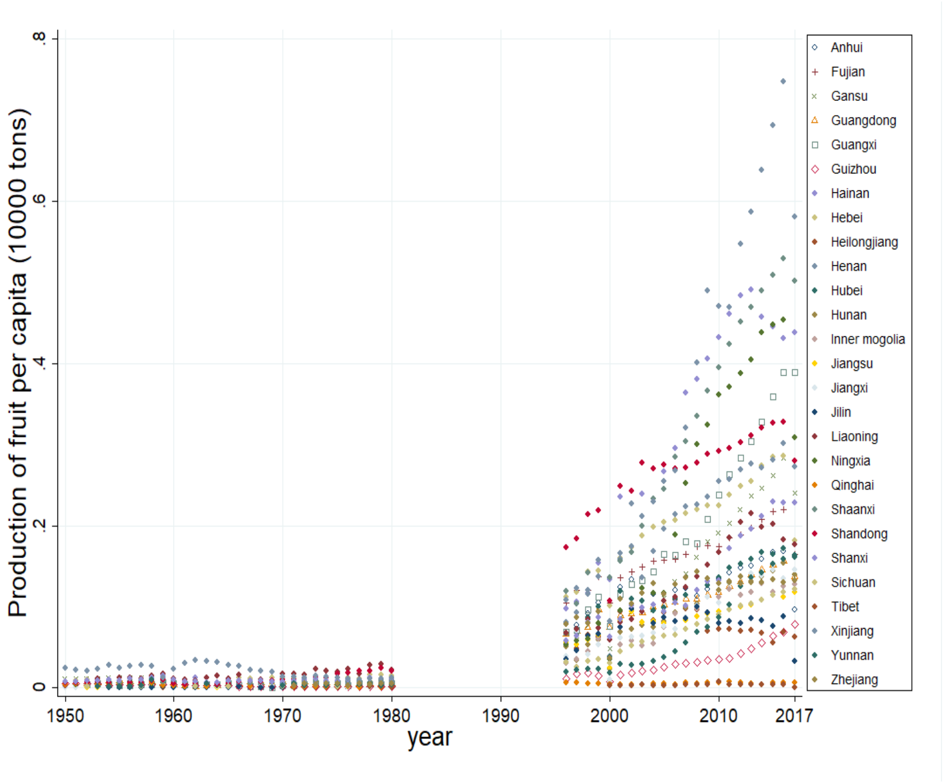


Figure F.32 Production of fruit per capita (10,000 tons) by province, 1950-2017

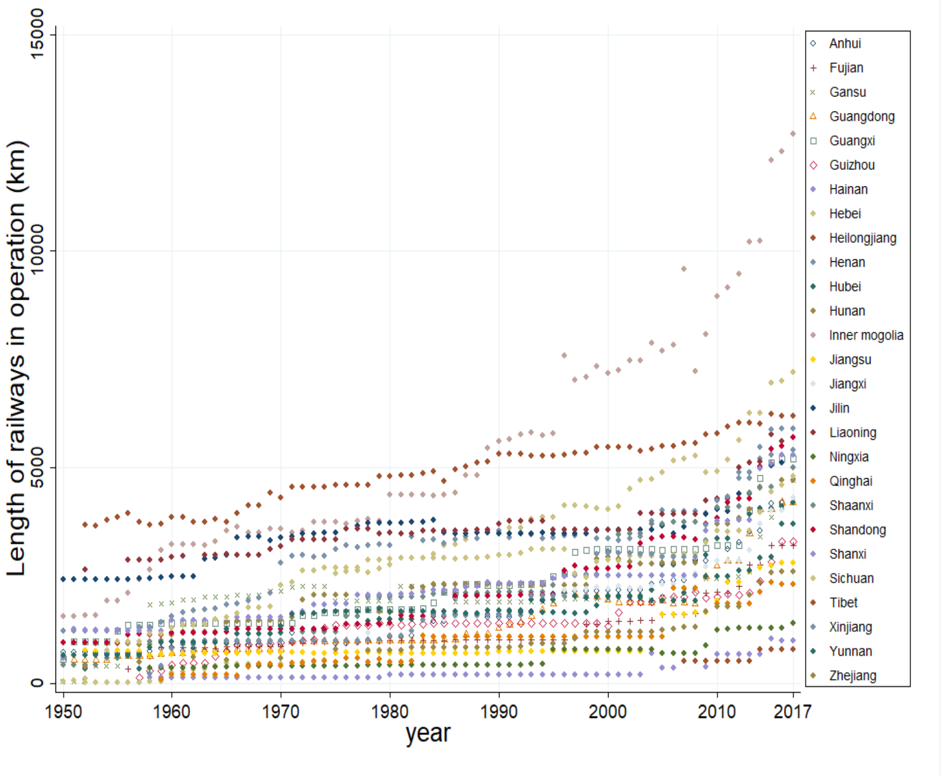


Figure F.33 Length of railways in operation(km) by province, 1950-2017

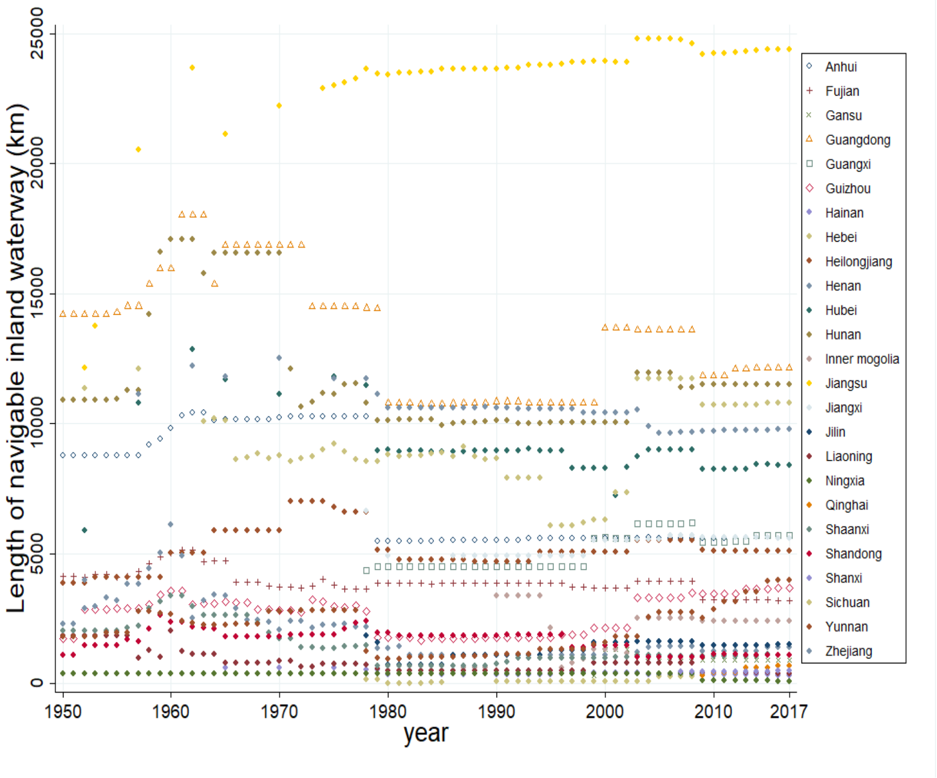


Figure F.34 Length of navigable inland waterway(km) by province, 1950-2017

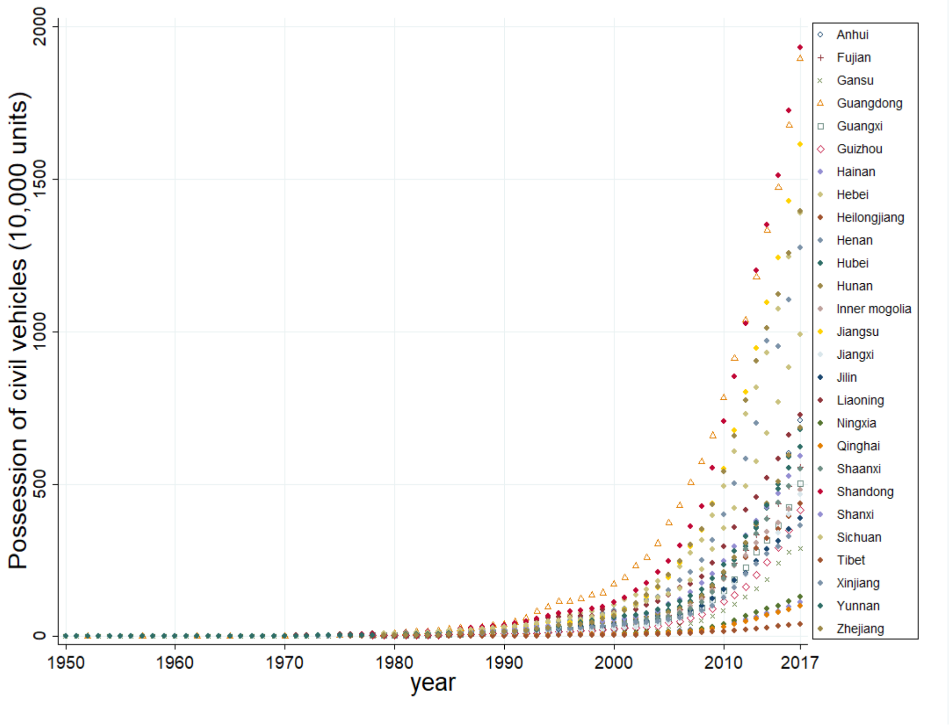


Figure F.35 Possession of civil vehicles (10,000 units) by province, 1950-2017

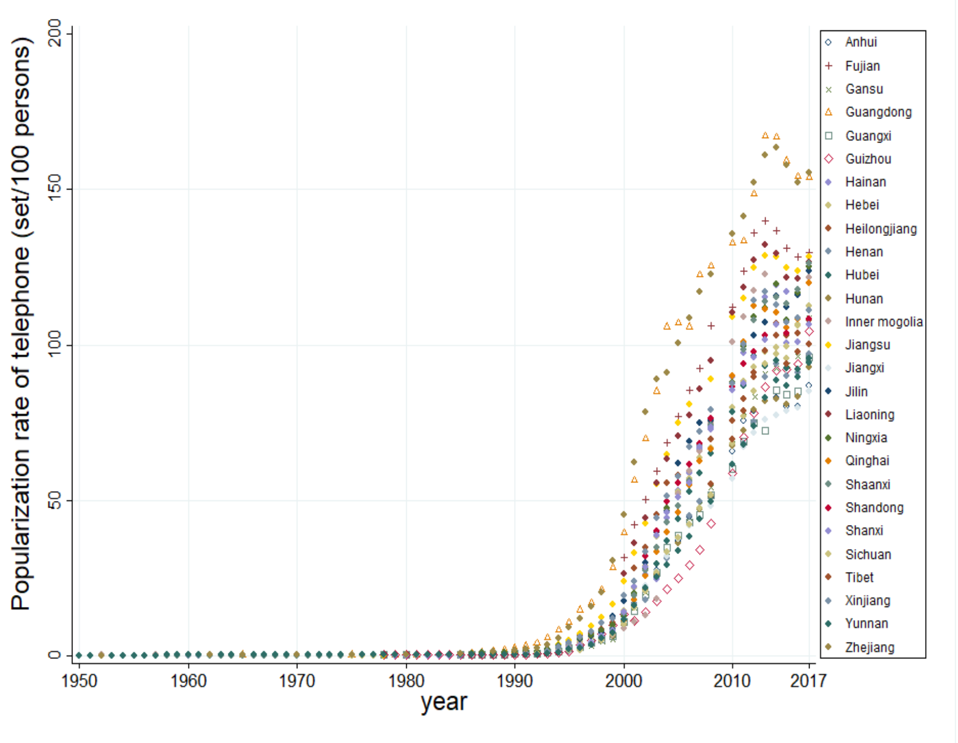


Figure F.36 Ownership of telephone (including mobile telephone) (set/100 persons) by province, 1950-2017

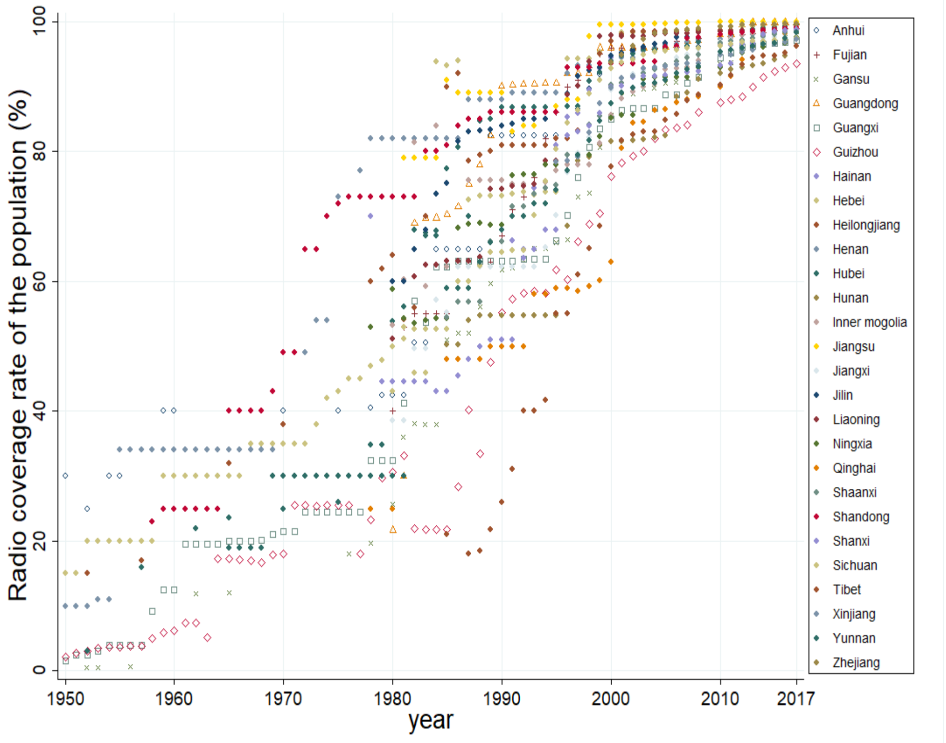


Figure F.37 Radio coverage rate of the population (%) by province, 1950-2017

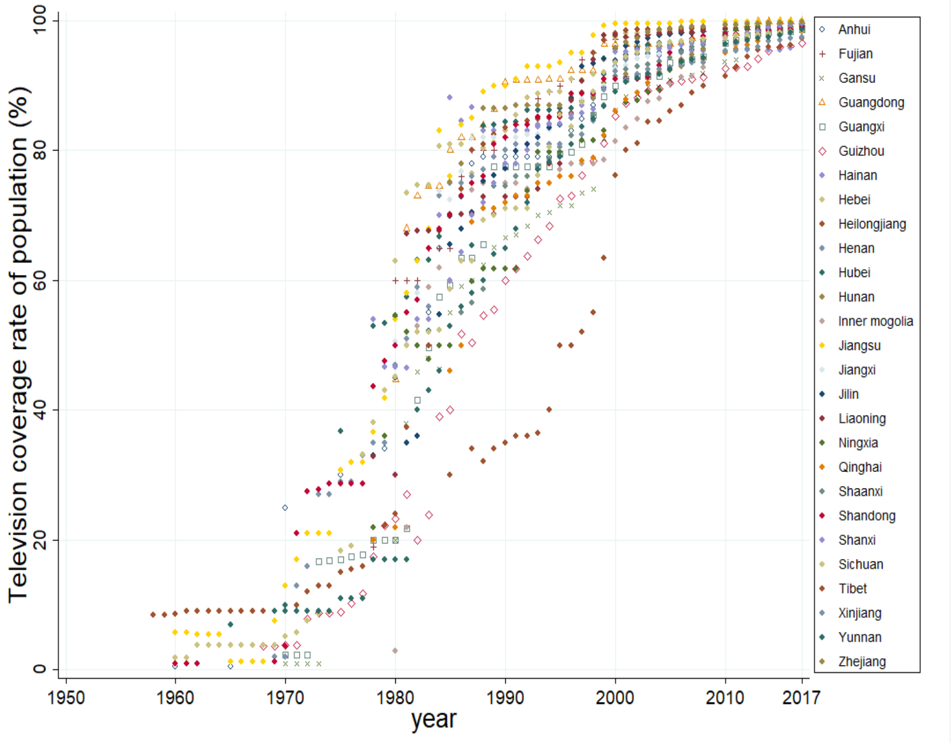


Figure F.38 Television coverage rate of the population (%) by province, 1950-2017

Appendix G. Additional results

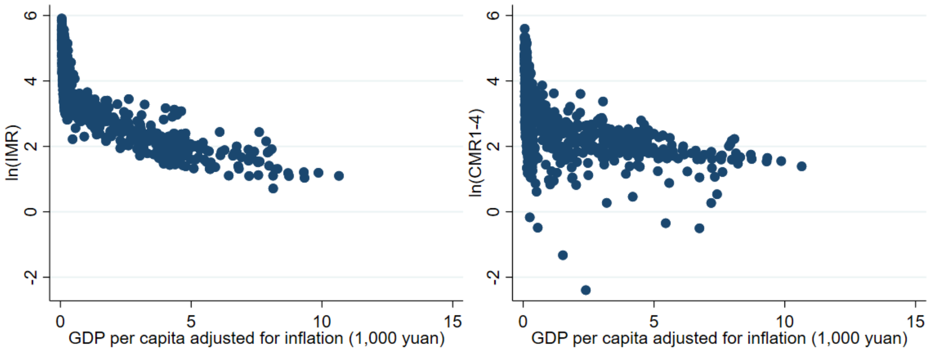


Figure G.1 Scatter plots between GDP per capita adjusted for inflation and the ln(IMR) and the ln(CMR1-4), 1950-2016

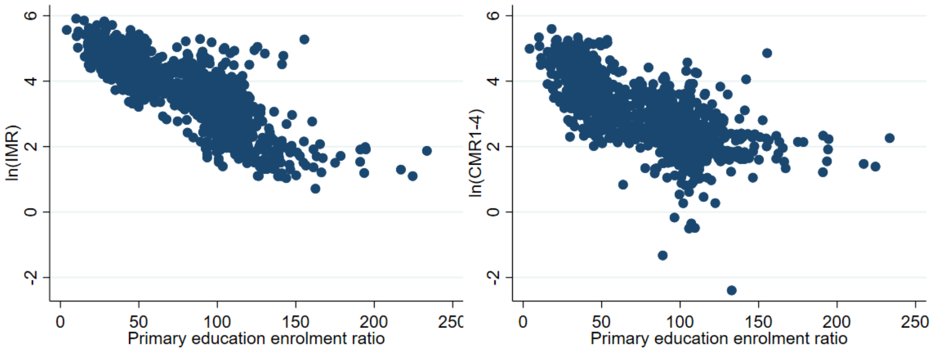


Figure G.2 Scatter plots between primary education enrolment ratio and the ln(IMR) and the ln(CMR1-4), 1950-2016

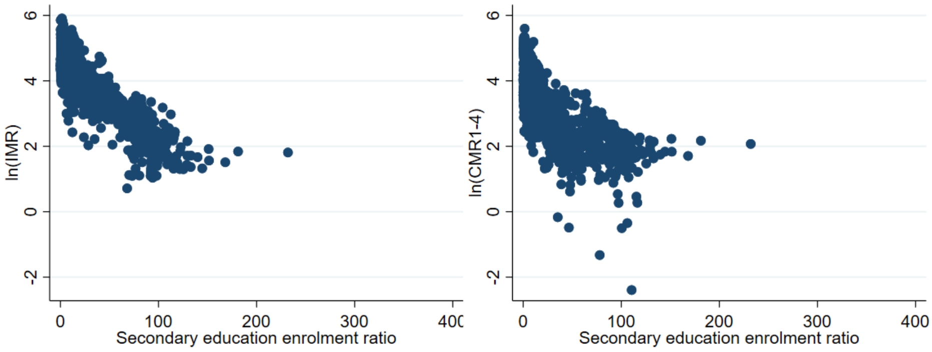


Figure G.3 Scatter plots between secondary education enrolment ratio and the ln(IMR) and the ln(CMR1-4), 1950-2016

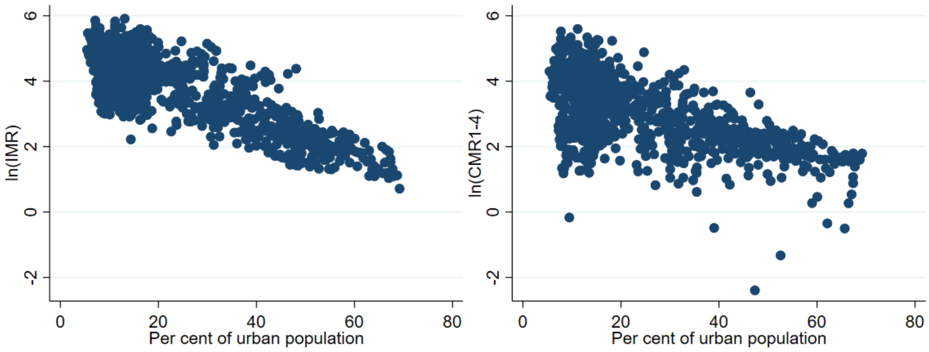


Figure G.4 Scatter plots between the per cent of urban population and the ln(IMR) and the ln(CMR1-4), 1950-2016

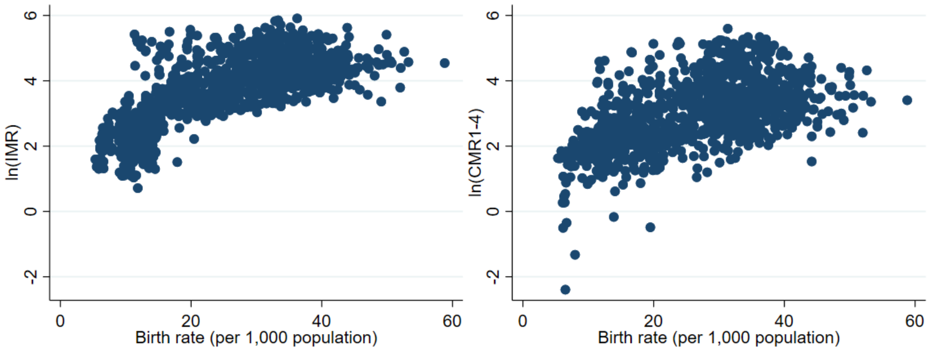


Figure G.5 Scatter plots between birth rate and the ln(IMR) and the ln(CMR1-4), 1950-2016

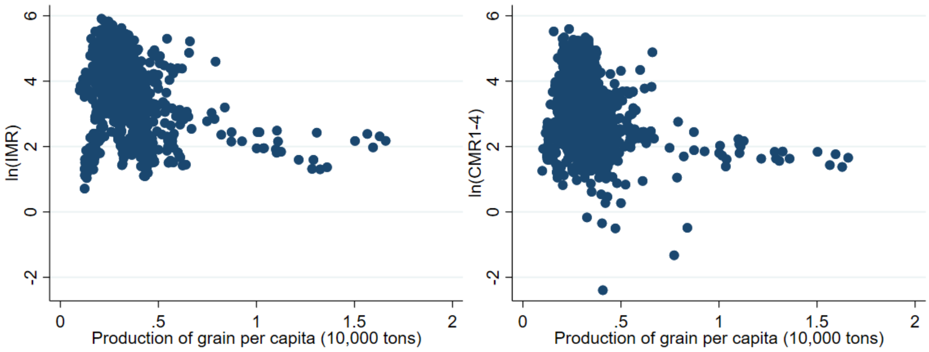


Figure G.6 Scatter plots between the production of grain per capita and the ln(IMR) and the ln(CMR1-4), 1950-2016

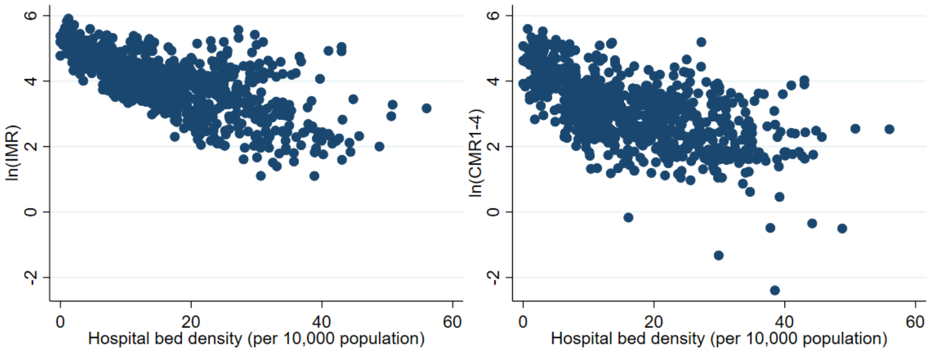


Figure G.7 Scatter plots between the hospital bed density and the ln(IMR) and the ln(CMR1-4), 1950-2016

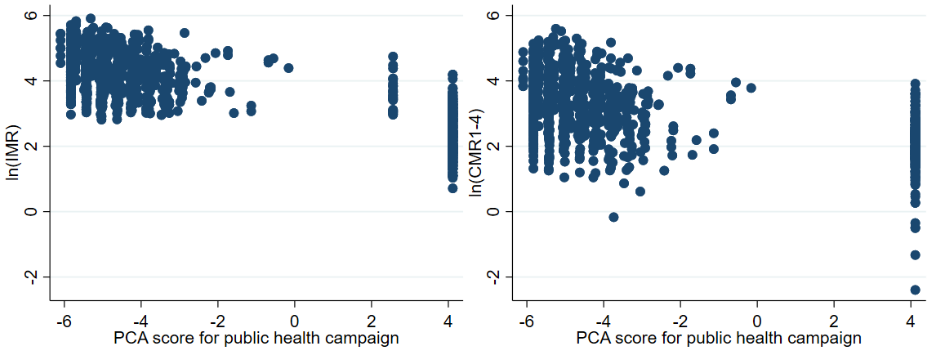


Figure G.8 Scatter plots between the PCA score for public health campaign and the ln(IMR) and the ln(CMR1-4), 1950-2016

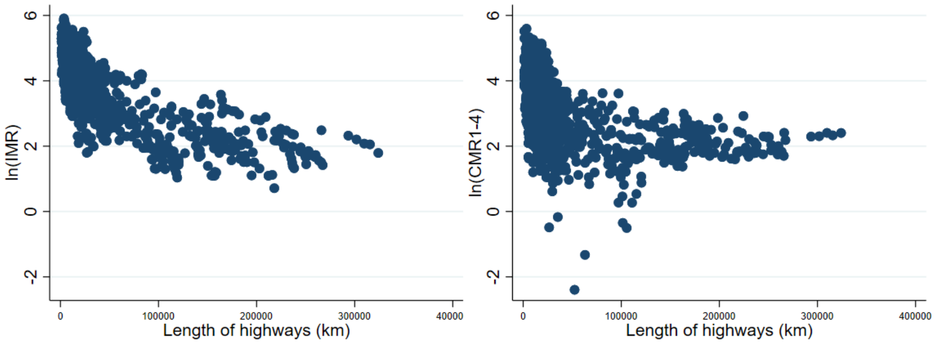


Figure G.9 Scatter plots between the length of highways and the ln(IMR) and the ln(CMR1-4), 1950-2016

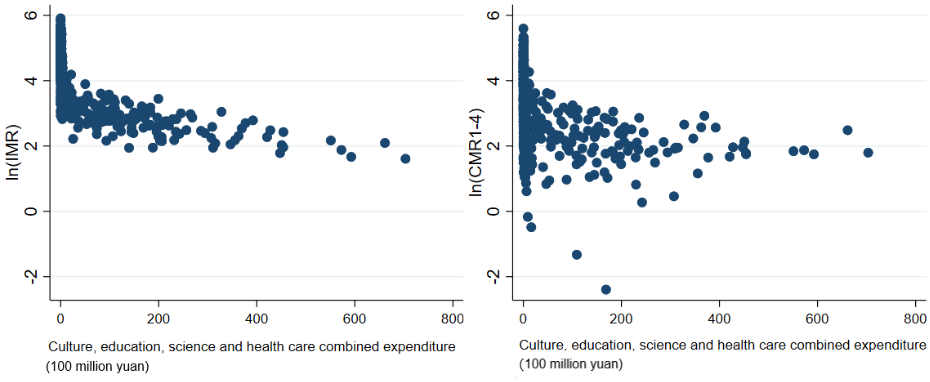


Figure G.10 Scatter plots between the culture, education, science and health care combined expenditure and the ln(IMR) and the ln(CMR1-4), 1950-2016

Table G.1: Relative risks of the IMR/CMR1-4 from multivariable analysis, further adjusting for region

	IMR (N=781, 70.9% missing)	CMR1-4 (N=778, 29.1% missing)
Doctor density (per 10,000 population)		
(1950-1964)	0.93 (0.0.91, 0.94)***	0.91 (0.88, 0.93)***
(1965-1980)	1.03 (0.99, 1.07)	1.01 (0.96, 1.06)
(2000-2016)	1.01 (0.98, 1.03)	0.98 (0.94, 1.02)
Period		
(1950-1964)	1 (ref)	1 (ref)
(1965-1980)	0.33 (0.24, 0.45)***	0.24 (0.16, 0.36)***
(2000-2016)	0.12 (0.06, 0.25)***	0.22 (0.06, 0.89)*
GDP per capita adjusted for inflation (1,000 yuan)		
(1950-1964)	0.99 (0.29, 3.48)	0.72 (0.10, 4.97)
(1965-1980)	0.08 (0.02, 0.30)***	0.12 (0.02, 0.66)*
(2000-2016)	0.86 (0.80, 0.92)***	1.06 (0.96, 1.16)
Primary education enrolment ratio	0.99 (0.99, 0.99)*	0.99 (0.99, 1.00)
Secondary education enrolment ratio	0.99 (0.98, 0.99)**	0.99 (0.98, 0.99)***
PCA score for public health campaign	1.03 (0.97, 1.09)	0.99 (0.88, 1.12)
Birth rate (per 1,000 population)	0.99 (0.99, 1.00)	1.00 (0.99, 1.01)
Production of grain per capita (10,000 tons)	0.93 (0.63, 1.37)	0.97 (0.64, 1.47)
Hospital bed density (per 10,000 population)	1.00 (0.99, 1.02)	0.99 (0.98, 1.01)
Length of highways (km)	0.99 (0.99, 1.00)	1.00 (1.00, 1.00)
Region		
East	1 (ref)	1 (ref)
Central	1.20 (1.02, 1.44)*	1.59 (1.18, 2.14)**
West	1.39 (1.15, 1.68)**	1.97 (1.53, 2.55)***

Notes: GDP per capita and government expenditure have been adjusted for inflation, i.e. GDP per capita has been divided by the inflation rate.

*p<0.05, **p<0.01, ***p<0.001.

Table G.2: Relative risks of the U5MR from multivariable analysis

	U5MR (N=1180, 25.9% missing)	U5MR (N=1180, 25.9% missing)
Doctor density (per 10,000 population)		
(1950-1964)	0.90 (0.88, 0.92)***	0.92 (0.91, 0.94)***
(1965-1980)	1.05 (1.02, 1.09)**	1.02 (0.98, 1.06)
(1990-1999)	1.00 (0.97, 1.03)	0.99 (0.96, 1.02)
(2000-2017)	1.01 (0.99, 1.04)	1.00 (0.98, 1.02)
Period		
(1950-1964)	1 (ref)	1 (ref)
(1965-1980)	0.23 (0.16, 0.32)***	0.30 (0.22, 0.40)***
(1990-1999)	0.33 (0.13, 0.82)*	0.24 (0.10, 0.56)**
(2000-2017)	0.18 (0.07, 0.44)***	0.13 (0.06, 0.30)***
GDP per capita adjusted for inflation (1,000 yuan)		
(1950-1964)	1.88 (0.47, 7.45)	0.78 (0.19, 3.26)
(1965-1980)	0.07 (0.01, 0.33)**	0.13 (0.05, 0.40)***
(1990-1999)	0.46 (0.37, 0.57)***	0.65 (0.56, 0.77)***
(2000-2017)	0.84 (0.78, 0.90)***	0.90 (0.85, 0.95)***
Primary education enrolment ratio	0.99 (0.99, 1.00)	0.99 (0.99, 1.00)
Secondary education enrolment ratio	0.99 (0.98, 0.99)***	0.99 (0.99, 0.99)**
PCA score for public health campaign	0.98 (0.91, 1.06)	1.02 (0.95, 1.10)
Birth rate (per 1,000 population)	1.01 (1.00, 1.02)*	1.00 (0.99, 1.01)
Production of grain per capita (10,000 tons)	0.87 (0.58, 1.30)	0.84 (0.64, 1.10)
Hospital bed density (per 10,000 population)	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)
Length of highways (km)	1.00 (0.99, 1.00)	0.99 (0.99, 1.00)
Region		
East		1 (ref)
Central		1.28 (1.09, 1.51)**
West		1.62 (1.36, 1.93)***

Notes: GDP per capita and government expenditure have been adjusted for inflation, i.e. GDP per capita has been divided by the inflation rate.

*p<0.05, **p<0.01, ***p<0.001.