Advances in Applied General Equilibrium Modeling

Xiujian Peng *Editor*

CHINAGEM—A Dynamic General Equilibrium Model of China: Theory, Data and Applications

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Acknowledgments

I first knew computable general equilibrium (CGE) modelling when I was in my second year of Ph.D. study at Monash University in 2003. At that time, I was struggling to find a suitable topic for my Ph.D. thesis. Despite knowing the area of my interest, I had yet to find a suitable approach. It wasn't until a fellow Ph.D. candidate introduced me to CGE modelling that I finally found what I was looking for. After reading a brief introduction of CGE model, I knew it was the ideal methodology for my research. Thanks to CGE modelling, I was able to analyze and gain insight into China's population dynamics and policy options, which were my primary interests.

I was thrilled to discover that Centre of Policy Studies (CoPS) at Monash University, the creator of the renowned CGE models such as ORANI, MONASH and TERM was just two floors above my office in the Menzies building. As luck would have it, I was able to secure the final spot for that year's CGE training course offered by CoPS. My luck continued when I was assigned Prof. Peter Dixon, the primary creator of the ORANI, MOANSH and USAGE models, as my main supervisor. At the time, I didn't fully appreciate just how fortunate I was. Dr. Yinhua Mai (my co-author of Chapters 3–4 and 9), as my secondary supervisor, primarily guided me during the early stages of my CGE study. However, as my thesis progressed to the core modelling parts, Prof. Dixon became increasingly involved. What stands out most in my memory is how Prof. Dixon used his Christmas holiday to read my thesis. After completing one chapter, he invited me to his home where he patiently and thoroughly explained how I could revise and improve that chapter. Using this approach, my thesis was fully revised and ready for submission by the end of the holiday. Thanks to his generous support, my thesis was awarded the prestigious Mollie Holman Award for the best thesis of the year. Professor Dixon's wisdom, patience, encouragement and foresight have left a lasting impression on me and have had a significant impact on my career development since graduating.

After only two years of CGE study, I graduated and left CoPS, but I quickly realized that I had only scratched the surface of this complex field. I still lacked the ability to use CGE to complete research projects independently, and I yearned to continue my education at CoPS. The opportunity arose after I worked for two years at the University of Adelaide. Yinhua was awarded a China-Australia Governor

Program funded by AusAID, which required the development of a new CGE model for China, the expansion of CGE capabilities for the Chinese government, and the analysis of labour market reform issues using the newly developed China model. I was fortunate enough to be offered a position at CoPS to assist Yinhua with this project. From that moment on, I was able to continue my CGE modelling study with Prof. Dixon, Yinhua and other scholars at CoPS.

After joining the China-Australia Governor Program, I have had the opportunity to travel to China almost every year to deliver CGE training courses. At the time, we mainly used two training materials for the dynamic CGE course. The first was a set of PowerPoint slides designed by Prof. Dixon, which were originally used for the MONASH model, the first dynamic model he created for the Australia economy. The second was the MONASH model book, co-authored by Profs. Dixon and Rimmer. This book became a frequently used reference for me. It was well-written, providing clear instructions on the CGE model and its dynamic mechanism, as well as detailed explanations of different modelling modes, and how to interpret modelling results using the BOTE model. Using the Australian motor vehicle industry as an example, the book is an invaluable tool for understanding CGE modelling from both a theoretical and a practical perspective.

As I gained more knowledge about CGE models, taught more in China and engaged in more research projects, I gradually realized that there was a need for a specific CGE modelling book on China. While the fundamental theory of dynamic CGE modelling remains the same, a book that describes the China model in detail, with its unique economic features, would be more insightful and beneficial for scholars and graduate students interested in both CGE modelling and China-related issues. Moreover, I observed that during CGE training courses in China, after completing all the lectures on model theory, hands-on practice of running the model, and understanding simulation results, a case study lecture demonstrating the application of the CHINAGEM model to simulate a specific policy issue is always highly attractive and useful. This realization prompted the formation of a framework for a China model book in my mind. The book should include not only the standard parts of model structure, theory and simulation but also case studies that showcase the model's applications.

Furthermore, based on my over ten years of experience in modelling training in China, I have learned that for the standard parts of model structure, theory and simulation, it must include two components: (1) a detailed, step-by-step instruction for closure development, and (2) a thorough, step-by-step guide on how to interpret simulation results. These are particularly useful for the model learners. For the application part, each case study must incorporate a model extension or modification based on the standard CHINAGEM model, showcasing the versatility and robustness of CHINAGEM in analysing practical economic and policy issues. Fortunately, my colleagues and I have completed a wealth of China-based work over the last 15 years, providing ample resources for the case study portion.

From the time I had the idea of writing a China CGE model book to when I finally submitted the manuscript to my editors at Springer, I received many suggestions and tremendous support from my colleagues, working partners in China, and friends. I would like to express my sincere gratitude to them. Particularly, I would like to thank Prof. Dixon, who carefully read each chapter of the first part of the book and provided detailed suggestions, as he did for my Ph.D. thesis. He even contributed one chapter to the book to show his generous support. I also want to thank Prof. Philip Adams, who not only co-authored several chapters with me but also provided extensive feedback on other chapters and offered encouragement during the COVID-19 lockdown. I am grateful to Prof. James Giesecke for giving me ample time to focus on the book and for co-authoring one chapter with me and my colleague, Prof. Glyn Wittwer. I would also like to thank my former colleague and friend, Dr. Yinhua Mai, for her valuable suggestions and encouragement. Dr. Jingliang (Charles) Xiao, who is working in Canada, deserves a special mention for immediately agreeing to contribute a chapter for the application part and delivering it on time. I would like to thank all the other authors in this book for their generous support as well.

I am grateful to my editors, Lucie Bartonek and Banu Dhayalan, for their patience, suggestions and guidance throughout the book's writing process.

Finally, I want to express my heartfelt thanks to my family: my daughter, who took on some family responsibilities, my son, who showed understanding despite not having much time with me, and my husband, whose unwavering support and understanding made this book possible.

Lastly, I would like to thank the readers who choose this book. I hope this book will be of some help to your study and research.

Melbourne, Australia
May 2023

Xiujian Peng

Contents

Part I
About the Computable General Equilibrium Modelling

This part includes an explanation of CGE model, a brief overview of the history of CGE model, its contribution to policy formation and the introduction to this book.

Chapter 1
Computable General Equilibrium Modelling: History, Contribution and What You Can Learn from This Book

Peter B. Dixon

Abstract This chapter defines CGE modelling by explaining the meaning of the "C", the "G" and the "E". It then identifies Leif Johansen's model of Norway, published in 1960, as the first CGE model, and outlines the subsequent evolution of the field. Since Johansen's time, CGE models have become dynamic, multi-regional and multi-national. As illustrated in CHINAGEM, there has been an enormous increase in the quantity of policy-relevant detail embraced by CGE models. This has enabled them to become the go-to tool for policy analysis in trade, micro-economic reform, environment, labour and many other areas. People new to CGE modelling sometimes ask what it offers beyond I–O (input–output modelling). The chapter answers that question. Finally, the chapter provides a list of what readers can expect to learn from the rest of the book.

Keywords CGE history · CGE definition · CGE model for China · CGE for policy · CGE versus I-O

This is right book to study if you are interested in computable general equilibrium (CGE) modelling for China. The book describes the theory and data requirements of a CGE model together with CGE analyses of issues of importance for the Chinese economy.

This chapter explains what a CGE model is and provides some historical context.

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1.1 What is a CGE Model?

The defining characteristics of CGE models are:

(a) They are **C**omputable. This means that they implemented with real-world data to derive numerical answers to questions about where the economy is going, and how the economy would react to changes in policy variables and other shocks such as natural disasters, pandemics and armed conflicts.

(b) They are **G**eneral. This means that they explicitly identify the behaviour of multiple actors or agents. These include households, industries, capital creators (investors), exporters, importers and governments. Typical behavioural specifications for these actors involve solutions of optimization problems. Households choose their consumption vector (bundle of consumption commodities) to maximize their utility subject to their budget constraint. Industries choose their input vectors to minimize the cost of satisfying demands for their products. Capital creators choose to finance investments in different industries according to their expectations of rates of return. Exporters and importers are guided by prices on domestic markets relative to prices on international markets. Governments are constrained in their expenditure decisions by their ability to raise taxes.

(c) They rely on **E**quilibrium assumptions. Optimizing behaviour by the agents generates demands for and supplies of commodities and factors of production (labour, capital and land). For example, the household specification may generate demands for commodities and supplies of labour. The industry specifications will generate demands for factors of production and commodities to be used as intermediate inputs. In a CGE model, demands and supplies are reconciled through price movements. The price movements needn't be instantaneous and gaps between demand and supply can persist for some time. This is particularly important in labour markets. CGE models can incorporate sticky wage adjustments which can leave workers unemployed. Nevertheless, equilibrium or market-clearing assumptions are fundamental in CGE models.

The first CGE model was created by Leif Johansen for Norway (Johansen 1960). The model was implemented with Norwegian input-output and national accounts data. Computations were performed to calculate the effects on the economy of changes in: technologies; demands for exports; demands by government; and the availability of factors of production. The model specified cost-minimizing behaviour by industries and utility-maximizing behaviour by households. Demands and supplies were brought into line by endogenously determined movements in the prices of commodities and factors of production.

Johansen's model was for a single country (Norway). It contained just 22 industries, one type of labour, one type of capital that could be shifted across industries and one type of land which was used in a single agricultural industry. The model was solved for one time period.

Since 1960, single-country CGE models have been built for most countries. They now encompass enormous amounts of detail. The model for China, CHINAGEM, described in this book has around 150 industries and can be extended to generate results for about 31 regions. Other CGE models have focused on labour markets and demands for different skills. A recent example for the U.S. distinguishes 233 occupations (Dixon and Rimmer 2022). Inclusion of environmental variables is now commonplace in CGE models (see for example Jorgenson et al. 2013; Adams and Parmenter 2013). Modern CGE models, including CHINAGEM, are normally multi-period (dynamic) with capital accumulation processes recognized for each industry.

Since the 1990s, multi-country CGE modelling has become prominent. The best known and most widely used multi-country CGE model is supplied by the Global Trade Analysis Project (GTAP) at Purdue University. The GTAP model is supported by a database covering 65 industries in about 140 countries. The GTAP network contains about 20,000 CGE practitioners in over 100 countries. Almost every trade agreement is analysed through GTAP simulations.[1]

CGE modelling has become popular in policy circles because of its ability to generate comprehensive, understandable results for an enormous range of questions. The issues to which CGE modelling has been applied include:

the effects on

macro, welfare, industry, regional, labour-market, distributional and environmental variables

of

taxes, public consumption and social security payments; tariffs and other interferences in international trade; environmental policies; pandemics, natural disasters and terrorism events; technological change; international commodity prices; interest rates; wage setting arrangements and union behaviour; mineral discoveries (the Dutch disease); immigration; micro-economic reform; and major projects.

CGE models are also used for historical analysis and baseline forecasting.

1.2 CGE Versus Input–output

As you will see in this book, input-output tables are the central data input around which CGE models are built. The first input-output table was created by Leontief (1936, 1941). It referred to the United States economy of 1919. The table showed purchases for that year of 41 commodities (intermediate inputs) by 41 producing industries and by final users (households, government, capital creators and foreigners). It also showed payments by industries to labour and to the owners of capital. Nowadays, highly detailed input-output tables are provided by statistical agencies in most countries. For example, China's National Bureau of Statistics published an input-output table for 2017 that identifies149 industries.

Leontief used his input-output table to create the first input-output model. An input-output model answers the question: how much does each industry need to

[1] The original GTAP model was described by Hertel (1997). Recent documentation is in Corong et al. (2017) and Aguiar et al. (2019).

produce to supply final users with a given vector of commodities (goods and services). In its simplest form, an input-output model can be written as:

$$X = A * X + Y \tag{1.1}$$

where

X is the vector of industry (or commodity) outputs;

Y is the vector of final demands for commodities; and

A is the matrix of input-output coefficients. The i, jth component of A is estimated from the input-output table. It is the amount of commodity i required to produce a unit of output of commodity j (e.g. wheat per unit of bread).

Leontief computed the output vector X needed to supply the final demand vector Y by solving Eq. (1.1):

$$X = B * Y \tag{1.2}$$

where

$$B = (I - A)^{-1} \tag{1.3}$$

Over the past 85 years, input-output practitioners have used Eq. (1.2) and variants to make projections relevant to many policy issues. For example, military strategists have used input-output calculations to estimate quantities of coal, iron ore, steel, and transport services required to support the delivery of given numbers of tanks and other armaments to the army. The i, jth component of the B matrix, known as Leontief's inverse, is the amount of commodity i required to deliver a unit of j to final users. B(i, j) is generally greater than A(i, j) because B(i, j) takes into account not only the amount of i used directly to produce a unit of commodity j but also the amount of commodity i used in producing all the other inputs required in the production of commodity j.

The input-output model has been extended in numerous ways. By adding coefficients showing labour and capital requirements in each industry, the model can be used to calculate the amounts of labour and capital required to supply a given Y vector. Similarly, by adding coefficients showing CO_2 emissions per unit of output in each industry, the quantity of CO_2 emissions associated with each component of final demand can be calculated.

The input-output model reflects conditions that applied in the 1930s when Leontief invented it. During that period the U.S. and many other countries were in recession, suffering extremely high rates of unemployment and excess capital capacity. In these circumstances, the main focus of economic policy was on increasing final demands, i.e. increasing components of the Y vector. Capital and labour constraints were largely irrelevant, meaning that an increase in Y could be translated into an increase in X as in Eq. (1.2) without worrying about bottlenecks caused by a scarcity of resources.

When Johansen was working on the first CGE model in the late 1950s, economies were booming, with high levels of employment and capacity utilization. Inflation was a major policy preoccupation. Reflecting this, Johansen included resource constraints in his model and emphasized price responses to demand stimulation.

The introduction of resource constraints and optimizing behaviour by different agents made Johansen's model a powerful framework for analysing issues of his time in which price-responsive behaviour was important. CGE models have largely replaced input-output models. They can do everything that is possible with an input-output model, and much more.

While the input-output model should now be confined to an honoured place in the history of economic thought, Leontief's other great invention, the input-output table, remains of central contemporary importance. Understanding the accounting conventions underlying input-output tables and how to use the tables are critical tasks for anybody who is setting up a CGE model.

1.3 About This Book

This book will teach you about the CHINAGEM model which has been developed over the past 20 year and applied to elucidate a large number of issues for numerous organizations concerned with economic policy in China. It will also introduce you to key strategies in CGE modelling.

The book is particularly strong on closure strategies. This refers to the division of variables between those whose values are determined by the model (endogenous variables) and those whose values are given to the model (exogenous variables). As you will see from the book, by varying the closure a CGE modeller can: estimate historical trends in consumer preferences and technologies (historical closure); explain past economic developments in terms of driving factors such as changes in technologies (decomposition closure); produce a baseline or business-as-usual forecast that incorporates historical trends (forecast closure); and generate deviations around the baseline caused by policy or other shocks to the economy (policy closure).

Another strategy that you will find in the book is the application of back-of-the-envelope (BOTE) explanations. CGE models such as CHINAGEM contain many thousands of equations and produce results for many thousands of variables. In theory, each result depends on the specification of every equation. So how can CGE modellers explain their results and decide which results are realistic and which results are simply the outcome of assumptions and data points of doubtful validity? Over many years, CGE modellers have discovered that the main results in any simulation can almost always be explained in terms of a small subset of the model's assumptions and data points. The relevant assumptions and data points vary from result to result and simulation to simulation. It requires skill and experience to isolate the particular assumptions and data points in a simulation that explain particular results. The explanatory process is undertaken with BOTE models. These are very small models of the CGE model. Good BOTE models explain not only the qualitative features of results but can also do a convincing job of explaining quantitative features. By mastering BOTE techniques, a CGE modeller can refute the black-box criticism. A BOTE model opens the black box and shows what's in it.

Creation of a valuable policy-relevant CGE model such as CHINAGEM relies on a cumulative strategy. The model does not come into existence at a given point of time and then stay as a fixed object. With almost every application the model evolves. Features are added. Improvements are made and data inputs are updated and sometimes corrected. The application chapters in this book are examples of this process. They show how the core CHINAGEM model has been enhanced by additional equations and datasets to facilitate applications concerned with: labour-market reforms, population ageing and the pension system; finance; water pricing; CO_2 policy; and regions.

The cumulative strategy requires good documentation and the ability to pass the model between researchers. For CHINAGEM this has been achieved by the use of GEMPACK software. This software is purpose-built for CGE analysis and has been developed since the 1980s by a team of software specialists working alongside the CGE modellers at the Centre of Policy Studies.[2] GEMPACK is a highly efficient platform for computing solutions for very large CGE models. Equally important, GEMPACK is an ideal platform for manipulating CGE data inputs, analysing results and transferring models between researchers.

1.4 Concluding Remarks

In reading any technical book, it is always helpful to have a list of what you can expect to learn. You can use this list to check your progress as you work through the book. Items on your list for this book might include being able to understand and discuss the following:

- the essential ingredients of a CGE model and how a CGE model differs from an input–output model;
- the directions in which CGE modelling has developed since its inception with the work of Johansen (1960);
- the range of CGE applications and how these applications depend on the price-sensitive, economy-wide features of CGE models;
- input–output data and how it is organized for use in a CGE model;
- the role of BOTE modelling in explaining CGE results;
- GEMPACK software and what it can do;
- the multi-step solution method used in GEMPACK;
- the concept of closure in CGE modelling;
- the setup of different closures and their purpose including short and long-run comparative static closures, historical and decomposition closures, and forecast and policy closures;

[2] The initial version of GEMPACK was created by Ken Pearson. Since then it has been continuously developed, see Codsi and Pearson (1988), Harrison and Pearson (1996) and Horridge et al. (2013).

- the relaxation in CGE modelling of market-clearing assumptions to allow for short-run unemployment (sticky-wage adjustment) and excess capital capacity;
- the importance of having a realistic baseline even if the focus is perturbation or policy analysis;
- the cumulative nature of CGE model building and application and the necessity of having software that facilitates the transferability of models;
- what CGE analysis indicates about a variety of issues for China such as the cost and feasibility of meeting announced CO_2 targets the economic implications of labour market reform; the extent to which raising the retirement age can mitigate the negative effects of fast population ageing on the pension system and the national economy; the effectiveness of the different monetary-fiscal regimes under the framework of financial CGE model, and the economic implications of water price reform.
- the top-down approach to decompose the national results into the regions.

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Part II
CHINAGEM Model and Its Simulation Modes

This part provides an overview of the CHINAGEM model including its database and equation structure. We also demonstrate how to develop closures to run the four modes of CHINAGEM to produce historical, decomposition, forecast and policy simulations. We aim to provide CHINAGEM users with a comprehensive model explanation, and a practical guide for closure development and simulation results analysis. Chapter "Introduction of the CHINAGEM Model" contains an introduction to CHINAGEM. In Chapter "Structure of the CHINAGEM Database" we introduce the model's database structure. The description of the equation system and its solution method are presented in Chapter "Equations and Solution Method of CHINAGEM". Closure development and simulations are explained in Chapters "Closure Development and Historical Simulation from 2012 to 2019", "Closure Development and Forecast Simulation from 2020 to 2030", "Closure Development and Policy Simulation–The Effects of Increasing Required Rate of Return on Capital" and "Closure Development and Decomposition Simulation from 2012 to 2019". Specifically, in Chapter "Closure Development and Historical Simulation from 2012 to 2019", we demonstrate how to develop a closure for historical simulation and how to incorporate observed data to develop the historical part of the baseline simulation from 2012 to 2019. In Chapter "Closure Development and Forecast Simulation from 2020 to 2030", we show how to use information derived from the historical simulation to develop the forecast part of the baseline. In Chapter "Closure Development and Policy Simulation–The Effects of Increasing Required Rate of Return on Capital", we demonstrate with a policy simulation how to use the CHINAGEM model to analyse the effects of a policy change. In Chapter "Closure Development and Decomposition Simulation from 2012 to 2019", we explain the growth of the Chinese economy from 2012–2019 in terms of driving factors such as labour force, technologies and changes in tastes and twists by using decomposition simulation.

Chapter 2
Introduction of the CHINAGEM Model

Xiujian Peng

Abstract This chapter presents an overview of the CHINAGEM model—a MONASH-style dynamic Computable General Equilibrium (CGE) model of the Chinese economy including the basic structure of the model and its simulation modes. This chapter highlights the extensive applications of CHINAGEM in various economic and policy issues related to China. Furthermore, it discusses the recent extensions made to the CHINAGEM model to enhance its modelling capacity. The chapter also offers the essential steps for building CGE analytical capacity via CHINAGEM, providing guidance for those interested in CGE modelling.

Keywords CHINAGEM · CGE · Application · Extension

2.1 Introduction

CHINAGEM is a MONASH-style dynamic Computable General Equilibrium (CGE) model of the Chinese economy. Its core CGE structure is based on ORANI, a static CGE model of the Australian economy (Dixon et al. 1982). Its dynamic mechanism is based on the MONASH model[1] of the Australian economy (Dixon and Rimmer 2002). It is a framework for:

- estimating changes in tastes and technologies and generating up-to-date input–output tables (historical simulations);
- explaining periods of economic history in terms of driving factors such as labour force growth, changes in world commodity prices and changes in tastes and technologies (decomposition simulations);

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[1] The MONASH model is now named as VU-National model.

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- generating forecasts for macroeconomic, industrial, occupational and regional variables using detailed extrapolations of trends in tastes and technologies together with a wide variety of projections from organizations specializing in macro, export, tourism and policy forecasting (forecast simulations); and
- calculating the deviations from explicit forecast paths for macro and micro variables that would be caused by the implementation of policy changes (policy simulations).

CHINAGEM is a large system of equations describing behaviours of economic agents and linkages between sectors of the economy and between China and the rest of the world. The core part of CHINAGEM contains widely accepted economic theories such as consumer and producer optimization behaviour. The core model can be applied with attached modules that capture specific characteristics of the Chinese economy such as rural-urban labour migration, population ageing and pension system, financial arrangements, climate change and carbon neutrality.

CHINAGEM simulations start from a base year for which a detailed input-output table is available, e.g., the year 2012. The input-output table is used to construct a model database that sketches a picture of the Chinese economy for that year. The model database provides an initial solution for the CHINAGEM equation system, which has a quantity and a price variable corresponding to every value in the input-output database. A CHINAGEM simulation moves each of the components of the input-output database, thereby taking us to another picture of the economy.

Typically the number of variables is larger than the number of equations in CHINAGEM. The equation system can be used to solve for changes in endogenous variables—the number of which equals the number of equations—in response to changes in exogenous variables. The classification of endogenous/exogenous variables—which variables are to be solved for by CHINAGEM—is flexible.[2] One variable can be endogenous in one simulation and exogenous in another.

A historical simulation moves each of the observable components of the input-output database for year t to their value in year t + 1, thereby taking us to the picture of the Chinese economy in the year t + 1. When we have arrived at a year where historical data are no longer available, the forecast simulations move the picture of the Chinese economy forward to a future year. The historical and forecast simulations form a baseline scenario (Fig. 2.1). A policy simulation displays the effects of a change in economic policy, e.g. implementing social security reform, as a deviation in economic variables from the baseline scenario (Fig. 2.1).

[2] A specification of endogenous/exogenous variables is called a closure.

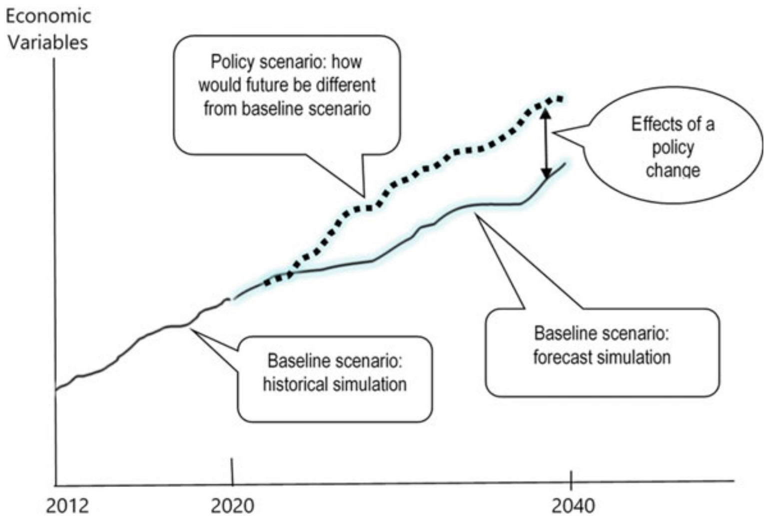

Fig. 2.1 Historical, forecast and policy simulations

2.2 The Application of CHINAGEM

CHINAGEM belongs to the family of the MONASH model (Dixon and Rimmer 2002)—a recursive dynamic CGE model of the Australian economy. The current versions of MONASH distinguish up to 140 industries, 56 regions and 340 occupations. Since the 1990s, the MONASH model has been applied in economic policy analysis on a broad range of issues such as trade reform, tax reform, competition reform, large project appraisals, contributions of various economic sectors to national economic performance, fiscal relationships between federal and regional governments, forecasting greenhouse gas emissions, forecasting regional employment by detailed occupations, population aging and related issues, effects of political events on tourism, employment and wage policies, macroeconomic policies during economic down-turn and so on. In the past three decades, the MONASH model has become a platform for developing dynamic CGE models for other economies. MONASH-style dynamic models are applied in policy analysis in Australia, the U.S.A., Finland, China, Vietnam, Malaysia, Poland, and many other countries.

MONASH-style modelling emphasizes the development of a realistic baseline to support policy analysis. Much modelling effort is devoted to incorporating historical data into the baseline with which policy scenarios compare. The advantage of calculating policy effects as deviations from a realistic baseline is that it brings a growth perspective into the analysis. The following are some examples:

- The Chinese finance and insurance sector has been growing faster than the national real GDP. If the trend continues, liberalisation of investment and services trade in a future year that leads to productivity improvement in the finance and insurance sector would have a bigger impact on the whole economy than would be calculated in a model that did not take account of the underlying trends.

- The realistic baseline allows the analysis to separate global trends and effects of policy. By taking out the effects of policy implemented from a realistic baseline, we separate growth in trade achieved in the presence of the trade barriers from the effects of reducing trade barriers. Growth achieved behind barriers is driven by technological evolution in the global economy. By adding onto a realistic baseline additional policy changes over both historical and forecast periods, we gain insights into how economic policies can help a nation adapt to changes in global economic trends.
- Liberalisation of investment and service trade may create new business opportunities in different parts of the world. In reality, businesses adjust to take advantage of such opportunities. Dynamic modelling based on realistic baselines allows policy changes to be analysed against such a background. For example, rapid productivity improvement in China creates trade and investment opportunities for other countries. Static simulation of such productivity improvement emphasises negative terms of trade impacts on neighbouring countries; however, dynamic simulation also shows positive factors on neighbouring countries due to businesses taking advantage of new opportunities in China (Mai et al. 2009). Such changes are picked up in the realistic baseline as increased trade and investment linkages between China and its neighbouring countries.
- China's energy structure has been changing towards a greener structure with more renewable energy being used in the economy. Energy efficiency is also improving in the economy. These trends will accelerate in the future given the global movement toward carbon neutrality. Building these trends into the baseline helps policy simulations. For example, when investigating the economic impacts of China's carbon neutrality in 2060 in the policy simulation, the realistic baseline that accounts for the building of energy structure changes and energy efficiency improvements helps generate more reliable predictions of changes in the carbon price, resulting in more reliable macro results such as the changes in real GDP, employment, investment and international trade.

The first version of the CHINAGEM model with the 2002 database was developed at CoPS in 2006. Since then it has been used by many research institutes, government agencies and universities to analyse a wide range of economic and policy issues concerning China.

2.3 The Extension of CHINAGEM

As the database of the CHINAGEM model is mainly based on China's Input-Output (IO) Table, which is only published every five years, the updating of the CHINAGEM model's database mainly relies on the availability of the newest IO table. The second version of the CHINAGEM model with the 2007 database was released in 2010 and the third version with the 2012 database became available in 2015. The latest version with the 2017 database was released in 2020. The full model includes 159 industries and 157 commodities. Though the core theory of the model has remained the same in the successive versions, CHINAGEM has been modified and expanded in many ways in the last 16 years.

Various modules have been developed that can readily be attached to the core model for more specialised analysis. These module developments also expanded CHINAGEM's modelling capacity. For example, China's unique household registration system (*hukou*) was considered a big barrier to the free movement of the abundant rural labour force in the 1990s and the early 2000s, A labour market module therefore was designed to capture the specific features of China's labour market with very detailed disaggregation of the labour force based on their *hukou* status. This innovative labour market module was used to describe the movement of rural labourer to urban sectors and quantitatively investigate the economic effects of the *hukou* system reform (see Chap. 9 for the details of the labour market module). Since then, the CHINAGEM model with its labour market module has been used to examine the effects of policies such as further relaxation of the *hukou system,* insurance schemes for rural migrant workers. A pension module was further developed based on the labour market module and was used to analyse the effects of pension reform and retirement age extension policies against the backdrop of the rapid population ageing in China (Chap. 10).

A financial CGE model which allows explicit policy analysis to be conducted on the financial sector is introduced in Chap. 11. We believe that this model helps provide clarity and improve learning and understanding of the interaction of fiscal and monetary policies in China and around the world.

With water becoming more scarce, a total water constraint module, and a water subdivision module allowing for substitution between various water sources were developed to analyse the impact of various water price reforms on water conservation and economic growth in China (Chap. 12).

With the Chinese government's recent commitment to peaking carbon emissions before 2030 and carbon neutrality before 2060, an energy and climate change-focused model, based on the CHINAGEM model, was developed to simulate the economic effects of China's decarbonisation and policy options for the optimal energy structure (see the details of carbon neutrality simulation in Chap. 13). Given the vast differences in the natural resource endowments and economic growth disparities between regions in China, a top-down approach was used to decompose the macro effects of carbon neutrality on China's 31 provincial regions (Chap. 14).

The flexibility of the CHINAGEM model, its readiness to link with other models,[3] its detail (with more than one hundred sectors) and its policy relevance make

[3] For example CHINAGEM can be linked with the Engineering model which has a detailed cost structure of different electricity generation. This link allows CHINAGEM to more accurately simulate the cost of decarbonisation. CHINAGEM can also be linked with the MONASH model to simulate the effects of China's economic transition on the Australian economy.

CHINAGEM a powerful tool for analysing a wide range of economic and policy issues.

2.4 Study of CHINAGEM

As the world economy becomes more fractured and complicated, there is an increasing demand for comprehensive analytical tools such as MONASH-style dynamic models. More importantly, there is an increasing demand for highly skilled CGE analysts. CHINAGEM is designed as an entry point for CGE modellers to develop their analytical skills. It is also designed as a platform for research institutes to develop CGE models suitable for their research portfolio. A comprehensive training program is offered by the Centre of Policy Studies (CoPS) in conjunction with the application of CHINAGEM.

The essential steps towards building CGE analytical capacity via CHINAGEM are the following:

Step 1: Attending basic training courses. The four fundamental courses offered at CoPS are:

- Practical GE Modelling Course;
- Dynamic GE Modelling Course;
- Constructing a CGE Database Course; and
- Regional GE modelling course.

Step 2: Applying existing CGE models, such as CHINAGEM, in policy applications with small modifications to the model and database. CoPS offers consultation services to help CHINAGEM users in policy applications.

Step 3: Developing your own model by adding new modules and relevant database to CHINAGEM to advance your institute's policy research. This stage requires your institute's modelling team to have a significant mathematical and economic background. CoPS offers consultation services to provide software and model development support.

Step 4: The ultimate skill in CGE modelling is the art of using CGE models as a thinking framework for policy and economic analysis. The key to developing this skill is the Back-Of-The-Envelop (BOTE) model technique that is introduced and reinforced throughout CoPS' training courses and consultation services. Often CGE modellers can be overwhelmed by the numerous numbers produced by the model. The BOTE model provides a map or a strategy for CGE analysts to understand the model results and derive policy insights.

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Chapter 3
Structure of the CHINAGEM Database

Xiujian Peng and Yinhua Mai

Abstract The database is a critical component of Computable General Equilibrium (CGE) models, and this chapter offers a comprehensive overview of the CHINAGEM model's database. It provides a detailed explanation of the database structure, including the major data matrices and the two balance conditions of the database. Furthermore, the chapter describes the approaches used to generate data and initial solutions for other years in the CHINAGEM model. Understanding the database of the CHINAGEM model is crucial for effectively utilizing the model and interpreting the modelling results, and this chapter serves as a valuable resource for researchers and practitioners interested in CGE modelling.

Keywords CGE · Database · Matrix · Initial solutions · Johansen/Euler computations

Like other CGE models, CHINAGEM has two parts: one is the equation part and the other is its database. In this chapter, we describe its database.

3.1 Structure of the CHINAGEM Database

Figure 3.1 sets out the structure of the CHINAGEM input–output database in three parts: an absorption matrix; a joint-production matrix; and a vector of import duties. The first row in the absorption matrix, V1BAS, V2BAS, V3BAS, V4BAS, V5BAS and V6BAS, shows flows in year t of commodities to producers, investors, households, exports, public consumption and inventory accumulation. Each of these

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matrices has C*S rows, one for each of C commodities from S sources. C is the number of commodities in the model (e.g. 137 for the year 2012 database, see Appendix 7.2) and S is the number of sources (domestic and imported). V1BAS and V2BAS each have *I* columns where *I* is the number of CHINAGEM industries (137 for the 2012 database). Thus, V1BAS is a three-dimension matrix. The typical component of V1BAS is the value of good c from source s [good(c,s)] used by industry i as an input to production, and the typical component of V2BAS is the value of good(c,s) used to create capital for industry i. V3BAS to V6BAS each have one column. In standard applications, CHINAGEM recognises one household, one foreign buyer, one category of public demand and one category of inventory demand.[1] In the input–output database, no imported commodity is exported without being processed in a domestic industry. Consequently, V4BAS(c,s) is zero wherever s = "imp".

All of the flows in V1BAS, …, V6BAS are valued at basic prices. The basic price of a domestically produced good (s = "dom") is the price received by the producer (that is the price paid by users excluding sales taxes, transport costs and other margin costs). The basic price of an imported good is the landed-duty-paid price, i.e., the price at the port of entry just after the commodity has cleared customs.

Costs separating producers or ports of entry from users appear in the input–output data in the margin matrices and the row of sales-tax matrices. The margin matrices, V1MAR, …, V6MAR, show the values of N margin commodities used in facilitating the flows identified in V1BAS, …, V6BAS. For the 2012 database, N = 8. The eight commodities that can be used as margins are rail transport, air transport, water transport, road transport, pipeline, storage, insurance, and trade (wholesale and retail trades). In the CHINAGEM model, imported goods are not used as margin services.

Each of the matrices V1MAR, …, V6MAR can be interpreted to have C*S*N rows. These correspond to the use of N margin commodities in facilitating flows of C commodities from S sources. V1MAR and V2MAR have *I* columns identifying *I* industrial producers and *I* industrial capital creators, and V3MAR to V6MAR each have one column. The typical components of V1MAR and V2MAR are the values of margin commodity n used in facilitating the flow of good(c,s) to industry i for current production and capital creation. Similarly, the typical components of V3MAR to V6MAR are the values of margin commodity n used in facilitating flows of good(c,s) to households, ports of exit,[2] governments and stocks of inventories.[3] As with the

[1] CHINAGEM can be extended to have more than one type of agent. For example, households can be disaggregated into rural households and urban households. Foreign buyers can be extended by country of residence. Public demand can be split into central government demand and provincial government demand.

[2] It should be emphasized that V4MAR contains transport and other margin costs incurred in facilitating export flows from Chinese producers to Chinese ports. It does not include transport and other margin costs incurred outside China.

[3] In the current implementation of the CHINAGEM model, there are no margins on inventory accumulation. Consequently, V6MAR does not appear in the TABLO code.

Absorption Matrix

	Size	1 Producers	2 Investors	3 Households	4 Exports	5 Government	6 Inventories
		← *I* →	← *I* →	← 1 →	← 1 →	← 1 →	← 1 →
Basic Flows	↑ *C*×*S* ↓	V1BAS	V2BAS	V3BAS	V4BAS	V5BAS	V6BAS
Margins	↑ *C*×*S*×*N* ↓	V1MAR	V2MAR	V3MAR	V4MAR	V5MAR	V6MAR
Sales Taxes	↑ *C*×*S* ↓	V1TAX	V2TAX	V3TAX	V4TAX	V5TAX	V6TAX
Labour	↑ *M* ↓	V1LAB_O					
Capital	↑ 1 ↓	V1CAP					
Land	↑ 1 ↓	V1LND					
Other Costs	↑ 1 ↓	V1OCT					
Production Taxes	↑ 1 ↓	V1PTX					

C = Number of commodities
I = Number of industries
S = 2; domestic and imported
M = Number of occupations
N = Number of commodities used as margins

Size	Joint Production Matrix
	← *I* →
↑ *C* ↓	MAKE

Size	Import Duty
	← 1 →
↑ *C* ↓	V0TAR

Fig. 3.1 The CHINAGEM input–output database

BAS matrices, all the flows in the MAR matrices are valued at basic prices. In the case of margin flows, we assume that there is no cost separation between producers and users, i.e., there are no margins on margins.[4] Hence, there is no distinction between

[4] Some readers may be concerned about the treatment of taxes charged on margin services such as road transport. These are handled as taxes paid by margin industries either on their outputs or their

prices received by the suppliers of margins (basic prices) and prices paid by users of margins (purchasers' prices).

V1TAX, ..., V6TAX record collections of sales taxes. The entries in these matrices show sales taxes. The typical component of V1TAX, for example, is the sales tax paid as a result of the flow of good (c,s) to industry i for use as an intermediate input. While most of the entries in sales-tax matrices are non-negative, it is possible to use negative entries to represent subsidies.

Unlike production taxes and import duties (both of which are included in the basic prices of commodities), sales taxes can be levied at different rates on different users. Consequently, in CHINAGEM database, the ratio of V1TAX(c,s,i) to V1BAS(c,s,i), for example, may differ from the ratio of V3TAX(c,s) to V3BAS(c,s). There may also be differences in the rates of sales tax implied by the database on flows of (c, "dom") and (c,"imp") to the same users. Such differences can arise from differences in the sub-commodities making up (c,"dom") and (c, "imp"). Consider, for instance, the commodity beverages & tobacco. Assume that domestically produced beverages & tobacco consist largely of tobacco while the imported commodity consists largely of beverages. If rates of sales taxes charged to households on tobacco differ from those charged on beverages, then V3TAX(c,"dom")/V3BAS(c,"dom") and V3TAX(c,"imp")/V3BAS(c,"imp") will differ.

Payments by industries for labour are recorded in Fig. 3.1 in the matrix V1LAB_O. The vectors V1CAP and V1LND show payments by industries for their use of fixed capital and land. The current CHINAGEM database shows non-zero land rentals only for agricultural and mining industries. Other industries are treated as though they use no scarce land. The vector V1OCT records other costs incurred by industries e.g. the costs of holding inventories. The vectors V1PTX show collections of taxes on production.

The final two data items in Fig. 3.1 are V0TAR and MAKE. V0TAR is a $C \times 1$ vector showing tariff revenue by imported commodity. Please note that, unlike the sales tax we just discussed, the tariff imposed on an imported commodity is independent of user. The joint-product matrix, MAKE, has dimensions $C \times I$. Its typical component is the output (valued at basic prices) of commodity c by industry i. In the 2012 CHINAGEM database, there is no off-diagonal number shown in the MAKE matrix which means that each industry only produces one commodity and the number of industries is the same as the number of commodities.[5]

Together, the absorption and joint-production matrices satisfy two balance conditions. First, the column sums of MAKE, which are values of industry outputs, are identical to the values of industry inputs. Hence, the i-th column sum of MAKE equals

inputs (e.g., petrol). They are not treated as charges which separate the price received by the margin producer from the price paid by the margin user. Consequently, they are not treated as charges which can cause different users to pay different amounts per unit of service received.

[5] As a MONASH style CGE model, CHINAGEM theory allows multiple industries to produce the same commodity, for instance, the conventional gas industry and the non-conventional gas industry produce the same commodity—natural gas. In theory, CHINAGEM also allows an industry to produce multiple commodities. In either case, there will be off-diagonal numbers in the MAKE matrix.

the sum of the i-th columns of V1BAS, V1MAR, V1TAX, V1LAB_O, V1CAP, V1LND, V1OCT and V1PTX.

Second, the row sums of MAKE, which are basic values of outputs of domestic commodities, are identical to basic values of demands for domestic commodities. If c is a non-margin commodity, then the c-th row sum of MAKE is equal to the sum across the (c,"dom")-rows of V1BAS to V6BAS. If c is a margin commodity, then the c-th row sum of MAKE is equal to the direct uses of domestic commodity c, i.e., the sum across the (c,"dom")-rows of V1BAS to V6BAS, plus the margins use of commodity c. The margins use of c is the sum of the components in the (cc,s,c)-rows of V1MAR to V6MAR for all commodities cc and both sources s.

An implication of the two balance conditions (reflecting the equality between the sum of the column sums and the sum of the row sums of MAKE) is that the total value of inputs to domestic production equals the total value of demands for domestic products.

$$\begin{aligned}
&\mathrm{Sum(V1BAS)} + \mathrm{Sum(V1MAR)} + \mathrm{Sum(V1TAX)}\\
&\quad + \ \mathrm{Sum(V1LAB_O)} + \mathrm{Sum(V1CAP)} + \mathrm{Sum(V1LND)}\\
&\quad + \mathrm{Sum(V1OCT)} + \mathrm{Sum(V1PTX)}\\
&\quad = \ \mathrm{Sum(V1BAS)} + \mathrm{Sum(V2BAS)} + \mathrm{Sum(V3BAS)}\\
&\quad + \ \mathrm{Sum(V4BAS)} + \mathrm{Sum(V5BAS)} + \mathrm{Sum(V6BAS)}\\
&\quad + \ \mathrm{Sum(V1MAR)} + \mathrm{Sum(V2MAR)} + \mathrm{Sum(V3MAR)}\\
&\quad + \ \mathrm{Sum(V4MAR)} + \mathrm{Sum(V5MAR)} + \mathrm{Sum(V6MAR)}\\
&\quad - \begin{bmatrix} \mathrm{Sum(V1BAS(imp))} + \mathrm{Sum(V2BAS(imp))} + \mathrm{Sum(V3BAS(imp))} + \\ \mathrm{Sum(V4BAS(imp))} + \mathrm{Sum(V5BAS(imp))} + \mathrm{Sum(V6BAS(imp))} \end{bmatrix}
\end{aligned} \tag{3.1}$$

where Sum(X) is the sum of all the components in the matrix X; and $\mathrm{V\phi BAS(imp)}$ is the matrix formed by the imports rows (s = "imp") of $\mathrm{V\phi BAS}$ for $\phi = 1 \ldots 6$.

From here we can show that the CHINAGEM input–output database satisfies the national income identity: GDP from the income side equals GDP from the expenditure side. The identity is established by subtracting Sum(V1BAS) and Sum(V1MAR) from the two sides of (3.1) and by adding Sum(V0TAR) and $\mathrm{Sum(V\phi TAX)}$, $\phi = 2,\ldots 6$, giving

$$\begin{aligned}
&\mathrm{Sum(V1LAB_O)} \ + \ \mathrm{Sum(V1CAP)} \ + \ \mathrm{Sum(V1LND)} \ + \ \mathrm{Sum(V1OCT)}\\
&\quad + \ \mathrm{Sum(V1PTX)} \ + \ \mathrm{Sum(V0TAR)} + \sum_{\phi=1}^{6} \mathrm{SUM(V\phi TAX)}\\
&\quad = \ \mathrm{Sum(V2BAS)} \ + \ \mathrm{Sum(V2MAR)} \ + \ \mathrm{Sum\ (V2TAX)}\\
&\quad + \ \mathrm{Sum(V3BAS)} \ + \ \mathrm{Sum(V3MAR)} \ + \ \mathrm{Sum(V3TAX)}\\
&\quad + \ \mathrm{Sum(V4BAS)} \ + \ \mathrm{Sum(V4MAR)} \ + \ \mathrm{Sum(V4TAX)}
\end{aligned}$$

$$+ \text{Sum(V5BAS)} + \text{Sum(V5MAR)} + \text{Sum(V5TAX)}$$
$$+ \text{Sum(V6BAS)} + \text{Sum(V6MAR)} + \text{Sum(V6TAX)}$$
$$- \left[\sum_{\phi=1}^{6} \text{SUM(V}\phi\text{BAS(imp))} - \text{Sum(V0TAR)} \right] \tag{3.2}$$

The LHS of (3.2) is the income measure of the GDP, i.e., returns to factors plus indirect taxes. The RHS of (3.2) is the expenditure measure of GDP, i.e., expenditure on investment *plus* expenditure on consumption *plus* expenditure on exports (f.o.b.)[6] *plus* public expenditure *plus* inventory accumulation *minus* imports (c.i.f.).[7]

As we move from the picture of the economy provided by our initial input–output database, Formula (3.2) provides an important check on our computations. We should always find that the percentage changes from the initial solution in the income and expenditure measures of GDP are equal.

3.2 Generating Data and Initial Solutions for Other years

From the data and initial solution for year 0, there are several ways of generating data and initial solutions for other years. One possibility is to use the same data and initial solution every year. This is the approach in Fig. 3.2, in which the initial solution for every year t, $\overline{V}(t)$ is $\overline{V}(0)$ or the model input–output database. Under this approach, the Johansen/Euler[8] calculation for year t generates the effects on endogenous variables by moving the exogenous variables from their initial year values (i.e., their year 0 values) to their required year t values. Another approach (Fig. 3.3) is to use the required solution for year t–1 (including the solution for the input–output flows)[9] as the initial solution for year t. We adopt this second approach for year-to-year CHINAGEM simulations because it usually involves Johansen/Euler computations of the effects of relatively small movements in the exogenous variables (from their year t–1 to their year t values). A difficulty of using the year 0 solution as the initial solution for all years is that as we move away from year 0, the Johansen/ Euler computations may require increasing numbers of steps to generate accurate solutions. This is because in year 10, for example, the values of the exogenous variables may be far from their values in year 0.

[6] F.o.b. stands for Free On Board and it means the cost of transporting your goods to the nearest port and loading them onto the ship is included in the price. As the buyer, you are then responsible for the cost of shipping the items from there to your location.

[7] C.i.f. stands for Cost, Insurance and Freight, which means the seller pays the cost of the freight to send the goods to its final destination, also including the cost of insurance.

[8] See the footnote number 2 in Chap. 4 for the details of the Johansen/Euler computation.

[9] Our solution for year t–1 contains values for all prices and quantities. From these, we can create year (t–1) input-output flows. These become the input-output data in our computation for year t.

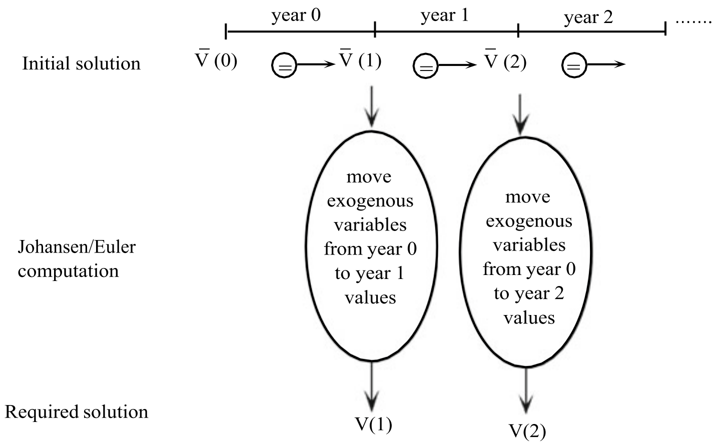

Fig. 3.2 A sequence of solutions using the solution for year 0 as the initial solution for year t. *Source* Dixon and Rimmer (2002)

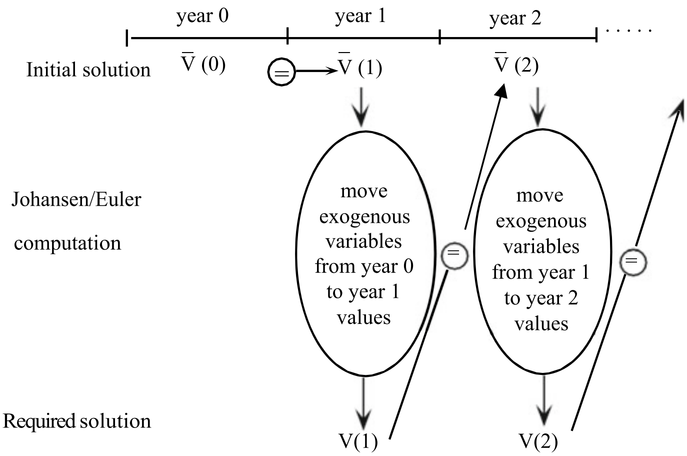

Fig. 3.3 A sequence of solutions using the required solution for year t–1 as the initial solution for year t. *Source* Dixon and Maureen (2002)

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Chapter 4
Equations and Solution Method of CHINAGEM

Xiujian Peng and Yinhua Mai

Abstract CHINAGM is a recursive dynamic Computable General Equilibrium (CGE) model. The computational approach that we have adopted for CHINAGEM depends on being able to solve the model year by year. By obtaining a sequence of linked solutions, we then generate time paths for endogenous variables. This chapter describes the Johansen/Euler solution method we used in CHINAGEM. The core part of the CHINAGEM equation system is explained in depth. Additionally, a stylized version of CHINAGEM, along with a trial closure, is presented to offer readers an intuitive understanding of where the major groups of the CHINAGEM equations fit into the overall structure of the model.

Keywords Johansen/Euler method · Initial solutions · Sequence of solutions · CGE equations · Closure

In this chapter, we describe the core part of the CHINAGEM equation system. In Sect. 4.1 we provide an overview of the mathematical structure of CHINAGEM and its solution method. In Sect. 4.2 we present a stylised version of the equation system.

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4.1 Overview of the Mathematical Structure of CHINAGEM and Introduction to the Johansen/Euler Solution Method

We represent CHINAGEM as

$$F(V(t)) = 0 \tag{4.1.1}$$

where V(t) is a vector of length n referring to prices, quantities and other variables for year t and F is a vector function of length m, m < n.

The computational approach that we have adopted for CHINAGEM depends on being able to solve the model one year at a time. For year t we specify values for n-m exogenous variables and solve (4.1.1) for the remaining m endogenous variables. By obtaining a sequence of linked solutions for years t, t + 1, t + 2, …, we generate time paths for variables. Links between the annual solutions are provided by lags. For example, we assume that capital stocks at the beginning of year t + 1 (variables in the solution for year t + 1) equal capital stocks at the end of year t (variables in the solution for year t).[1]

Within any sequence of solutions, we obtain the solution for year t [i.e., we solve (4.1.1)] by the Johansen/Euler[2] method. This method requires an initial solution, $\overline{V}(t)$ satisfying (4.1.1). Starting from this initial solution, we obtain the required solution for year t by calculating the effects on endogenous variables of moving the exogenous variables away from their values in the initial solution to their values in the required solution.

Johansen/Euler deviation computations are made by solving systems of linear equations. In a one-step computation, we can use the system

$$H\big(\overline{V}(t)\big)dV = 0 \tag{4.1.2}$$

where $H(\overline{V}(t))$ is the $m \times n$ matrix of first-order partial derivatives of F evaluated at $\overline{V}(t)$ and dV is the $n \times 1$ vector of deviations in the values of the n variables away from $\overline{V}(t)$. The LHS of (4.1.2) is an approximation to the vector of changes in the F functions caused by changing the values of the variables from $\overline{V}(t)$ to $\overline{V}(t)$+ dV. Because we are looking for a new solution to (4.1.1), we set this vector of approximate

[1] We may also wish to impose forward links. For example, we may wish to assume that profit expectations held in year τ (variables in the τ solution) depend on profit outcomes in year $\tau + 1$ (variables in the $\tau + 1$ solution). Forward links pose difficulties for our one-year-at-a-time computational method. These can be overcome by an iterative method (see Dixon and Rimmer 2002, Sect. 21; Dixon et al. 2005).

[2] So named in recognition of the contributions of Johansen (1960) who applied a version of this method to solve his CGE model of Norway, and Euler, the eighteenth-century mathematician who set out the theory of the method as an approach to numerical integration. Early examples of applications of the Johansen method include Taylor and Black (1974), Staelin (1976), Keller (1980), Dixon et al. (1977), and Dixon et al. (1982).

changes equal to zero. We recognize that going from the initial solution for year t to the new solution, we must leave the values of the F functions unchanged from zero.

Rather than using systems such as (4.1.2) in which all the variables are changes [dV], we work with systems in which some of the variables are ordinary changes and some are percentage changes. Percentage changes are more convenient than ordinary changes because with percentage changes we don't have to worry about units of measurement. But not all variables can be treated as percentage changes because some variables (e.g. the balance of trade) naturally pass through zero. In this case, percentages become undefined.

With the variables being a mixture of ordinary changes and percentage changes, (4.1.2) becomes

$$A\left(\overline{V}(t)\right)v = 0 \tag{4.1.3}$$

where (with the t omitted for convenience) the (q,r)th component of A($\overline{V}$) is given by:

$$A_{q,r}\left(\overline{V}\right) = \begin{cases} H_{q,r}\left(\overline{V}\right) * \dfrac{\overline{V}_r}{100} & \text{if r is a percentage change variable} \\ H_{q,r}\left(\overline{V}\right) & \text{if r is an ordinary change variable} \end{cases} \tag{4.1.4}$$

To solve the model we must first separate the variables into two groups, n-m exogenous variables and m endogenous variables. Then, we rewrite (4.1.3) as

$$A^{\alpha}\left(\overline{V}\right) * v_{\alpha} + A^{\beta}\left(\overline{V}\right) * v_{\beta} = 0 \tag{4.1.5}$$

where

$A^{\alpha}\left(\overline{V}\right)$ is the $m \times m$ matrix formed by the m columns of $A\left(\overline{V}\right)$ corresponding to the endogenous variables;

$A^{\beta}\ \left(\overline{V}\right)$ is the $m \times (n-m)$ matrix formed by the n-m columns of $A\left(\overline{V}\right)$ corresponding to the exogenous variables; and.

v_{α} and v_{β} are the vectors of movements in the endogenous and exogenous variables.

Given values for the n-m exogenous variables, we solve (4.1.5) in a one-step Johansen/Euler procedure for the endogenous variables as

$$v_{\alpha} = -\left(A^{\alpha}\left(\overline{V}\right)\right)^{-1} * A^{\beta}\left(\overline{V}\right) \times v_{\beta} \tag{4.1.6}$$

Among the questions which will have occurred to the reader are the following:

(i) how do we obtain the initial solution $\overline{V}(t)$?
(ii) can we be sure that $A^{\alpha}\left(\overline{V}\right)$ is non-singular?
(iii) how do we evaluate the coefficients of systems such as (4.1.3), i.e., how do we evaluate $A\left(\overline{V}\right)$? and

(iv) does (4.1.6) produce an accurate solution for the effects on the endogenous variables of movements in the exogenous variables away from their initial values, and if not what can be done?

Detailed answers to all these questions can be found in Dixon and Rimmer (2002, Chap. 3) and Dixon et al. (1982, Chap. 5). Here we provide brief intuitive answers.

The answer to question (i) is that $\overline{V}$ comes mainly from the model's input–output database which shows the value of flows of commodities and factors to each industry. By adopting suitable units for quantities, we can assume that prices are initially one and that the input–output data reveals not only values but also quantities. The balance properties of the input–output database (discussed in Chap. 3) mean that these quantity flows satisfy the condition that demands equal supplies for each commodity. At the same time, the value flows satisfy the condition that costs equal revenues for each industry. The input–output prices and quantities also fit the demand and supply functions in CHINAGEM. This is because these prices and quantities are used in calibrating the demand and supply functions. For example, assume that our model contains Cobb–Douglas demand functions of the form:

$$X(i) = \delta(i) * \frac{C}{P(i)} \tag{4.1.7}$$

where X(i) is household demand for commodity *i*; P(i) is the price of commodity *i*; C is total household expenditure, and δ (i) is a parameter. Values for P(i) and X(i) can be deduced from the input–output data after applying our units convention and C can be observed directly from the input–output data. These values for P(i), X(i) and C satisfy (4.1.7) because the value for the parameter δ (i) is set from the input–output table at the share of commodity *i* in household expenditure.

The answer to question (ii) is that the singularity of $A^{\alpha}\left(\overline{V}\right)$ will cause the Johansen/Euler method to fail. However, this is not a computational difficulty. Rather, it indicates that we have not set our model a question that it can answer by any computational method. This is because the singularity of $A^{\alpha}\left(\overline{V}\right)$ implies that the variables we have chosen to be endogenous [V_{α}] are not functions of those we have chosen to be exogenous [V_{β}]. This means that there are either no values or multiple values for the endogenous vector that are compatible with the specified movements in the exogenous vector (see Dixon et al. 1982, Sects. 8, 30–36 and 47).

The answer to question (iii) is that many of the components of $A\left(\overline{V}\right)$ are zeros and positive ones or negative ones. For example (4.1.7) in percentage changes form is

$$x(i) - c - p(i) = 0 \tag{4.1.8}$$

where $x(i)$, c, and $p(i)$ are percentage changes of the corresponding uppercase variables. The row of $A\left(\overline{V}\right)$ corresponding to (4.1.8) would have a positive one in the column for $x(i)$, a negative one in the column for c, a negative one in the column for $p(i)$ and zero in all other columns. Other equations are represented in $A\left(\overline{V}\right)$ by more complicated coefficients. However, most of these are evaluated by applying simple formulas to the model's database. Many of these formulas combine cost and sales shares calculated from input–output data with substitution parameters.

Figure 4.1 is a helpful diagram for thinking about the answer to question (iv). The curve in this figure represents (4.1.1) as a one-equation, two-variable model. If we use (4.1.6) to compute the effect of moving V_β from V_β (initial) to V_β (final) then the error is V_α (1step)–V_α (true). However, we can reduce this error by a multi-step computation. In a two-step procedure, we start by using (4.1.6) to compute the effect of moving V_β halfway from its initial value to its final value. Then we see what has happened to all prices and quantities and we update the database. In the second step, we compute the effects of V_β moving from its halfway value to its final value. In this second step, we use (4.1.6) but with V set at the value it reached at the end of the first step. In effect, we use (4.1.6) with an updated value for the derivative of V_α with respect to V_β. Note that Figure 4.1 implies that the errors in a one-step procedure are approximately halved in a two-step procedure. This idea can be exploited in GEMPACK to generate highly accurate solutions in a very small number of steps.

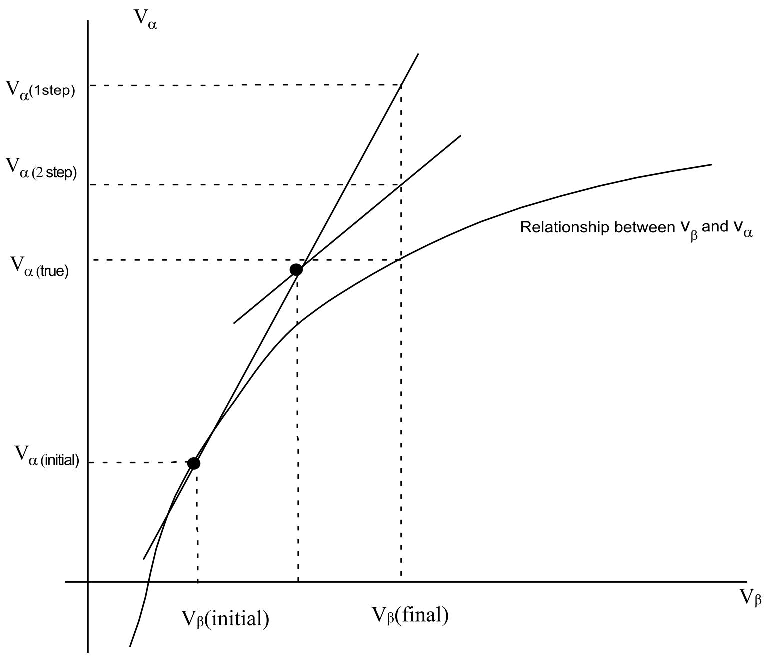

Fig. 4.1 The effects on V_α of moving V_β from V_β(initial) to V_β(final) computed by 1 and 2 step Johansen/Euler procedures

4.2 Stylised Version of the CHINAGEM Model

This section describes a stylized version of CHINAGEM together with a trial closure. Our aim is to give readers an intuitive understanding of where the major groups of the CHINAGEM equations fit into the overall structure of the model.

Table 4.1 lists the stylized equations in groups. Table 4.2, which is presented in three parts, defines the notation used in Table 4.1. The first two parts of Table 4.2 list the endogenous and exogenous variables in the trial closure. The third part lists other notations from Table 4.1. In subsection 4.2.1 we work through Table 4.1 and then in subsection 4.2.2, we discuss the closure set out in Table 4.2.

4.2.1 Equations in the Stylized Version

(a) ***Composition of outputs and inputs***

The first five equations in Table 4.1 describe the compositions of industry outputs and inputs. Each industry in CHINAGEM can produce a variety of domestic commodities, (c, 1) c = 1, 2, …, N_C.[3] Industry i chooses the composition of its output to maximize revenue subject to a transformation frontier. This gives commodity supply functions of the forms shown in (4.2.2) and (4.2.1). In (4.2.2) the total output of (c, 1) [X0COM(c)] is the sum over industries of outputs [X0(c, 1, i), i = 1, 2, …, N_i], and in (4.2.1) the output of (c, 1) by industry i is a function of prices (P1) of domestic commodities and of the level of i's activity [X1TOT(i)]. The level of i's activity determines the distance of i's transformation frontier from the origin. We assume constant returns to scale implying that an x per cent increase in X1TOT(i) allows industry i to produce x per cent more of all commodities. Thus, as indicated in Eqs. (4.2.3–4.2.5), i's demands for inputs are proportional to X1TOT(i). They also depend on input prices and on technology variables (A_{1i}, A_{PFi}) that affect the location and shape of i's isoquants. The input prices enter i's demand functions via cost-minimizing assumptions. With the particular production functions adopted in CHINAGEM, the demands by industry i for inputs of domestic and imported goods c [X1(c, s, i), s = 1, 2] depend on the prices [P_s(c), s = 1, 2] of the two varieties of good c, and the demands by industry i for primary factors [L(i) and K(i)] depend on the wage rate (W) and the rental price [Q(i)] of i's capital.

(b) ***Inputs to capital creation and asset prices***

With the capital-creation functions used in CHINAGEM, cost-minimizing assumptions produce input-demand functions of the form (4.2.6): the demand for inputs of commodity c from source s to be used by industry i for capital creation depends on the quantity of capital creation [X2TOT(i)] in industry i, on the prices of domestic and

[3] This feature of one industry producing multi-products is not implemented in the version of CHINAGEM used in this book.

Table 4.1 Stylized representation of the CHINAGEM equations

	Dimension	Identifier
Composition of outputs and inputs		
$X0(c, 1, i) = X1TOT(i)*\psi_{0c1i}(P_1)$	$N_C N_I$	(4.2.1)
$X0COM(c) = \Sigma_i X0(c, 1, i)$	N_C	(4.2.2)
$X1(c, s, i) = X1TOT(i)*\psi_{1csi}(P_1(c), P_2(c), A_{1i}, A_{TWIST})$	$N_C N_S N_I$	(4.2.3)
$L(i) = X1TOT(i)*\psi_{Li}(W, Q(i), A_{PFi})$	N_I	(4.2.4)
$K(i) = X1TOT(i)*\psi_{Ki}(W, Q(i), A_{PFi})$	N_I	(4.2.5)
Inputs to capital creation and asset prices		
$X2(c, s, i) = X2TOT(i)*\psi_{2csi}(P_1(c), P_2(c), A_{2i}, A_{TWIST})$	$N_C N_S N_I$	(4.2.6)
$PI(i) = \psi_{PIi}(P_1, P_2, A_{2i})$	N_I	(4.2.7)
Household demands for commodities		
$X3(c, s) = \psi_{3cs}(C, P3_1, P3_2, A_3, A_{TWIST})$	$N_C N_S$	(4.2.8)
Exports		
$X4(c) = \psi_{4c}(PE(c) + A_4(c))$	N_C	(4.2.9)
Government demands		
$X5(c, s) = A_5(c, s)*A_{(5)}$	$N_C N_S$	(4.2.10)
Demands for margin services		
$X3MAR(c, s, k) = A3MAR(c, s, k)*X3(c, s)$	$N_c N_s N_c$	(4.2.11)
Supply equals demand for commodities		
$X0DOM(c) = \Sigma_i X1(c, 1, i) + \Sigma_i X2(c, 1, i) + X3(c, 1) + X4(c) + X5(c, 1) + \Sigma_k \Sigma_s X3MAR(c, s, k)$	N_C	(4.2.12)
$X0IMP(c) = \Sigma_i X1(c, 2, i) + \Sigma_i X2(c, 2, i) + X3(c, 2) + X5(c, 2)$	N_C	(4.2.13)
Zero profits in production, importing, exporting and distribution		
$\Sigma_c P_1(c)X0(c, 1, i) = \Sigma_c \Sigma_s P_s(c)X1(c, s, i) + W*L(i) + Q(i) *K(i)$	N_I	(4.2.14)
$P_2(c) = [PM(c)/\Phi]*TM(c)$	N_C	(4.2.15)
$P_1(c) = [PE(c)/\Phi]/T4(c)$	N_C	(4.2.16)
$P3_s(c) = P_s(c)*T3(c, s) + \Sigma_k P_1(k)*A3MAR(c, s, k)$	$N_C N_S$	(4.2.17)
Indirect taxes		
$T4(c) = A_{0T}(c)*A_{4T}(c)$	N_C	(4.2.18)
Definitions of macro variables		
$CPI = \psi_{CPI}(P3_1, P3_2)$	1	(4.2.19)
$WR = W/CPI$	1	(4.2.20)
$LTOT = \Sigma_i L(i)$	1	(4.2.21)
$KTOT = \Sigma_i K(i)$	1	(4.2.22)

(continued)

Table 4.1 (continued)

	Dimension	Identifier
$GDP = C + \Sigma_i PI(i)* X2TOT(i) + \Sigma_s \Sigma_c P_s(c)*X5(c, s) + \Sigma_c [PE(c)/\Phi]*X4(c) - \Sigma_c [PM(c)/\Phi]*X0IMP(c)$	1	(4.2.23)
Capital stocks, investment and rates of return		
$K_+(i) = (1 - D(i))*K(i) + X2TOT(i)$	N_I	(4.2.24)
$IKRATIO(i) = X2TOT(i)/K(i)$	N_I	(4.2.25)
$K_+(i)/K(i) - 1 = \Psi_{KG}(EROR(i)) + A_{KG}(i) + A_{KGT}$	N_I	(4.2.26)
$EROR(i) = \Psi_{ERORi}(Q(i), PI(i)) + A_{EROR}(i)$	N_I	(4.2.27)
Balance of payments and GNP		
$NFLF_+ = NFLF + CAD*\Phi$	1	(4.2.28)
$CAD = \Sigma_c (PM(c)/\Phi)*X0IMP(c) - \Sigma_c (PE(c)/\Phi)*X4(c) + R0IF*(NFLF/\Phi)$	1	(4.2.29)
$GNP = GDP - R0IF*(NFLF/\Phi)$	1	(4.2.30)
Function for private and public consumption		
$C + \Sigma_s \Sigma_c P_s(c)*X5(c, s) = A_C*GNP$	1	(4.2.31)
The government accounts		
$PSD = \Sigma_s \Sigma_c P_s(c)X5(c, s) - \Sigma_s \Sigma_c[T3(c, s) - 1]P_s(c)X3(c, s) - \Sigma_c(TM(c) - 1)[PM(c)/\Phi]X01MP(c) - \Sigma_c(T4(c) - 1) * P_1(c) * X4(c) + TRANSFERS$	1	(4.2.32)
Sticky-wage specification for policy simulations		
$\left[\frac{WR}{WR_f} - 1\right] = \left[\frac{WR_{lag}}{WR_{flag}} - 1\right] + \alpha\left[\frac{LTOT}{LTOT_f} - 1\right] + A_{WR}$	1	(4.2.33)
Technical and preference change		
$A_3(c) = A_{3G}(c) * A_{3F}(c)$	N_C	(4.2.34)
$A_{3G}(c) = A_{CG}(q), \forall i \in G(q)$	N_C	(4.2.35)
Equations for facilitating historical and forecast simulations		
$CG(q) = \Sigma_{c\in G(q)} \Sigma_s X3(c, s)$	N_{CG}	(4.2.36)
Total number of equations		
$N_c N_s N_c + N_C N_I + 3N_C N_S + 2N_C N_S N_I + 8N_I + 9N_C + N_{CG} + 11$		

imported commodity c, and on variables (A_{2i}) reflecting the technology for creating units of capital for use in industry i. As implied by (4.2.7), the cost [PI(i)] of a unit of capital in industry i depends on input prices and technology. We assume that the

Table 4.2 Notation in the stylized model

		Dimension	Determining equation
I. Endogenous variables in the trial closure			
T4(c)	Power of tax on exports of commodity c	N_C	(4.2.18)
P_1	Basic prices of domestic commodities	N_C	(4.2.16)
P_2	Basic prices of imported commodities	N_C	(4.2.15)
$P3_1$, $P3_2$	Vectors of household purchasers' prices for domestic and imported commodities	$N_C N_S$	(4.2.17)
CPI	Consumer price index	1	(4.2.19)
W	Wage rate	1	(4.2.20)
Q(i)	Rental rate on capital in industry i	N_I	(4.2.14)
X1TOT(i)	Activity level in industry i	N_I	(4.2.5)
X0(c, 1, i)	Output of commodity (c, 1) by industry i	$N_C N_I$	(4.2.1)
X0COM(c)	Total output of commodity (c, 1)	N_C	(4.2.2)
X1(c, s, i)	Input of (c, s) to production in industry i	$N_C N_S N_I$	(4.2.3)
L(i)	Employment in industry i	N_I	(4.2.4)
PI(i)	Asset price of capital in industry i	N_I	(4.2.7)
EROR(i)	Expected rate of return in industry i	N_I	(4.2.27)
K_+(i)	End-of-year stock of capital in industry i	N_I	(4.2.26)
X2TOT(i)	Investment in industry i	N_I	(4.2.24)
IKRATIO(i)	Ratio of investment to capital in industry i	N_I	(4.2.25)
X2(c, s, i)	Input of (c, s) to i's capital creation	$N_C N_S N_I$	(4.2.6)
A_3(c)	Household preferences with respect to good c	N_C	(4.2.34)
X3(c, s)	Household consumption of commodity (c, s)	$N_C N_S$	(4.2.8)
X5(c, s)	Government consumption of good (c, s)	$N_C N_S$	(4.2.10)
X3MAR(c, s, k)	Margin use of domestic good k in facilitating the flow of (c, s) from producers and ports of entry to households	$N_c N_s N_c$	(4.2.11)

(continued)

Table 4.2 (continued)

		Dimension	Determining equation
X4(c)	Exports of commodity c	N_C	(4.2.12)
X0IMP(c)	Total imports of commodity c	N_C	(4.2.13)
A_4(c)	Slack in export-demand function for c	N_C	(4.2.9)
LTOT	Total employment	1	(4.2.21)
KTOT	Total start-of-year capital stock	1	(4.2.22)
GDP	Gross domestic product	1	(4.2.23)
CG(q)	Consumption in qth group of commodities	N_{CG}	(4.2.36)
A_{WR}	Slack in wage-determination equation	1	(4.2.33)
PSD	Public sector deficit	1	(4.2.32)
CAD	Current account deficit	1	(4.2.29)
$NFLF_+$	End-of-year net foreign liabilities in foreign currency	1	(4.2.28)
GNP	Gross national product	1	(4.2.30)
A_C	Aggregate propensity to consume	1	(4.2.31)
A_{3G}(c)	Household preferences corresponding to A_{CG}(q)	N_C	(4.2.35)
Total number of endogenous variables:			
$N_c N_s N_c + N_C N_I + 3N_C N_S + 2N_C N_S N_I + 8N_I + 9N_C + N_{CG} + 11$			
II. Exogenous variables in the trial closure			
K(i)	Start-of-year capital stock in industry i		
NFLF	Start-of-year net foreign liabilities in foreign currency		
WR_{lag}	Real wage rate in previous year		
WR_{flag}	Forecast for real wage rate in previous year		
WR_f	Forecast for real wage rate		
$LTOT_f$	Forecast for total employment		
TM(c)	Power (one plus the rate) of tariff on imports of commodity c		
T3(c, s)	Power of tax on household consumption of good (c, s)		
TRANSFERS	Transfers from the public sector to households, e.g., unemployment benefits and interest on the public debt		

(continued)

Table 4.2 (continued)

		Dimension	Determining equation
PM(c)	Foreign currency c.i.f. price of imports of commodity c		
ROIF	Rates of interest or dividends applying to net foreign liabilities		
Φ	Exchange rate		
C	Total household expenditure		
WR	Real wage rate		
PE(c)	Foreign-currency price of exports of commodity c		
All the A's except A_C, A_{WR} and $A_4(c)$, $A_{3G}(c)$ and $A_3(c)$ for all c	Potential slack variables and variables used to represent shifts in technologies and preferences		
III. Other notation			
N_C	Number of commodities (The 2012 version of CHINAGEM has 137 commodities)		
N_I	Number of industries (The 2012 version of CHINAGEM has 137 industries)		
N_S	Number of sources (2 in CHINAGEM: domestic and imported)		
N_{CG}	Number of commodity groups for which data on household consumption are available		
D(i)	Depreciation rate in industry i, treated as a parameter		
G(q)	Set of industries in the group q		
α	Positive parameter		

cost of creating a unit of capital is also the price at which a unit can be sold (the asset price).

(c) ***Household demands for commodities***

Demands for commodities by households are derived in CHINAGEM from utility maximization subject to a budget constraint. A stylized version of the resulting demand functions is given in (4.2.8) which shows household demands as functions of the household budget (C); of variables reflecting household preferences (A_3); and of purchasers' prices to households of domestic commodities ($P3_1$) and imported commodities ($P3_2$). In CHINAGEM, all demands for commodities depend on purchasers' prices. In the stylized version, we simplify CHINAGEM by assuming that margins occur only on commodity flows to households and that the only indirect taxes are tariffs, export taxes and taxes on consumption. Thus, in (4.2.3), (4.2.6) and (4.2.7) we use basic prices.[4]

(d) ***Exports***

The treatment of exports in CHINAGEM differs between two groups of commodities.[5] In the stylized version we show only one treatment: we relate foreign demand for domestic goods c [X4(c)] to the foreign currency price [PE(c)] and a shift variable [A_4(c)] as shown in (4.2.9). If the shift variable is exogenous, then by shocking it we can simulate the effects of movements in the foreign demand curve for commodity c. If the shift variable is endogenous, then it can be adjusted to accommodate an exogenous forecast for X4(c).

(e) ***Government demands***

In CHINAGEM, equations such as (4.2.10) allow for different treatments of government demands for commodities. Changes in government demand for a particular commodity (c, s) or all commodities can be introduced by shocks to A_5(c, s) or $A_{(5)}$. Alternatively, $A_{(5)}$ can be used as an endogenous variable that adjusts so that government spending meets a budget constraint.

(f) ***Demands for margin services***

With A3MAR(c, s, k) set exogenously, (4.2.11) implies that the use of commodity k (e.g. retail trade) as a margin service in facilitating the flow of commodity (c, s) from producers or ports of entry to households is proportional to household demand for (c, s). CHINAGEM contains equations similar to (4.2.11) for flows of commodities to all users. As mentioned in the discussion of (4.2.8), in the stylized version we assume that there are no margin services associated with commodity flows except those to households.

(g) ***Supply equals demand for commodities***

In (4.2.12) we equate the supply (output) of commodity (c, 1) to the sum of demands for (c, 1). Similarly, in (4.2.13) we equate the supply (imports) of (c, 2) to the sum

[4] The basic price of a domestic commodity is the price received by producers and the basic price of an imported commodity is the landed-duty-paid price.

[5] In CHINAGEM, commodities are divided into two groups: traditional and non-traditional export commodities. There is an individual export demand equation for each traditional export commodity while the non-traditional export commodities are treated as collective commodities without individual export demand equation.

of demands for (c, 2). Consistent with CHINAGEM, imported commodities are not directly exported or used to satisfy margin demands.

(h) ***Zero profits in production, importing, exporting and distribution***

Equations (4.2.14–4.2.17) are stylized versions of CHINAGEM zero-pure-profits conditions for production, importing, exporting and distribution. The LHS of (4.2.14) is revenue in industry i and the RHS is the corresponding cost. The LHS of (4.2.15) is the price [P_2(c)] received by importers of commodity c and the RHS is the cost of importing a unit of c made up of the foreign-currency price [PM(c)] converted to domestic currency via the exchange rate [Φ] and inflated by the power of the tariff [TM(c)]. The LHS of (4.2.16) is the cost of exporting a unit of commodity c (that is the revenue foregone by not selling on the domestic market) and the RHS is the revenue received per unit of export made up of the foreign-currency price [PE(c)] converted to domestic currency and deflated by the power of the export tax [T4(c)]. The LHS of (4.2.17) is the price paid by households for commodity (c, s). This equals the cost of supplying a unit of (c, s) to households and is made up of the price received by producers or importers [P_s(c)] inflated by the power of the consumption tax [T3(c, s)] *plus* the costs of transferring units of (c, s) from producers or ports of entry to households. As mentioned in our discussion of (4.2.12) and (4.2.13), we assume that transferring (margin) activities use only domestic commodities, e.g. domestic transport and domestic retail trade. Thus, the cost of commodity k used in transferring a unit of (c, s) to households is the price of domestic commodity k [P_1(k)] multiplied by the number of units of c [A3MAR(c, s, k)] required per unit of transfer.

(i) ***Indirect taxes***

CHINAGEM contains many equations expressing the power (one plus the rate) of an indirect tax as the product of various shift variables. Equation (4.2.18) is an example. The shift variable A_{0T}(c) in (4.2.18) links the power of export tax for a commodity to the power of tax for consumer, intermediate, or investment use of the commodity. With this facility we can simulate a reduction in the power of tax for a commodity (e.g. petrol) to all users.

(j) ***Definitions of macroeconomic variables***

Equations (4.2.19–4.2.23) are a sample of the macro definitions used in CHINAGEM. Equation (4.2.19) defines the consumer price index (CPI) as a function of the vectors [$P3_1$ and $P3_2$] of consumer prices for domestic and imported goods. Equation (4.2.20) defines the real wage rate as the nominal wage rate deflated by the CPI. Equations (4.2.21) and (4.2.22) define total employment and total capital stock as sums across industries, and Eq. (4.2.23) is the GDP identity in nominal terms.

(k) ***Capital stocks, investment and rates of return***

Equation (4.2.24) relates the capital stock in industry i at the end of the year [K_+(i)] to the depreciated capital stock from the beginning of the year [(1-D(i))*K(i)] and investment during the year [X2TOT(i)]. Equation (4.2.25) defines the ratio of investment to capital in industry i. When the shift variable, $A_{KG}(i)$, in (4.2.26) is exogenous, capital growth in industry i during the year and, hence, investment is determined by i's expected rate of return [EROR(i)]. If $A_{KG}(i)$ is endogenous, then investment in industry i can be determined by an alternative mechanism, for example via (4.2.25) with IKRATIO(i) set exogenously. With its shift variable [$A_{EROR}(i)$] set exogenously, (4.2.27) determines the expected rate of return in industry i as a function of the current rental rate [Q(i)] and asset price [PI(i)] of i's capital. Under this treatment, expectations are static or adaptive.

(l) ***Balance of payments and GNP***

CHINAGEM contains a detailed description of the balance of payments. This includes equations for the year-to-year accumulation of different types of foreign assets and liabilities and equations for associated incomes and payments. In the stylized version given in (4.2.28) and (4.2.29), we show a single accumulation equation relating the end-of-year foreign currency value of net foreign liabilities to the start-of-year value and to the foreign currency value of the current account deficit (CAD*Φ). The current account deficit is shown as the trade deficit (imports less exports) plus interest and dividend payments on net foreign liabilities.

Equation (4.2.30) defines GNP as GDP less the domestic currency value of net interest and dividend payments to foreigners.

(m) ***Function for private and public consumption***

With the shift variable A_C set exogenously, (4.2.31) links movements in total household and government expenditure to movements in GNP.

(n) ***The government accounts***

Equation (4.2.32) defines the public sector deficit (PSD) as government consumption expenditures *less* tax collections *plus* transfers. In this stylized equation, we recognize only the taxes (consumption taxes, import duties and export taxes) appearing in other stylized equations and we treat transfers as a single item with no explanatory equations. The core CHINAGEM also contains other taxes and other sources of government income.

(o) ***Sticky-wage specification for policy simulations***

Policy results are generated in CHINAGEM as deviations from explicit forecasts. This requires several equations that relate policy values for variables to forecast values. For example, as indicated by (4.2.33), we often assume in policy simulations that the proportionate deviation in year t in the real wage rate from its forecast value [WR/WR_f-1] equals the proportionate deviation in year t-1 [$WR_{lag}/WR_{flag}-1$] *plus* a positive multiple of the proportionate deviation in year t in total employment [$LTOT/LTOT_f-1$]. In other words, we assume that while employment is above its forecast level, the real wage deviation will be increasing. In simulations in which we want a different approach to wage determination, we can endogenise the shift variable A_{WR}.

(p) ***Technology and preference change***

CHINAGEM contains many equations that represent various technology and preference changes. Equations (4.2.34) and (4.2.35) give an example. Variable $A_{3G}(q)$ represents consumer preference with respect to groups of consumption goods (for example, food, consumer durables and household services). Each of these groups contains many commodities. The variable $A_{3G}(q)$ allows a change in consumer preference in favour of, for example, consumer durables to be simulated. With $A_{3F}(c)$ exogenised and no change, $A_{3G}(c)$ moves all preference variables for $c \in G$ in the same way.

In CHINAGEM, this subsection of the model code also contains other technical change equations that allow changes in the ratio of capital to labour, domestic to imported goods, etc.

(q) ***Equations for facilitating historical and forecast simulations***

Available data in China on outputs, inputs, prices, consumption, and other variables are presented in various industrial/commodity classifications. In order to use these data, we include in CHINAGEM many equations that define variables at different levels of aggregation. This is illustrated by (4.2.36) which defines consumption [CG(q)] in the qth group of commodities, e.g. all commodities in the agricultural sector. In most simulations, sectoral variables such as CG(q) are endogenous. However, in historical simulations they may be exogenised and given shocks reflecting observed movements. When CG(q) is exogenised, we endogenise a variable, $A_{CG}(q)$ in Eq. (4.2.35), which moves the preference of commodities in group q.

4.2.2 A Trial Closure of the Stylized Version of CHINAGEM

To check our understanding of the stylized model, it is useful to write a trial list of exogenous variables that we think should constitute a closure. We have composed such a list in part II of Table 4.2. If we cannot show that our trial list constitutes a closure, then we should check the list and equations. If we fail to find an error, then we should reassess our understanding of how the stylized model transforms values of exogenous variables into outcomes for endogenous variables.

In writing our trial list, we had in mind a short-run policy closure.[6] In such a closure we would expect to be able to include in the exogenous list all start-of-year stock variables, all lagged variables, all forecast variables and all policy instruments.

[6] By a short-run closure, we mean one that is used in computing a solution for year t + 1 starting from a solution for year t. By a policy closure, we mean one that is used in computing deviations from a forecast path caused by changes in policy variables or in other naturally exogenous variables.

This explains the inclusion in part II of Table 4.2 of the variables from K(i) down to TRANSFERS. PM(c) and ROIF are included because both are naturally exogenous: there are no equations in the stylized model (or in CHINAGEM) for explaining either foreign currency import prices or foreign rates of interest. For the numeraire in our trial closure we use the exchange rate (Φ).[7]

In a short-run policy simulation, none of the next three variables [C, WR and PE(c)] in part II of Table 4.2 would normally be exogenous. We would expect to explain movements in C by movements in national income via (4.2.31); movements in WR by deviations in total employment and lagged deviations in WR via (4.2.33); and movements in PE(c) by movements in exports of c via (4.2.9). In the trial closure we exogenise C, WR and PE(c) because, as we will see shortly, this makes it easy to establish that our trial exogenous list is a closure. To exogenise C, WR and PE(c), we endogenise the shift variables A_C, A_{WR} and $A_4(c)$ appearing in (4.2.31), (4.2.33) and (4.2.9), respectively. Because we would expect in a short-run policy simulation to exogenise taste and technology variables, almost all the other A variables are exogenous. The only exception is $A_3(c)$ which is endogenised due to Eq. (4.2.34).

Establishing the validity of our trial closure now becomes an easy recursive exercise with this particular list of exogenous variables in our stylized model. As indicated by the last column in part I of Table 4.2, we can start a solution of the stylized model by using (4.2.18) to determine T4(c). Having determined T4(c) we can then use (4.2.16) to determine $P_1(c)$ for all c. Equation (4.2.15) can be used to determine $P_2(c)$ for all c, then allowing us to use (4.2.17) to determine $P3_1$ and $P3_2$. Proceeding in this way through part I of Table 4.2, we establish the validity of our trial closure by showing that a value for each endogenous variable can be determined for any given values of the exogenous variables.

The only slight difficulty occurs when we reach the rental rate on i's capital, Q(i). As indicated in part I of Table 4.2, Q(i) can be computed using (4.2.14) after the determination T4(c), P1, P2, …,W. This can be done by first using (4.2.1–4.2.5) to eliminate the quantity variables [X0(c, 1, i), X1(c, s, i), L(i) and K(i)] from (4.2.14) and then cancelling out X1TOT(i), thereby creating an equation in which Q(i) is the only unknown. In effect, we create an equation which exploits constant returns to scale to express the rental rate on i's capital purely in terms of input prices and technology variables.

We develop new closures for CHINAGEM by starting from a simple closure and making variable-by-variable modifications. This process can be visualized via our stylized model. For example, starting from the exogenous list in part II of Table 4.2, we could develop a more interesting short-run policy closure by endogenising C, WR and PE(c) and exogenising A_C, A_{WR}, $A_4(c)$. This would give us a closure in which policy shocks could affect aggregate consumption, the real wage and export prices by affecting national income, employment and export volumes.

[7] Exchange rate, consumer price index, or GDP price index is normally used in the CHINAGEM model as the numeraire. The numeraire serves as a price base relative to which changes of other price variables are measured.

We could then move to a long-run closure by endogenising the start-of-year capital stock, K(i) and exogenising EROR(i); by endogenising A_{KG}(i) and exogenising IKRATIO(i); and by endogenising A_{WR} and exogenising LTOT.

Table 4.3 presents the list of the exogenous variable of the long-run closure for the stylised version of CHINAGEM. It also presents swaps between endogenous and exogenous variables performed to generate this long-run closure from the trial closure presented in Table 4.2.

Finally, we could move towards historical and forecast simulations by exogenising variables for which we have either forecasts or historical observations and endogenising corresponding terms representing shifts in technologies, consumer preferences and export-demand functions. For example, by exogenising CG(q) and endogenising A_{3G}(q), we can inform model observed changes to the consumption of groups of commodities (for example, household appliances, food and household services), and solve for changes in consumer preferences with respect to these

Table 4.3 A long-run closure for CHINAGEM

I. List of exogenous variables of the trial closure presented in Table 4.2	
EROR(i)	Expected rate of return in industry i
NFLF	Start-of-year net foreign liabilities in foreign currency
WR_{lag}	Real wage rate in previous year
WR_{flag}	Forecast for real wage rate in previous year
WR_{f}	Forecast for real wage rate
$LTOT_{f}$	Forecast for total employment
TM(c)	Power (one plus the rate) of tariff on imports of commodity c
T3(c, s)	Power of tax on household consumption of good (c, s)
TRANSFERS	Transfers from the public sector to households, e.g., unemployment benefits and interest on the public debt
IKRATIO(i)	Ratio of investment to capital in industry i
A_4(c)	Slack in export-demand function for c
All the A's (Except A_{WR}, A_{KG}(i), A_{3G}(c), and A_3(c) for all c)	Potential slack variables and variables used to represent shifts in technologies and preferences
II. Swap of exogenous and endogenous variables from trial closure of Table 4.2 to generate a long-run closure presented below	
Swap	WR = LTOT
Swap	K(i) = EROR(i)
Swap	A_{KG}(i) = IKRATIO(i)
Swap	PE(c) = A_4(c)
Swap	C = A_C

commodity groups using a simulation with the historical closure. The development of the historical and forecast closures will be discussed in detail in the next two chapters.

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Chapter 5
Closure Development and Historical Simulation from 2012 to 2019

Xiujian Peng

Abstract The historical simulation described in this chapter is an attempt to understand how the Chinese economy evolved from 2012 to 2019. The historical simulation also serves to update the CHINAGEM model's database year-to-year. A detailed step-by-step guide on how to develop a closure for historical simulation is presented. The back of the envelope (BOTE) model is employed to explain the process of conducting a historical simulation. The results of the historical simulation reveal that during the period of 2012 to 2019 (1) China experienced an average annual growth of 3.3% in all-factor augmenting technology improvement; (2) domestic consumers showed a preference for domestically produced goods and services despite import growth; (3) there was a strong outward shift in overall export demand curve indicating continued demand for China's goods and services from the rest of the world; and (4) China's average propensity to consume increased, contributing to the decline in its trade surplus after decades of accumulation.

Keywords Historical simulation · Closure development · Data consistency · BOTE analysis · CGE · China

As mentioned in Chap. 4, the CHINAGEM model contains more variables (N) than equations (M). Hence only M variables can be model-determined (i.e., endogenous) with the remaining variables (N-M) being user-determined (i.e., exogenous). A specification of endogenous/exogenous variables is called a closure.

As with the MONASH model, the classification of endogenous variables and exogenous variables in CHINAGEM is flexible, and is determined in line with the

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requirements of the simulation being conducted. In this chapter we identify four generic simulation types. The simulations are called:

- *Historical* where we update the CHINAGEM database and estimate changes in technologies and preferences through a historical period typically starting in the year of record of the database (2012);
- *Decomposition* where we use the model to explain a period of history in terms of driving forces such as changes in technologies and consumer preferences;
- *Forecast* where we derive base case forecasts for the macro economy and industries through future time that are consistent with trends from the historical simulation and with available expert opinions; and
- *Policy* where we derive changes (or deviations) away from the base case forecast simulation caused by hypothetical policy interventions.

In this chapter, we will only focus on the historical simulation.
A historical simulation generally has two purposes.

1. *Updating the model's database*. The database of CHINAGEM is mainly derived from published Input–Output (IO) tables. But the national IO table is only updated every five years in China. To make reliable and convincing policy simulations using the CHINAGEM model, its database has to be updated frequently. Historical simulation is a way to update the model's database when the new IO table is not available. We can use the observed data published by the statistical bureau or other sources to update the model's database.
2. *Estimating historical trends in the values of unobservable variables such as technology variables, taste variables and shift variables*. The estimated results of these unobservable variables can be used for the forecast and decomposition simulations.

In this section, we will demonstrate how to incorporate historical data into the CHINAGEM model to update its database and understand how the Chinese economy evolved from one year to another. We will also demonstrate how the unobservable variables can be calculated through historical simulation. For these purposes, we start from the 2012 input-output database and perform historical simulations year on year to 2019.[1] Specifically, in Sect. 5.1, we explain the choice of endogenous/exogenous variables and how to build a closure for the historical simulation step by step. In Sect. 5.2 we explain how we inform CHINAGEM of changes in macroeconomic variables over the historical period. In Sect. 5.3 we discuss the results of the historical simulation and give estimates of trends in technology and taste variables over the historical period.

[1] Though economic growth data for 2020 are available, we didn't include year 2020 in the historical simulation. The reason is that the path of China's economic growth was interrupted by the outbreak of the COVID-19. To avoid the unexpected and short-term pandemic to distort the calculation of technology and preference changes during the historical period, we didn't include 2020 data.

5.1 How to Develop a Closure for Historical Simulation

The long-run closure shown in Table 4.3 of Chap. 4 is a typical closure used in simulations with CGE models. In this closure, quantities and prices of outputs and inputs, consumption, international trade, etc., are all endogenous variables; while technology and consumer preferences are exogenous variables. In a conventional policy simulation, the CGE model traces the effects of a change in technology or policy variables (such as a deterioration in agricultural productivity or a tariff cut), and the model calculates the resulting changes in GDP, consumption, output, employment and other endogenous variables.

In a historical simulation, the model operates in a reverse fashion treating GDP, production, consumption and international trade as exogenous, and the corresponding technology and preference change variables (such as all-primary factor augmenting technical change) endogenous. In other words, in a historical simulation, the model is informed by changes in GDP, consumption, investment, and other observed variables across a historical period. It then calculates the necessary changes in technologies and preferences to generate these changes in the *observable* variables.

When configuring the model for historical simulations it is generally best to start with closure changes that allow data for macroeconomic variables to be imposed. Then follow with changes that allow the inclusion of data for more detailed industry and commodity variables such as industry output.

Generally a step-by-step approach works best, combined with careful analysis to understand the effects of each successive change. Typically this step-analysis will employ Back-Of-The-Envelope (BOTE) analyses to verify simulation results when each piece of information is incorporated into the model. A BOTE model that proves very useful in this regard is shown in Box 5.1.[2] In the following paragraphs, we use the BOTE model presented in Box 5.1 to explain how to conduct a historical simulation.

The historical simulation described in this chapter is an attempt to understand how the Chinese economy evolved from 2012 to 2019. We do so by identifying a limited set (macroeconomic only) of observable variables for which values will be imposed. In the context of the BOTE model, we force the model to replicate observed growth in the following macroeconomic variables from 2012 to 2019:

- Real household consumption (C), real investment (I), real government consumption (G), volumes of exports (X) and volumes of imports (M)[3];
- GDP price index (Pg), and
- Population (POP) and employment in persons (LTOT).

[2] The BOTE model can have more or fewer equations than those listed in Box 5.1. For a detailed discussion of the BOTE analysis, see pages 293–298 in Dixon et al. (1982) and pages 108–109 in Dixon and Rimmer (2002).

[3] We calculated the real growth of each macro variable by using the constant price valued GDP, C, I, G, X and M.

- Wage share, which is a new variable in the full CHINAGEM model defined as the ratio of the nominal wage payment to nominal GDP.

We run the historical simulation year on year from 2012 to 2019 (2012 is the database year). For the first year of the historical simulation (2013), growth in K (aggregate capital stock) is determined by I (investment) in the database for 2012. In subsequent years, once we inform the model of growth in investment (I), growth in aggregate capital stock (K) is then determined by the equation block modelling the accumulation of capital through investment.

We start the historical simulation by informing the model about C, I, G, X, and M. Real GDP represented by Y is thus determined by Eq. (5.1) in Box 5.1. Since we have informed the model of I, K in the next year is determined by Eq. (5.5). Since Y and K have been determined, once we inform the model about employment (L), changes in technology (A) will be solved by the aggregate production function, Eq. (5.2). Because growth in the GDP price index (P_g) is also tied down, Eq. (5.3) will solve for the capital rental (Q) and Eq. (5.4) will solve for the wage level (W). In the CHINAGEM model, we assume that the import price is determined by the world market, so P_m is an exogenous variable in the model. The nominal exchange rate, θ, is the numeraire in CHINAGEM. Hence it is exogenous as well. With M, Y, P_g known and P_m and θ exogenous, the model will solve the twist[4] variable in Eq. 5.6. Similarly, with P_g and X known and θ fixed, the model will determine A_4 in Eq. 5.7.

We now show how we set up the historical closure in CHINAGEM. Starting from the long-run closure, we make the following closure changes as we need to introduce macroeconomic data into CHINAGEM.

- **Step 1.** *Closure changes to activate capital supply and capital accumulation equations.* In the long-run comparative static closure, capital is endogenous and the rate of return on capital is exogenous. Investment is determined via a fixed ratio of investment to capital. For the historical closure, we put in place dynamic equations which connect capital available for production in the solution year t to investment and capital (after depreciation) in year t-1, and the mechanism that relates capital growth in year t (i.e., investment in year t) to the expected rate of return on capital for a given required rate of return. This is done by making A_{KG} (i)—a general capital growth shifter by industry exogenous and endogenising IKRATIO(i)—the ratio of investment to capital by industry (see Eqs. (4.2.25) and (4.2.26) in Table 4.1, Chap. 4); and by making endogenous the expected rate of return—EROR(i), with a shift variable, del_f_ac_p_y(i)[5] exogenous. These two swaps allow capital in each industry—K(i) in the first historical simulation year—2013 to be determined by the total amount of investment reported in the

[4] As we explained in Eq. (5.6), the twist variable represents the preference between domestically produced goods and imported goods.

[5] Del_f_ac_p_y(j) is a shift variable in the capital accumulation equation for year-to-year simulation in the standard CHINAGEM model. It can be used to turn on or turn off the capital accumulation equation in the CHINAGEM model.

database in 2012—this is equivalent to K(i) being exogenous (see Eqs. (4.2.24) and (4.2.27) in Table 4.1).

- **Step 2**. *Incorporate changes in total real private consumption (C).* To incorporate historical changes in C, we exogenise C and endogenise the average propensity to consume A_C so that national savings can adjust to match the effect on national investment. This keeps the balance on current account unchanged (see Eq. (4.2.31) in Table 4.1, Chap. 4).[6]
- **Step 3**. *Incorporate changes in total real investment (I).* To incorporate historical changes in I, we exogenise I and endogenise A_{KGT}—an economic-wide general capital growth shifter (see Eqs. (4.2.26) in Table 4.1, Chap. 4). The variable A_{KGT} captures all factors that affect investment other than changes in expected rates of return. Such factors might include perceptions of risk and government policies designed to encourage investments in certain sectors.
- **Step 4**. *Incorporate changes in total real public consumption (G).* To impose values for G we endogenise a shift variable of the ratio $G/C - A_{(5)}$ (see Eq. (4.2.10) in Table 4.1, Chap. 4).
- **Step 5**. *Incorporate changes in the volume of imports (M).* To incorporate historical changes in M, we exogenise M and endogenise the preference change variable, A_{TWIST} (Eqs. 4.2.3, 4.2.6, and 4.2.8 in Table 4.1). The positive/negative change of this shift variable means that consumers in China are in favour of/against imports relative to domestically produced goods. A_{TWIST} is a uniform variable that applies to all commodities.[7]
- **Step 6**. *Incorporate changes in the volume of exports (X).*To incorporate historical changes in X, we endogenise the all-factor augmenting technical change variable, A. Why is it necessary to endogenise A ? We know that from the BOTE model in Box 5.1, after we inform the model X, on the left-hand side of Eq. (5.1), GDP is determined by $C + I + G + X - M$. Meanwhile, on the right-hand side of Eq. (5.2), K is pre-determined by I in the database; and LTOT is already exogenous in the

[6] At this step, we should also incorporate historical changes in population due to the way that consumption demand is specified in CHINAGEM. Here population represents the total number of households. The population is one of the variables which affect the demand for each specific commodity. For example, an increase in population will drive households' demand for subsistence consumption to increase more and luxury consumption to increase less compared to the situation without the population increase. As population is an exogenous variable in the long-run closure, we do not need to change the closure in order to incorporate historical changes in population into CHINAGEM.

[7] In the CHINAGEM model, apart from the uniform preference change variable A_{twist}, there is also a preference change variable for each commodity, $A_{twist}(c)$. This variable is exogenous in the long-run closure. After endogenising A_{twist}, we also need to endogenise $A_{twist}(c)$ to allow the preference for each commodity to change following uniform preference change of the whole economy, A_{twist}. We endogenise $A_{twist}(c)$ by exogenising a shift variable f_twistsrc(c). Furthermore, In the CHINAGEM model, we have a mechanism to convert preference changes into technology changes to meet the changing demand caused by preference changes. To make this mechanism work, we have to endogenise the relevant technology variables for example, a1(c), a2(c).a3(c) by exogenising f_a1(c), f_a2(c) and f_a3(c), respectively.

long-run closure shown in Table 4.3. If we do not endogenise A, then GDP will be over-identified (structural singularity).

- **Step 7**. *Incorporate changes in the GDP price index.* To incorporate historical changes in the GDP price index we exogenise the GDP price index, P_g and endogenise the shift variable of the export demand curve (a non-commodity specific equivalent of A4(c) in (4.2.9) in Table 4.1). We choose to exogenise the GDP price index because after we inform the change of volume of exports in step 6, the GDP price index has to make a necessary change to meet the required change of exports. With the shift variable of the export demand curve exogenised (see Eq. 5.7 in Box 5.1), the change in the GDP price index will always be big and will result in a big change in the terms of trade.[8] These resulting changes will not be consistent with what happened in the historical period. Furthermore, the export demand curve in the historical period normally changed but this change was not observable, so by exogenising the GDP price index, endogenising the shift variable of the export demand curve and informing the model by actual changes in the GDP price index will not only bring the historical change of the terms of trade and also calculate the unobservable change of the export demand curve.
- **Step 8**. *To incorporate the change in aggregate employment (L).* To incorporate the historical change in employment, we have two options. The first option is no closure change. Because LTOT is exogenous in the long-run closure (Table 4.3) we do not need to make closure changes to incorporate historical changes in LTOT. The second option is to make a swap. In the full CHINAGAM model, we have two variables measuring the percentage change of total employment of the whole economy: employ_i and emp_person. But different weights are used when calculating these two variables. The variable employ_i which is also called *aggregate employment—wage bill weight* in the CHINAGEM model, is calculated by averaging the percentage change of employment in each industry using the value of the wage payment of each industry as weights. While the other variable emp_person which is called *aggregate employment—persons*, is calculated by averaging the percentage change of employment in each industry using the employment in persons of each industry as weights. Since the data on employment in persons in each year is available from statistical yearbooks, we can choose to shock the changes of employment in persons instead of LTOT (employ_i). But emp_person is an endogenous variable in the long-run closure. So we can endogenise LTOT and exogenise emp_person through swapping LTOT with emp_person.
- **Step 9**. *To exogenise the wage share and endogenise the shift variable—twistlab for all industries.* In the standard CHINAGEM model, we introduced a new variable—wage share, which is defined as the ratio of the nominal wage payment to nominal GDP. This variable is naturally endogenised. The experimental historical simulation without the shock of wage share shows that the wage share increased rapidly over the period 2012 to 2019. This is not consistent with the observed data in China. In this case, we choose to exogenise wage share and endogenise a shift

[8] Please refer to pages 240–261 in Dixon and Rimmer (2002) for a detailed explanation.

variable twistlab—which captures the cost neutral changes in the labour/capital ratio due to factors other than changes in relative factor prices.

The above steps are necessary for CHINAGEM to replicate the evolution of the macroeconomic environment in China during a given historical period. It is important to at least inform the model about how the income and expenditure sides of GDP evolved and how the price level changed.[9] This provides a macroeconomic framework for the industry/commodity part of the historical simulation to begin with.

After we inform CHINAGEM of the macro variables, we then move to the industry/commodity variables. At the industry level, we force the model to replicate historical growth for output (Y_i), employment (L_i), wages (W_i) and the price of output (P_i).[10] Consequently, the industry versions of the aggregate production function (5.2) and factor market equilibrium conditions (5.3) and (5.4) can jointly solve for the industry-specific capital stock (K_i), rental (Q_i) and technology (A_i).

When introducing historical changes of the industry/commodity variables into CHINAGEM, a good strategy is to first look at changes in aggregate sectors, such as output and employment changes in the agricultural, industrial, and service sectors. A close study of more detailed industries, such as output, exports, imports, and employment in the coal mining, crude oil, gas or wheat industries can follow afterwards. As discussed in Chap. 4, via variables like CG(q) and A_{3G}(q), users can incorporate, e.g., consumption data by main categories (grain, fruit and vegetables, meat and egg, beverages, consumer durables and various services) instead of by all 137 commodities for which statistics are normally not available.

Here we give an example of the closure changes if we want to tell the model the output changes of the three aggregate sectors: agriculture, industry and service. The data on output of these three broad sectors are normally available from statistical yearbooks or international organizations' databases.

To tell the model of the output changes of the three aggregate sectors, we have to exogenise the aggregate variable which is equivalent to X0(c,1,i) in Eq. 4.2.1, and endogenise a technical change variable, A_{1i} in the Eq. 4.2.3 for the aggregated sectors.[11]

Box 5.1 The BOTE Model

The two key BOTE relationships are the GDP identity and the aggregate production function:

$$Y = C + G + I + X - M \tag{5.1}$$

[9] If the historical data related to net foreign liabilities/assets are available, we recommend informing CHINAGEM as well so that the model can calculate the changes in the general national income (GNI) apart from the changes in the GDP.

[10] I denotes industry. In the 2012 database, there are 137 industries.

[11] In the standard CHINAGEM model, to allow A_{1i} changes, we have to further free each sector's technology variable which is represented as *ac*.

and

$$Y = \frac{1}{A} F(K, L) \tag{5.2}$$

where Y is real GDP;
C is real household consumption;
I is real investment;
G is real government expenditure;
X is volume of exports;
M is volume of imports;
K is aggregate capital stock;
L is aggregate employment, and
A is technology variable. A decrease in A allows for technological progress.

Equilibrium in the capital market requires the real cost of using capital to equal the marginal product of capital. Hence:

$$\frac{Q}{P_g} = \frac{1}{A} * F_k(K/L) \tag{5.3}$$

where
Q is the rental price per unit of capital;
P_g is the price of a unit of GDP valued at factor cost, therefore $\frac{Q}{P_g}$ is the real cost of capital;
F_k is the partial derivative of F with respect to K. We write F_k as a function of K/L under the assumption that F is homogenous of degree one.

Labour-market equilibrium requires:

$$\frac{W}{P_g} = \frac{1}{A} * F_l(K/L) \tag{5.4}$$

where
W is the nominal wage rate, $\frac{W}{P_g}$ is the real cost of labour; and
F_l is the partial derivative of F with respect to L.

The next equation in our BOTE model explains capital in next year as the sum of net capital in the current year plus investment. Hence:

$$K_1 = K + I - D. \tag{5.5}$$

where
K and K_1 are the capital stock in the current and following year;
I and D are investment and depreciation in the current year.

The next equation describes import demand. Consistent with the detailed CHINAGEM specification, the volume of imports M is a function of real GDP (i.e., the level of activity), the ratio of the price index of GDP P_g to the import price P_m measured in the Chinese currency based on the nominal exchange rate, θ, and a twist variable—$twistsrc\_c$. The price ratio is a measure of the real exchange rate. An increase, or appreciation means all else unchanged that domestically-produced goods and services are less competitive relative to foreign-produced products. The twist variable represents the preference between domestically produced goods and imported goods.

$$M = F\left(Y, \frac{P_g}{\theta * P_m}, twistsrc\_c\right) \tag{5.6}$$

Equation 5.7 is the BOTE representative of the export price equation in the CHINAGEM model. The foreign currency price of export price $\theta * P_g$[12] is the function of export volume X and a shift variable A_4 that can move the export demand curve.

$$\theta * P_g = F(X, A_4) \tag{5.7}$$

5.2 Data Sources and Data Consistency Issues

The following is a list of useful data and their sources for developing historical simulations for China:

- World Bank: World Development Indicators (WDI) for data on income and expenditure sides of GDP in both constant and current prices in local currency or US dollars; data on population and working-age population; Data for the output growth of macro sectors;
- International Monetary Fund (IMF): data on foreign assets and liabilities;
- China input–output tables 1992, 1997, 2002, 2007, 2012 and 2017;
- China Statistical Yearbook: income and expenditure sides of GDP; price indices; industry output; wages; etc.
- China Statistical Yearbook: data on population, total employment, rural employment and urban employment, unemployment;
- China Labour Statistical Yearbook: employment and wage by industries;
- United Nations Population Division: population and labour force data;
- Population institutes that are experts on population forecast for population and labour force data;

[12] P_g includes the price of exports but not the price of imports. In the BOTE model, P_g is a proxy for the domestic currency export price. After multiplying it with the nominal exchange rate, θ, we get the foreign currency export price P_e.

- Population census data for detailed information related to different categories of labour;
- China Rural Statistical Yearbook and the Cost and Revenue of Agricultural Products in China for agricultural output and labour productivity;
- United Nations COMTRADE for trade statistics;
- China Energy Statistical Yearbook, BP and the International Energy Agency (IEA) for energy data.

You will notice that the list above contains multiple sources of data for the same variable. For example, there are several alternative sources of information on population and labour force. It is very useful to cross-verify data from different sources and check if they tell the same story. The strategy for incorporating seemingly contradictory information is to decide which number or source has priority and is consistent with the key variables. Box 5.2 shows an example of the practice.

In Box 5.2, we identify real GDP as the key variable, the growth rate of which is to be consistent with the growth rate published in the WDI report. To ensure this is the case in the historical simulation where we target all components of GDP, we must adjust the growth rates imposed for each of the expenditure components such that when weighted by the initial levels data in the CHINAGEM database we get exactly the growth rate of GDP as reported in the WDI.

This process of data reconciliation does not apply only to GDP and its components. For example, if we were to impose growth rates in consumption by commodity it is possible that these growth rates imply growth in total consumption that is different from that calculated for the GDP identity. If this is the case, then a good strategy is to take *aggregate* consumption as the priority. To maintain changes in the pattern of consumption the adjustment necessary to achieve consistency for aggregate consumption should be applied in an equi-proportionate way across all items in the household budget.

Table 5.1 presents the growth rates of real GDP and its expenditure components during 2013–2019 derived from the WDI database. Using the scaling method we described in Box 5.2, we get the growth rates of GDP components shown in Table 5.2. These growth rates are imposed as shocks for the historical simulation.

Box 5.2 Data Consistency Issues

Data from different sources are invariably inconsistent with one another; even data from the same source could be inconsistent for various reasons. To understand what happened to the Chinese economy during 2012–2019, a major task is to absorb the information presented from various data sources and make them coherent.

For example, the growth rates of consumption, investment, government expenditure, exports, imports and real GDP from 2012 to 2019 should be consistent with the GDP identity. Here we take *World Development Indicators*

Table 5.1 WDI: growth rates of real GDP and its components (2013–2019,%)

	Real GDP	GDP price index	Real household consumption	Real investment	Real government expenditure[a]	Export volumes[a]	Import volumes[a]
2013	7.8	2.2	8.9	9.4	8.1	5.9	6.7
2014	7.4	1.0	9.2	7.5	6.0	3.5	4.6
2015	7.0	0.0	8.7	3.6	8.2	−4.1	−10.6
2016	6.9	1.4	8.9	7.2	7.2	−0.5	4.9
2017	7.0	4.2	9.5	6.3	9.5	5.1	8.3
2018	6.8	3.5	8.3	6.8	9.6	4.9	10.6
2019	6.0	1.3	6.4	4.0	5.9	5.6	1.3
Average of 2013–2019	**7.0**	**2.0**	**8.6**	**6.4**	**7.8**	**2.1**	**3.0**

Source [a]These data are calculated based on the data from China Statistical Yearbook, 2020. All other data are from World Development Indicators (WDI), World Bank online database

Table 5.2 Historical simulation: growth rates of real GDP and its components (2013–2019,%)

	Real GDP[a]	GDP price index[b]	Real household consumption	Real investment	Real government expenditure	Export volumes	Import volumes
2013	7.8	2.2	8.2	8.6	7.5	5.4	6.2
2014	7.4	1.0	9.4	7.6	6.1	3.6	4.7
2015	7.0	0.0	9.3	3.8	8.8	−4.4	−11.3
2016	6.9	1.4	9.5	7.7	7.6	−0.5	5.2
2017	7.0	4.2	9.1	6.0	9.0	4.8	7.9
2018	6.8	3.5	8.3	6.7	9.6	4.9	10.6
2019	6.0	1.3	6.6	4.1	6.1	5.8	1.3
Average of 2013–2019	**7.0**	**2.0**	**8.6**	**6.4**	**7.8**	**2.7**	**3.3**

Source [a]Real GDP growth rates are calibrated simulation results. [b]The GDP price index is from WDI. GDP components results from 2013 to 2019 are scaled results using the method we explained in Box 5.2

(WDI) as the data source for the growth rates of real GDP and its expenditure components.

Before we impose on the model these growth rates, we check whether the real GDP growth and the growth rates of its components satisfy the GDP identity:

$$Y = C + I + G + X - M \tag{5.8}$$

where GDP, C, I, G, X, and M are levels of GDP, consumption, investment, government expenditure, exports and imports.

To do this, we multiply the levels of C, I, G, X and M in the 2012 CHINAGEM database (for which the main source of data is the 2012 input-output table) with their respective WDI growth rates to see if the implied changes in GDP components sum to the initial level of GDP in the CHINAGEM database multiplied by the WDI growth rate for real GDP. We illustrate this here for the year 2013.

	2012 levels in CHINAGEM database (10 million yuan)	WDI growth rates in 2013 (%)	Resulting changes in 2013 (10 million yuan)	Scaled growth rates (%)
	(a)	(b)	(a)*(b)/100	
Consumption	1980,964	8.9	175,513	8.2
Investment	2383,522	9.4	223,336	8.6
Government	731,276	8.1	59,233	7.5
Stock	126,934	0	0	0.0
Exports	1368,740	5.9	80,756	5.4
Imports	−1030,086	6.7	−69,119	6.2
Real GDP	5561,350	**7.8**	**432,117**	–
Sum of GDP components	–	–	**469,720**	–

Note Changes in stock are assumed to be zero because in the BOTE we ignore stocks

We can see from the above calculation that the growth rates of GDP components imply a larger change in real GDP (469,720) than that suggested by the real GDP growth rate of 7.8% (432,117).

To deal with this inconsistency in data, we scale the growth rates of GDP components proportionally so that they are consistent with the real GDP growth rate of 7.8% for the year 2013 (in terms of GDP identity). In this case, we choose to believe real GDP growth rate as being more reliable than the growth rates of its components, and we, therefore, maintain the real GDP growth as 7.8% for China in 2013.

While the growth rates of GDP components are adjusted, the pattern presented by the WDI data is preserved. That is, household consumption and investment grew faster than real GDP (see the middle and last column in the table above), and trade grew slower than real GDP.

Via this way, we have incorporated information presented by the WDI database on the growth rates of all six macroeconomic variables into the historical simulation while ensuring data coherence in terms of the GDP identity.

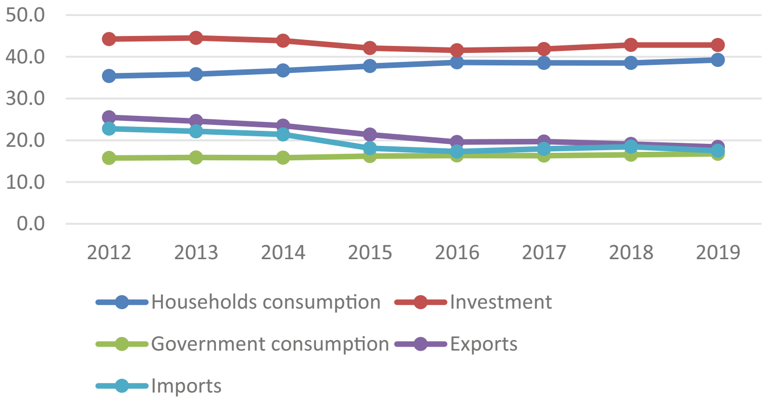

Fig. 5.1 Shares of the GDP components (2012–2019, %). *Source* Author's calculation based on the simulation results

Tables 5.1 and 5.2 show that China experienced growth in real GDP of 7.0% annually from 2013 to 2019. Within Gross National Expenditure (GNE), real private and government consumption grew slighter faster than real investment (or gross fixed capital formation), although the latter grew strongly as well. This growth pattern is different from China's experience in the 1980s, 1990s and 2000s when investment grew much faster than consumption. The new growth pattern indicates that China has gradually moved away from relying on investment to boost its economic growth. Figure 5.1 also shows that the share of investment in China's GDP displays a declining trend while the share of household consumption presents a rising trend in the period 2012–2019.

Both export and import volumes grew on average much slower than real GDP and GNE. Again, this pattern is different from what China experienced in the 1990s and 2000s when trade growth was significantly higher than domestic consumption growth. This suggests that China has relied more on domestic consumption to sustain its economic growth. This pattern can also be observed in Figure 5.1 where the shares of imports and exports in GDP have been declining in the period 2012–2019. We also notice that the annual growth rates of both exports and imports fluctuate dramatically during the historical period.

On average, the volume of imports grew faster than the volume of exports. This fact contributed to the decline of China's trade surplus during the period. Again, this picture is different from what happened in the 2000s when China's exports grew faster than its imports and China accumulated a large amount of trade surplus.

We now look at the production factors, for example, employment. Table 5.3 shows that the growth rate of total employment has been declining from 2013 to 2017 and it turned negative in 2018. Much of this declining trend in employment growth is due to a declining working-age population arising from population ageing. Table 5.3 shows that total population grew between 2012 and 2017 but at a low rate. The growth rates in 2018 and 2019 are much smaller than those from 2013 to 2017. The population growth

Table 5.3 Growth rates of employment and population (2013–2019, %)

	Number of persons employed (China Statistical Yearbook)	Number of persons employed (WDI)	Total population (China Statistical Yearbook)	Total population (WDI)
2013	2.7	n.a[a]	0.5	0.5
2014	2.8	n.a	0.5	0.5
2015	2.0	n.a	0.5	0.5
2016	1.5	n.a	0.6	0.5
2017	0.4	n.a	0.5	0.6
2018	−0.5	n.a	0.4	0.5
2019	−1.2	n.a	0.3	0.4
Average of 2013–2019	**1.1**		**0.5**	**0.5**

[a]n.a. means not available

Source China Statistical Yearbook 2020 and WDI, World Bank online database

data from both sources (China Statistical yearbook and WDI) are similar though WDI has higher growth rates in most years. Since the employment data (number of persons employed) is not available from WDI, in order to keep the employment data consistent with population data we choose to use both employment and population data from China Statistical Yearbook. We would like to point out that the difference in the growth rates between population and the number of persons employed comes from several reasons: the change in the unemployment rate, the change of labour force participation rates, the change in the growth rate of the working-age population, and shifts in the population structure.

After we get the data for the macro variables, we begin to look for the data at the industry level. Here we give an example of three aggregate sectors: agriculture, industry and service. Table 5.4 shows that the agricultural sectors grew much slower than the industry and service sectors, and the service sectors grew much faster than the industry sectors. The CHINAGEM historical simulation maintains this pattern presented in WDI data. However, the numbers are different because they are adjusted to agree with the 2012 input-output database and real GDP growth. The adjustment was carried out in a similar manner to the GDP expenditure components adjustments discussed in Box 5.2.

Table 5.4 Growth rates of three macro sectors (2013–2019, %)

	Data from World Bank			Data used in the simulation		
	Agriculture	Industry	Service	Agriculture	Industry	Service
2013	3.8	8.0	8.3	3.9	8.1	8.4
2014	4.1	7.2	8.3	4.1	7.2	8.3
2015	3.9	5.9	8.8	3.8	5.7	8.4
2016	3.3	6.0	8.1	3.3	6.0	8.0
2017	4.0	5.9	8.3	3.9	5.6	8.1
2018	3.5	5.8	8.0	3.4	5.7	7.9
2019	3.1	4.9	7.2	3.0	4.8	7.3
Average of 2013–2019	**3.7**	**6.2**	**8.1**	**3.6**	**6.2**	**8.0**

Source WDI World Bank online database

5.3 Historical Simulation Results Analysis

After we inform the model the changes in the exogenous variables, the historical simulation will update the CHINAGEM model's database year-to-year from 2012 to 2019. Meanwhile, as we mentioned in the previous section, one of the purposes of the historical simulation is to calculate the changes of unobservable variables such as technology, preference and shift variables.

Table 5.5 shows changes in the unobservable variables deduced in our simulation for 2012 to 2019. Numbers in column 2 are for growth rates in the observable variables. Numbers in column 5 are the implied growth rates in the unobservable variables. Thus for example, the exogenously imposed growth in consumption of 8.6% per annum is accompanied by an increase in the average propensity to consume of 0.9% per annum.

In order to understand the growth pattern of the Chinese economy over the period 2012 to 2019, we also display the historical simulation results from 2002 to 2007 using the CHINAGEM model 2002 database undertaken by Mai et al (2010).

Comparing the two sets of results yields a number of interesting stories.

- China's average propensity to consume increased between 2012 and 2019 (Column 5, Table 5.5), but decline between 2002 and 2007. This corroborated our assumption in Sect. 5.1 that China changed its growth pattern away from relying on investment and trade to relying more on domestic consumption. This is one of the reasons that China's trade surplus began to decline after accumulating for more than two decades.
- Between 2012 and 2019, to accommodate the given increase of investment, the general capital growth shifter, which is related to the required rate of return on capital, has to change by 0.004 annually on average (Column 5, Table 5.5). The positive change of this variable implies that the risk of investment is higher. This is consistent with the lower growth rate of investment in this period (6.4% on average) compared with a high growth rate of 11.3% in the last period 2002–2007.
- Different from the period of 2002–2007 when the government expenditure increased relatively faster than the household consumption (Shifter in the ratio

Table 5.5 Historical simulation results: changes in preference, technology and shift variables (average annual growth rate, %)

Macro variables	(1) 2002–2007[b]	(2) 2012–2019	(3) Corresponding preference and technical change variables	(4) 2002–2007	(5) 2012–2019
Real household consumption	6.8	8.6	Average propensity to consume (A_C)	−4.1	0.9
Real investment	11.3	6.4	General capital growth shifter[a] (A_{KGT})	−0.003	0.004
Real government expenditure	7.4	7.8	Shifter in the ratio G/C ($A_{(5)}$)	1.2	−0.8
Volume of exports	20.9	2.7[c]	All-factor augmenting technical change (A)	−6.7[d]	−3.3[d]
Volume of imports	15.0	3.3[c]	Twist towards imported goods (A_{TWIST})	6.3	−8.9
GDP price index	4.9	2.0	Shifter in the foreign demand curve (A_4)	48.1	6.6
Wage share	–	0.3	Cost-neutral change in labour/capital ratio (twistlab)	–	−1.6
Output by aggregate sectors					
Agriculture	4.6	3.6	Shifter in technology change for agricultural products (fac_a(aff))	−6.4	−1.5
Industry	12.3	6.2	Shifter in technology change for industrial products (fac_a(ind))	0.0	0.0
Service	12.1	8.0	Shifter in technology change for service products (fac_a(srv))	2.0	0.2

Note [a]This is an ordinary change variable instead of a percentage change variable
[b]Because of the 2008 and 2009 global financial crises, we didn't include these two years in the simulation
[c]The average annual growth rates of imports and exports are low because of the negative growth in some years
[d]In the CHINAGEM model, a negative number of the technology variable means technology improvement, specifically it means that producing the same amount of goods needs less inputs
Source Columns (1) and (2) are the shocks we gave to the model. Column (4) is the simulation results using the 2002 database and column (5) is the simulation results using the 2012 database

G/C, $A_{(5)}$ is positive, 1.2 %, Column 4, Table 5.5), government expenditure over the period 2012–2019 increased relatively slower than household consumption ($A_{(5)}$ is negative, −0.8%, Column 5, Table 5.5).

- In both periods the outward shift in overall export demand (the positive result of shifter in the foreign demand curve A_4) was strong. However, growth of demand in the latter period is not as strong as in the period 2002 to 2007 when the export demand curve had a very large outward shift (48% annually, Column 4, Table 5.5). That was due to rapid growth in exports of the heavy manufacturing products in the period 2002–2007 when China started to export TVs, refrigerators, washing machines, iron and steel, etc. in addition to clothing and toys. The heavy manufacturing industries were opened up to foreign and domestic private capital following China's WTO entry in 2001 (Mai 2001). The reform greatly facilitated the production and export growth of these goods. After more than ten years of rapid growth, export growth slowed down in the 2010s. This is consistent with our assumption that China has changed its growth pattern by relying less on exports to sustain its economic growth.
- In contrast to the period 2002–2007 when the import/domestic preference (*twistsrc_c*) is strongly positive (6.3%, Column 4, Table 5.5) which means that Chinese consumers strongly preferred imported goods, the import/domestic preference became negative in the period 2012 to 2019 (−8.9%, Column 5, Table 5.5). This means after decades of development the products and services provided by China's industries have gained the trust of domestic consumers. Domestic consumers started to favour domestically produced goods and services, though imports have been growing at an average of 3.3% annually in this period.
- During the period of 2012 to 2019, all-factor augmenting technology improvement *(A)*[13] was around 3.3% annually which is much slower than that during the period 2002 to 2007. This is understandable. After more than three decades of rapid growth driven partly by technology catching up, China is very close to the technology frontier. Further economic growth will rely more on technological innovation.
- Twitstlab—a cost neutral change of labour/capital ratio experienced an annual −1.6% change across all industries. This means during the historical period 2012 to 2019 all industries in China intended to use more capital and less labour. There is no calculation for the variable twistlab in the historical simulation for the period of 2002–2007.
- For the three aggregated sectors during 2012 to 2019, there is a much smaller technology improvement in the agricultural sectors (−1.5%, Column 5, Table 5.5) comparing with the period of 2002 to 2007 (−6.4%, Column 4, Table 5.5). Same reason as what's happened to all-factor augmenting technology improvement. After many years rapid catching-up, the technology improvement became slower. Furthermore, a large amount of surplus labour moving out of agricultural sectors

[13] The technical variable A in CHINAGEM represents all primary factors (labour, capital and land) augmenting technology improvement. It does not include intermediate input saving technology improvement.

and moving into industrial and service sectors also contributed to rapid increase in the technology improvement in the period of 2002 to 2007 while in the 2010s, with the running out of rural surplus labour, this contribution became smaller. There is no much technology changes in the industrial sectors in both simulation periods. The service sectors suffered a smaller technology deterioration in the period of 2012 to 2019 (0.2%, Column 5, Table 5.5) comparing with the period of 2002–2007.

The preference, technology, shift of export demand curve and other behaviour and structural change variables calculated from the historical simulation shown in Table 5.5 can be used as references in the forecast simulation in the next chapter.

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Chapter 6
Closure Development and Forecast Simulation from 2020 to 2030

Xiujian Peng

Abstract This chapter provides a comprehensive explanation of how to develop a closure for forecast simulation, an integral part of baseline development, with a focus on the Chinese economy. Additionally, we illustrate how to take into account possible future changes that may cause the Chinese economy to deviate from its historical growth path. Compared with the historical period 2012 to 2019, the key features of the forecast simulation results for the period 2020 to 2030 include: (1) Real GDP growth in the forecast period is lower than in the historical period mainly due to the negative growth in the labour force and the consequent lower growth in capital stock; (2) China has to rely on productivity improvement to sustain its economic growth; (3) Real wage will keep growing at a higher rate reflecting the continuous strong technology improvement and declining growth in the labour force; and (4) growth of imports will be higher than that of exports, therefore China's trade surplus will further decline.

Keywords Forecast simulation · Closure development · CGE · China

In this chapter, we will explain how to develop a closure for the forecast simulation. We will also illustrate how to take into account possible future changes that may cause the Chinese economy to deviate from its historical growth path. We then run the forecast simulation from 2020 to 2030 and discuss the simulation results.

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6.1 How to Form a Closure for Forecast Simulation

Forecast closures are similar to historical closures. "Instead of exogenising everything that we know about the past, in forecast closures, we exogenise everything that we think we know about the future" (Dixon and Rimmer 2002).

We start by assembling a credible set of forecasts for the macro economy to be imposed in the forecast simulations. For example, the real GDP growth rate. The Chinese government's Five Year Plan normally provides the goal of real GDP growth. International organizations such as the World Bank and the International Monetary Fund also have an economic growth outlook for China. For the specific variables such as growth of labour force and population, we normally can find the information from the United Nations' World Population Prospects and from some population research institutes in China such as China Academy of Social Sciences, Shanghai Academy of Social Sciences. Regarding energy production and trade, the International Energy Agency (IEA) is a good place to look at. But for the other macro variables such as the expenditure-side components of GDP, relatively little information is available from external sources.

A typical forecast closure is very similar to a typical historical closure. In the latter all variables that can be observed are exogenous while a corresponding number of unobservable variables are endogenous. In a forecast closure all variables for which we have reliable forecasts are exogenous with a corresponding number of variables endogenous.

Since the forecast for the real GDP growth is normally available, so we will chose to exogenise real GDP growth and exogenise a corresponding variable for example, all factor augmenting technology variable. Normally the forecasts for the components of GDP from the expenditure side are few and the results among different organizations vary. In this case, if we believe that China will continue its growth pattern in the forecast period, for example:

- China will continue to rely more on the domestic market to sustain its economic growth, and then both consumption and investment will grow at a higher rate than exports and imports. The recent global economic downturn, the COVID-19 pandemic and the trade war between the United States and China raised the alarm for China that revenues from exports may no longer be as reliable as they were in the last several decades. Export demand conditions look less promising with increasing anti-globalization and other trade dispute cases with the United States and Australia.
- China will continue to rely more on consumption and less on investment to sustain its economic growth, and then both household consumption and government consumption will grow at a slightly higher rate than investment.
- Service sector will continue to grow faster than both industrial and agricultural sectors and
- Industrial sectors will continue to grow faster than the agricultural sectors.

Table 6.1 Shocks in the forecast simulation: growth rates of real GDP, its components, labour force and population (2020–2030, %)

	(1) Real GDP[a]	(2) Real household consumption	(3) Real investment	(4) Real government expenditure	(5) Exports	(6) Labour force	(7) Population
2020[a]	2.4	−2.1	4.4	1.7	2.4	−0.4	0.3
2021	8.1	8.5	7.9	7.8	8.3	−0.4	0.2
2022	5.5	5.9	5.4	5.6	4.8	−0.5	0.1
2023	5.3	5.7	5.2	5.4	4.8	−0.2	0.1
2024	5.2	5.6	5.1	5.3	4.5	0.2	0.0
2025	5.1	5.5	5.0	5.2	4.4	0.0	−0.0
2026	4.9	5.3	4.8	5.0	4.2	0.3	−0.1
2027	4.8	5.1	4.7	4.8	4.1	−0.5	−0.1
2028	4.6	5.0	4.5	4.6	4.0	−1.1	−0.1
2029	4.5	4.8	4.4	4.5	3.8	−0.7	−0.2
2030	4.3	4.6	4.2	4.3	3.7	−0.8	−0.2

Source [a]Real GDP growth rates in 2020 and 2021 were from the World Development Indicators, World Bank online database obtained in June 2022. Real GDP growth rates from 2022 to 2030 are from the World Economic Outlook and International Monetary Fund. GDP components are scaled results using the method we explained in Box 5.2 in Chap. 5. Labour force and population data are from the Shanghai Academy of Social Sciences

Then we can use the same scaling method we discussed in Chap. 5 to get the growth rates of the GDP components on the expenditure side—C, G, I, and E for the forecast period 2020–2030 (Table 6.1).

Table 6.1 shows the value of macroeconomic variables that are tied down in our forecast simulation out to 2030. To introduce these shocks we make the following closure changes.[1]

- **Step 1**. Same as the historical closure, closure changes to activate capital supply and capital accumulation equations. For this purpose, we exogenise A_{KG}(i) and endogenise IKRATIO(i), endogenise the expected rate of return on capital, EROR(i) and exogenise the shifter variable del_f_ac_p_y(i).
- **Step 2**. Same as the historical closure we exogenise C and endogenise average propensity to consume A_C.
- **Step 3**. Same as the historical closure, we exogenise I and endogenise the shift variable in the capital supply curve, A_{KGT}.
- **Step 4**. Same as the historical closure, we exogenise G and endogenise $A_{(5)}$.

[1] Alternatively, for steps 2 and 6, we do not need to have swaps, we simply impose on the model values for household tastes and technology changes that are extrapolations of the values projected in the historical simulation.

Table 6.2 Shocks in the forecast simulation: growth rates of three macro sectors (2020–2030, %)

	(1) Agriculture	(2) Industry	(3) Service
2020[a]	3.0	2.6	2.1
2021	4.2	8.2	8.6
2022	2.9	4.6	6.8
2023	2.9	4.5	6.7
2024	2.8	4.5	6.6
2025	2.8	4.4	6.6
2026	2.6	4.2	6.1
2027	2.6	4.1	6.1
2028	2.6	4.1	6.0
2029	2.5	4.0	5.9
2030	2.5	4.0	5.8

Source [a]Data for three macro sectors in 2020 are scaled results based on the statistical data from the World Development Indicators, World Bank online database. Data for three sectors from 2021 to 2030 are scaled results using the method we explained in Box 5.2, Chap.5

- **Step 5**. Different with historical closure, we exogenise X and endogenise the shift variable in the export demand curve (a non-commodity-specific equivalent of A_4(c) in Eq. (4.2.9) in Table 4.1, Chap. 4.
- **Step 6**. Different with historical closure, we exogenise GDP and endogenise all-factor augmenting technical change (A).
- **Step 7**. Same as the historical closure, we exogenise the wage share and endogenise the shift variable—twistlab. Without controlling the wage share growth, the decline of the labour force and the improvement in technology would drive the real wage to increase rapidly. This would result in an unrealistically fast increase in the share of labour in primary factor inputs and a fast decline in the share of capital and a slow growth of the capital stock.

We also inform CHINAGEM changes to other exogenous variables such as labour force and population. For these variables, in this chapter we take on board trends predicted by the Shanghai Academy of Social Sciences in China (Columns 6 and 7, Table 6.1).[2]

Furthermore, in the forecast simulation, we also shock the growth of three macro sectors (columns 1–3 in Table 6.2).[3]

[2] Though the United Nations and World Bank also have the population projection available, we think that their assumptions for the fertility rates in China are relatively too high.

[3] We also can incorporate into the forecast simulation preference and technical change variables at the commodity and industry level if we have such information available.

6.2 Forecast Simulation and Its Results

After we shock the macro and specific industrial variables shown in Tables 6.1 and 6.2 in the forecast simulation, we get the results for the forecast period from 2020 to 2030. Because of the COVID-19, China experienced a very low economic growth in 2020 and a rapid recovery growth in 2021. These two years' economic growth fluctuation affect the general economic growth trend and the average annual growth rate between 2020 and 2030. To avoid the distortion, we also calculate the average annual growth rates of macro variables from 2022 to 2030 which we think are more comparable with the historical period of 2012 to 2019 (Column 3,Table 6.3). Comparing with the historical period 2012 to 2019, the key features of the forecast simulation results (Column 3, Table 6.3) are as follows.

1. Real GDP growth in the forecast period is lower than in the historical period mainly due to the negative growth in labour force (Column 6, Table 6.1) and the consequent lower growth in capital stock.

Table 6.3 Historical and forecast simulation results: macroeconomic indicators (average annual growth rate, %)

	Historical	Forecast	
	(1) 2012–2019	(2) 2020–2030	(3) 2022–2030
Exogenously given			
Real GDP	**7.0**	5.0	**4.9**
Real household consumption	**8.6**	4.9	**5.3**
Real investment	**6.4**	5.1	**4.8**
Real government expenditure	**7.8**	4.9	**5.0**
Volume of exports	**2.7**	4.4	**4.2**
Employment (Persons)	**1.1**	−3.7	**−3.7**
Model generated results			
All-factor augmenting technical change	**−3.3**	−3.0	**−3.0**
Capital stock	**5.5**	4.7	**4.7**
Effective labour input (employment-wage bill weight)	**1.7**	−0.0	**0.0**
Real wage	**6.0**	5.1	**4.9**
Volume of imports	**3.3**[a]	3.7	**4.3**
GDP price index	**2.0**[a]	−0.0	**0.4**
Real devaluation	**−1.9**	0.0	**−0.4**
Terms of Trade	**1.9**	0.1	**0.4**

Source [a]This is exogenously given shock. Simulation results

2. China has to rely on productivity improvement to sustain its economic growth. The growth rate of the all-factor augmenting technology improvement is around 3% annually on average which is more than 0.3 percentage points lower than the last decade.
3. Real wage will keep growing at a higher rate reflecting the continuous strong technology improvement and declining growth in labour force.
4. Growth of imports will be higher than that of exports, therefore China's trade surplus will further decline.
5. To support a higher import growth, there needs a real appreciation of the Chinese currency (real devaluation is −0.4% annually on average from 2022–2030).
6. The positive change of the GDP price index also implies an improvement of the Terms of Trade[4] (Terms of trade is 0.4% higher annually on average from 2022–2030).

The forecast simulation also generates changes in the endogenous technology and preference variables (Columns 6 and 7 in Table 6.4). In general, the slower growth rates of the macro variables generate slower changes in the technology and preference variables. But the growth pattern of those variables in the forecast simulation are similar with the historical period:

- China's average propensity to consume will continue to increase. This is consistent with our assumption that China will continue to rely more on domestic consumption to sustain its economic growth;
- The risk of investment will slightly increase (a positive change of general capital growth shifter, A_{KGT}, column 7, Table 6.4)
- Government expenditure will increase relatively slower than household consumption (a negative change of $A_{(5)}$, Column 7, Table 6.4).
- The outward shift in overall export demand for Chinese goods (the positive result of shifter in the foreign demand curve A_4) will still be strong.
- All-factor augmenting technology improvement (A) will keep increasing to sustain China's economic growth.
- A cost neutral change of labour/capital ratio will continue to be negative (a negative change of twitlab). This means all industries in China will continue their historical trend: using more capital and less labour.
- For the three aggregated sectors, there will be a small technology improvement in the agricultural and industrial sectors (negative changes of *fac_a(aff)* and *fac_a(ind),* Column 7, Table 6.4), while the service sectors suffer a minor technology deterioration (a positive change of *fac_a(srv),* Column 7, Table 6.4).

Figure 6.1 shows the level of GDP in current prices obtained from the historical and forecast simulations. If historical trends prevail, China's GDP is likely to achieve about 165.5 trillion RMB by 2029.

[4] Terms of trade is defined as price of exports/price of imports. With the fixed imports price, the increase in the GDP price index (which include exports) means the increase of the terms of trade.

Table 6.4 Results of historical and forecast simulations: changes in preference, technology and shift variables (average annual growth rate, %)

Macro variables	(1) 2012–2019	(2) 2020–2030[a]	(3) 2022–2030	(4) Corresponding preference and technical change variables	(5) 2012–2019	(6) 2020–2030	(7) 2022–2030
Real household consumption	8.6	4.9	5.3	Average propensity to consume[a] (A_C)	0.9	−0.3	0.2
Real investment	6.4	5.1	4.3	General capital growth shifter (A_{KGT})	0.004	0.002	0.002
Real government expenditure	7.8	4.9	5.0	Shifter in the ratio[a] G/C ($A_{(5)}$)	−0.8	0.0	−0.3
Volume of exports	2.7	4.4	4.2	Shifter in the foreign demand curve (A_4)	6.6	4.7	5.1
Volume of imports	3.3	3.7	4.3	Twist towards imported goods (A_{TWIST})	−8.9	–	–
GDP price index	1.9	−0.0	0.4	All-factor augmenting technical change (A)	−3.3	−3.0	−3.0
Wage share	0.3	−0.1	−0.1	Cost-neutral change in labour/capital ratio (twistlab)	−1.6	−2.6	−2.5
Output by aggregate sectors				fac_a (A_{1i})			
Agriculture	3.6	2.9	2.7	Shifter in technology change for agricultural products[a] (fac_a(aff))	−1.5	−0.6	−1.1
Industry	6.2	4.5	4.3	Shifter in technology change for industrial products (fac_a(ind))	0.0	−0.1	−0.2
Service	8.0	6.1	6.3	Shifter in technology change for service products (fac_a(srv))	0.2	1.3	1.6

Sources Historical and forecast simulations. [a]The average results were affected by the economic fluctuation from 2020 to 2021 because of the COVID-19

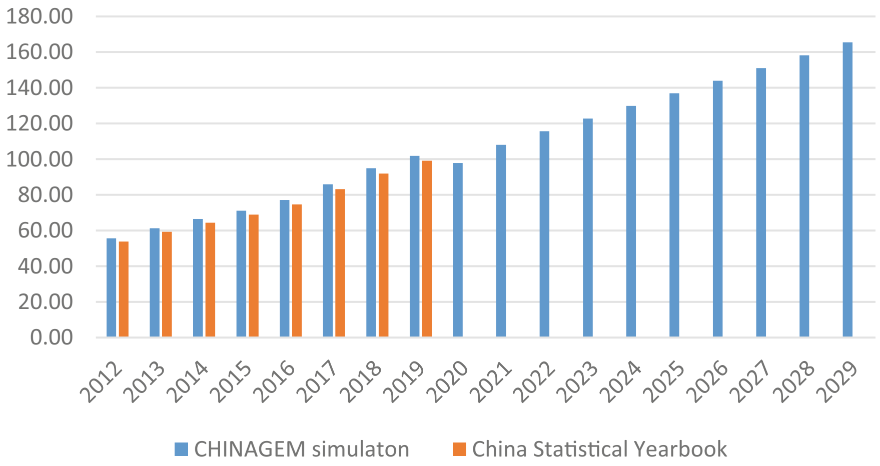

Fig. 6.1 Historical and forecast simulations: Current price GDP (2012–2029, trillion RMB). *Source* Simulation results

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Chapter 7
Closure Development and Policy Simulation—The Effects of Increasing Required Rate of Return on Capital

Xiujian Peng and Philip Adams

Abstract The CHINAGEM model has been widely utilized to analyse various policies in China. In this chapter, we delve into the process of forming a policy closure and conducting policy deviation analysis using a Back Of the Envelope (BOTE) model in detail. We illustrate this approach by analysing the effects of an exogenously imposed uniform increase to the required rate of return on capital in each industry as an example. The increase in the required rate of return on capital reflects a decline in the business confidence in investment or an increase in the risk of investment in a certain market. The simulation results reveal that in the first year, the policy shock leads to a decline in investment. Employment falls as a result of increased cost of labour induced by the policy shock, which generates a lower real GDP. By the end of simulation period in 2030, the increase in the required rate of return on capital dampens China's real GDP growth primarily by reducing capital growth.

Keywords Closure development · BOTE model · CGE · Policy simulation · Rate of return on capital · China

Policy simulations are used to project the economic costs and benefits of exogenously imposed changes, such as the implementation of a new government policy or global events that affect China's trade position. Typically, the effects are expressed as differences between two alternative projections (see Fig. 2.1, Chap. 2): one without the exogenous shock (baseline scenario) and one with the policy shock in place (policy scenario). CHINAGEM has been used by many organizations to analyse a range of policies in China. In this chapter, we discuss how to form a policy closure and how to analyse policy deviations using a BOTE (Back Of The Envelope) model. We illustrate this approach by analysing the effects of an exogenously imposed uniform

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increase to the required rate of return on capital in each industry as an example. The increase in the required rate of return on capital reflects a decline in the business confidence in investment or an increase in the risk of investment in a certain market. Many factors would bring around an increase in the required rate of return in China, for example, concerns of global investors (including Chinese investors) surrounding population ageing and the damage that might occur to Chinese economic growth in the future, or concerns surrounding the growing friction between China and the U.S. in the trade area in recent years and the rising risks that may bring.

7.1 How to Form a Policy Closure

The purpose of the policy simulation is to investigate the effects of a policy shock on the macro economy and industries. Hence key variables such as real GDP, capital, employment, consumption, investment, exports and imports must be endogenous.

The policy closure, which is imposed in each year of the simulation, is similar to a long-run comparative-static closure (Table 4.3, Chap. 4), with year-to-year dynamic equations allowed to operate. Starting with the long-run closure, we generate a typical policy closure in five steps.

- Step 1. Activate capital supply and capital accumulation equations. In the long-run comparative static closure, capital is endogenous and the rate of return on capital is exogenous. Investment is determined via a fixed ratio of investment to capital. But for the policy closure, we put in place dynamic equations which connect capital available for production in the solution year t to investment and capital (after depreciation) in year t−1, and the mechanism that relates capital growth in year t (i.e., investment in year t) to the expected rate of return on capital for a given required rate of return. This is done by making exogenous a general capital growth shifter—A_{KG} (i) and endogenising IKRATIO(i)—the ratio of investment to capital (see the Eqs. (4.2.25) and (4.2.26) in Table 4.1, Chap. 4), and by making endogenous the expected rate of return EROR(i), with the shift variable, del_f_ac_p_y(i) in the capital accumulation equation exogenous (see the Eqs. (4.2.24) and (4.2.27) in Table 4.1, Chap. 4).
- **Step 2**. In the long-run comparative static closure household consumption adjusts to ensure that the effect of a shock on national savings matches the effect on national investment, thereby keeping the balance on current account unchanged. For a policy closure, we require a more conventional treatment of household consumption, with consumption moving with income (GNP). This requires us to exogenise the average propensity to consume A_C and endogenise the shift variable f3tot (see Eq. (4.2.31) in Table 4.1, Chap. 4).

- **Step 3**. In the long-run comparative static closure government (public) consumption is exogenous. In a policy simulation, we normally link government consumption with household consumption. To do so, we exogenise the shift variable f5tot2 and endogenise $A_{(5)}$.[1]
- **Step 4**. In the long-run comparative static closure, national employment is exogenous and the real wage rate endogenous. In the policy closure we want to put in place the sticky wage adjustment equation (Eq. (4.2.33) in Table 4.1, Chap. 4), which allows for slow real wage adjustment to progressively eliminate the initial effects of the shock on employment. This is done by endogenising aggregate employment and exogenising the shift variable in the wage adjustment equation (A_{WR} in Eq. (4.2.33), Table 4.1, Chap. 4). With the sticky wage adjustment mechanism activated, in the short run, the wage is sticky and in the long run, the real wage will adjust to driving the employment back to the baseline level if the policy shock causes the employment to deviate from its base case level.
- **Step 5**. Check the variable which will be used for the policy shock is exogenous. If it is not, then we have to make a closure change by swapping this variable with a related endogenous variable. For our illustrative simulation, we shock the required rate of return on capital, which is the variable A_{KGT} in Eq. (4.2.26) in Table 4.1, Chap. 4. This is a naturally exogenous variable, so we do not need to make a closure change.

7.2 How to Explain the Policy Simulation Results

7.2.1 The Approach to Understanding the Simulation Results

When a simulation is run, results for thousands of variables are generated. Where to start? The answer to that question depends on the policy shock and nature of the policy closure. However, experience has shown that the following strategy works well in most cases.

(1) **Start by looking at the macroeconomic results before moving to detailed industry results**. As a detailed macroeconomic-based model, CHINAGEM embeds a number of important macroeconomic mechanisms which have significant effects on structural variables. A good example is the real exchange rate, which moves to ensure that changes in the net volume of trade (X–M) reconcile changes in real GDP from the input side (Y) and changes in real Gross National Expenditure (C+I+G) from the expenditure side. At the industry level, changes

[1] In the standard CHINAGEM model, there is an equation to link government consumption with household consumption, x5tot=x3tot+f5tot2, where x5tot and x3tot are the aggregated real government and household consumption, respectively, and f5tot2 is a shift variable that can be used to turn on or turn off this equation. For example, when we exogenise f5tot2 and no shock is given to it, the equation becomes x5tot=x3tot, then government consumption is linked with household consumption.

in the real exchange rate are an important determinant of changes in production for traded-good industries.

(2) **Focus on the first-round effects of the shock**. In other words, focus on direct (immediate) effects of the shock. For the illustrative shock being considered here—an increase in required rate of return on capital—the immediate effects are on industry investment. On the other hand, if the shock was, for example, to import tariffs then the immediate effects will be on the demand for imports.

(3) **Understand the policy closure**. This is the key to understanding the simulation results. The policy closure is set up based on the policy questions that the modeller would investigate. It imposes important macro-level constraints on the model. For example, as noted in the previous section, it is the policy closure that forces real household consumption to move with real GNP and public consumption to move with household consumption. Thus, if we can understand what happens to real GNP, then through our understanding of the policy closure we have a clear explanation for what happens to private and public consumption.

(4) **Use a BOTE model.** CGE models have thousands of equations and variables and detailed databases. Nevertheless, as explained in Dixon and Rimmer (2002, pages 88–92), key results from CGE simulations can often be explained by calculations carried out with Back-Of-The Envelope (BOTE) models.

(5) **For the industrial results: focus on the industrial output first.** x1tot (i) is the variable that represents industrial output in the CHINAGEM model. There are 137 industries in the CHINAGEM model with the 2012 database. In part 2 of this book, we aggregated the original database into 45 industries.[2] When looking at the industrial output, look for the industries which expand most or contract most. The average change of all the industries' output equals the change of the real GDP. For example, if real GDP in the policy simulation is 10 per cent higher than the base case, but one industry's output is only one per cent higher than its base case, this means that this industry barely gets benefits from this policy change.

7.2.2 Using the Closure and the BOTE Models

The closure and the links between key variables for understanding policy deviations is shown in Box 7.1 and Fig. 7.1 where we use Δ to represent the changes of the variable after the policy shock. Please note that Fig. 7.1 is a flow diagram for one commodity CGE model. Therefore it does not illustrate relative price or other structural effects. While these are important, Fig. 7.1 is nevertheless, a helpful representation of the main macro assumptions underlying our policy simulation. Exogenous variables in the policy closure are represented by rectangles while endogenous variables are shown in ovals.

[2] Please refer to Appendix 7.1 for the details of the aggregated 45 industries and commodities, and Appendix 7.2 for the details of the original 137 industries and commodities in the CHINAGEM model.

We look at the results of the first year after the shock. In Fig. 7.1, three variables are coloured in red. They are predetermined. The first variable ΔW/P3 is the change in the real wage rate which is assumed to be sticky in the short run and flexible in the long run. This means that increasing the required rate of return on capital will have little effect on the real wage rate in the first year but aggregate employment can change. In the long run, we assume that the real wage rate can adjust so that the increase in the required rate of return on capital has no effect on aggregate employment. This assumption is consistent with the lagged wage adjustment mechanism described in Chap. 4.

The second variable ΔK is the change in aggregate capital stock, which is predetermined in a solution for year t by what happened to the net investment in year t−1.

The third variable ΔNFL is another stock variable, the change of net foreign liabilities which was also predetermined by the previous year's change in investment and saving (see Chap. 4).

Box 7.1 The BOTE model

The Eqs. (7.1) to (7.4) used here are the same as we discussed in Box 5.1, Chap. 5. Equation (7.5) is derived from Eqs. (7.3) and (7.4). The aggregate production function (7.1) and GDP identity (7.2) are two most important BOTE models for the CHINAGEM model.

$$Y = \frac{1}{A} F(K,\ L) \tag{7.1}$$

$$Y = C + G + I + X - M \tag{7.2}$$

where Y is real GDP, K is aggregate capital stock, L is aggregate employment, and A is technology. A decrease in A allows for technology progress. C is real household consumption, I is real investment, G is real government expenditure, X is volume of exports and M is volume of imports.

Equilibrium in the capital market requires the real cost of using capital to equal to the marginal product of capital. Hence:

$$\frac{Q}{P_g} = \frac{1}{A} * F_k\left(\frac{K}{L}\right) \tag{7.3}$$

where Q is the rental price per unit of capital, P_g is the price of a unit of GDP valued at factor cost, $\frac{Q}{P_g}$ is the real cost of capital, and F_k is the partial derivative of F with respect to K. We write F_k as a function of K/L under the assumption that F is homogenous of degree one.

Labour-market equilibrium requires:

$$\frac{W}{P_g} = \frac{1}{A} * F_l\left(\frac{K}{L}\right) \tag{7.4}$$

where W is the nominal wage rate, $\frac{W}{P_g}$ is the real cost of labour and F_l is the partial derivative of F with respect to L.

Or based on Eqs. (7.3 and 7.4), we can get

$$\frac{Q}{P_g} = g\left(\frac{1}{A}, \frac{W}{P_g}\right) \tag{7.5}$$

where, the real cost of capital, $\frac{Q}{P_g}$ is the function of technology and real cost of labour.

As we discussed in Sect. 7.2.1, when we look at the simulation results, we have to first focus on direct (immediate) effects of the shock. In this simulation, the increase in the required rate of return on capital will immediately reduce the investment (line ⑫in Fig. 7.1).[3]

Now let's look at the real GDP. We know that the income side of real GDP (ΔGDP) is determined by capital (ΔK), employment (ΔL) and technology (ΔA) (lines ①, ②, and ③, Fig. 7.1 and Eq. (7.1) in Box 7.1). In the first year of simulation, technology (ΔA) is exogenous and capital (ΔK) is predetermined, so the change in real GDP in the first year can only be determined by the change in employment (ΔL). But how is employment determined? Based on the diagram, technology (ΔA), real cost of labour (W/P_g), and capital (ΔK) all affect employment (lines ④, ⑤ and ⑥). But technology is exogenous and capital is predetermined, with the real wage ($\Delta W/P_3$) sticky in the first year, it seems if the consumer price deflator (P_3) and the GDP deflator (P_g) move together, then $\Delta P_3/P_g$ has no change), so the real cost of labour ($\Delta W/P_g$) cannot change (lines ⑦ and ⑧). Therefore there will no change in employment (However, P_3 and P_g do not move together. We will discuss why P_3 and P_g do not move together later).

Based on the diagram, if there is no change in real GDP (ΔGDP), with the change in the NFL (ΔNFL) predetermined, then we will know real GNP will also have no change (lines ⑬and ⑭). Since both household consumption and government consumption are linked with GNP (as we explained in the policy closure, Sect. 7.1, household consumption is linked with GNP via the exogenous variable—average propensity to consume (A_C) and government consumption is linked with private consumption via an exogenous shift variable f5tot2.), then there will also no change in household consumption and government consumption (ΔC+ΔG) (lines ⑮). Base on the GDP identity at the bottom of the diagram and Eq. (7.2) in Box 7.1, with C and G no change, and I (investment) falls, the trade balance (ΔBOT) must move toward surplus (X must increase relative to M) via the depreciation of the real exchange rate. This produces a decline in the terms of trade (Line ⑯).

[3] The reason will be discussed in Sect. 7.2.3.

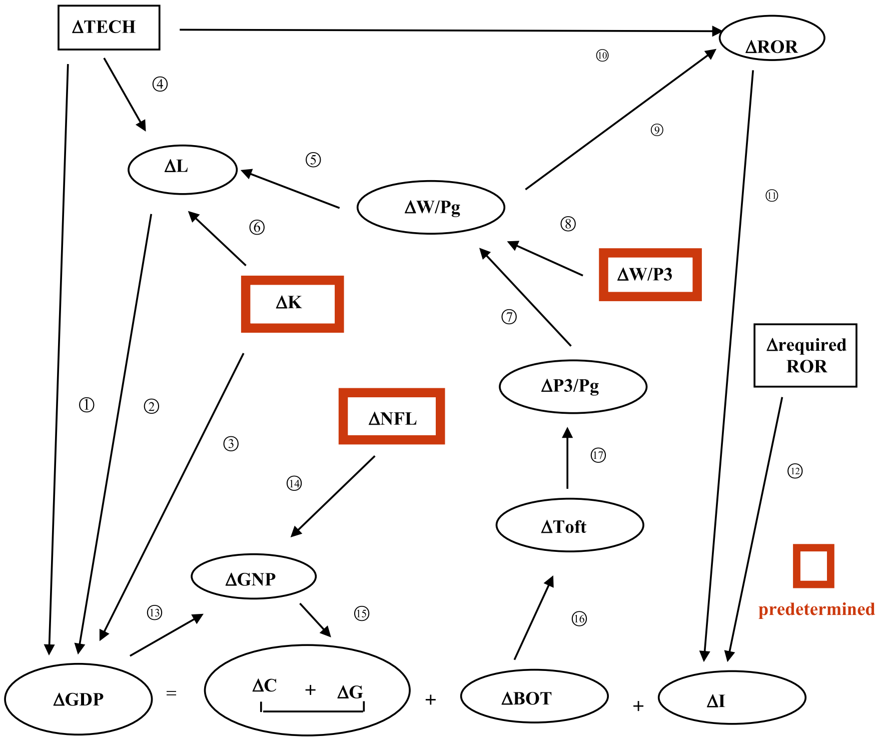

Fig. 7.1 Policy closure, year-to-year (for the required rate of return shock)

Recall we assume that the consumer price deflator P_3 and the GDP deflator P_g move together. But P_3 and P_g actually do not move together. Now we will explain the reason. The deterioration of the terms of trade reduces the GDP deflator P_g relative to the domestic expenditure deflators such as the consumer price deflator P_3. This is because the GDP deflator includes the prices of exports but excludes the prices of imports, whereas the opposite is true for domestic expenditure deflators. With the real wage rate (W, the price of labour, in Box 7.1 and Fig. 7.1, divided by P_3) sticky in the first year, an increase in $\frac{P_3}{P_g}$ generates an increase in the marginal product of labour (MPL). This follows from the marginal productivity condition for labour:

$$MPL = \frac{W}{P_g} = \frac{W}{P_3} * \frac{P_3}{P_g} = Real\ wage * \frac{P_3}{P_g} \tag{7.6}$$

With competitive markets, the MPL equals the real cost of labour, $\frac{W}{P_g}$. Because technology A is exogenous, and K is predetermined, the increase in the real cost of labour in the left hand of the Eq. (7.4) in Box 7.1 implies that the employment (L) in the right hand of equation has to fall. This employment change caused by the changes in the terms of trade is reinforced by a structural effect. The reduction in the investment as a direct result of the policy shock changes the industrial composition of the economy away from construction. Although there is also an increase in export production and import replacement, construction is more labour intensive than these trade oriented activities. Thus the switch from investment activities (particularly construction) towards trade activities is employment reducing.

The fall of employment leads to a fall in the real GDP. With NFL predetermined, real GNP falls as well. The decline of real GNP leads to a fall of both household and government consumption.

The increase in MPL will be accompanied by a fall in the marginal product of capital (MPK). The reason is that based on Eq. (7.3) in Box 7.1, with the exogenous technology A and predetermined K, the fall of employment leads to an increase in the K/L ratio.

With competitive markets, the MPK equals the real cost of capital, $\frac{Q}{P_g}$ (Q is the rental price per unit of capital).[4] The real cost of capital, $\frac{Q}{P_g}$, affects the expected rate of return on capital, ΔROR (lines ⑨ and ⑩). In our simulation, the cost of capital goods rises slightly relatively to GDP deflator (−3.79% compared with −4.03%). This effect combined with the reduction of the MPK ensures a reduction of the rate of return. Consequently, there is a further negative effect on the investment (line ⑪). In terms of Fig. 7.2, the reduction in investment arises from not only the upward shift in capital supply curve (from S1 to S2), but also a downward movement in the actual rate of return (move down along the new capita supply curve S2).

7.2.3 Explain the Macroeconomic Results of the Policy Simulation—First Year

Now we will explain the specific macroeconomic results of this policy simulation. The shock in this simulation is the variable d_f_eeqror, which is a shift variable in the capital supply equation in the standard CHINAGEM model. As we see from Fig. 7.2, the capital supply is a reverse logistic curve. Giving d_f_eeqror a shock of 0.005 means to move the capital supply curve vertically up by 0.005 (from S1 move to S2 in Fig. 7.2). The economic meaning of this move is that for a given expected rate of return on capital, the economy undertakes a smaller capital growth. This implies that the investment risk becomes higher. The only way to reduce the capital growth rate in the CHINAGEM model based on the capital growth equation (Eq. (4.2.24), Chap. 4) is to reduce investment.

Table 7.1 shows the results of some key macroeconomic variables at the first year—2021 after the policy shock. As always, we express the results as changes (%) away from values in the baseline scenario.

[4] The fall of the real cost of capital, $\frac{Q}{P_g}$, can be derived from the Eq. (7.5), Box 7.1 as well because Eq. (7.5) is about the relationship between the real cost of labour and the real cost capital and it is derived from Eqs. (7.3) and (7.4) in Box 7.1.

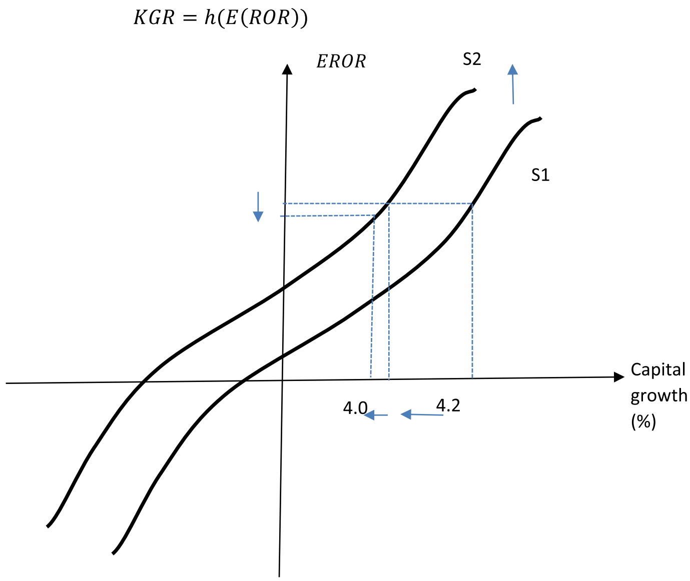

Fig. 7.2 Capital supply curve in the CHINAGEM model

First thing to observe is that the increase in required rate of return causes total real investment to be 5.1% lower than the baseline scenario. This can be thought of as the first-round effect of the shock which leads to changes throughout the economy. Next, we look at the implications for real GDP.

Table 7.1 shows that real GDP in the first year falls by 0.6% relative to baseline. This is consistent with our analysis using closure and BOTE models in the last section. When we think of what happens to real GDP, we normally start from the income side of GDP. According to the first BOTE Eq. (7.1) in Box 7.1, real GDP changes in response to changes in technology, capital and labour. In the first year, technology is exogenous and cannot change, and capital is predetermined by the capital stock and investment in 2020, therefore capital stock should have zero difference compared with the baseline scenario in 2021. The only way to change the real GDP in the first year is via employment change.

Table 7.1 shows that employment falls by 0.9% compared to its baseline level. According to our BOTE model (Eq. (7.4) in Box 7.1) and our explanation in the Sect. 7.2.2, in the first year changes in employment reflect changes in the real cost of labour, W/P_g (where the price of labour, W is represented by p1lab_io and the GDP deflator, P_g is represented by p0gdpexp in Table 7.1), which increases by 0.2% (p1lab_io−p0gdpexp in Table 7.1). Given the assumption (see Sect. 7.1) that the real wage rate, which is defined as nominal wage rate W deflated by the consumer price index or deflator, P_3 (p3tot in Table 7.1) is sticky in the short run, the increase of real cost of labour is caused by the relatively larger decline of the GDP deflator compared

Table 7.1 Selected macroeconomic results in 2021 (Deviations from the baseline scenario, %)

Variables (in CHINAGEM)	Variables	2021
x0gdpexp	Real GDP	−0.6
cap_at_t_i	Real capital stock	0.0
employ_i	Employment—wage bill weight	−0.9
x1lnd_i	Land	0.0
x3tot	Real household consumption	−0.8
x2tot_i	Real investment	−5.1
x5tot	Real government consumption	−0.8
x4tot	Volume of exports	5.6
x0imp_c	Volume of imports	−7.3
real wage	Real wage	−0.2
Gnpreal	Real GNP	−0.8
p0gdpexp	GDP price deflator	−4.0
p0toft	Terms of trade	−2.7
p0realdev	Real devaluation	4.2
p3tot	Consumer price index	−3.6
p2tot_i	Aggregate investment price index	−3.8
Pror	Rate of return on capital	−1.3
p1lab_io	Price of labour	−3.8
p1cap_i	Capital rentals	−5.0

Source CHINAGEM policy simulation results

with the consumer price index (p3tot−p0gdpexp) resulting from the deterioration of terms of trade (p0toft declines by 2.7%).

The decline in employment across the economy, with unchanged capital and technology leads to a fall in real GDP shown in Table 7.1.

As we explained in the previous session, the increase in MPL will be accompanied by a fall in the marginal product of capital (MPK). With competitive markets, the MPK equals the real cost of capital, $\frac{Q}{P_g}$ (Q is the rental price per unit of capital, it is represented by P_{1cap_i} in Table 7.1). As shown in Table 7.1, the real cost of capital falls by around 1% ($P1cap\_i \; - \; P0gdpexp$), which reinforces the reduction in investment.

Next, we look at the expenditure side of GDP, starting with private and public consumption (C+G). As noted earlier, real consumption moves with real income as measured by real Gross National Product (GNP). Table 7.1 shows that real GNP is down 0.8%, leading to similar reductions in real private and public consumption. The fall in real GNP in the first year reflects two factors: the fall in total income generated in the economy (i.e., the fall in real GDP) and the fall in the economy's terms of trade of 2.7%. The latter reduces the amount of goods and services that the economy can buy from a given level of real income (i.e., real GDP).

With the decline of C, G and I what will happen to the Balance of Trade (X−M)? Based on the BOTE Eq. (7.2) in Box 7.1, the change of the right-hand side, ΔC+ΔG+ΔI+ΔX−ΔM must equal the change of the left-hand side, ΔGDP. From Table 7.1, we notice that real GDP, C and G are 0.6% and 0.8% lower than the baseline scenario, respectively, while I declines much more than GDP. Hence X−M must shift further into surplus. In our model, (X−M) improves *via* real devaluation of the exchange rate. Real devaluation makes China's goods more competitive relative to goods produced outside of China and therefore allows exports to expand. On the other hand, it will make imports more expensive and therefore, all else unchanged, reduces imports. According to Table 7.1, in the first year the increase in the required rate of return leads to real devaluation of 4.2%, which results in an increase in exports of 5.6%. For imports, the negative effects of real devaluation coupled with the projected fall in overall final demand reduces imports in total by 7.3% .

Real devaluation shifts export supply schedules for China products on world markets out (from S1 to S2 in Fig. 7.3) and moves down the corresponding export demand schedules. Hence, accompanying the real devaluation is a reduction in world prices of Chinese exports (the export price drops from P_{x1} to P_{x2}, Fig. 7.3). With no change in world import prices (exogenously determined by the world market in the CHINAGEM model), the declines in export prices drive the terms of trade to deteriorate. As noted above, China's terms of trade is projected to fall by 2.7% relative to its value in the baseline (Table 7.1).

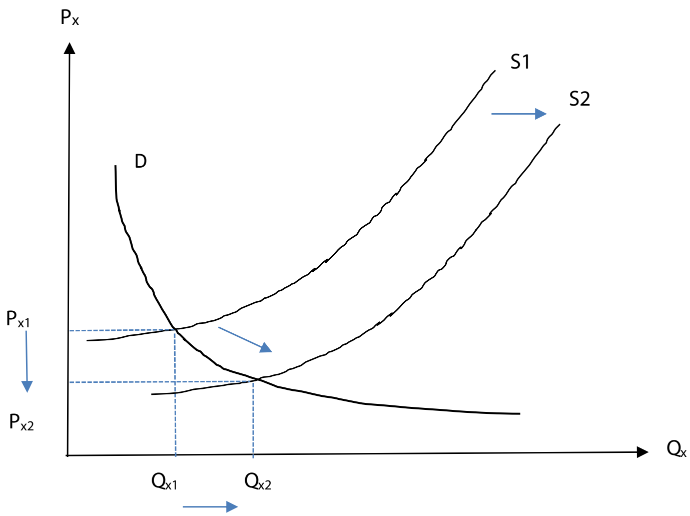

Fig. 7.3 The effects on the export market

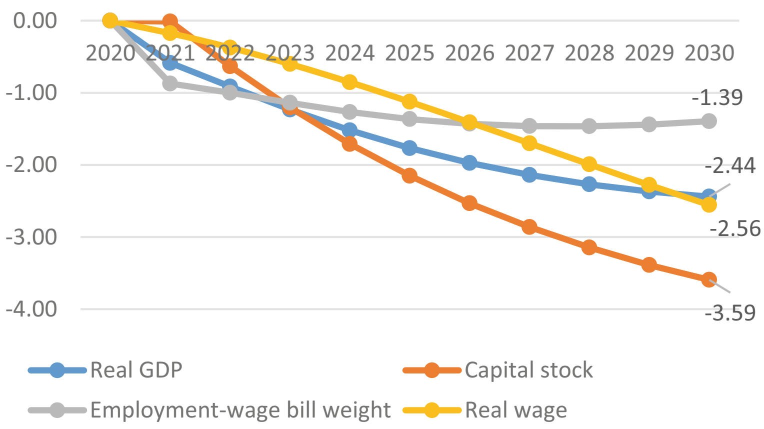

Fig. 7.4 Policy simulation results—income side of real GDP and real wage—cumulative deviations from baseline case (%) *Source* Policy simulation

7.2.4 Explain the Macroeconomic Results of the Policy Simulation—the Following Years

In this simulation there is only one year shock—the shock in 2021. What happens after 2021 reflects the dynamic mechanisms for investment, capital, the real wage and employment in CHINAGEM.

As we explained earlier, what happened in the investment in 2021 will not affect the capital stock in 2021 but will affect it in 2022. Also, the real wage rate is sticky in 2021, but thereafter the real wage will progressively fall (compared to its baseline value) in order to return employment to its baseline level because of the wage lagged adjustment mechanism. Declines in the real wage rate will lead to increases in the real cost of capital to the point where actual rates of return are brought back into line with the permanently increased required rate of return. As the real cost of capital rises relative to the real cost of labour, so the economy-wide ratio of capital to labour will fall. With employment rising back to baseline, capital will be displaced below its baseline level. This means reduced needs for replacement investment and a permanent lower level of investment.

Figure 7.4 shows projected changes in some key macro variables between 2020 and 2030.[5] By the end of the simulation period 2030, the capital stock is 3.6% lower than the baseline case. Employment has not returned to its baseline level, but is heading in the right direction as the real wage rate falls away. In 2030, employment is down 1.4% and the real wage rate has fallen 2.6%. Real GDP is down 2.4%, which is close to the weighted average of the falls in capital and labour (remember, technology is unaffected by the shock).

[5] There is no policy shock in 2020.

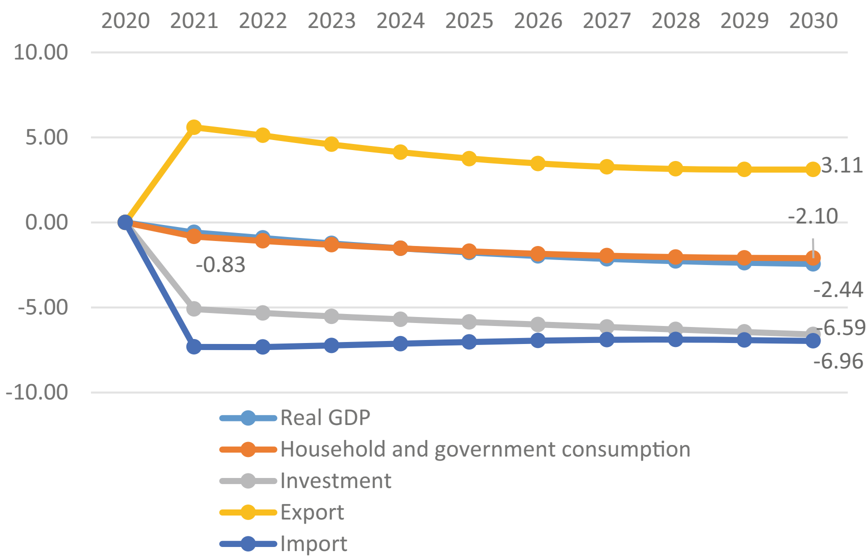

Fig. 7.5 Policy simulation results—expenditure side of real GDP—cumulative deviations from baseline case (%). *Source* Policy simulation

Over time, this one-off shock will permanently push the investment down (investment is 6.6% lower in 2030, Fig. 7.5, therefore reduce the capital stock, and permanently change the real GDP (real GDP is 2.4% lower in 2030 in Fig. 7.4). Different from the short-term (the first year in 2021), the decline of real GDP in the long-run is mainly from the declining capital stock (capital stock is 3.6% lower in Fig. 7.4) and less from the change of employment (employment is 1.4% lower in Fig. 7.4) with the real wage falling (real wage is 2.6% lower than the baseline in 2030 in Fig. 4).

The declining real GDP drives real GNP down. Household consumption and government consumption fall as well (both are 2.1% lower in 2030 in Fig. 7.5). As we discussed previously, the GDP identity (Eq. (7.2) in Box 7.1) requires the balance of trade to improve. This is achieved via real devaluation. Figure 7.6 shows that real devaluation is 1.9% higher than the baseline scenario in 2030. The improving competitiveness in the world market because of the real devaluation stimulates exports. Figure 7.5 shows that exports are 3.1% higher while the imports are 7.0% lower. The terms of trade deteriorate because of the lower export price and fixed import price (the terms of trade is 1.5% lower than the baseline case in 2030, Fig. 7.6).

In summary, in the long run, the increase in the required rate of return on capital leads to a smaller economy that is more export-focused and more labour-intensive with workers receiving a lower wage rate.

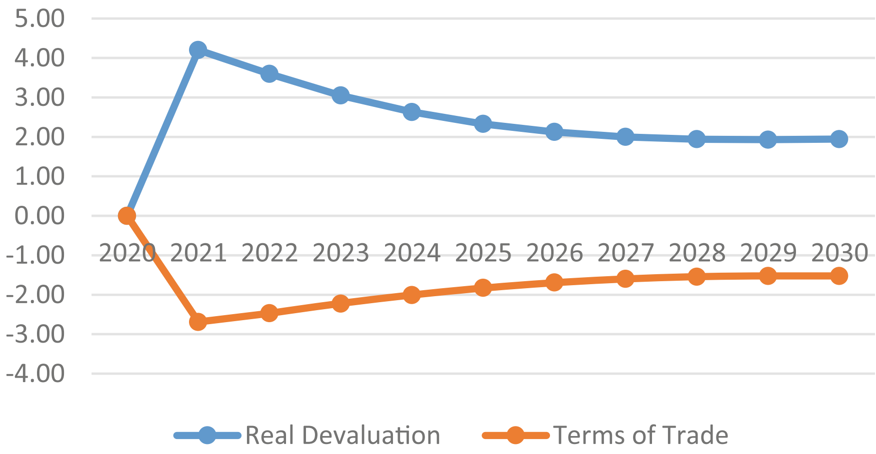

Fig. 7.6 Policy simulation results—real devaluation and terms of trade—cumulative deviations from baseline case (%)

7.2.5 *Industry Results*

For simplicity we focus only on results for industry output. Other industry results typically follow once output has been explained. In the CHINAGEM model, the variable for industry output is x1tot.

Figure 7.7 shows projected deviations from baseline in production for a selection of industries: the industries most affected by the increase in required rate of return on capital. Initially we focus only on results for the first year, 2021.

In the first year some industries have a gain in output relative to baseline levels, while other industries lose output. Recall that the increase in the required rate of return affected the whole economy negatively, with real GDP 0.6% lower than the baseline scenario in 2021. Thus, on average we expect all industries to lose some output.

The industry that loses most *is Construction*, with a projected fall in production of 4.3% in the first year. As explained above, the shock causes an across-the-board fall in investment. Therefore the industries that sell most of their output to investment will be hit hard. Table 7.2 shows the sale structure of 45 sectors which are aggregations of the full 137 industries in the CHINAGEM model. For the construction sector, 92.7% of its sales goes to the investment. The second most negatively affected industry is *Software and IT services* whose output is 4.1% lower than in the baseline case. Like construction, the software industry is investment-focused, with over 75% of its output going to investment (Table 7.2).

We also notice that *Public Administration, Social work and Management of Public Facilities, Environment and Water Conservancy* suffer from this policy shock. The reason is that these are government consumption related industries (95% of *Public Administration's output is consumed by government.* More than 80% of

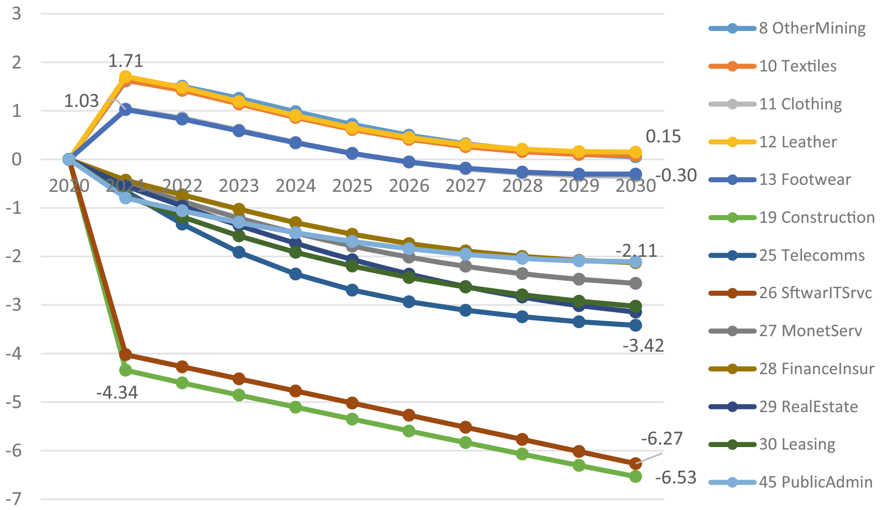

Fig. 7.7 Policy simulation results—selected industry results—cumulative deviations from baseline case (%)

the output from *Social work and Management of Public Facilities, Environment and Water Conservancy* are purchased by government, Table 7.2). We also know that government consumption is 2.4% lower than the baseline scenario in the first year.

The typical industry that gains from the increase in required rate of return is trade focussed, with little direct connection to investment demand. Recall from our discussion of the macroeconomic results that the fall in investment is accompanied by relatively strong real devaluation of the exchange rate which improves the competiveness of Chinese exporting and import-competing industries. Figure 7.7 shows that the output of *Clothing* and *Footwear* industries are more than 1% higher than those of the baseline scenario in 2021. We notice that they are export-oriented (about 40% and 37% of their outputs are exported, respectively, Table 7.2).

We also notice that both *Textile* and *Leather* gain from this policy shock. Export-oriented is one reason for their output expansion (13.8% and 24.4% of their output are exported, respectively, Table 7.2). The other important reason is the input-output linkage. *Textile* is the upstream industry of *Clothing* (more than 30% of textile was sold to *clothing* industry) and *Leather* is the upstream industries of both *Footwear* and *Clothing* (about 19% of leather was sold to *Footwear* industry and 15% was sold to *Clothing* industry). The output expansion of *Clothing* and *Footwear* industries increases the demand from their upstream industries.

We also notice that the *Other mining* industry has a positive increase in the first year after the shock. But its products neither go to investment nor go to export. Almost all its products are used as intermediate inputs. But why does this industry benefit from the increase in the required rate of return on capital? The reason is

Table 7.2 Sale structure of aggregated 45 industries in CHINAGEM (%)

	Intermediate	Investment	Household	Export	Government	Stocks	Margins	Total
1 Crops	76.4	0	18.3	1.3	0	4	0	100
2 Livestock	54.2	11.3	28.9	0.2	0	5.4	0	100
3 Forestry	99.7	0	1.1	0.2	0	−1.0	0	100
4 Fishing	52.4	0	37.3	0.8	0	9.5	0	100
5 Agriculture services	80.9	0	0	0	19.4	−0.3	0	100
6 Mining and washing of coal	98.6	0	0.5	0.4	0	0.5	0	100
7 Extraction of petroleum and natural gas	97.9	0	0	0.7	0	1.4	0	100
8 Other mining	99.4	0	0	0.7	0	−0.1	0	100
9 Food and drinks	54.1	0	39.5	3.2	0	3.2	0	100
10 Textiles	82.1	0	2.1	13.8	0	2	0	100
11 Clothing	25.2	0	34.3	39.4	0	1.1	0	100
12 Leather	55.9	0	17.5	24.4	0	2.3	0	100
13 Footwear	16.9	0	44.6	36.7	0	1.8	0	100
14 Wood products	91.1	0	1.5	6.2	0	1.2	0	100
15 Other Manufacturing	72.3	11.1	3.4	12.7	0	0.3	0	100
16 Electricity	95.5	0	4.5	0.1	0	−0.1	0	100
17 Gas supply	53.9	0	43.4	0	0	2.7	0	100
18 Water supply	58.1	0	42.2	0	0	−0.4	0	100
19 Construction	6.3	92.7	0	0.6	0	0.4	0	100
20 Trade	0.6	0.1	0.1	0.2	0	1.5	97.5	100
21 Transport	26.1	1.7	6.1	2.8	3.4	0.5	59.5	100

(continued)

Table 7.2 (continued)

	Intermediate	Investment	Household	Export	Government	Stocks	Margins	Total
22 Transport services, storage and post	66.4	1.3	4.1	2.2	0.2	0.7	25	100
23 Hotels	78.1	0	16	6.1	0	−0.1	0	100
24 Restaurant	42.5	0	56	1.3	0	0.3	0	100
25 Tele-communications	61.2	0	37.8	0.8	0	0.1	0	100
26 Software and IT services	16.3	75.6	1.1	7.1	0	−0.1	0	100
27 Monetary services	87.7	0	10.4	0.3	1.6	0	0	100
28 Finance and insurance	47.2	0	29	1.9	1.3	−0.4	21.1	100
29 Real estate	29.8	25.4	44.7	0	0	0.1	0	100
30 Leasing	92.6	0	1	7.6	0	−1.2	0	100
31 Business services	82.5	0	2.8	11.4	3.2	0	0	100
32 Technology, science and research	66.7	5.6	1	0.3	26.6	−0.3	0	100
33 Management of public facilities, environment and water conservancy	7.3	0	9.4	1.1	82.4	−0.2	0	100
34 Residence services	16.8	0	81.5	0.5	0	1.2	0	100
35 Other services	86.7	0	11.5	1.1	0	0.7	0	100
36 Education	6.3	0	29.9	0.2	63.6	−0.1	0	100
37 Health	2.2	0	52.2	0.2	45.5	−0.2	0	100
38 Social work	0	0	14.1	0	85.2	0.7	0	100
39 Journal and publishing activities	45.3	0	42.8	10.1	3.5	−1.8	0	100
40 Arts, films and TV	32.3	0	29.5	1.7	36.8	−0.4	0	100
41 Culture and arts	13.8	0	25.1	4	57.5	−0.4	0	100
42 Sports	8.2	0	44.8	9.2	36.7	1.3	0	100

(continued)

Table 7.2 (continued)

	Intermediate	Investment	Household	Export	Government	Stocks	Margins	Total
43 Entertainment	59.6	0	29.2	9.9	0	1.4	0	100
44 Social welfare	33.4	0	0	0	65.4	1.2	0	100
45 Public administration	3.3	0	1	0.2	95.5	0	0	100

Source CHINAGEM 2012 aggregated database that *Other Mining* is an import-competing sector. In China, around 31% of *Other Mining* commodities are imported. As discussed above, read devaluation improves the competitiveness of import-competing industries such as *Other mining,* driving demand for domestically produced other-mining products to increase. This is the reason for the expansion of the *Other Mining* industry.

The effects of this once-off shock on industries, in the long run, are similar to the effects in the first year (Fig. 7.7). But we have to emphasize several points.

(a) The overall negative effects on the macro economy become larger (real GDP is 2.4% lower by the end of simulation period while it is only 0.6% lower in the first year after the shock), so the negative effects on the industries also become bigger.
(b) Over time with the investment trending further down, the industries that sell most of their output to investment will be hit even harder. That's why we see the outputs of both *Construction* and *Software and IT services* are more than 6% lower than the baseline case by the end of simulation period, compared with more than 4% lower in the first year after the shock).
(c) The more capital-intensive industries will tend to experience progressively greater reductions in output. As discussed above, over time as the economy adjusts so the reduction in capital (relative to its baseline level) gets larger. Thus industries which are more capital intensive such as the *Telecommunication and Real Estate* (their capital shares are 80% and 85%, in Table 7.3) will be affected more. By the end of the simulation period in 2030, production of *Telecommunication* is down by 3.4%, compared with 0.7% down in the first year, and production of *Real Estate* services is down by 3.1% (0.6% in the first year).
(d) Over time, as both household and government consumption decline further, the industries that sell most of their output to consumption will experience larger fall in output. For example, the outputs of *Public Administration, Social work, Health and Education* are more than 2% lower than the baseline case by the end of the simulation period 2030, compared with less than 1% down in the first year.
(e) In the long run, the gain in the output that the export oriented industries (such as the *Clothing* and *Footwear)* and import competing industry (such as *Other mining)* experienced due to the relatively strong real devaluation in the first year after the policy shock will gradually become less as the real devaluation (relative to its baseline level) becomes weaker (Figs. 7.6 and 7.7).
(f) Due to the input-output linkage between industries, *Textile* and *Leather*—the upstream industries of the *Clothing* and *Footwear*, will experience similar output change in the long run (the output of both *Textile* and *Leather* will be less than 0.2% higher than the baseline case in 2030, compared with more than 1% higher in 2021).
(g) Furthermore, in the long run, China's economy will become more labour intensive (relative to the baseline level) because of the declining capital stock and lower real wage rates. As we discussed in the analysis of the macro results, the

Table 7.3 Primary factor cost in CHINAGEM aggregated 45 industries (%)

	Labour	Capital	Land	Total
1 Crops	59.4	27.2	13.4	100
2 Livestock	58.2	28	13.8	100
3 Forestry	59.8	26.9	13.3	100
4 Fishing	59.6	27.1	13.3	100
5 Agriculture services	60.1	39.9	0	100
6 Coal mining processing	64.2	24	11.8	100
7 Crude oil and gas mining	28.9	47.6	23.5	100
8 Other mining	51.1	34.1	14.8	100
9 Food and drinks	44.4	55.6	0	100
10 Textiles	55.5	44.5	0	100
11 Clothing	65.3	34.7	0	100
12 Leather	58.7	41.3	0	100
13 Footwear	60.5	39.5	0	100
14 Wood products	52.2	47.8	0	100
15 Other manufacturing	48.9	51.1	0	100
16 Electricity	34.3	65.7	0	100
17 Gas supply	31.8	68.2	0	100
18 Water supply	56	44	0	100
19 Construction	70.9	29.1	0	100
20 Trade	44.1	55.9	0	100
21 Transport	44.7	55.3	0	100
22 Transport services, storage and post	48.9	51.1	0	100
23 Hotels	64.2	35.8	0	100
24 Restaurant	76	24	0	100
25 Tele-communications	19.7	80.3	0	100
26 Software and IT services	62.3	37.7	0	100
27 Monetary services	67.2	32.8	0	100
28 Finance and insurance	67.9	32.1	0	100
29 Real estate	15.1	84.9	0	100
30 Leasing	36.7	63.3	0	100
31 Business services	56	44	0	100
32 Technology, science and research	58.5	41.5	0	100
33 Management of public facilities, environment and water conservancy	57.2	42.8	0	100
34 Resident services	78.5	21.5	0	100
35 Other services	67.1	32.9	0	100

(continued)

Table 7.3 (continued)

	Labour	Capital	Land	Total
36 Education	45	55	0	100
37 Health	37.1	62.9	0	100
38 Social work	59.7	40.3	0	100
39 Journal and publishing activities	57.6	42.4	0	100
40 Arts, films and TV	59.1	40.9	0	100
41 Culture and arts	72.6	27.4	0	100
42 Sports	65.9	34.1	0	100
43 Entertainment	49	51	0	100
44 Social welfare	34.9	65.1	0	100
45 Public administration	48.3	51.7	0	100
Total	50.8	47	2.2	100

Source CHINAGEM 2021 database

real wage rate is lower than in the baseline scenario in 2030. The lower wage rate encourages employers to hire more labour.

(h) The effects of the policy shock on most industries are similar to those on the real GDP (Fig. 7.7). In other words, most industries will experience a small contraction in output along with real GDP. But we have to emphasize that the change in the output for each industry is the combined result of the above factors (the primary factor structure, the sale structure, domestic and import competition, and input-output linkage between industries).

Appendix 7.1 List of Industries and Commodities in 2012 CHINAGEM Aggregated Database

1	Crops	24	Restaurant
2	Livestock	25	Telecommunication and other
3	Forestry	26	Software and IT services
4	Fishing	27	Monetary services
5	Agriculture services	28	Finance and insurance
6	Mining and washing of coal	29	Real estate
7	Extraction of petroleum and natural gas	30	Leasing
8	Other mining	31	Business services
9	Food and drinks	32	Technical services, science and research

(continued)

(continued)

10	Textiles	33	Management of public facilities, environment and water conservancy
11	Clothing	34	Residence services
12	Leather	35	Other services
13	Footwear	36	Education
14	Wood products	37	Health
15	Other manufacture	38	Social work
16	Electricity	39	Journal and publishing activities
17	Gas supply	40	Arts, film and TV
18	Water supply	41	Culture and arts
19	Construction	42	Sports
20	Trade	43	Entertainment
21	Transport	44	Social welfare
22	Transport service, storage and post	45	Public administration
23	Hotels		

Appendix 7.2 List of Industries and Commodities in 2012 CHINAGEM Original Database

1	Farming	69	Manufacture of cultural and office machinery
2	Forestry	70	Manufacture of other general purpose machinery
3	Animal husbandry	71	Manufacture of special purpose machinery for mining, metallurgy and construction
4	Fishery	72	Manufacture of special purpose machinery for chemical industry, processing of timber and non-metals
5	Service in support of agriculture	73	Manufacture of special purpose machinery for agriculture, forestry, animal husbandry and fishery
6	Mining and washing of coal	74	Manufacture of other special purpose machinery
7	Extraction of petroleum and natural gas	75	Manufacture of automobiles
8	Mining of ferrous metal ores	76	Manufacture of automobile components
9	Mining of non-ferrous metal ores	77	Manufacture of railroad transport and urban metro equipment
10	Mining of non-metal ores	78	Manufacture of boats and ships

(continued)

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11	Service in support of mining and other ores	79	Manufacture of other transport equipment
12	Grinding of grains	80	Manufacture of generators
13	Processing of forage	81	Manufacture of equipment for power transmission and distribution and control
14	Refining of vegetable oil	82	Manufacture of wire, cable, optical cable and electrical appliances
15	Manufacture of sugar and sugar products	83	Manufacture of battery
16	Slaughtering and processing of meat	84	Manufacture of household electric and non-electric appliances
17	Processing of aquatic product	85	Manufacture of other electrical machinery and equipment
18	Vegetables, fruits, nuts and other agricultural products	86	Manufacture of computers
19	Manufactures of convenience food	87	Manufacture of communication equipment
20	Manufacture of dairy products	88	Manufacture of broadcasting equipment and radar
21	Manufacture of flavouring and ferment products	89	Manufacture of audio-visual apparatus
22	Manufacture of other foods	90	Manufacture of electronic component
23	Manufacture of alcohol and wine	91	Manufacture of other electronic equipment
24	Manufacture of soft drinks and purified tea	92	Manufacture of measuring equipment
25	Manufacture of tobacco	93	Other manufacture products
26	Spinning and weaving, printing and dyeing of cotton and chemical fibre	94	Scrap, waste, recycled products
27	Spinning and weaving, dyeing and finishing of wool	95	Manufacture of metal products, repairs of machinery and equipment
28	Spinning and weaving of hemp and tiffany	96	Production and supply of electric power and heat power
29	Manufacture of knitted fabric and its products	97	Production and distribution of gas
30	Manufacture of textile products	98	Production and distribution of water
31	Manufacture of textile wearing apparel	99	Construction of household buildings
32	Manufacture of leather, fur, feather and its products	100	Civil engineering
33	Footwear	101	Construction installation
34	Processing of timbers, manufactures of wood, bamboo, rattan, palm and straw products	102	Construction decoration and other construction services
35	Manufacture of furniture	103	Wholesale and retail trades

(continued)

(continued)

36	Manufacture of paper and paper products	104	Rail transport
37	Printing, reproduction of recording products	105	Road transport
38	Manufactures of articles for culture, education and sports activities	106	Water transport
39	Processing of petroleum, nuclear fuel	107	Air transport
40	Coking	108	Pipeline
41	Manufacture of basic chemical raw materials	109	Loading, unloading and transport agent services
42	Manufacture of fertilizers	110	Storage
43	Manufacture of pesticides	111	Post
44	Manufacture of paints, printing inks, pigments and similar products	112	Hotels
45	Manufacture of synthetic materials	113	Catering services
46	Manufacture of special chemical products	114	Telecom and other information transmission services
47	Manufacture of chemical products for daily use	115	Software and information technical services
48	Manufacture of medicines	116	Monetary finance and other financial services
49	Manufacture of chemical fibre	117	Capital market service
50	Manufacture of rubber	118	Insurance
51	Manufacture of plastic	119	Real estate
52	Manufacture of cement, lime and plaster	120	Leasing
53	Manufacture of products of cement, lime and plaster	121	Business services
54	Manufacture of bricks, stone and other building materials	122	Research and experimental development
55	Manufacture of glass and its products	123	Professional technical services
56	Manufacture of pottery	124	Science and technology exchanges and promotion
57	Manufacture of fire-resistant materials	125	Management of water conservancy
58	Manufacture of graphite and other non-metallic mineral products	126	Ecological protection and environment management
59	Steel-making, iron-smelting	127	Management of public facilities
60	Rolling of steel	128	Services to households
61	Smelting of ferroalloy	129	Other services
62	Smelting of non-ferrous metals and manufacture of alloys	130	Education
63	Rolling of non-ferrous metals	131	Health

(continued)

(continued)

64	Manufacture of metal products	132	Social work
65	Manufacture of boiler and prime mover	133	Journal and publishing activities
66	Manufacture of metalworking machinery	134	Broadcasting, movies, televisions and audio-visual activities
67	Manufacture of lifters	135	Cultural and art activities
68	Manufacture of pump, valve and similar machinery	136	Sports activities
		137	Entertainment, social security, public management and social organization

Chapter 8
Closure Development and Decomposition Simulation from 2012 to 2019

Xiujian Peng and Philip Adams

Abstract This chapter employs the decomposition function of the CHINAGEM model to analyse China's economic growth from 2012 to 2019. To do so, we first conduct a historical simulation to estimate changes in factors such as technology, twists, and preference variables, which have contributed to China's economic growth. Using the estimated results, decomposition simulations are run individually to elucidate the effects of each variable on the macro economy. A cross-column analysis is then used to decompose the effects of these variables on China's economic growth during the study period. The simulation exercise reveals that technology improvement, cost-neutral change towards capital and employment growth are the key drivers of China's remarkable economic growth from 2012 to 2019, with technology improvement being the most significant factor. These findings hold particular significance for policymakers, as China's labor force has started to decline since 2018.

Keywords Closure development · Decomposition simulation · BOTE model · CGE · Economic growth · China

A specific feature of a MOASH style CGE model is to decompose the economic growth for a certain period using decomposition simulation. In this chapter we explain how to form a decomposition closure and how to use the historical simulation results as shocks for the decomposition simulation, and how to explain the decomposition results by decomposing China's economic growth from 2012 to 2019 as an example.

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8.1 Historical and Decomposition Closures

A decomposition simulation heavily relies on historical simulation as policy simulation relies on forecast (base case) simulation. As we explained in Chap. 5, apart from updating the model's database, the other purpose of the historical simulation is to find out the changes of unobservable variables. We tell the model the growth of observable variables such as labour force, investment, private and government consumption, exports and imports, GDP price deflator and etc., then the model will generate the changes of unobservable variables such as average propensity to consume, technology and tastes (for example, preference changes for domestic or imported goods). In the decomposition simulation, we then use the generated results from the historical simulation to evaluate the contributions of these unobserved variables to economic growth.

We have explained in detail the closure development of a historical simulation in Chap. 5 where we run the historical simulation from 2012 to 2019. In this historical simulation, the movements in the exogenous variables are from their values in one year to their values in the next year, for instance, from 2012 to 2013, then from 2013 to 2014, etc. Correspondingly, the results for the endogenous variables refer to the movements from one year to the next. However, in the historical and decomposition simulations conducted in this chapter, the initial solution is for 2012, which is the database year of the CHINAGEM model used in this chapter and the movements in the exogenous variables refer to changes over the seven years from 2012 to 2019. Therefore, in these simulations the movements in the endogenous variables refer to the seven years period from 2012 to 2019.

As we explained in previous chapters, the CHINAGEM model allows many closure choices, that is the choices of $n - m$ variables (n is the total number of variables in the CHINAGEM model and m is the total number of variables which have equations to explain) to be included in the exogenous sets.[1] In a historical closure, we include the observable variables in its exogenous set. Observable variables are those for which movements can be readily observed from statistical sources for the period of interest. For example in our 2012 to 2019 historical simulation, the observable variables include many macro variables such as investment, imports and exports. In a decomposition closure, we include in the exogenous set all naturally exogenous variables, for example, variables not normally explained in a CGE model. These may be observable variables such as tax rates and population, or unobservable variables, such as technology and preference variables.

Table 8.1 displays the partitioning of variables adopted for our historical simulation from 2012 to 2019, where X represents variable, H denotes exogenous and $\overline{H}$ denotes endogenous in the historical closure, $\boldsymbol{D}$ denotes exogenous and $\overline{\boldsymbol{D}}$ denotes endogenous in the decomposition closure.

[1] Please refer to pages 10–15 in Dixon and Rimmer (2002) and (2004) for the detailed explanation of what variables should be included in the exogenous set in historical closure and what variables should be included in the exogenous set in decomposition closure.

Table 8.1 Categories of variables in the historical and decomposition closures

Selected exogenous variables in the historical simulation $X(H\overline{D})$	Corresponding endogenous variables in the historical simulation $X(\overline{H}D)$
Real household consumption—C (x3tot)	Average propensity to consume (apc_gnp)
Real investment—I (x2tot)	Investment/capital ratio (r_inv_cap_u)
Real government consumption—G (x5tot)	Shift variable of the ratio of government consumption/household consumption (f5tot2)
Volume of imports—M (x0imp_c)	Twist towards imported goods (twistsrc_c)
Volume of exports—X (x4tot)	All-factor augmenting technical change (a1primgen)
GDP price deflator (p0gdpexp)	Shift in the foreign demand curve (feq_gen)
Wage share which is the share of nominal wage bill over nominal GDP (wageshr)	Cost-neutral change in labour/capital ratio for all industry (twistlab)
Selected exogenous variables in the historical and decomposition closures $X(HD)$	
Population (pop) Total employment in person (emp_person)	
Selected endogenous variables in the historical and decomposition closures $X(\overline{HD})$	
Capital growth (cap_at_t_i) Real wage rate (realwage)	

Starting with the long-run closure displayed in Table 4.3, Chap. 4, to get the historical closure as we show in Table 8.1, we have to make some swaps as we did in Chap. 5:

- Step 1, to incorporate historical change in real household consumption—C, we exogenise C and endogenise average propensity to consume A_C (see Eq. (4.2.31) in Table 4.1, Chap. 4). In the full CHINAGEM model, we use apc_gnp to represent $A_{c;}$
- Step 2, to incorporate historical change in real investment—I, we exogenise I and endogenise the investment/capital ratio, r_inv_cap_u, which is a weighted average of IKRATIO(i) in Eq. (4.2.25) in Table 4.1, Chap. 4.
- Step 3, to incorporate historical change in real government consumption—G, we have to exogenise G and endogenise a corresponding exogenous variable. In the standard CHINAGEM model there are two shift variables related to the real aggregate government consumption: f5tot2 and f5tot which is $A_{(5)}$ in Eq. (4.2.10) in Table 4.1, Chap. 4. f5tot2 is a shift variable representing the government/household consumption ratio in Equation x5tot = x3tot + f5tot2, where x5tot is G, x3tot is C. f5tot is normally exogenous while G and f5tot2 are normally endogenous. We swap G with f5tot, make G exogenise and f5tot endogenise. When we shock x5tot and x3tot with the observed changes in the historical period, the change in the government/household consumption ratio, f5tot2 will be solved.
- Step 4, to incorporate historical changes in the volume of imports—M, we exogenise M and endogenise the preference change variable, A_{twist_c}, a twist

variable for all commodities which is equivalent to the commodity-specific variable A_{twist} (Eqs. (4.2.3), (4.2.6), and (4.2.8) in Table 4.1, Chap. 4). Both A_{twist_c} and A_{twist} are variables allowing for cost-neutral changes in preferences between imported and domestically produced goods.[2] In the full CHINAGEM model, we use twistsrc_c to represent A_{twist_c} and twistsrc to represent $A_{twist.}$

- Step 5, to incorporate historical changes in the volume of exports—X, we exogenise X and endogenise all factor augmenting technology variable A, where in the full CHINAGEM model, a1primgen is used to represent A;
- Step 6, to incorporate historical changes in the GDP price index, we exogenise the GDP price index, P_g and endogenise the shift variable of export demand curve A4_c (a non-commodity specific variable equivalent of A4(c) in Eq. (4.2.9) in Table 4.1, Chap. 4) to estimate the vertical shift of the export demand curve. In the full CHINAGEM model, we use p0gdpexp and feq_gen to represent P_g and A4_c, respectively.
- Step 7, to incorporate historical changes in the wage share, we endogenise the shift variable of cost-neutral change in labour/capital ratio for all industries, twistlab.

Table 8.2 shows the shocks for the above exogenous variables, which are the observed movements of these variables between 2012 and 2019. The fourth column is the simulation results of the corresponding endogenous variables and other endogenous variables.

The historical simulation reveals the changes in technology, preference and twist variables from 2012 to 2019. For example, the all-factor augmenting technology has improved by 21.2% in this period. In the decomposition simulation we will calculate how much this all-factor augmenting technology improvement contributed to the GDP growth. The average propensity to consume, apc_gnp, which is defined as the ratio of total nominal private and government consumption to the nominal GNP, has increased by 8.1%. This means that government and private consumption has increased at a faster rate than GDP. This trend is consistent with the Chinese government's new growth strategy—to rely more on domestic consumption to sustain China's economic growth.

We also notice that the ratio of government consumption/private consumption, represented by the shift variable f5tot2 has declined by more than 5%, which means that government consumption fell relatively to household consumption between 2012 to 2019. The import/domestic preference variable, twistsrc_c declined by 52%, which reveals that there is a strong increase in favour of domestic goods. The demand for China's exports is also very strong because the export demand curve moved outward by more than 50%, which suggests a strong increase in export demand for China's goods. The *twistlab* for all industries declined by more than 18% implying the whole economy has a favour for capital because of the increased labour cost which is shown by the increased wage share. Lastly, we notice that the economic wide investment to capital ratio (r_inv_cap_u) dropped by nearly 6%, which indicates a slight decline in

[2] Cost neutrality is imposed to include twist terms in the demand equations for both domestic and imported goods in such a way that these terms allow for the replacement of domestic goods with imported goods of equal cost of users (Dixon and Rimmar 2002, 2004).

Table 8.2 Shocks and results of the historical simulation from 2012 to 2019

1 Exogenous macro variables	2 Growth rate (%)	3 Corresponding endogenous variables	4 Growth rate (%)
Real household consumption (x3tot)	78.3	Average propensity to consume (apc_gnp)	8.1
Real investment (x2tot)	53.9	Investment/capital ratio (r_inv_cap_u)	– 5.8
Real government consumption (x5tot)	69.1	Ratio of government/household consumption (f5tot2)	– 5.2
Volume of imports (x0imp)	25.3	Twist towards imported goods (twistsrc_c)	– 52.0
Volume of exports (x4tot)	20.8	All-factor augmenting technical change (a1primgen)	– 21.2
GDP price index (p0gdpexp)	14.4	Shift in the foreign demand curve (feq_gen)	50.9
Wage share (wageshr)	1.8	Cost-neutral change in labour/capital ratio for all industry (twistlab)	– 18.3
Population (pop)	3.4		
Aggregate employment in person (emp_person)	1.0		
		Capital stock	59.8
		Real wage rate	59.0

Source Data in Column 2 are authors' calculation based on the data from World Bank online database. Column 4 are simulation results

the investors' confidence. We will find out the contributions of these unobservable variables to GDP growth between 2012 and 2019 in the next section.

8.2 The Decomposition Simulation from 2012 to 2019

Having completed the historical simulation, we now start the decomposition simulation. In the decomposition closure, technology, taste and twist variables are exogenous as we displayed in Column 2, Table 8.1. By setting these variables at their values estimated from the historical simulation (Column 4, Table 8.2), we get the results in the decomposition simulation for consumption, investment and other endogenous variables identical to those in the historical simulation shown in Column 2, Table 8.2. In this section, we will first discuss the decomposition closure, then we will analyse the macro results in Table 8.3, column by column.

Table 8.3 Results of the decomposition simulations from 2012 to 2019 (%, macro variables)

	1 Technical change	2 Changes in import/domestic preferences	3 Shift in export demand curve	4 Growth in employment	5 Cost neutral change in labour/capital ratio	6 Change in government/household consumption ratio	7 Change in average propensity to consume	8 change in investment/capital ratio	9 Total
1 Real devaluation	20.0	– 13.3	– 13.1	1.4	– 1.5	– 0.1	– 7.2	3.5	– 12.7
2 Real wage rate (Pg deflated)	43.6	4.9	6.9	– 1.0	– 1.3	– 0.01	3.5	– 1.6	59.2
3 Capital stock (K)	18.4	3.0	4.8	3.2	20.1	0.04	3.0	– 0.9	59.9
4 Real investment (I)	20.5	3.3	4.7	3.2	19.7	0.3	4.3	– 6.9	54.1
5 Employment (L-wage bill weight)	0.0	0.0	0.0	3.7	0.0	0.0	0.0	0.0	3.7
6 Real GDP	35.7	0.7	3.3	3.3	9.7	0.1	1.9	– 0. 7	60.3
7 Real GNP (Pg deflated)	32.6	2.5	5.5	3.1	10.0	0.1	3.0	– 1.1	63.2
8 Real Household consumption (C)	34.9	1.8	4.5	3.2	9.7	1.5	10.7	– 0.9	78.4

(continued)

Table 8.3 (continued)

	1 Technical change	2 Changes in import/domestic preferences	3 Shift in export demand curve	4 Growth in employment	5 Cost neutral change in labour/capital ratio	6 Change in government/ household consumption ratio	7 Change in average propensity to consume	8 change in investment/ capital ratio	9 Total
9 Real government consumption (G)	34.9	1.8	4.5	3.2	9.7	– 3.7	10.7	– 0.9	69.2
10 Imports, volume	– 5.4	– 20.8	34.8	0.9	15.6	0.2	14.0	– 7.3	25.2
11 Exports, volume	34.1	– 21.1	21.0	2.2	2.3	– 0.1	– 11.1	5.6	20.8
12 GDP price deflator (Pg)	– 16.7	15.3	15.1	– 1.4	1.6	0.1	7.7	– 3.3	14.5
13 Consumer price indicator (P3)	– 15.9	14.0	13.6	– 1.2	1.8	0.1	7.1	– 3.0	13.1
14 Price deflator for investment (Pi)	– 13.0	12.2	11.4	– 1.1	1.0	0.04	5.9	– 2.6	12.0
15 Terms of trade	– 13.7	12.6	11.7	– 1.1	1.2	0.1	6.0	– 2.7	11.8

Source simulation results

8.2.1 Macroeconomic Assumption in the Decomposition Simulation

For understanding the results in Table 8.3, following Dixon and Rimmer (2002, 2004), we use a flow diagram displayed in Fig. 8.1 to help us. This flow diagram is for a one-commodity CGE model, therefore, it does not illustrate relative-price or other structural effects. While these are important, Fig. 8.1 is, nevertheless, a helpful representation of the main macro assumption underlying our CHINAGEM decomposition simulation.

Exogenous variables in the decomposition closure are represented in Fig. 8.1 by rectangles while endogenous variables are shown in ovals. The change in aggregate employment between 2012 and 2019 (ΔL), for example, is exogenous. Thus we assume that changes in technology and changes in other exogenous variables between 2012 and 2019 did not affect aggregate employment in 2019. We also assume, as is conventional in macro modelling, that employment effects over the medium term are eliminated by adjustments in wage rates.

Lines ①, ② and ③ impose a production function: the change in output (ΔGDP) between 2012 and 2019 is a function of ΔTECH, ΔL and ΔK. As we discussed in

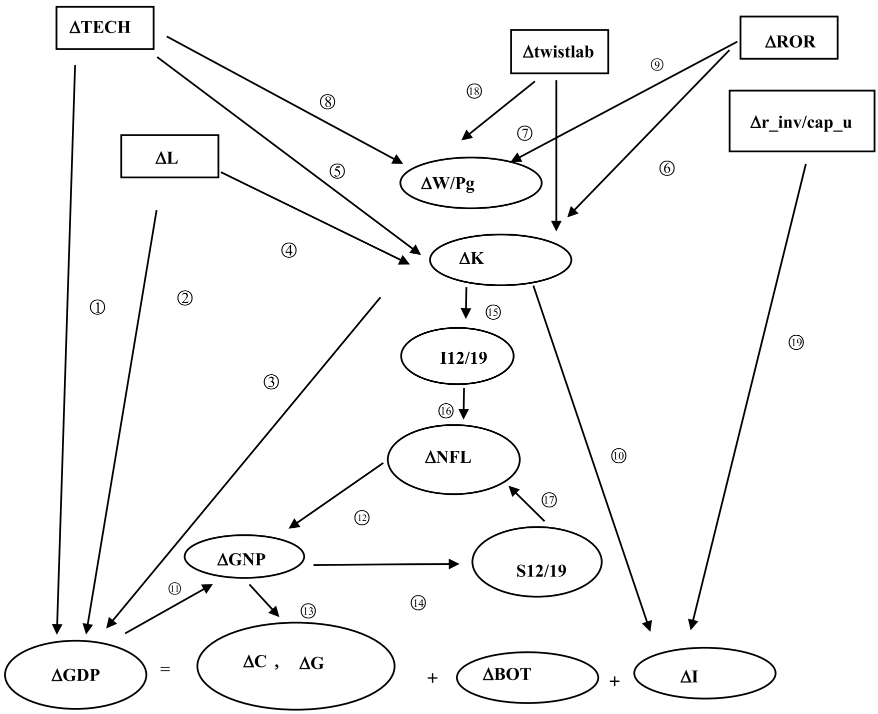

Fig. 8.1 Macro connections in the decomposition simulation for 2012 to 2019

Chaps. 5 and 7, we assume that capital earns the value of its marginal product, that is, marginal product of capital (MPK). MPK is the ratio of the rental price of capital to the price of the product (In a one-commodity model, the price of the product can represent the asset price). Therefore, rate of the return on capital (ROR) can be represented by the rental/asset price ratio. Under the constant-returns to scale (assumed in CHINAGEM), MPK is the function of K/L, TECH and twistlab (as shown in the BOTE Eqs. (5.3), Box 5.1 in Chap. 5, where we ignored the twist variable, twistlab). Thus ΔK is determined by ΔTECH, ΔL, ΔROR and Δtwistlab (lines ④, ⑤, ⑥ and ⑦).

In our decomposition simulation, ΔROR is exogenous as indicated in Fig. 8.1. When we focuse on analysing the effects of particular shocks over periods as long as seven years (2012 to 2019) it is conventional to assume that capital adjusts to restore rates of return. For instance, in isolating the effects of technology changes between 2012 and 2019, we assume that rates of return are unaffected. i.e. ΔROR = 0.[3]

With capital earning the value of its marginal product, labour also is paid according to the value of its marginal product. Therefore, via the factor-price frontier (the relationship between the MPK, MPL and TECH, Samuelson 1962), ΔROR and ΔTECH determine the real wage rate. This is indicated by lines ⑧ and ⑨ in Fig. 8.1.

Exogenisation of the rate of return can be thought of as tying down the capital stock in 2019. While tying down capital stocks for 2019 ties down aggregate investment between 2012 and 2019, it does not determine investment in 2019. We link investment in 2019 to capital in 2019 (line ⑩ in Fig. 1). In isolating the effects of changes in technology and etc. We assume that such changes have no impact on business confidence. Thus we treat the investment/capital ratio (a reflection of business confidence) as exogenously determined.

Lines ⑪and ⑫allow for the calculation of the change in gross national product between 2012 and 2019 (ΔGNP). This is GDP subtracting the change in net interest/dividend payments to foreigners (a proportion of the change in start-of-year net foreign liabilities, ΔNFL).

We assume in line ⑬that the changes in household and government consumption (ΔC, ΔG) are exogenously given proportions of the change in GNP (that is apc_gnp). With ΔGDP, ΔC, ΔG and ΔI now determined, the change in the balance of trade (ΔBOT) falls out as a residual.

Line ⑭links accumulated excess savings (S12/19) to ΔGNP. S12/19 is the difference between the value of the accumulated saving over the period 2012 to 2019 and the value it would have had in the absence of any change over the period in GNP. In deriving the link between S12/19 and ΔGNP, we assume that saving in each year between 2012 and 2019 is a fixed proportion of GNP (aps_gnp). Under a smooth growth assumption applied to GNP, this allows us to specify the accumulated excess savings as a function of ΔGNP.

By again invoking a smooth growth assumption, we can specify in our model the excess accumulated cost of investment (I12/19) between the beginning of 2012

[3] In CHIANGEM decomposition simulation, it is only the average rate of return across industries that is treated exogenously.

and the beginning of 2019 in terms of the change between these two dates in the capital stock (ΔK). The excess cost of investment is the difference in the value of the accumulated investment and the value it would have had in the absence of any change over the period in the aggregate capital stock. The link between I12/19 and K is indicated in Fig. 8.1 by line ⑮.

Another set of relations in Fig. 8.1 are lines ⑯and ⑰. They determines ΔNFL, as a result of investment I12/19 subtracting S12/19.

In this decomposition exercise, we also involve two exogenous variables *twitlab* and *r_inv_cap_u*. As we explained in the last section, the shock of the *twistlab* will change the demand for capital and labour. It also affects the real wage rate. With exogenous employment (ΔL), the change of *twistlab* (Δ*twistlab*) will affect capital (line ⑦) and real wage rate (line ⑱). The shock of *r_inv_cap_u* will affect the investment/capital ratio and directly affect investment (line ⑲).

8.2.2 Decomposition Simulation—Macro Results

The last column in Table 8.3 shows the final results of the decomposition simulation for macro variables of the Chinese economy from 2012 to 2019. Columns 1 to 8 provide a decomposition of these outcomes computed through simulations 1 to 8 with the closure illustrated in Fig. 8.1. This closure is also consistent with the model-generated long-run decomposition closure presented in Table 4.3 in Chap. 4. Note that columns 1 to 8 do not add exactly to the overall results shown in Column 9. This is because of the nonlinear nature of the model.

The main feature of the Chinese economy over the period 2012 to 2019 was rapid growth in consumption relative to GDP whereas the increase in real GDP was 60.2% and the increases in household consumption and government consumption were 78.3% and 69.1%, respectively. This is different from the period 2002 to 2009 when China's trade grew rapidly relative to GDP (the average annual growth rates of exports and imports were 17 and 12%, while the average annual growth rate of GDP was 10% and household consumption was only 7%) (Mai et al. 2010). We will use our decomposition table to explain the rapid increase in consumption from 2012 to 2019. But first, we will start to analyse the decomposition results by looking at each factor from columns 1 to 8 individually.

Column 1: Technical Change (All Factor Augmenting Technical Change)

The macro effects of the historically estimated movements in technology variable (a1primgen – all-factor augmenting technical change) are shown in column 1 of Table 8.3. We notice that China has experienced rapid technical improvements in this period—a remarkable 21.2%. With fixed employment and fixed rates of return on capital, technical improvements increase the real wage rate and increase GDP directly via the production function (line 1, Fig. 8.1) and indirectly via increase in capital stock (Lines 5 and 3). Table 8.3 shows that technical changes over the period 2012 to 2019 drive the capital stock to increase by 18.4% (row 3, column 1), which is more than one-quarter of the total increase of capital over this period (row 3, column 9). The technical changes also drive the real wage rate to increase by 43.6% (row 2, column 1), which is almost three-quarters of the total increase of the real wage rate over this period (row 2, column 9). The technical change also stimulates the real GDP to increase by 35.7% (row 6, column 1), which is more than half of the total growth over this period (row 6, column 9).

The increase in the real GDP also resulted in an increase in real GNP (lines 11 and 12). Household and government consumption therefore also increased (line 13) (both C and G increased by 34.9%, rows 8 and 9, column 1). With capital growth of 18.4%, investment increased as well (line 10) (20.5%, row 4). Based on the GDP identity, with an almost same increase in C, G and GDP, the lower increase in I relative to GDP implies that the balance of trade has to be improved. The mechanism is real devaluation (20.0%, row 1), which stimulates exports (34.1%, row 11) and reduces imports (−5.4%, row 10). The expansion in exports causes a deterioration of the terms of trade (−13.7%, row 15).

Another reason for the change of China's trade is that the strong technology improvement increases the competitiveness of the Chinese goods in the world market, which stimulated exports but decreased imports resulting from the declined demand for import-competing goods.

Column 2: Change in Import/Domestic Preferences

Column 2 displays the macro effects of aggregate import/domestic twist (*twistsrc_c*) from 2012 to 2019. As we discussed in Sect. 8.1 there was a strong twist away from imported goods (−52%, column 4, Table 8.2). The effect of the sharp preference change on import volumes is a huge decline in imports (−20.8%, row 10, column 2, Table 8.3). With L, ROR and TECH held constant, Fig. 8.1 suggests that the *twistsrc_c* should have little effect on K and I (rows 3 and 4, column 2). With little impact on I there is little impact on the balance of trade. Thus a sharp decline in exports (−21.1%, row 11) is required to match the sharp decline in imports via real appreciation (−13.3%, row 1). The percentage decrease in export volumes exceeds that in import volumes because export contraction causes an increase in the terms of trade (12.6%, row 15). The improvement of terms of trade increases the purchasing power of GNP and real household and government consumption.

Another effect of the improvement of terms of trade is to decrease $\frac{P_i}{P_g}$, which causes structural effects on K, I and GDP. In other words, the terms of trade improvement increases the GDP deflator $\left(P_g\right)$ relative to the price deflator of GNE. This is because the GDP deflator includes the prices of exports but excludes the prices of imports, whereas the opposite is true for the GNE deflator. Even with the terms of trade improvement, it is possible for the price deflator of a component of GNE to increase relative to the price deflator for GDP. However, for a relative import-intensive component of GNE (e.g. investment) this is unlikely. In column 2, we see that the investment goods price index P_i (12.2%, row 14) increases less relative to the price deflator for GDP, P_g (15.3%, row 12). With ROR (the rental price of capital divided by the asset price) held constant, a decrease in $\frac{P_i}{P_g}$ generates a decrease in the marginal product of capital (MPK). This follows from the marginal productivity condition for capital:

$$MPK = \frac{Rental}{P_g} = \frac{Rental}{P_i} * \frac{P_i}{P_g} = ROR * \frac{P_i}{P_g} \quad (8.1)$$

With employment and technology fixed, a decrease in MPK requires an increase in K (3.0%, row 3, column 2). This produces an increase in both GDP (0.7%, row 6) and I (3.3%, row 4). The real wage rate rises (4.9%, row 2) reflecting the increase in the K/L ratio and the consequent increase in the marginal product of labour.

As we just discussed the increase of the purchasing power of GNP and real household and public consumption resulting from the improvement of the terms of trade will lead to a higher increase of household and government consumption (1.8%, rows 8 and 9) relative to that of GDP (0.7%, row 6).

Column 3: Shift in the Export Demand Curve

The third column of Table 8.3 shows the effects of changes in China's export demand condition over the period of 2012 to 2019. The historical simulation in the last section reveals that there is a large outward movement of the downward slopping export demand curve (50.9%, row 6, column 4, Table 8.2). This change was favourable to China and stimulated exports which increased by 21% (row 11, column 3, Table 8.3). The outward shift of the export demand curve, which means the increase in demand for China's goods at the same price, also improved China's terms of trade by 11.7% (row 15, column 3).

Same mechanism as we discussed in column 2, the improvement of terms of trade generates an increase in K, I and real GDP (4.8%, 4.7% and 3.3%, rows 3, 4 and 6). With fixed L, the increase in K raises the K/L ratio resulting higher marginal product of labour, which increases the real wage rate (6.9%, row 2).

By generating an increase in the price deflator for GDP relative to the price deflator for private and public consumption $\left(P_g / P_c\right)$ (P_g and P_c increased by 15.1 and 13.6%, rows 12 and 13), the terms of trade improvement in column 3 causes an increase in "purchasing-power" GNP (=GNP $*$ P_g/P_c) relative to real GDP. This explains the higher growth in real household consumption and government consumption (4.5%, rows 8 and 9) relative to the growth of real GDP (3.3%, row 6). With a higher increase in household and government consumption and a higher increase in investment relative to the growth of real GDP, the GDP identity implies a decline in the balance of trade via real appreciation (−13.1%, row 1). Since exports grow strongly resulting from the upward movement of the export demand curve, the only way to deteriorate the balance of trade is to let imports increase even higher than exports. That is why we see a 34.8% increase in imports (row 10).

Column 4: The Effects of Employment Growth and Growth in Population

Column 4 of Table 8.3 displays the effects over the period 2012 to 2019 of growth in employment and population. The increases of total employment in person and population over this historical period were 1.0% and 3. 4%, respectively. In the CHINAGEM model, as we explained in Chap. 5, there is another aggregate employment variable which is measured by using wage bill weight. The shock of one per cent increase in aggregate employment in persons generated a 3.7% increase in the wage bill weighted aggregate employment. In the CHINAGEM model, it is the variable—wage bill weighted aggregate employment—which is used in production function.

With constant return to scale, fixed rates of return (ROR), fixed I/K ratios, no cost-neutral change in labour/capital ratios (*twistlab*) and no change in technology, we would expect the system depicted by lines 1 to 10 in Fig. 8.1 to transform a 3.7% increase in employment into 3.7% increase in K, I and GDP with no change in the real wage rate. However, a larger domestic economy produces more exports with an associated decline in the terms of trade (−1.1%, row 15, column 4). The deterioration of the terms of trade increases $\frac{P_i}{P_g}$ (P_i and P_g decreased by 1.1% and 1.4% respectively, rows 14 and 12, column 4), thus restricting the increase in K and GDP to 3.2% and 3.3% (rows 3 and 6). With a reduction in the K/L ratio, there is a reduction in the marginal product of labour and in the real wage rate (−1.0%, row 2).

By generating a decrease in the price deflator for GDP relative to the price deflator for private and public consumption $\left(P_g \middle/ P_c\right)$, the terms of trade deterioration in column 4 cause a decrease in "purchasing-power" GNP (=GNP $*$ P_g/P_c) relative to real GDP. This explains the lower growth in real household consumption and government consumption (3.2%, rows 8 and 9) relative to the growth of real GDP (3.3%, row 6). The subdued increase in household and government consumption relative to real GDP requires an increase in the balance of trade facilitated by real devaluation (1.4%, row 1). That's why we see a higher increase in exports (2.2%, row 11) than in imports (0.9%, row 10) in column 4, Table 8.3.

Column 5: **Cost-Neutral Change in Labour/Capital Ratios by Industry**

The fifth column of Table 8.3 shows the effects of cost-neutral changes in the labour/ capital ratio for all industries over the period 2012 to 2019. The historical simulation in the last section reveals that all industry has a uniform 18.3% decline in *twistlab* (column 4, Table 8.2). The negative change of *twistlab* implies that the industries twist away from labour and chose to use more capital. This is the reason for the strong increase in capital and investment (20.1% and 19.7%, rows 3 and 4, column 5, Table 8.3).

With no change in employment and technology and with the average share of capital in the primary factor inputs of 48%, the 20.1% increase in capital transformed into a 9.7% increase in real GDP (row 6, column 5). Since there are not much structural effects caused by the change in *twistlab*, therefore no much changes in the price deflator resulting in a similar growth in real GNP (10.0%, row 7), real household and government consumption (9.7%, rows 8 and 9). With the strong increase in investment resulting from a strong increase in capital, the GDP identity requires a deterioration in the balance of trade facilitated by real appreciation (−1.5% row 1). The real appreciation reduced exports and stimulated imports (−2.3% and 15.6%, rows 11 and 10). The other reason for the relatively strong increase in imports is that investment is normally import-oriented. The real appreciation also improved the terms of trade (1.2%, row 15).

Columns 6: The Change in the Ratio of Government/Household Consumption, G/C

Column 6 shows the effects of the change in G/C ratio (f5tot2) over the period 2012 to 2019. A negative change of 5.2% which was estimated for this ratio in the historical simulation (column 4, Table 8.2) indicates a lower growth in government consumption relative to the growth in household consumption. The fall of G/C explains the negative result for government consumption (−3.7%, row 9, column 6, Table 8.3) and positive result for household consumption (1.5%, row 8, column 6, Table 8.3). Since the government-related sectors are all labour intensive, the decline in government consumption will spare more labour to move to other sectors. The employment reallocation causes a structural effects on the economy. But with fixed employment and technology, the structural effects on K, GDP and I are very small (0.04%, 0.1% and 0.3%, rows 3, 6 and 4). With tiny increases in GDP, offsetting changes in C and G, and a relatively large increase in I, the GDP identity requires a decrease in the balance of trade via real appreciation (−0.1%, row 1). Real appreciation explains the expansion in imports (0.2%, row 10), contraction in exports (−0.1%, row 11) and improvement in the terms of trade (0.1%, row 15). Overall the effects of change in G/C on the economy are very mild.

Column 7: The Changes in the Average Propensity to Consume, (C + G)/GNP

Column 7 shows the effects of change in average propensity to consume ((C + G)/GNP) over the period 2012 to 2019. The historical simulation reveals an 8.1% increase in the average propensity to consume (column 4, Table 8.2). This positive change explains the strong increase in household and government consumption (10.7%, rows 8 and 9) in column 7, Table 8.3. Again as we explained in the last paragraph, with fixed employment and technology, the structural effects caused by the increase in the consumption only generate small impacts on K, GDP and I (3.0%, 1.9% and 4.3%, rows 3, 6 and 4). With a large increase in C and G, the GDP identity requires a decrease in the balance of trade facilitated by a real appreciation (−7.2%, row 1). Real appreciation explains the strong expansion in imports (14.0%, row 10), large contraction in exports (−11.1%, row 11) and improvement in the terms of trade (6.0%, row 15).

Column 8: The Change in the Investment/Capital Ratio, I/K

The historical simulation shows a 5.8% decline in the I/K ratio (Column 4, Table 8.2). The effects of the change in this ratio are displayed in Column 8, Table 8.3. The fall of the I/K ratio reduces the investment directly (−6.9%, row 4). As we discussed above, again with fixed employment and technology, the structural effects caused by the fall in the investment only generate small impacts on K and GDP (−0.9% and −0.7%), rows 3 and 6). Consistent with GDP, GNP and C and G also suffered a very small decline. With a slight fall in real GDP, C and G, and the large fall in I, the GDP identity requires an increase in the balance of trade facilitated by a real devaluation (3.4%, row 1). Real devaluation reduces imports (−7.3%, row 10), stimulates exports (5.6%, row 11) and deteriorates the terms of trade (−2.7%, row 15).

8.2.3 Cross-Column Analysis—Growth of China's Economy from 2012 to 2019

China's economy has experienced remarkable growth from 2012 to 2019 (real GDP increased by more than 60 per cent, row 6, column 9, Table 8.3). We discussed the effects on the macro economy of changes in each individual factor through columns 1 to 8 in Table 8.3 in the last section. Now we will focus on the cross-column analysis and try to understand why China's economy grew so fast between 2012 and 2019.

The first 6 rows in Table 8.4 are directly copied from Table 8.3. The seventh row shows the percentage change in the volume of trade in China as the average percentage change in exports and imports. The last row is the percentage change in trade relative to GDP calculated by subtracting the percentage increase in GDP from the percentage change in trade.

Column 9 in Table 8.4 shows the growth of the macro variables during this period, the outstanding feature is the fast growth of household consumption and government consumption (78.4% and 69.2%, rows 8 and 9, column 9). Investment growth is also remarkably strong (53.9%, row 4), though a bit slower than the real GDP growth. While China's trade has a relatively slower growth compared with the three components of GNE.

Why did China's economy grow so fast over this period? From row 1 in Table 8.4 we notice that three factors stand out for contributing to the rapid GDP growth. The first factor is the technical change. The significant technology improvement contributed 35.7 percentage points, which is more than half of the total growth of real GDP (60.2%). As we explained in the last section, the technology improvement generates a higher real GDP directly through production function and also indirectly by stimulating capital growth. The second factor is the cost-neutral change in the labour/capital ratio, which contributed 9.7 percentage points to the real GDP growth. As we discussed in the last section, the negative cost-neutral change in the labour/capital ratio generates a higher real GDP via capital growth. Employment is the third factor, which contributed 3.3 percentage points to the real GDP growth by direct stimulate GDP growth and indirectly via capital growth. The outward shift in the export demand curve also contributed positively to China's economic growth (3.3 percentage points). China's strategy of increasing domestic consumption to sustain economic growth is successful given that increase in the average propensity to consume contributed 1.9 percentage points to GDP growth. The preference change towards domestically produced goods is another positive factor that contributed to the economic growth (0.7 percentage points). The small business confidence decline

Table 8.4 Decomposition of China's economic growth from 2012 to 2019 (%)

	1 Technical change	2 Changes in import/domestic preferences	3 Shift in export demand curve	4 Growth in employment	5 Cost-neutral change in labour/capital ratio	6 Change in government/household consumption ratio	7 Change in average propensity to consume	8 change in investment/capital ratio	9 Total
1 Real GDP	35.7	0.7	3.3	3.3	9.7	0.1	1.9	− 0.7	60.3
2 Real investment (I)	20.5	3.3	4.7	3.2	19.7	0.3	4.3	− 6.9	54.1
3 Real household consumption (C)	34.9	1.8	4.5	3.2	9.7	1.5	10.7	− 0.9	78.4
4 Real government consumption (G)	34.9	1.8	4.5	3.2	9.7	− 3.7	10.7	− 0.9	69.2
5 Imports, volume	− 5.4	− 20.8	34.8	0.9	15.6	0.2	14.0	− 7.3	25.2
6 Exports, volume	34.1	− 21.1	21.0	2.2	− 2.3	− 0.1	− 11.1	5.6	20.8
7 Trade	14.4	− 21.0	27.9	1.6	6.6	0.1	1.5	− 0.9	23.0
8 Trade/GDP	− 21.3	− 21.7	24.7	− 1.7	− 3.1	− 0.03	− 0.4	− 0.2	− 37.3

Source simulation results

is the only factor that contributed negatively to China's economic growth (−0.7 percentage points, column 8, row 1).

Now we will discuss why household and government consumption has had a faster growth than real GDP. When we compare the contribution of the above factors to the real GDP with their contribution to real household and government consumption, we noticed that except for average propensity to consume, the other factors make more or less similar contributions to both real GDP and real consumption. The increase in the propensity to consume contributed 10.7 percentage points to the growth of consumption while it only contributed 1.86 percentage points to real GDP. This is the main reason for the faster growth of consumption relative to the GDP over the period 2012 to 2019.

Now let's look at China's trade during this period. The growth of trade is only 23% (column 9, row 7, Table 8.4), which is far below the growth of real GDP. This led to the trade as a share of GDP decreased by more than 37% (column 9, row 8). There are several reasons for the change:

- The strong technology improvement which stimulated GDP growth significantly also promoted exports considerably. This is because the strong improvement of total-factor productivity makes China's goods more competitive in the world market, which stimulates exports (34.1%). But meanwhile, it also decreases imports for the import-competing goods (−5.4%). The combined change of exports and imports made a 21.3 percentage points contribution to the decline in trade relative to GDP (row 8, column 1).
- The significant increase in the preference towards domestically produced goods made the largest contribution to the decline in trade relative to GDP (−21.7 percentage points, column 2, row 8). The preference changes towards domestically produced goods directly reduced imports and indirectly reduced exports via real appreciation (see discussion of column 2 in the last section).
- The large outward shift of the export demand curve increased exports directly. It also expanded imports via real appreciation (see the discussion of column 3 in the last section). The significant increase in both exports and imports makes the outward shift of the export demand curve the only positive factor which contributed to the change of trade relative to GDP (nearly 25 percentage points, column 3, row 8).
- Though the growth in employment drove increases in both imports and exports, their growth rates are lower than those of GNE (consumption and investment) and GDP. The lower growth of trade explains its contribution to the decline in trade relative to GDP (−1.7 percentage points, column 4, row 8).
- The negative cost-neutral change in the labour/capital ratio, which is twisted toward capital, directly stimulates capital growth, resulting in a strong increase in investment. Since investment is normally import-intensive, which generates a higher import growth. But the decline in exports via real appreciation (as the discussion in column 5 in the last section) offset the positive contribution of imports to trade. As a result, the negative cost-neutral change in the labour/capital

ratio contributed 3.1 percentage points to the decline in trade relative to GDP (column 5, row 8, Table 8.4).

- The decline of business confidence (negative change in the investment/capital ratio) reduced investment directly, which is the reason for the contraction of imports. The expansion of exports could not offset the negative impact of imports on trade. As a result, the decline of business confidence contributed 0.2 percentage points to the decline in trade relative to GDP (column 8, row 8, Table 8.4).
- The increase in the average propensity to consume and the decline in the government/household consumption ratio all contributed to the contraction of trade relative to GDP, though their effects are very small (−0.4 and − 0.03 percentage points, respectively, columns 6 and 7, row 8, Table 8.4).

8.3 Summary

This chapter focused on using the decomposition function of the CHINAGEM model to decompose China's economic growth from 2012 to 2019. To do so, we have to conduct a historical simulation to estimate changes in factors such as technology, twists, and preference variables, which have contributed to China's economic growth. Using the estimated results of these variables, we then run the decomposition simulations individually and explain the effects of each variable on the macro economy. At the end, we decompose the effects of these variables on China's economic growth during this period by a cross-column analysis.

We notice that technology improvement, cost-neutral change towards capital and employment growth are the main factors that have contributed to China's remarkable growth over the period 2012 to 2019, among which technology improvement is the most important factor. This finding is particularly useful for the policy maker given the backdrop of China's labour force having started to decline since 2018.

The increased export demand for China's products from the rest of the world and the strong preference change towards domestically produced goods also made a considerable contribution to China's economic growth, though the latter is the main reason for the decline in China's trade relative to GDP.

The faster growth of consumption relative to GDP is the main feature of the Chinese economy during this period. The Chinese government's strategy of stimulating domestic consumption to grow is the main answer for this feature.

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Part III
Extensions of the CHINAGEM Model and Their Applications

As a platform of the CGE model of the Chinese economy, CHINAGEM is flexible to be modified or extended based on the users' needs. This part includes the extensions of the CHINAGEM model and their applications on the practical policies analysis. Chapter "Labour Market Module and Its Application—The Economic Effects of Facilitating the Flow of Rural Workers to Urban Employment in China" presents a labour market module and its application on China's labour market reform. A pension model which was developed based on the labour market module and was incorporated into CHINAGEM is presented in Chapter "Pension Module and Its Application—Population Ageing and the Impact of Retirement Age Extension on the Economy and Pension System in China". It is applied to analyse the effects of retirement age increase on China's economy. With its core similar to the CHINAGEM model, a financial CGE model and its application are discussed in Chapter "Financial CGE Model for China and Its Application". A water account and water subdivision module is presented in Chapter "Water Subdivision Module and Its Application—Impact of Water Price Reform on Water Conservation and Economic Growth in China". This extended CGE model was used to analyse the effect of water price reform in China. Based on CHINAGEM, a dynamic energy CGE model was developed and applied to investigate the implications of China's carbon neutrality policy. This newly developed energy model and its application are presented in Chapter "CHINAGEM-E: An Energy and Emissions Extension of CHINAGEM—And Its Application in the Context of Carbon Neutrality in China". As a national model, the modelling results of CHINAGEM can be disaggregated into a regional level. Regional extension of CHINAGEM and its application are discussed in Chapter "Regional Extension and Its Application—The Regional Economic Implications of Carbon Neutrality in China".

Chapter 9
Labour Market Module and Its Application—The Economic Effects of Facilitating the Flow of Rural Workers to Urban Employment in China

Yinhua Mai, Xiujian Peng, Peter B. Dixon, and Maureen Rimmer

Abstract China's household registration system—*hukou* system prevents rural workers from freely moving to the urban sectors. In this chapter, we introduced an innovative labor-market module to the CHINEGEM model to simulate the economic effects of relaxing the *hukou* system from 2008 to 2020. The extended CHINAGEM model allows us to model a gradual accumulation of workers in urban activities with a corresponding decumulation in agricultural activities in response to a dismantling of restrictions on rural-urban mobility. Our modelling results reveal that reducing the institutional restriction to rural labour movement will encourage rural workers to move into urban sectors. This enhanced labour movement will not only increase China's GDP and real consumption of households but also increase the real wages of agricultural and rural non-agricultural workers. Although the real wage of rural migrant workers will increase at a slightly lower rate than in the baseline scenario, rural migrant workers remain considerably better paid than agricultural and rural non-agricultural workers.

Keywords China · CGE modelling · Labour market · *hukou* system reform · Rural-urban migration · Economic growth

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9.1 Introduction

When China started its economic reform in 1979, over 70 per cent of the population were earmarked rural by a residential registration system, the *hukou* system. The *hukou* system kept rural residents in rural areas and thus denied them access to an iron-rice bowl—a job at a work unit in an urban area and the social security benefits and social services provided by the work unit.

Rapid industrialisation in the past thirty years has resulted in rapid growth in labour demand in urban areas. While the *hukou* system has lived on till today, its effectiveness in keeping rural residents in rural areas has been reduced significantly by work permits issued by the government to rural workers working in urban areas. The Second Agricultural Survey revealed that during 2006 about 130 million rural people spent more than a month working outside the township of their residence. Most of these migrant workers engaged in industrial and service activities—86 per cent in 2006 according to the National Fixed-Site Survey of Rural Households conducted by the Research Centre for Rural Economy (RCRE) of the Ministry of Agriculture.[1] The rest worked in agriculture, forestry and fishing.

However, being rural still means lack of access to social security benefits and social services in urban areas—schools, medical services, unemployment benefits, retirement benefits, and housing. For those rural workers who spend most of their time working in cities, sending their children to school requires an access fee in addition to what a city person pays.

While belonging to a socially disadvantaged group, rural migrant workers have played a significant role in China's rapid economic growth in recent decades. They have been an important source of labour supply to the rapidly growing non-agricultural sectors. They have served to maintain China's price competitiveness by slowing down the growth of labour costs in industrial sectors. By moving to industrial and service sectors where they have a higher level of labour productivity, they have improved overall labour productivity in China—a direct contribution to economic growth.

The rural–urban migration in recent decades has had a fundamental impact on China's social and economic environment. It has therefore commanded priority in research on a broad range of government policy reforms, such as land policy, fiscal policy, infrastructure, and the social-security reforms.

In recent years, the government has initiated policies to provide social security benefits and social services including children's education to the rural workers working in urban areas. This has further undermined the *hukou* system. The purpose of this chapter is to understand the economic effects of the gradual dismantling of institutional barriers to movement of labour from rural to urban areas such as has happened in recent years.

[1] The RCRE survey defines migrant workers as those who worked for over three months outside their township. The percentage who worked in non-agricultural activities is calculated from the number of days spent in different activities.

An extensive literature on rural migration in China has been evolving since the 1980s. Four major themes can be distinguished in this literature:

- the determinants of rural–urban migration;
- the earnings differential of rural and urban workers;
- labour market reforms such as the reform of the household registration (*hukou)* system;
- the contribution of rural–urban migration to economic growth; and
- the impact of rural migration on agricultural production and rural development.

Applied work in this area has mainly used econometric analysis based on time-series data or sample survey data (for instance, Cai and Wang (1999); Démurger et al. (2009); Kuijs and Wang (2005); Meng and Zhang (2001); Seeborg et al. (2000); Shi et al. (2007); World Bank (1997); Zhao (1999); Zhu (2002)). This has been augmented by the application of CGE modelling, in particular to the analysis of labour market distortions. Xu (1994) started this development with the introduction of rural surplus labour into a three-sector CGE model. Subsequently, further labour market distortions such as urban wage rigidity, imperfect labour mobility and transaction costs that contribute to the wage differential between agriculture and urban non-agricultural sectors have been incorporated into CGE models.

Recent CGE research on rural–urban mobility in China has two strands: multi-country modelling and single-country modelling. In the first strand, the multi-country GTAP (Global Trade Analysis Project) model has been used to explore the effects on income inequality of China's trade reform (for instance WTO accession) in the presence of labour market distortions (Anderson et al. (2004); Chen and Ravallion (2004); and Gilbert and Wahl (2003)). This work is limited by the lack of explicit modelling of the labour market.

In the second strand, single country models have been used to investigate the effect of China's WTO accession on household income inequality by comparing alternative scenarios with and without labour market reform (Hertel and Zhai (2006); Zhai and Li (2000); and Zhai and Wang (2002)). These studies model the labour market explicitly.

Zhai and Li (2000) distinguish between three categories of labour: agricultural labour, production workers and professionals. They capture the partial mobility of the labour force by allowing for migration of agricultural labour and production workers in response to changes in relative wages.

Zhai and Wang (2002) extend the labour market model by introducing wage rigidity of urban unskilled labour to reflect the abundant supply of unskilled labour in the Chinese economy. They simulate the effects of increasing rural–urban labour mobility during China's WTO accession process while the real wage rate of urban labour is fixed. They find that when more rural workers migrate to the city the rigid urban labour market, which cannot absorb all the unskilled labour, causes urban unemployment to increase sharply with consequent reductions in urban household income and saving. In an alternative simulation they relax the fixed wage assumption and find that the higher level of rural labour mobility leads to a higher level of welfare gain. The gain from WTO accession doubled with full labour market reform. Their simulation exercises suggest a need for co-ordination between China's rural–urban migration policy, labour market reform and the implementation of trade liberalisation. The net benefit from WTO membership will be maximised if China adopts a policy of gradually relaxing its rural–urban migration control in conjunction with its labour market reform.

Hertel and Zhai (2006) examine the consequences of land reform for rural urban migration. They measure the transaction costs of rural migration in a more sophisticated way than had been the case in earlier studies. They find that reforms in the rural land rental market and the *hukou* system, as well as increasing off-farm labour mobility, would reduce urban–rural income inequality dramatically. Furthermore, the combination of WTO accession and factor market reforms improves both efficiency and equality.

A common feature of these CGE analyses is the combination of China's labour market distortions with trade reform. In this chapter we look at the economic effects of rural–urban mobility directly by extending the CHINAGEM model, a recursive dynamic CGE model of China.

The features of the extended CHINAGEM model that are most relevant for this chapter concern the labour market module. This is adapted for Chinese conditions from Dixon and Rimmer (2003) and Démurger et al. (2009). Section 9.1 contains a brief description of CHINAGEM and a detailed explanation of the labour market module incorporated in CHINAGEM. This material is non-technical and will be sufficient for readers who want just an overview of our approach to modelling the labour market. Section 9.2 presents the technicalities of our labour market specification, including equations. Section 9.3 includes a brief explanation of our baseline scenario. Section 9.4 discusses results from our first simulation, conducted under the assumption that there is no surplus rural labour and that rural workers are paid the value of their marginal product. In Sect. 9.5 a second set of simulation results is discussed. The second simulation is conducted under the assumption of considerable labour surplus, with payments to agricultural workers reflecting the value of their average product rather than their marginal product. Concluding remarks are in Sect. 9.6.

9.2 Modelling Framework and Labour Market Module

9.2.1 CHINAGEM Model

CHINAGEM model is a dynamic CGE model of the Chinese economy as we explained in Part 2 of the book. The model used in this chapter includes 137 sectors and its base data reflects the 2002 input–output structure of the Chinese economy.

In CHINAGEM, production is modelled using nested constant elasticity of substitution (CES) and Leontief production functions which allow substitution between domestic and imported sources of produced inputs and between labour, capital and land. The production functions are subject to constant returns to scale. Household demand is modelled by the linear expenditure system (ELES). Trade is modelled using the Armington assumption for import demand and a constant elasticity of transformation (CET) for export supply. China is considered as a small open economy in import markets where foreign import prices are determined in world markets. Exports are demanded according to constant-elasticity demand curves for most of commodities. In the model, capital stock is accumulated through investment activities (net of depreciation). Investors respond to changes in expected rate of return.

9.2.2 Labour Market Module and Labour Market Categories and Activities

For analysing the economic effects of labour market reform such as the relaxation of the *hukou* system in China, we introduced a labour market module into CHINAGEM which captures the specific features of China's labour market. Two crucial concepts in the CHINAGEM labour market module are categories and activities of labour supply. At the start of year t, the person-years of labour that will be available during the year are allocated to categories of labour supply. The categories are determined mainly on the basis of employment during year (t − 1). Activities in year t are what people do in that year. The relationship between activities and categories is illustrated in Fig. 9.1.

This extended CHINAGEM model contains ten labour supply categories: five employment categories, three unemployment categories, and two new entrant categories (Table 9.1). The first eight of these categories are associated with corresponding activities. For example, the category AG for year t refers to the number of person-years of employment in rural agriculture in year t − 1 that is still available for employment in year t. The activity AG for year t refers to the number of person-years actually absorbed in rural agricultural employment in year t. Most of the AG category labour in year t is employed in activity AG in year t. However, some AG category labour may flow to other activities, and some labour from other categories may flow to the AG activity.

Different categories have different labour supply behaviour and there are different degrees of mobility between categories. To illustrate, the *hukou* registration system slices China's labour force into two segments: rural labour and urban labour.

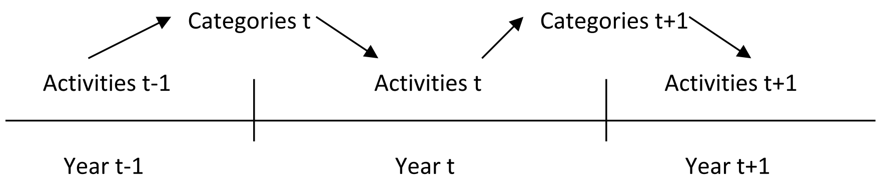

Fig. 9.1 Labour market dynamics

Table 9.1 Categories and activities

Employment categories and activities	
AG	**AG**riculture—Person-years of employment in rural agriculture sectors with rural residential status
RNAG	**R**ural **N**on-**AG**riculture—Person-years of employment of rural people in non-agriculture industries within their township of residence, such as in township and village enterprises and private enterprises in rural areas
RUE	**R**ural–**U**rban **E**mployment—Person-years of employment of rural people in non-agriculture industries outside of their township of residence
UUSE	**U**rban **U**n**S**killed **E**mployment—Person-years of employment of urban people in unskilled occupations
USE	**U**rban **S**killed **E**mployment—Person-years of employment of urban people in skilled occupations
Unemployment categories and activities	
RAGU	**R**ural **AG**ricultural **U**nemployment—Person-years spent by rural workers without a job in their township of residence
RUU	**R**ural–**U**rban **U**nemployment—Person-years spent by rural workers without a job outside their township of residence
UU	**U**rban **U**nemployment—Person-years of urban labour force that are not employed
New entrants categories (no corresponding activities for these categories)	
NRUR	**N**ew entrants **RUR**al—Person-years of new entrants into labour force with rural residential status
NURB	**N**ew entrants **URB**an—Person-years of new entrants into labour force with urban residential status

Although rural workers have permission to work in urban sectors as rural migrants they still have no right to access the social services and social security benefits that are available to urban workers (as discussed in Sect. 9.1). The wage rate of this urban "floating population" is on average lower than that of urban unskilled workers but higher than that of rural labour working in the agricultural and rural non-agricultural sectors. Our labour market module goes beyond the labour force disaggregation based on their *hukou* registration status by distinguishing also between rural urban migrant workers and other rural workers. Rural workers are disaggregated into five categories: rural urban employment; agricultural employment; rural non-agricultural employment; rural agricultural unemployment; and rural urban unemployment.

- Rural urban employment (**RUE**) is defined as—Person-years of employment of rural labour in non-agriculture industries outside of their township of residence. Therefore, RUE represents the rural–urban migrant category.
- Agricultural employment (**AG**) includes all workers employed in rural agriculture. This category has the lowest wage.

- Rural non-agricultural employment (**RNAG**) represents workers employed in the non-agricultural sectors such as township and village enterprises and private enterprises. Their wage on average is normally higher than that of the rural workers who are only working in agricultural sectors.

We treat the entire rural labour force as unskilled workers and we assume that all rural employment and unemployment categories can only make offers to work in rural activities (AG, RNAG, and RUE) because of the *hukou* system. The change of residential status of rural migrant workers can be simulated as a policy change that shifts the workers exogenously from the RUE category to an urban employment category (for example, UUSE). However, when someone is in the RUE category, he or she cannot directly make offers to urban categories of employment.

But rural new entrants (NRUR) can make offers to rural as well as urban activities. This is based on the assumption that some urban enterprises recruit new entrants from rural areas and grant them urban residential status. Rural new entrants with university degrees may acquire a job in a skilled urban occupation and obtain urban residential status.

The CHINAGEM model does not have a rural surplus labour category. Instead, the model treats all rural workers not working in RUE and RNAG activities as agricultural workers and puts them into the AG category. Any rural surplus labour is reflected in disguised unemployment in the AG category. In order to deal with the rural surplus labour issue, we set up two different equations to capture the labour supply behaviour of AG workers. In one equation AG workers' pay is based on their marginal product of labour (MPL) and in the other it is based on their average product of labour (APL).

For the urban labour force we disaggregate into two employment categories, urban skilled employment (**USE**) and urban unskilled employment (**UUSE**); one unemployment category (**UU**); and one new entrant category (**NURB**). We assume that urban categories make offers only to urban activities (UUSE and USE).

We assume no voluntary unemployment in China. Consequently, no category makes offers to unemployment. We summarized the labour supply categories and activities in Table 9.1.

The number of persons employed in an activity in the current year is determined by the demand for and supply to that activity. Those who make an offer to an employment activity but do not get a job in that activity will be forced back to their previous employment activity or to the relevant unemployment activity.

Please refer to Mai et al. (2014) for the detailed calculation of the labour market employment data for each labour category.

9.2.3 The Equation System of the Labour Market Module

The labour market module of the CHINAGEM model has the following equation blocks:

- demand for and employment of labour by activity;

- supply of labour by category;
- wage adjustment reflecting the gap between demand and supply;
- the determination of everyone's activity in year t; and
- linking the number of people in activity o in year t to number of people in category c in year t + 1.

9.2.3.1 Demand for and Employment of Labour by Employment Activities

In the CHINAGEM model, to produce a certain level of output, a representative producer in an industry mixes intermediate inputs and a composite primary factor with Leontief technology. Once the level of the primary-factor composite is determined, the representative producer chooses the levels of capital, land and composite labour to minimise costs subject to a CES constraint. The derived demand for composite labour in year t for each industry, $D_t^1(j)$, is a function[2] of: capital, $K_t(j)$; productivity (or technology), $A_t(j)$; and the real before-tax wage rate to the industry, $BTW_t^1(j)$:

$$D_t^1(j) = f_j^1\left(BTW_t^1(j);\; K_t(j);\; A_t(j)\right),\; j = \text{industry}. \tag{9.1}$$

The real before-tax wage rate to industry j in year t is a function of the real before-tax wage rates of labour by employment activities or equivalently occupations, $BTW_t(o)$:

$$BTW_t^1(j) = g_j^1(BTW_t(o), \forall \text{ employment activities } o),\; j = \text{industry}. \tag{9.2}$$

The representative producer in industry j chooses labour in different occupations via a CES function given the required level of labour composite. The derived demand for labour by occupation and industry, $D_t(o, j)$, is represented by:

$$\begin{aligned} &D_t(o, j) = D_t^1(j) * h_{o,j}(BTW_t(oo)\ \forall \text{ employment activities } oo),\\ &o = \text{employment activity},\; j = \text{industry} \end{aligned} \tag{9.3}$$

where $BTW_t(o)$ is real before-tax wage rate of labour in employment activity o.

The total demand for labour in an employment activity o, $D_t(o)$, is the sum of demands over all industries:

$$D_t(o) = \sum_j D_t(o, j),\; o = \text{employment activity}. \tag{9.4}$$

The employment of labour in an employment activity, $E_t(o)$, is determined by demand:

[2] For simplicity, we ignore land in this stylized representation of the labour market module but not in our CHINAGEM computations.

$$E_t(o) = D_t(o), \; o = \text{employment activity}. \tag{9.5}$$

9.2.3.2 Planned Labour Supply from Categories to Activities

The offer from each labour category c to each employment activity o, $L_t(c; o)$, is determined by an optimisation procedure where people in category c choose $L_t(c; o)$, for all activities o.

to maximise

$$U_c[ATW_t(o) * L_t(c; o) \; \forall \text{ activities } o]$$

.

subject to

$$\sum_o L_t(c; o) = CAT_t(c),$$

where $CAT_t(c)$ is the number of people in category c; $ATW_t(o)$ is the real after-tax wage rate of labour in employment activity o; and U_c is a homothetic function with the usual properties of utility functions (positive first derivatives and quasi-concavity). In CHINAGEM, U_c has the CES form. Giving labour-supply functions of the form:

$$L_t(c; o) = CAT_t(c) * \left[\frac{(B_t(c; o) * ATW_t(o))^{\eta}}{\sum_q (B_t(c; q) * ATW_t(q))^{\eta}} \right], \tag{9.6}$$

$$c = \text{category}, \; o = \text{employment activity},$$

where $B_t(c; o)$ is a variable reflecting the preference of people in category c for earning money in activity o in year t; and $\eta > 0$ is a parameter reflecting the ease with which people feel that they can shift between activities.

The variable $B_t(c; o)$ captures non-wage factors that might motivate people from category c to offer their labour to employment activity o. An example of such factors is a reduction in institutional barriers that might motivate people in rural categories to offer to urban employment activities. A 30% increase in $B_t(c; o)$ has the same effect on category c's labour supply as a 30% increase in the real after-tax wage rate $ATW_t(o)$.

$B_t(c; o)$ also allows the calibration of (9.6) to reflect the properties of different labour supply category. For example, by setting $B_t(c; o) = 0$ for all categories c and for all unemployment activities o, we ensure that there are no offers to unemployment activities:

$$L_t(c; u) = 0; c = \text{category}, u = \text{unemployment activity}; \tag{9.7}$$

The planned labour supply to each employment activity a, $L_t(a)$, is determined as the sum of offers to the activity by people from all categories:

$$L_t(a) = \sum_c L_t(c;\ a),\ a = \text{employment activity}. \tag{9.8}$$

The real after-tax wage rate $ATW_t(o)$ for each employment activity o is linked to the real before-tax wage rate $BTW_t(o)$ via:

$$ATW_t(o) = BTW_t(o) * (1 - T_t),\ o = \text{employment activity}, \tag{9.9}$$

where T_t is the payroll and income tax rate.

This equation can be thought of as determining the real before-tax wage rate $BTW_t(o)$. The real after-tax wage rate $ATW_t(o)$ is determined by wage adjustment equations to be discussed in the next subsection.

9.2.3.3 Wage Adjustment Equations Reflecting Demand and Supply

In policy simulations, we assume that wage rates adjust according to:

$$\frac{ATW_t(o)}{ATW_t^{base}(o)} - \frac{ATW_{t-1}(o)}{ATW_{t-1}^{base}(o)} = \alpha\left(\frac{D_t(o)}{D_t^{base}(o)} - \frac{L_t(o)}{L_t^{base}(o)}\right), \tag{9.10}$$
$$o = \text{employment activity},$$

where the superscript "base" refers to values in the base case forecast and α is a positive parameter.

This equation implies that if a policy causes the market for employment in activity o in year t to be tighter than it was in the base case forecast (i.e., if the policy causes a larger percentage deviation in demand than supply), then there will be an increase between years t − 1 and t in the deviation in activity o's real after-tax wage rate. In other words, in periods in which a policy has elevated demand relative to supply, real wages will grow relative to their base case values (for a more detailed discussion of the wage adjustment equation, see Dixon and Rimmer 2003).

9.2.3.4 The Determination of Everyone's Activity

The wage adjustment equations imply that gaps between supply and demand in employment activity o are allowed in the model. We therefore need to specify which offers to employment activity o are accepted and what activities are undertaken by those whose offers to employment activities are not accepted. For this purpose, we specify the flow from each category to each activity $H_t[c;\ a]$ in year t. Notice that $H_t[c;\ a]$ includes flows from all categories (employed, unemployed and new entrants) to all activities (employed and unemployed).

The starting point for determining $H_t[c;\ a]$ is the specification of vacancies, $V_t(o)$, in employment activity o:

$$V_t(o) = E_t(o) - H_t[o;\ o],\ o = \text{employment activity.} \tag{9.11}$$

where vacancies equals employment less jobs filled by incumbents, $H_t[o;\ o]$.

Next, "off-diagonal" flows are determined according to:

$$H_t(c;\ o) = V_t(o) * \left[\frac{L_t(c;\ o)}{\sum_{s \neq o} L_t(s;\ o)}\right], \quad c = \text{category},\ o = \text{employment activity; and } c \neq o. \tag{9.12}$$

Equation (9.12) specifies that jobs in activity o given to non-incumbents are proportional to vacancies in o and to the share of category c in the supply of labour to activity o from people outside category o. Thus, if people in category c account for 10 per cent of the people outside category o who want jobs in employment activity o, then people in category c fill 10 per cent of the vacancies in o.

"Diagonal" flows are determined as a residual:

$$H_t(o;\ o) = CAT_t(o) - \sum_{a \neq o} H_t(o;\ a), \quad o = \text{employment category and activity.} \tag{9.13}$$

Equation (9.13) specifies that the number of incumbents, $H_t[o;\ o]$, who remain in employment-activity o equals the number of people in category o less the number who move out of activity o to other employment activities as well as to unemployment activities.

The flows from each employment category to each unemployment activity are determined by:

$$H_t(c;\ u) = DUMMY(c;\ u) * \mu(c) * CAT_t(c), \quad c = \text{employment category; } u = \text{unemployment activity.} \tag{9.14}$$

where $\mu(c)$ is the fraction of category c people who become involuntarily unemployed. A dummy variable is included in (9.14) to ensure that involuntarily unemployed people move to the relevant unemployment activity: rural agricultural and rural non-agricultural people to rural agricultural unemployment; rural–urban people to rural–urban unemployment; and urban people to urban unemployment.

Normally, $\mu(c)$ is exogenous. However, it is possible for (9.14) in conjunction with (9.12) to give values for $H_t(c;\ c)$ in (9.13) that exceed $E_t(c)$. In this case, we see from (9.11) that $V_t(c)$ would be negative. We avoid this situation by treating $\mu(c)$ as an endogenous variable. If $V_t(c)$ is greater than zero, then $\mu(c)$ equals an exogenously given minimum value determined by the rate at which individuals are dismissed because of their performance or other factors unrelated to overall demand for people in activity c. Alternatively, $\mu(c)$ moves sufficiently above its minimal value to ensure that $V_t(c)$ equals zero. When $\mu(c)$ is above its minimum value, then there are involuntary flows from employment category c to unemployment caused by overall shortage of jobs. In a fast growing economy such as China's, endogenous determination of $\mu(c)$ will rarely be required.

The flow from an unemployment or new-entrant category c to unemployment is given by the number of people in c less those who find a job:

$$H_t(c;u) = DUMMY1(c,u) * \left(CAT_t(c) - \sum_{a \in \text{employment activity}} H_t(c;a)\right) \quad (9.15)$$

$$c = \text{unemployment or new category;}$$

$$\text{and } u = \text{unemployment activity.}$$

The dummy coefficient in (9.15) is used to ensure that: rural new entrants who don't get a job go to rural agricultural unemployment; urban new entrants who don't get a job go to urban unemployment; and people in unemployment category c who don't get a job stay in unemployment activity c; The number of people in unemployment activities equal to the sum of the flow from all categories to unemployment activities:

$$E_t(a) = \sum_{c \in \text{categories}} H_t(c;a),\ a = \text{unemployment activity;} \quad (9.16)$$

A similar equation is not required for employment activities. Such an equation is implied by (9.11) and (9.12).

9.2.3.5 Linking the Previous-year Activities to the Current-year Categories

From (9.1) to (9.16), we can determine the number of people in each employment and unemployment activity in year t given the number of people in each category of labour supply at the beginning of the year and demands during the year. To complete the equation system, we need to determine the number of people in each category of labour supply at the beginning of year t. If t is the first year of a simulation, then we determine the number of people in categories mainly on the basis of data on activities for year $t - 1$. If it is a subsequent year then we determine the number of people in categories mainly on the basis of results for activities in year $t - 1$.

For all except new entrant categories:

$$\begin{aligned} & CAT_t(c) = ACT_{t-1}(c) * S(c), \\ & c = \text{category; and } c \neq \text{new entrant;} \end{aligned} \tag{9.17}$$

where

$ACT_{t-1}(c)$ is the number of people in activity c in year $t - 1$; and S(c) is the proportion of people in activity c in year $t - 1$ who are allocated to category c at the start of year t.

In CHINAGEM, we assume $S(c) = 0.99$. This allows one per cent of people in every activity in year $t - 1$ to drop out of the workforce at the beginning of year t either through retirement or death.

For new-entrant categories:

$$CAT_t(c) = \text{exogenous, } c = \text{new entrant.} \tag{9.18}$$

9.3 Baseline Scenario

To analyse the economic effects of a policy change, we first develop a base case forecast or a baseline, a business-as-usual scenario without the implementation of the policy change.[3] Then we conduct a policy simulation, an alternative forecast with the policy change in place. The effects of the policy change are measured by deviations of variables in the alternative forecast from their baseline levels.

To develop the baseline scenario, we first update the database to 2007. Then for the forecast period of 2008 to 2020 we assume that the growth pattern of the Chinese economy will follow its historical trend but will grow at a lower rate (for example, the average annual growth rate of real GDP between 2002 and 2007 is 10.3 per cent while we assume that the average growth rate of real GDP from 2008 to 2020 is 9.5 per cent). The growth rates of rural migrant workers and other labour categories in the baseline scenario are endogenized and determined by the exogenous macro variables such as investment, exports and imports, the growth rates of agricultural, industrial and service sectors, and the growth rate of total labour force (refer to Table 9.2 for the baseline results). The growth rate of the exogenous variable, total labour force, is calculated based on the growth rate of working age population (which is from the United Nations medium variant population projection 2010) and aggregate labour force participation rate (which is assumed to stay at the 2005 level during the forecast period).

The baseline scenario shows a continuous decrease of agricultural employment (−1.91 per cent annually on average from 2008 to 2020) and continuous growth of

[3] For more detail about how the business-as-usual scenario is developed for the CHINAGEM model, see Part 2, Chaps. 5 and 6.

Table 9.2 Summary of baseline calibration*

	2008	2012	2015	2018	2020
Exogenously specified variables					
Annual growth rate (%)					
Investment	8.64	8.34	8.12	7.34	6.31
Imports	12.25	11.83	11.52	10.41	8.95
Exports	12.56	12.13	11.80	10.67	9.17
Labour force	1.03	0.52	0.52	− 0.14	− 0.14
Output of					
Agricultural sectors	3.22	3.22	3.20	3.18	3.18
Industrial sectors	8.95	8.94	8.89	8.83	8.81
Service sectors	8.53	8.52	8.48	8.42	8.40
Calibrated results					
Annual growth rate (%)					
Real GDP	9.17	9.79	9.72	9.10	8.22
Capital stock	9.16	8.90	8.71	8.51	8.14
Consumption	8.37	9.84	9.83	9.40	8.81
Real wage rate	9.69	10.79	10.41	9.51	8.46
Agricultural employment (AG)	− 1.18	− 1.81	− 2.13	− 2.23	− 2.09
Rural non-agricultural employment (RNAG)	1.59	1.83	1.88	1.80	1.67
Rural urban employment (RUE)	1.62	1.70	1.70	1.60	1.48
Urban unskilled employment (UUSE)	1.59	1.82	1.84	1.72	1.56
Urban skilled employment (USE)	1.66	1.91	1.92	1.82	1.68

Source Baseline simulation results
* Only selected years results are displayed in this table

rural non-agricultural (1.79 per cent annually) and rural urban employment (1.64 per cent annually).

9.4 The Effects of Facilitating the Flow of Rural Labour to Urban Employment—First Policy Simulation

This section contains an analysis of the economic effects of shifting people from agricultural and rural non-agricultural employment to urban jobs through reducing institutional barriers to such movement. In the simulation, we assume that the policy is implemented in five years from 2008.

In order to examine the potential influence of rural surplus labour we conduct two policy simulations. The first simulation (discussed in this section) is based on the assumption that there is no surplus labour and that the wage of AG workers reflects their marginal product. The second simulation (reported in Sect. 9.6) captures the hypothetical scenario of the existence of surplus labour. In this scenario, we assume that the wage in the AG activity is based on the average product of labour.

The reduction in institutional barriers is simulated by increasing the variable $B_t(c;\ o)$, for c = AG, RNAG, RUE, RAGU, RUU and NRUR for o = RUE for five year from 2008. $B_t(c;\ o)$ is a variable in the labour supply function reflecting the preference of worker in category c for offering labour in activity o in year t.[4] The policy shock to the relevant $B_t(c;\ o)$ variables increases the enthusiasm of the agricultural (AG), rural non-agricultural (RNAG) workers and unemployed rural workers (RAGU) and new rural entrants (NRUR) to offer to work as rural–urban workers (RUE) and for existing RUE workers and unemployed rural–urban workers (RUU) to stay as RUE workers. The increase in the relevant $B_t(c;\ o)$ variables was calibrated so that the gap between the wages of RUE and AG workers is reduced by about 28 per cent at the end of the policy implementation period. Shi (2002) found that approximately 28 per cent of the rural–urban wage difference can be explained directly by the coefficient on the institutional barriers to rural–urban labour flow.

9.4.1 Labour Markets and Effective Labour Input

The increase in the preference to work in the RUE activity leads to more rural workers moving out of AG and RNAG categories. As a result, the supply of RUE workers exceeds the demand for RUE workers which causes the real wage of RUE workers to decline (Fig. 9.2). The excess supply of RUE labour widens during the five years when the policy is implemented and subsequently narrows during the post-policy period. As a result, the real wage for RUE labour decreases relative to the baseline before it reaches its long-run deviation level.

As more workers move out of the AG and RNAG categories, supply of AG and RNAG workers declines which leads to an excess demand for AG and RNAG workers. Consequently, real wages for these categories increase relative to the baseline scenario (Fig. 9.3).

In the long-run (2019), the changes in the markets for AG, RNAG and RUE workers will lead to an increase in employment of RUE workers of 6.15 per cent relative to baseline scenario while AG and RNAG employment will decrease by 1.82 per cent and 1.67 per cent relative to the baseline scenario. The changes in urban employment are small compared to the changes in rural employment. Urban unskilled employment (UUSE) will be 0.01 per cent lower and urban skilled employment (USE) will be 0.04 per cent higher than in the baseline scenario.

The movement from AG and RNAG to RUE leads to a greater long-run increase in effective labour input measured by wage-bill weights than employment of persons,

[4] Refer to Sect. 9.3 for the detailed equations and explanation.

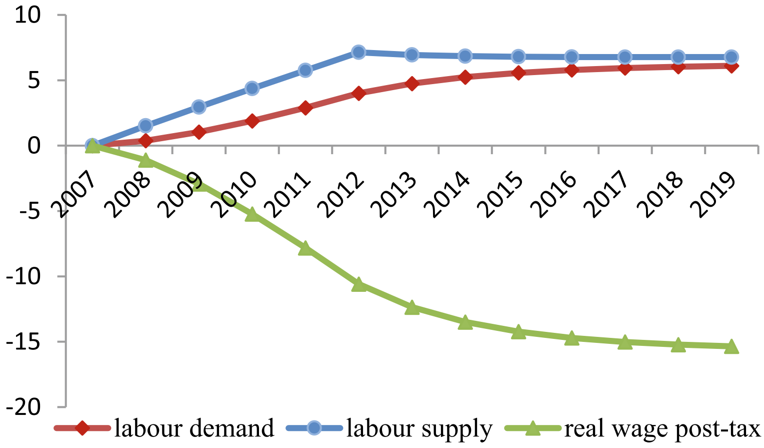

Fig. 9.2 Moving people from rural to urban: market for rural–urban workers (RUE) (cumulative deviation from baseline, %)

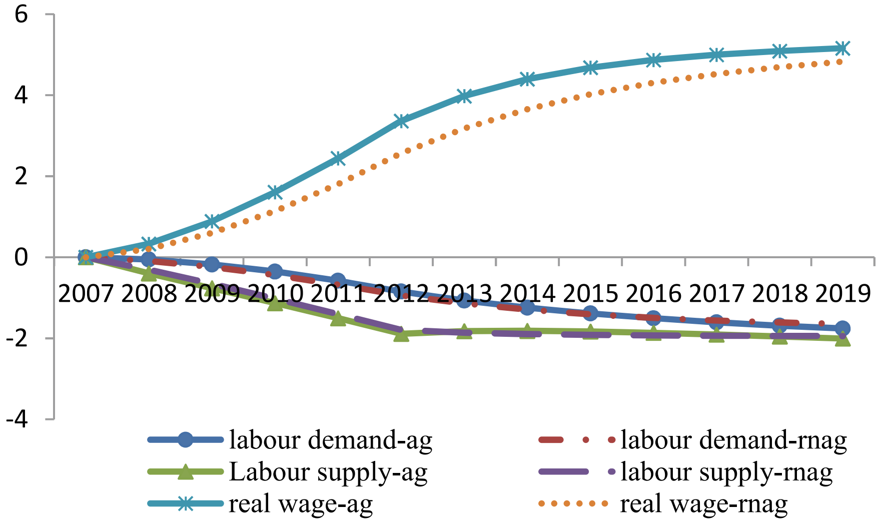

Fig. 9.3 Moving people from rural to urban: market for agricultural workers (AG) and rural non-agricultural workers (RNAG) (cumulative deviation from baseline, %)

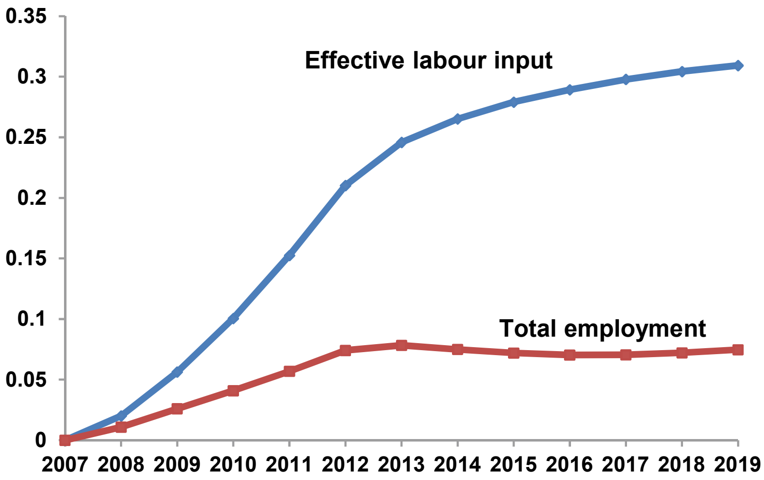

Fig. 9.4 Moving people from rural to urban: total employment and effective labour input (cumulative deviation from baseline, %)

0.30 per cent compared with 0.07 per cent (Fig. 9.4).[5] This is because labour productivity is higher in the RUE activity than in the AG and RNAG activities, reflecting the difference in their wage rates.

In Table 9.3 we present a calculation in order to comprehend the magnitude of the increase in effective labour input (0.30 per cent). This calculation is important because the magnitude of the increase in effective labour input determines the magnitude of the increase in real GDP due to the policy change.

Table 9.3 shows that, in terms of number of person-years, the percentage decreases in AG and RNAG employment means about 6.42 million (column 5: 4.1548 m + 2.2626 m) people are moved out of the AG and RNAG activities. The 6.15 percentage increase in RUE employment relative to baseline means about 6.92 million jobs are generated in RUE work due to the policy change (there are 112.4 million of person-years in RUE employment in 2019 in the baseline scenario. The reduction of institutional barriers will increase the RUE employment to 119.3 million person-years in 2019). These changes result in an increase of 162,607 million RMB in total wage-bill employment which is 0.30 per cent of the total wage-bill employment in year 2019 in the baseline.

[5] While we identify 2019 as the long run, it is apparent that the economy has not completely adjusted to the shocks applied in 2008 to 2012. This explains why aggregate employment measured in people is still slightly above its baseline level in 2019: average real wages across the economy have not adjusted sufficiently to completely eliminate the increase in employment associated with the productivity-enhancing movement of people.

Table 9.3 Why does effective labour input increase by 0.30 per cent?

	Baseline 2019			Deviation from baseline 2019		
	Wage rate	Employment	Wage bill	Employment	Employment	Wage bill employment
	('000RMB)	(million)	(10million RMB)	(per cent)	(million)	(10million RMB)
Categories	(1)	(2)	(3) = (1) ∗ (2)	(4)	(5) = (4) ∗ (2)	(6) = (1) ∗ (5)
1 Agriculture (AG)	30.56	228.6836	698,744	− 1.82	− 4.1548	− 12,709.3
2 Rural non-agriculture (RNAG)	44.46	135.362	601,769.56	− 1.67	− 2.26256	− 10,058.5
3 Rural urban (RUE)	56.25	112.4177	632,312.94	6.15	6.915882	38,899.58
4 Urban unskilled (UUSE)	92.53	287.7529	2662,701.75	− 0.01	− 0.0271552	− 251.279
5 Urban skilled (USE)	174.98	49.52141	866,539	0.04	0.02172752	380.194
Total or Average	67.12	813.7376	5,462,067.25	–	48.84117	16,260.66
Percentage increase in effective labour input = 100 ∗ 16,260.66/5462067.25 = 0.30 per cent						

9.4.2 Real GDP and Aggregate Capital Stock

The reduction of the institutional barriers to the rural labour movement will boost China's economic growth. Figure 9.5 shows that in the long-run, real GDP will be 0.36 per cent higher than that of baseline scenario. There are two reasons for the higher real GDP. First, enhanced labour movement from the agricultural (AG) and rural non-agricultural (RNAG) categories into the rural urban (RUE) category increases the effective labour input which boosts economic growth directly. As we discussed in the above section, the effective labour input is 0.30 per cent higher than that of the baseline scenario.

Secondly, higher capital stock contributes to higher GDP growth. In the long run aggregate capital stock will be 0.42 per cent higher than that of baseline scenario (Fig. 9.5). The long-run increase in capital stock relative to baseline is due to two factors: an increase in effective labour input and an increase in the capital-labour ratio.

- First, more people moving out of agricultural sectors reduces the price of investment goods relative to consumption goods (Fig. 9.6). Moving labour from AG and RNAG activities to the RUE activity increases real labour costs in the agriculture sectors relative to the industrial sectors. Meanwhile the contraction of agricultural output as a result of increased migration from agricultural to urban sectors also drives the food price to increase (agricultural output is 1.41 per cent lower than in the baseline scenario in 2019 while industry and service output is 0.54 and 0.62 per cent higher, respectively (Fig. 9.7)). This raises the price of consumer goods relative to industrial goods, increasing the desired capital-labour ratio (the consumer price index is 0.92 per cent higher and investment price index is 0.28 per cent lower than in the baseline as shown in Fig. 9.6). In the long run this will cause the capital stock to increase.

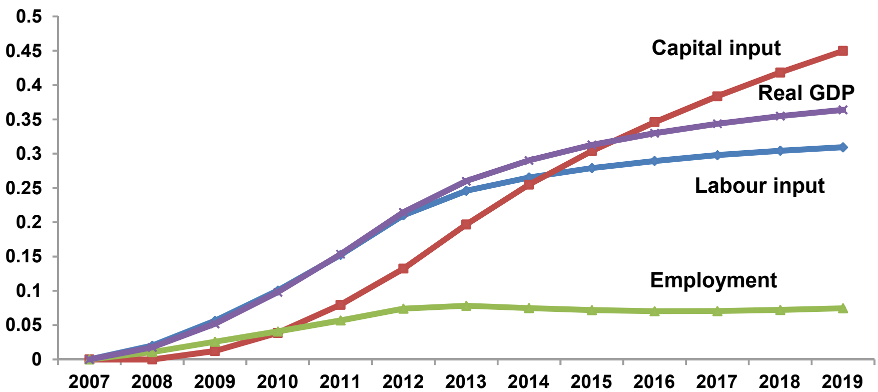

Fig. 9.5 Moving people from rural to urban: real GDP and factor inputs (cumulative deviation from baseline, %)

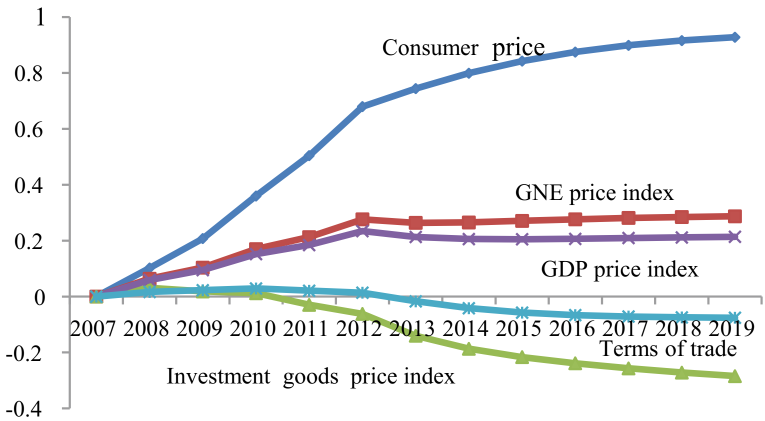

Fig. 9.6 Moving people from rural to urban: price indices and terms of trade (cumulative deviation from baseline, %)

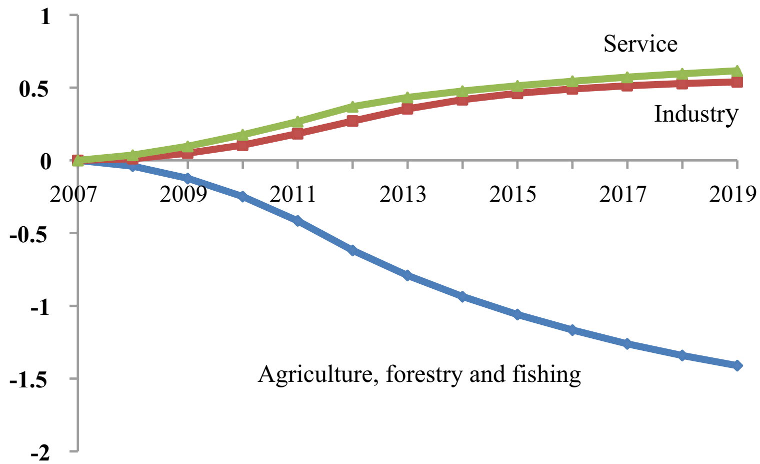

Fig. 9.7 Moving people from rural to urban: outputs of aggregate sectors (cumulative deviation from baseline, %)

- Secondly, more people moving out of agricultural sectors causes a change in output structure. Moving people from AG and RNAG activities to the RUE activity leads to lower labour costs for the urban industrial and service sectors, allowing these sectors to expand more rapidly than the agricultural sectors (Fig. 9.7). This is another factor that motivates an increase in the long-run capital-labour ratio because the industrial and service sectors are more capital intensive than the agricultural sectors.

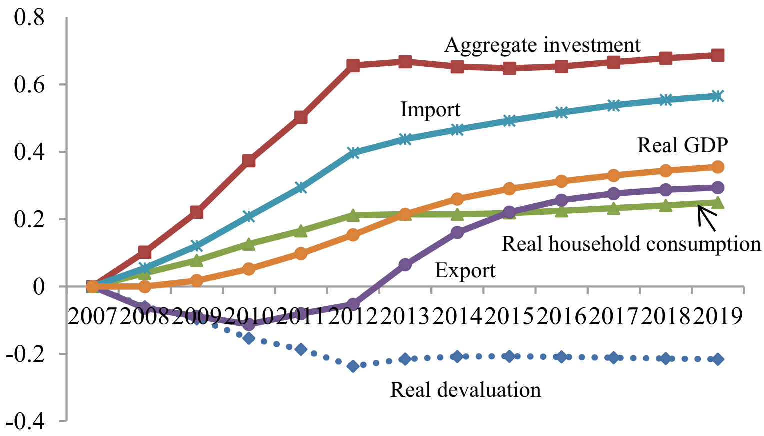

Fig. 9.8 Moving people from rural to urban: expenditure-side of GDP (cumulative deviation from baseline, %)

9.4.3 GDP Expenditures and Household Income

Due to the strong increase in capital stock, aggregate investment increases strongly relative to its baseline path (Fig. 9.8).

In the long-run the increase in the labour movement from rural to urban sectors stimulates the growth of China's exports. As Fig. 9.8 shows, exports will be 0.29 per cent higher than in the baseline scenario. The reason is that with the slower growth of the wage rates of RUE workers, the labour cost in export sectors, especially in manufacture sector is reduced. This further increases the competitiveness of Chinese exports in the world market. As a result Chinese exports expand. The expansion of exports implies more employment opportunities which may further attract rural migrants. However, in the short-to medium-run when capital stock is being accumulated, export performance is damped by real appreciation associated with an increased level of investment activities (Fig. 9.8).

The increased movement of rural labour also improves households' living standards measured by real consumption. As Fig. 9.8 shows, real consumption is 0.25 per cent higher than in the baseline scenario. We notice that the increase of consumption is lower than that of real GDP. One reason is the deterioration of China's terms of trade associated with the expansion of exports. In 2019 the terms of trade are 0.07 per cent lower than in the baseline scenario (Fig. 9.6). The second reason is faster growth of the price of the consumer goods driven by the higher price of agricultural products (Fig. 9.6).

We also notice that increased rural labour movement reduces the income gap between urban and rural households. In China the ratio of urban to rural incomes has increased from 2.57 in 1978 to 3.33 in 2009. The increasing income inequality has caused concerns from Chinese government and scholars (Hertel and Zhai 2006;

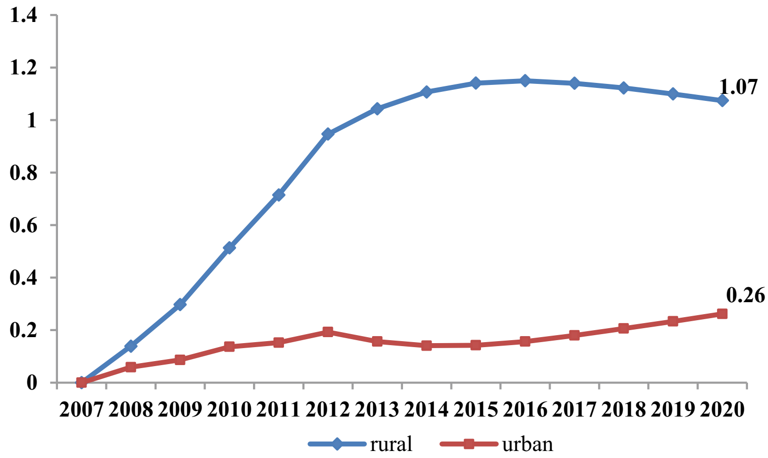

Fig. 9.9 Moving people from rural to urban: urban and rural household per capita disposable income (cumulative deviation from baseline, %)

Luo and Zhu 2008; Treiman 2012). The reduction of the institutional barriers to the rural labour movement will help reduce the income inequality by increasing rural household income at a faster rate than urban household income. Figure 9.9 shows that in 2019 rural household income will be 1.07 per cent higher than the baseline scenario, while urban income will only be 0.26 per cent higher than in the baseline case.[6]

9.5 The Effect of Facilitating the Flow of Rural Labour to Urban Employment—Second Policy Simulation

Whether China has run out of rural surplus labour is still hotly debated (Cai and Du 2011; Ge and Yang 2011; Golley and Meng 2011; Knight et al. 2011; Peng and Mai 2012 and Zhang et al. 2011). If there still exists surplus labour in rural areas then the marginal product of labour will be very low. In that situation it is no longer sensible to assume that agricultural workers are paid based on their marginal product. To test the sensitivity of our results to the adoption of the surplus-labour assumption we made two changes to our model for the second simulation. First, we altered the database so that the marginal product of labour in agricultural activities was half that in the original simulation. Reducing the marginal product of labour captures the existence of rural surplus labour. Secondly, we change the labour supply behaviour of agricultural workers by assuming that the wage rate is determined by the average product of labour instead of the marginal product. With the existence of rural surplus labour we expect

[6] Please refer to Mai and Peng (2011) for the detailed discussion of the effects of rural labour movement on rural urban income inequality in China.

the same policy shock to push more rural labour out of the agricultural sectors. The existence of rural surplus labour is also expected to moderate the negative effect on agricultural output and the positive effect on food prices of labour moving out of agricultural activities compared with the first simulation.

Table 9.4 displays the simulation results. As expected, compared to the first simulation more workers leave the agricultural sectors (5.21 million compared with 4.15 million in simulation one) and more rural workers are employed as RUE workers (7.43 million compared with 6.92 million in simulation one). With more people moving from low paid agricultural sectors into high paid industrial and service sectors in urban areas the effective labour input (measured by wage bill weight) increases. As shown in Table 9.5, compared to the baseline scenario the effective labour input is 0.49 per cent higher in simulation two but only 0.30 per cent higher in simulation one. The higher effective labour input also causes the capital stock to increase at a higher rate. The deviation in the aggregate capital stock is 38 per cent higher in simulation two than in one (0.58 per cent higher than baseline in simulation two and 0.42 per cent higher in simulation one). The higher effective labour input combines with the higher capital stock to increase GDP growth. Real GDP is 0.48 per cent higher in simulation two (0.36 per cent in simulation one) than in the baseline scenario. The percentage deviation in household real consumption (0.32) is also higher than in simulation one (0.25).

We notice that more people leaving the agricultural sectors does not reduce agricultural output as much as in simulation one (Table 9.5). Agricultural output in simulation two is only 1.13 per cent lower than baseline while it is 1.41 per cent lower in simulation one. The food price in simulation two is 0.61 per cent higher

Table 9.4 Results of policy simulations—deviations from baseline in 2019

	Simulation 1		Simulation 2	
	Per cent	Persons (million)	Per cent	Persons (million)
Employment				
AG	− 1.76	− 4.15	− 2.46	− 5.21
RNAG	− 1.74	− 2.26	− 1.53	− 2.21
RUE	6.11	6.92	6.31	7.43
UUSE	− 0.01	− 0.03	0.02	0.05
USE	0.04	0.02	0.05	0.02
Real wage rate				
AG	5.16		5.19	
RNAG	4.83		5.17	
RUE	− 1535		− 1527	
UUSE	0.03		0.56	
USE	0.06		0.57	

Source Policy simulation results

Table 9.5 Results of policy simulations—deviations from baseline in 2019 (per cent)

	Simulation 1	Simulation 2
Real GDP	0.36	0.48
Employment in number of persons	0.07	0.04
Employment by wage bill weights	0.30	0.49
Capital stock	0.42	0.58
Investment	0.69	0.75
Consumption	0.25	0.32
Exports	0.29	0.48
Imports	0.57	0.56
Real wage rate	− 0.38	− 0.36
Terms of trade	− 0.07	− 0.12
Real devaluation	− 0.22	− 0.08
Output of agricultural sectors	− 1.41	− 1.13
Output of industrial sectors	0.54	0.62
Output of service sectors	0.62	0.65
Consumer price index	0.92	0.61
Investment goods price index	− 0.28	− 0.33

Source Policy simulation results

than baseline while it is 0.92 per cent higher in simulation one.[7] This demonstrates that the negative effects of the labour loss on agricultural output and food price are moderated by the presence of surplus labour. The reduction in output is 14 per cent smaller and food prices increase 32 per cent less than in the absence of surplus labour (simulation one).

We also notice that the real wage improves in all activities in the presence of surplus labour (Table 9.4). This reflects the combined effects of the higher output growth and the lower inflation in food prices. In simulation two the wage rate of agricultural workers increases by 5.19 per relative to baseline and by 5.16 per cent in simulation one. At the same time, the increase in employment in the urban sectors by rural migrants is associated with a slightly smaller reduction in the real wage of RUE workers (15.27 per cent versus 15.35 per cent in simulation one).

[7] Refer to consumer price index in Table 9.5 for the food price index. In China agricultural and food products dominate consumption bundle.

9.6 Concluding Remarks

China's *hukou* system prevents rural workers from freely moving to the urban sectors. This chapter shows that reducing the institutional barriers will increase the rural labour movement and China will benefit from the resulting increase in rural–urban employment. Using a dynamic CGE model, we found that a reduction of restrictions that encouraged an extra 6.3 million workers[8] to move out of agricultural and rural non-agricultural employment and into rural–urban employment would, by 2019:

- increase China's GDP by 0.36 per cent;
- increase households' real consumption by 0.25 per cent; and
- increase the real wages of agricultural and rural non-agricultural workers, China's lowest paid workers, by about 5 per cent while reducing the real wages of rural–urban workers by about 15 per cent. Even with these wage changes, rural–urban workers stay considerably better paid than agricultural and rural non-agricultural workers.

To test the robustness of this finding and, simultaneously, identify some implications of the existence of surplus labour, we ran a second simulation in which all surplus labour was absorbed into the agricultural category with a real wage based on the average product of labour. This simulation showed that the presence of surplus labour strengthens the positive effects of the same policy shock on the economy.

Our CGE model includes a relatively detailed labour-market module in which members of the labour force are allocated to categories at the beginning of each year, depending mainly on their labour market activity of the previous year. Separate labour supply behaviour is specified for each category. This allows us to model a gradual accumulation of workers in urban activities with a corresponding decumulation in agricultural activities in response to a dismantling of restrictions on rural–urban mobility. We expect that a similar approach to that adopted in this chapter could be used to model other policy changes that affect the relative attractiveness of rural and urban work. An example is the current reform of social security arrangements which are likely to affect the welfare of agricultural workers differently from that of urban workers.

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[8] This is a movement of about 1.7 per cent of agricultural and rural non-agricultural workers into rural–urban employment.

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Chapter 10
Pension Module and Its Application—Population Ageing and the Impacts of Retirement Age Extension on the Economy and Pension System in China

Xuejin Zuo, Xiujian Peng, Xin Yang, Philip Adams, and Meifeng Wang

Abstract By introducing a pension module into the CHINAGEM model, this chapter explores the implications of raising the retirement age on economic growth and pension sustainability in China over the period of 2020 to 2100. In the baseline scenario, we assume that China maintains its current retirement age, China's pension account will accumulate huge debts because of the rapid population ageing. The debts plus the interest obligation will put high pressure on the general government budget. In the policy scenario, we assume that China will gradually increase the retirement age from 58 to 65 years old starting from 2020. The simulation results show that increasing the retirement age is an effective policy in the short to medium term. It will boost China's economic growth and reduce the pension fund deficit significantly. However, the effectiveness of the policy depends on how much the labour force participation rate for people aged 58 to 65 can be increased.

Keywords Population ageing · Later retirement · Labour force participation · Pension · Economic growth · CGE model

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10.1 Introduction

Population in China is ageing rapidly as a result of the sustained low fertility and increasing life expectancy. At the end of 2019, the elderly-65 and older-accounted for 12.6% of the total population, compared to about 4.9% in 1982 and 7% in 2000 (NBS 2019).

Population ageing has profound and long-lasting impacts on a country's economic growth. Ageing implies slower or even negative growth of the working-age population, driving up the scarcity and costs of labour. Based on the life cycle hypothesis (Modigliani 1966), ageing also implies a lower saving rate or investment rate of the economy. The process of ageing is often accompanied by a country's changing competitive advantage in international markets. Hence ageing leads to a re-adjustment of the sources of growth and the industrial structure of the economy.

China's fertility decline and the consequent "demographic bonus" provided by the increased ratio of working-age population to dependent population had contributed to China's economic miracle of startling growth for decades (Cai 2010). However, the progressive ageing of the population has been converting the "demographic bonus" into a "demographic deficit" that presents severe challenges to the country's future development. One such challenge is the financial sustainability of the country's public pension system.

10.1.1 China's Pension System and the Impact of Population Ageing on Its Sustainability

At present, there are two public pension schemes in China: the Basic Pension for Urban Employees (PUE) and the Basic Pension for Urban and Rural Residents (PURR). PUE is pooled and operated at the prefecture-level localities. By design, it is a combination of social pooling and individual saving accounts. The social pooling pillar is a pay-as-you-go (PAYGO) defined benefits (DB) system. Financed by employers' contribution which typically equals 16% of the total payroll.[1] Some provinces which experienced a large inflow of migrants, such as Guangdong and Zhejiang, are able to lower the contribution rate to around 14%. The pillar of individual saving accounts is a funded, defined contribution (DC) system financed by employees' contributions of 8% of their individual wages. Workers who have participated in the scheme and have been making contributions to the pension funds for at least 15 years upon retirement are entitled to receiving benefits from the social pooling pillar. The benefits are calculated on the basis of their years of contribution, their own wages, and the average wage in the locality. The benefits from their individual saving accounts are paid out as an annuity equal to the balance of their individual saving

[1] It was 20% for many years prior to May 2019, when the Central government decided to lower the contribution rate as one of the measures to lower the tax and fee burden on enterprises in China (General Office of the State Council 2019).

accounts at the time of retirement divided by the government-determined number of months reflecting the remaining life expectancy at retirement.

Employees who had contributed to the pension fund for less than 15 years at the time of retirement are not entitled to receiving benefits from the social pooling pillar. They can receive only a lump-sum payment equal to the balance of their individual saving accounts upon retirement.

Although PUE has been set up in prefecture-level localities all over the country since the late 1990s, its high contribution rates tend to exclude the low-income rural workers and self-employed workers from participating in the scheme. Consequently, these groups enjoy only a low pension coverage by the scheme. According to the Ministry of Human Resources and Social Security (MOHRSS 2019), at the end of 2018 PUE covered 301.04 million working employees and 117.98 million retirees, totalling 419.02 million participants.

The second pension scheme, PURR has three sources of revenue: government subsidies, individual contributions, and rural collective subsidies if available at all. The central government sets a minimum nationwide standard pension benefit[2] for all eligible elderly participants. This minimum-standard benefit is 100% financed by the central government for the western and middle provinces, and 50% is financed for the eastern provinces. The provincial/local governments are encouraged to provide additional pension benefits with their own sources of funding.[3] Among the three sources of revenues government subsidies have remained the predominant source, accounting for over three-quarters of the total revenues of the scheme. At the end of 2018 PURR covered a total of 523.92 million participants, including 158.98 million pensioners, of which 21.96 million were urban and rural elderly in poverty (MOHRSS 2019).

The ageing of population has driven up the deficits of China's pension schemes. PUE's contributions have been surpassed by total expenditures since 2013. In the meantime, the government's pressures to fill the gap between revenues and expenditures have been increasing.

The above data describe the overall revenues and expenditures of the PUE without distinguishing the funded individual saving accounts from the social pooling pillar based on PAYGO. A huge amount of funds in the individual accounts have been used to pay pension benefits, rather than being invested to generate returns. This practice has created the problem of "empty accounts." In 2015, the PUE's empty individual accounts amounted to ¥4714.4 billion, exceeding the scheme's accumulated surplus of ¥3534.5 billion (Zheng 2016). It is expected that the accumulated surplus of the scheme will be exhausted in the near future.

In addition, since the PUE is pooled at the prefecture-level localities, the financial situations of local pension pools tend to be worse than the national aggregate. The massive flow of migrant workers from the inland to coastal provinces creates transfers of pension contributions from the origin to the destination places. These transfers

[2] The minimum standard of the basic pension was ¥55 in 2014, ¥70 in 2015–2017, and ¥88 in 2018 and onward (MOHRSS and MOF 2015, 2018).

[3] See Zuo et al. (2020) for the details of PURR scheme.

in turn have created financial difficulties in the inland provinces. In 2015, out of 31 provinces in China, 24 ran deficits if government subsidies were not taken into account. Only seven provinces, including Guangdong, Beijing, Zhejiang, Jiangsu, Shandong, Fujian and Tibet, mostly in the coastal provinces, had surpluses (Zheng 2016).

10.1.2 Enhancing Financial Sustainability of China's Pension System: Policy Options and Later Retirement

China's population ageing and the deteriorating financial sustainability of the country's pension system have activated discussions about responsive policies. The proposed policy options include, among others, a nationwide social pooling pillar of the PUE; lowering the mandatory contribution rate to achieve a higher participation rate of the PUE, linking the participants' pension benefits more closely to their contributions, and mandating later retirement.

Among these options, later retirement is an efficient one. It can reduce the number of retirees and, hence, the expenditures on pension benefits, while at the same time increasing the number of working employees and, hence, the contributions into the scheme. Later retirement as a policy option has drawn much attention in China because mandatory retirement has been quite early. The present retirement age in China's urban sectors is 60 for men, 50 for women workers, and 55 for women officials. Those workers who are engaged in physically demanding or hazardous jobs should retire five-year earlier, that is, 55 for men and 45 for women (Ministry of Labour and Social Security 1999). This standard was set in 1953 when life expectancy in China was only about 40 years. Life expectancy had almost doubled to 77 years in 2018 (National Health Commission 2019), whereas the mandatory retirement age remains unchanged.

Given the difficulties of financing of the PUE scheme, it is natural to think of later retirement as an attractive policy option. An important official document identified later retirement as one of the reform measures to enhance China's pension system (CPC Central Committee 2013). However, the operational details of such a reform have not been publicized so far. It seems that the government has hesitated to carry out such reform, perhaps due to the concern over its impact on the employment of the younger cohorts and the public outcry on the internet against the reform.

However, population ageing and the deteriorating financial sustainability of the pension system necessitate the later retirement policy. This chapter is aimed to explore the implications of later retirement on economic growth and pension sustainability in the framework of CGE modelling.

10.2 Methodology and Modelling Framework

The model we used is an extended version of CHINAGEM. The original database of the CHINAGME model includes 139 sectors and its base data reflect the 2012 input–output structure of the Chinese economy. For this research, we aggregated the original 139 sectors into 45 sectors. Detailed information about the CHINAGEM model is in part 2 of this book.

10.2.1 Extension of the CHINAGEM Model—Pension Module

The original version of CHINAGEM lacks the capacity to model pension issues in detail. There is only one type of labour and no pension account or government account. Given that different types of labour in China are eligible to participate in different pension insurance schemes, it is necessary to have different labour types in the model. Mai et al. (2014) introduced a labour market module into the CHINAGEM model. This module is designed to capture China's unique household registration system and other institutional barriers in the labour market. Please refer to Chap. 9 for a formal presentation of the labour market module. In this chapter, we extended the labour market module by introducing a pension module into CHINAGEM.

There are ten labour supply categories in the labour market module: five employment categories, three unemployment categories, and two new entrant categories. The category of labour supply in the labour market module is consistent with China's pension insurance schemes. Based on the relevant statistics, we assume that all the urban skilled workers (USE) and 80% of the urban unskilled workers (UUSE) participate in the Basic Pension for Urban Employees—PUE (Scheme 1).[4] The remaining 20% of UUSE workers participate in the Basic Pension for Urban and Rural Residents—PURR (Scheme 2) (see Table 10.1). PURR may include some self-employed urban workers and some workers who are employed in small private factories or companies.

According to the Statistical Bulletin on Human Resources and Social Security Development of China, there are around 262.61 million rural-urban migrant workers (RUE) in the urban area in 2012 (MOHRSS 2019). However, the majority of them

[4] In 2012 China's total urban employment was 371.02 million including 163.36 million migrant rural workers and 207.66 million local urban employees (non-migrant rural workers). In the same year, the PUE covered 229.811 million urban employees, including 45.43 million migrant workers and 184.38 million local employees. We can thus calculate that the participation rate of migrant workers was 27.81%, and that of local employment was 88.79%. We assume that the skilled workers accounted for 20% of local urban employees, and their participation rate is 100%; unskilled workers accounted for 80% of local urban employees, and their participation rate can be calculated as 85.99%. Due to the high mobility of migrant workers and the consequent interruption of their pension participation, in the model we lower the participation rate of migrant workers to 25% and urban unskilled workers to 80%.

Table 10.1 China's current pension system—coverage of each pension scheme

Labour category	Basic pension for urban employees (Scheme 1)	Basic pension for urban and rural residents (Scheme 2)
USE	100%	–
UUSE	80%	20%
RUE	25%	75%
AG	–	100%
RNAG	–	100%
UU	–	100%
RAGU	–	100%
RUU	–	100%
REST*	–	100%

* REST includes urban and rural new entrants (NURB and NRUR) and the rest of all labour force and residents who do not include in the labour categories in Table 10.1

were not covered by the PUE scheme (MOHRSS 2019). There are many reasons for the low participation rate: (1) high contribution rate: Since RUE workers, in general, earn low wages, the high contribution rates tend to discourage them from participating in the scheme. (2) unstable jobs: The nature of RUE workers implies that their jobs are not very secure. Changing jobs or moving back to their home villages after a short period of work in the urban area is very common for RUE workers (Shi and Chen 2017). (3) Portability problems: Based on the current policy, when RUE workers move between localities they encounter difficulties in carrying with them their benefit entitlements from the social pooling accounts to their place of retirement. This portability problem discourages RUE workers to participate in the PUE.

We assume that all the agricultural workers (AG) and rural non-agricultural workers (RNAG) participate in PURR or Scheme 2, and so do all unemployed workers including UU, RAUU, RUU, urban and rural new entrants, and the rest of urban and rural residents (REST) as shown in Table 10.1.

The pension module we developed for this study captures China's current pension system. Both schemes–PUE and PURR have two pillars: a social pooling pillar and individual saving accounts. However, pillar two is very small in PURR.[5] In the current version of the pension module, for PURR, we ignore pillar two and only consider pillar one.

Basic Pension for Urban Employees (PUE)–Scheme 1

- ***Pillar one***

We first define the contribution by labour category to pillar one:

[5] The average annual contribution to individual accounts per PURR participant was ¥169.78 in 2012, and ¥178.51 in 2013 (Zheng 2017). Most participants in western and middle provinces contributed to their individual accounts only ¥100 per annum.

$$CONTRIBUTION1\_1(o)_t = CRATE1*Wagelevel(o)_t*Emperson(o)_t *COVERAGE(o)*P\_ACON\_P1\_O1_t \quad (10.1)$$

where $CONTRIBUTION1\_1(o)_t$ is the contribution made to pillar one, Scheme 1 at year t by labour category o, referring to the labour category of USE, UUSE and RUE. $CRATE1$ is the contribution rate which is 20% of their wage for these labour categories.[6] $Wagelevel(o)_t$ is the wage level of catogory o in year t. $Emperson(o)_t$ is the total number of employed persons of catogory o in year t. $COVERAGE(o)$ is the coverage (participation) rate of catogory o in this scheme. As we discussed in the last section, the participation rate of USE, UUSE and RUE is 100%, 80%, and 25% for USE, UUSE and RUE, respectively. $P\_ACON\_P1\_O1_t$ is the compliance rate in year t. Some workers participated in the scheme but did not regularly pay the contribution or stopped paying contribution after contributing several years before meeting the minimum 15 consecutive years' contribution requirement. Here the compliance rate is the actual participation rate after excluding those participants. The compliance rates from 2012 to 2016 are calculated by using historical data. From 2017 onwards, we assume that the compliance rate remains at its 2016 level.

$$Stock1\_1_t = Stock1\_1_{t-1}(1 + IntRate) + \sum_o Contribution1\_1(o)_t + Government1\_1_t - \sum_o Payment1\_1(o)_t \quad (10.2)$$

Equation (10.2) is the equation about the pension stock of pillar one, Scheme 1. It says that the pension stock in year t is last year's stock plus interest earned, the workers' contribution and government subsidies in year t, then subtract the payment to retired eligible workers in year t. Where $Stock1\_1_t$ and $Stock1\_1_{t-1}$ is the pension stock of pillar one in year t and year t-1, respectively. IntRate is the interest rate of the economy. $\sum_o Contribution1\_1(o)_t$ is the sum of contributions paid by different labour category o in year t. $Government1\_1_t$ is the government subsidies to pillar one in year t. $\sum_o Payment1\_1(o)_t$ is the sum of payment to retired workers by labour category o in year t.

Based on China's current pension policy, the pension payment is paid to eligible workers based on the year in which the eligible worker started to work and the year when the eligible workers retired. Eligible workers who retired before 1996 are called "old pensioners". Their pension payment in year t is simply 40% of the average wage level in year t. We did not disaggregate pension payment to the "old" workers by their labour category because the government pays these workers 40% of the current year's average wage level regardless of their labour category. Furthermore, there are no rural–urban migrant workers (RUE) included in these "old" workers.

$$Payment\_Old_t = Wagelevel_t * 40\% \quad (10.3)$$

[6] After we completed this study, China reduced the contribution rate for pillar one from 20% to 16%.

where $Payment\_Old_t$ is the payment in year t to eligible "old workers" who were retired before 1996.

For the "new" workers who started working in 1996 or later at the labour category o, their pension payment for pillar one in year t, $Payment\_New(o)_t$ is one percent of their wage level in year t-1 times years worked. Every eligible worker may have a different span of working years when he/she retires (Eq. 10.4). In this chapter, we use the average span of working years for all labour categories. The average span of working years is calibrated in the model from year 2013 to 2016 based on the actual pension payment data and the number of workers who received a pension payment from this scheme. From year 2017 onwards, we assume that the span of working years remains the same as in the year 2016.

$$Payment\_New(o)_t = Wagelevel(o)_{t-1} * years\ of\ working * 1\% \tag{10.4}$$

For the "middle" workers who started to work before 1996 and did not retire before 1996, the pension payment includes two parts: the first part is one percent of the wage level of the labour category o in year t−1 times years of working; the second part is 0.3% of the wage level of the labour category o in year t−1 times years of working before 1996.

$$\begin{aligned} Payment\_Middle(o)_t = {} & Wagelevel(o)_{t-1} * years\ of\ working * 1\% \\ & + Wagelevel(o)_{t-1} * (1996 - Year\ Started) * 0.3\% \end{aligned} \tag{10.5}$$

Then the total payment in year t is the sum of payment paid to those three categories of pensioners.

$$\begin{aligned} Payment1\_1_t = {} & Payment\_Old_t + \sum_o Payment\_New(o)_t \\ & + \sum_o Payment\_Middle(o)_t \end{aligned} \tag{10.6}$$

- ***Pillar two***

When we define the contribution to pillar two (individual account), we start with the individual contribution.

$$Con\_PP2\_1(a, o)_t = Crate2\_1 * Wagelevel(o)_t \tag{10.7}$$

where $Con\_PP2\_1(o)_t$ is pension contribution made to pillar two per worker of labour catogory o and aged a in year t. $Crate2\_1$ is the contribution rate of pillar two, which is currently 8% of the wage level for all labour categories. Equation (10.7) means that contributions made to pillar two by a individual worker at category o and aged a are simply eight percent of his/her salary.

Stock of accumulated contributions in each worker's individual account of labour category o at age a, at the start of year t, is the stock accumulated in the last age, a-1, in year t-1, plus the interest earned and the contribution made at age a.

$$\begin{aligned} Stock\_PP2\_1(a, o)_t = {} & Stock\_PP2\_1(a-1, o)_{t-1} \\ & + Stock\_PP2\_1(a-1, o)_{t-1} * IntRate \\ & + Con\_PP2\_1(a, o)_t \\ where\, a \in 20-57 \end{aligned} \tag{10.8}$$

As mentioned earlier, the retirement age is 60 for male employees, 55 for female officers and 50 for female workers. In the CHINAGEM model, we do not have gender disaggregation, so we assume that the average retirement age is 58 in 2012.[7] We assume that the average retirement age of the labour force is 58 from 2012 onwards if the Chinese government keeps its current retirement policy. In Eq. (10.8), we calculate per worker's pension stock accumulated in pillar two at age a, where age a ranges from 20 to 57.

In Eq. (10.8), $Stock\_PP2\_1(a, o)_t$ is the pension stock of pillar two per worker of category o at age a, at the beginning of year t. The pension stock per worker after he/she has retired is calculated using the following equation:

$$\begin{aligned} Stock\_PP2\_1(a, o)_t = {} & Stock\_PP2\_1(a-1, o)_{t-1} * (1 + IntRate) \\ & - Payment\_PP2\_1(a, o)_t \quad where\ 58 \le a \le 100 \end{aligned} \tag{10.9}$$

Equation (10.9) shows that an eligible worker's pension stock at the start of year t after he/she has retired equals his/her pension stock in the previous age in year t−1 plus the interest earned, then deduct the pension he/she received in year t. Where $Payment\_PP2\_1(a, o)$ is the pension received by the eligible worker of labour category o. $Payment\_PP2\_1(a, o)$ is calculated in Eq. (10.12).

The total pension stock of pillar two for the working-age workers (age 20–57) is calculated as follows

$$\begin{aligned} Stock\_AG2\_1(a, o)_t = {} & Stock\_PP2\_1(a, o)_t * EMPERSON(a, o)_t \\ & * COVERAGE(o)_t * P\_ACON\_P2\_1_t \ where\ a \in 20-57 \end{aligned} \tag{10.10}$$

where $Stock\_AG2\_1(a, o)_t$. is the aggregated pension stock of labour category o at age a in year t. $P\_ACON\_P2\_1_t$. is the compliance rate of pillar 2, scheme 1 in year t. Equation (10.10) says that the total pension stock of pillar two for working-age workers of laboratory o at age a in year t is the per person pension stock of labour category o at age a in year t times the total number of employed persons of category

[7] We assume that men account for 60% of the total labour force and retire at 60 and women account for 40% and retire at 55, and hence the weighted average of retirement age for both genders is 58.

o at age a in year t indexed by the coverage rate of category o and the compliance rate in year t.

For retired workers (aged 58 and older), the total pension stock of pillar 2 is

$$\begin{aligned} Stock\_AG2\_1(a,o)_t = {} & Stock\_PP2\_1(a,o)_t \\ & *PopRetire(a,o)_t * COVERAGE(o)_t \\ & *P\_ACON\_P2\_1_t \text{ where } 58 \le a \le 100 \end{aligned} \quad (10.11)$$

where $PopRetire(a,o)_t$ is the eligible retired worker of category o at age a in year t. The aggregated pension stock of labour category o at age a in year t is per worker's pension stock of category o at age a in year t times the number of retired workers of category o at age a in year t indexed by the coverage of pension scheme and compliance rate of pension scheme in year t.

The annual pension payment of each eligible retired worker received from pillar two or his/her individual account is simply one-fifteenth of his/her pension stock at age 58 (Eq. 10.12). This means that the government assumes that the remaining life expectancy upon retirement of eligible retired worker is 15 years. If an eligible worker is still alive after fifteen years of their retirement, then the government will continue to pay his/her pillar two pension even though his/her individual account has been exhausted.

$$Payment2\_1(o) = Stock\_PP2\_1(''58'', o)/15 \quad (10.12)$$

Where Payment2_1(o) is the annual payment an eligible worker of category o received from his/her individual account. Stock_PP2_1 ("58", o) is the pension stock a worker of category o has accumulated when he reaches his retirement age 58.

Basic Pension for Urban and Rural Residents (PURR)–Scheme 2

Under China's current pension system, all the residents aged 20 and over should participate in either Scheme 1 or Scheme 2.

- **Contribution to the scheme**

The pension fund for Scheme 2 is financed by three sources: (1) government subsidies; (2) individual contributions and interests earned, and (3) collective subsidies. Among these three sources, the subsidies from the central and local governments have been predominant.

The total contribution to this scheme is calculated as follows:

$$\begin{aligned} & ContributionAG\_2A(o)_t = Con\_PP\_2_t * Persons\_2(o)_t \\ & where\ o\ belongs\ to\ USE, UUSE\ and\ RUE \end{aligned} \quad (10.13)$$

$$Persons\_2(o)_t = (1 - Coverage(o)) * \left(\sum_a Emperson(a,o) \right)_t$$

$$where\ a \in (20 - 57) \tag{10.14}$$

Equation (10.13) says that for labour category of USE, UUSE and RUE workers, their contribution to a pension fund, $ContributionAG\_2A$ in year t equals the contribution paid per person in year t times the total number of workers in each category who participate in the scheme in year t, $Persons\_2(o)$. Equation (10.14) shows that $Persons\_2(o)$ in year t equals the employed persons summed by age who do not participate in PUE. As we displayed in Table 10.2, the coverage rate of Scheme 1 for USE, UUSE and RUE workers is 100%, 80% and 25%, respectively. The corresponding coverage rate for Scheme 2 for USE, UUSE and RUE workers would be zero, 20% and 75%, respectively.

For workers who belong to the rest of the labour category and the residents listed in Table 10.2, the contribution to the pension fund in year t equals the contribution paid per person Con_PP_2 in year t times the total number of persons in each labour category in year t, $Persons\_2(o)$ and then adjusts using the compliance rate P_ACON_P2 in year t. Here we assume that per person's contribution to the fund is the same for all labour categories.

$$ContributionAG\_2B(o)_t = Con\_PP\_2_t * Persons\_2(o)_t * P\_ACON\_P2_t \tag{10.15}$$

where o belongs to the labour category AG, RNAG, UU, RAGU, RUU and REST.

The stock of the pension fund is defined as

$$Stock\_2_t = Stock\_2_{t-1}(1 + IntRate) + \sum_o ContributionAG\_2(o)_t + Goverment\_2_t - PaymentAG\_2_t \tag{10.16}$$

Equation (10.16) suggests that the stock of the pension fund in year t is the stock of last year plus the interest earned plus the sum of the contribution made in year t by all labour categories and the government subsidy in year t, then subtract the payment paid to the eligible residents in year t, $PaymentAG\_2_t$.

- **Pension benefits of the scheme**

Eligible residents will receive their pension benefits from the scheme after they reach the retirement age which on average is 58 years old. The pension benefit is defined as

$$PaymentAG\_2_t = PaymentPP\_2_t * PersonsPay\_2_t \tag{10.17}$$

where $PaymentPP\_2_t$ is the pension payment per person from the scheme in year t, which is determined by the government. According to the Yearbook of China Social Security, the average pension benefit per annum was ¥880 in 2012 and ¥1408 in 2016. We assume that pension benefits will increase at the rate of GDP growth from

Table 10.2 Pension account of basic pension for urban employees-PUE (¥ billion)

	Pensioners (1)	Contribution (2)	Government subsidy (3)	Investment returns and other (4) = (5)−(2)−(3)	Total revenue (5)	Total expenditure (6)	Annual surplus (7) = (6)−(5)	Accumulated surplus (8)
2012	74.46	1646.7	264.8	88.6	2000.1	1556.2	443.9	2394.1
2013	80.41	1863.4	301.9	90.3	2268	1847	408.62	2838.0
2014	85.93	2033.4	359.4	118.0	2531	2175.5	334.92	3246.6
2015	91.42	2301.6	471.6	127.93	2934.1	2581.3	319.83	3581.5
2016	101.03	2676.8	651.1	129.74	3505.8	3185.4	272.245	3901.4

Source Bulletin on the Development of Human Resources and Social Security in China, 2012 to 2015; Annual Report on the Development of Chinese Social Insurance, 2014 and 2016

2017 and onwards in the baseline scenario. $PersonsPay\_2_t$ is the total number of eligible residents who will receive pension payment from this scheme in year t. It is defined as

$$PersonsPay\_2_t = \left\{ PopRetire_t - \sum_o PopRetire(o)_t \right\} * EliRate_t$$
$$where\ o\ belongs\ to\ USE,\ UUSE\ and\ RUE \qquad (10.18)$$

The total number of residents who are eligible to get the pension payment from Scheme 2 in year t is the total retired population in year t less the persons who get the pension payment from scheme one, then adjusted using the eligible rate in year t. The eligible rate is calibrated using the historical data from 2012 to 2016. From 2017 and onwards, we assume that the compliance rate remains at its 2016 level.

10.2.2 Extension of the CHINAGEM Model—Government Account

In China, central and local governments provide subsidies to both PUE and PURR. With the expected rapid ageing, we would like to know if the Chinese government maintains the current pension system, and how large a deficit of the social pool (pillar one) will accumulate. If the government chooses to finance the deficit we would like to know the effect on the government general budget deficit and the impact of the deficit on the macro economy. To answer these questions, we introduce the government account into the CHINAGEM model. Please refer to Zuo et al. (2020) for the details of the government account in CHINAGEM.

10.3 Development of Baseline Scenario and Simulation Results

To analyse the economic effects of later retirement policy, we first develop a baseline scenario - a business as usual without introducing any policy changes.[8] Then we conduct a policy simulation, an alternative forecast with the change in the retirement age. The effects of the policy change are measured by deviations of variables in the alternative forecast from their baseline levels.

[8] For more details about how the business-as-usual scenario is developed for the CHINAGEM model, please see Chaps. 5 and 6.

10.3.1 Macro Variables in the Baseline Scenario

To develop the baseline scenario, using the data from China Statistical Yearbooks and the World Bank Development Indicators database, we first update the model's database to 2016. Then for the forecast period from 2017 to 2100 we assume that the growth pattern of the Chinese economy will follow its historical trend but at progressively lower rates.

The growth rates of rural migrant workers and other labour categories in the baseline scenario are endogenised and determined by the exogenous macro variables such as investment, export, GDP, and the growth rate of the total labour force. The growth rate of the exogenous variable such as total labour force is calculated based on the growth rate of the working-age population and the aggregate labour force participation rate (LFPR). In the baseline scenario, we assume that the cohorts' LFPRs will remain at their 2010 levels until 2100. The growth rate of the working-age population is from the medium variant of population projection conducted by Zuo et al. (2021).

10.3.2 Variables and Data Related to the Pension Module

Table 10.2 shows the details of the pension account of Scheme 1 (total amount of pillar one and pillar two) from 2012 to 2016. The retired pensioners of Scheme 1 have increased from 74.46 million in 2012 to more than 100 million in 2016. We can see that from 2012 to 2016 the pension fund is in surplus and the pension stock has increased (accumulated surplus) from ¥2394 billion in 2012 to ¥3901 billion in 2016. However, as reported by Zheng (2015), the stock of pension fund of pillar one (social pool) in 14 provinces has run out in 2011 and has been in deficit since then. The government has to use the money in pillar two (individual accounts) to pay the pension benefits for the retired workers. To accurately forecast the accumulation of pension funds from 2017 to 2100, we have to split Table 10.2 and get the pension accounts for pillar one and pillar two, respectively. Please refer to Zuo et al. (2020) for the details of how we split the data.

Based on the pension account data for pillar one, PUE (Table 10.4 in the Annex), using Eq. (10.1), we calibrated the compliance rate of pillar one from 2012 to 2016. The compliance rate was only 42.1% in 2012 and 42.4% in 2013, and it increased to 45.5% in 2016. The low compliance rate reflects the flaw of the current pension policy. If a worker has continuously contributed to pillar one, Scheme 1, for a minimum of 15 years, he/she will be eligible to get the pension from the social pool after he/she retires. This policy obviously discourages workers to continue to contribute to the social pool after they have completed their "15 years" compulsory contribution. In the forecast period of 2017 to 2100, we assume that the compliance rate of pillar one, Scheme 1, will remain at the 2016's level of 45.5%.

Based on the pension account data for pillar two (Table 10.5 in the Annex), using Eq. (10.10) in Sect. 10.2, we calibrate the actual participation rate of pillar two, which is only 38.6% in 2012, and 40.5% in 2013. It increased to 44.7% in 2016. We assume that the actual participation rate of pillar two, Scheme 1 will remain at the 2016 level of 44.7% in the forecast period from 2017 to 2100.

Table 10.3 shows the details of the pension account of PURR (Scheme 2). Similarly, we split the data in Table 10.3 into pillars one and two, We then use Eq. (10.15) in Sect. 10.2 to calculate the compliance rate (actual participating rate) of pillar one, Scheme 2. In the forecast period of 2017 to 2100, we assume that the participation rate of Scheme 2 remains at its 2016 level of 61.3%.

To simulate the change in the pension fund in the baseline scenario for the period of 2017 to 2100, we assume that the Chinese government will keep its current pension system and the current contribution rates for each scheme. To simulate the impact of pension payments on the government general budget balance we also assume that the shares of all general government revenue items over the GDP and the shares of all general government expenditure items over the GDP keep their historical patterns over the forecast period.

10.3.3 The Impact of Population Ageing on the Pension Fund and Government Budget Balance

As we discussed in the last section, the stock of pillar one is negative and the Chinese government uses the money in pillar two to pay the retired workers their pillar one pensions. Meanwhile, the eligible retired workers also receive their pension from their personal account-pillar two. If the current pension system remains, then the stock of pension fund will run out of surplus and turn negative in 2025 and the deficit will accumulate to nearly ¥10,000 trillion in 2099, which accounts for 261% of GDP in 2099 (Fig. 10.1). The main reason for the pension fund becoming negative is the accumulated deficit of pillar one—the annual payment to retired workers is much larger than the annual revenue (the sum of contribution, government subsidy, interests and other income).

With rapid population ageing, the gap between the revenue and pension payment increases because of the decline in the labour force which contributes to the pension scheme (the negative growth of the labour force) and the increase in the number of pensioners who receive pension payments (the rapid growth of old population). From Fig. 10.2 we can see that in the middle of the century, the labour force will decline to 609 million, which is a 23% drop from its 2012 number (792 million). By the end of the century, the labour force will further decline to 332 million, which is less than half of its 2012 number. Meanwhile, the retired workers who are eligible to receive a pension from Schemes 1 and 2 will increase to 545 million in the middle of the century, which is a 166% increase from its 2012 number. The number of retired workers will surpass the size of labour force at 2064. By the end of the century, there will be 55 million more retired workers than the labour force.

Table 10.3 Revenues and expenditures of PURR, 2012–16 (¥ billion)

	Pensioners (million) (1)	Contribution (2)	Government subsidy (3)	Interest income and other (4) = (5)−(2)−(3)	Total revenue (5)	Total expenditure (6)	Annual surplus (7) = (6)−(5)	Accumulated surplus (8)
2012	130.75	59.4	112.65	10.85	182.9	115	67.9	230.2
2013	137.68	63.6	137.03	4.57	205.2	134.8	70.4	300.6
2014	143.13	66.6	149.75	14.65	231	157.1	73.9	384.5
2015	148.00	70	205.33	10.17	285.5	211.7	73.8	459.2
2016	152.70	73.2	207.31	12.79	293.3	215.1	78.2	538.5

Source Bulletin on the Development of Human Resources and Social Security in China, 2012 to 2015; Annual Report on the Development of Chinese Social Insurance, 2014 and 2016

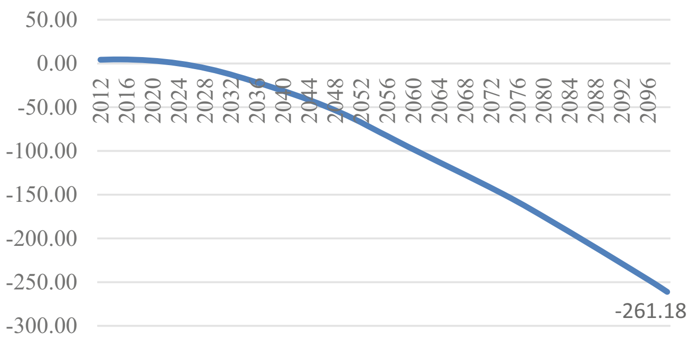

Fig. 10.1 Stock of pension fund PUE as share of GDP, 2012 to 2099 (%). *Source* Baseline simulation result

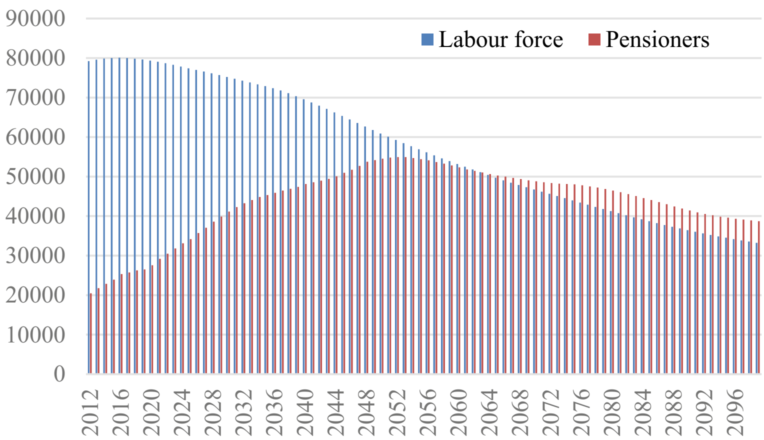

Fig. 10.2 Declining labour force and increasing pensioners, 2012 to 2099 (10,000 persons). *Source* Population projection and baseline simulation result

We also notice that among 545 million pensioners, there are 217.3 million pensioners who receive pensions from Scheme 1 (Fig. 10.3).

Figure 10.4 shows the stock of pension fund PURR as a share of GDP. The pension payment to each pensioner in PURR is small (only ¥880 in 2012 and it increased to ¥1409 in 2016). We assume that its payment will increase at the rate of real GDP annually. The total pension payment compared with PUE is still relatively small. As we discussed in Sect. 10.2, this pension fund mainly relies on government subsidies. We assume that the government will subsidize the gap between the pension payment and the contribution. That means if the pension payment in year t is ¥20 million and the contribution in year t is only ¥5 million then the government will contribute ¥15 million. Meanwhile, we also assume that the share of government subsidies to Scheme 2 over the GDP will be fixed at 0.22% of GDP during the simulation period of 2017 to 2100. With the increase in the retired population and the fixed share of

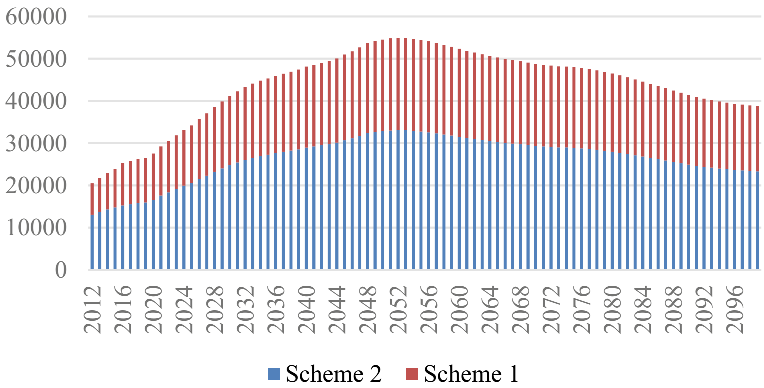

Fig. 10.3 Increasing pensioners in two pension schemes, 2012 to 2099 (10,000 persons). *Source* Population projection and baseline simulation results

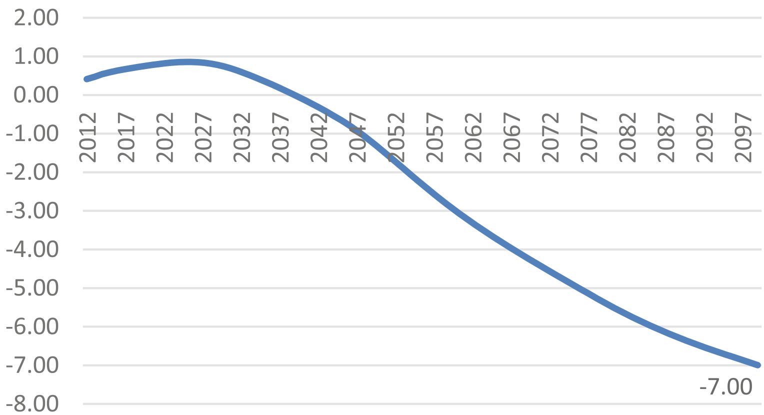

Fig. 10.4 Stock of PURR pension fund as share of GDP, 2012 to 2099 (%). *Source* baseline simulation results

the government subsidies over the GDP, the stock of the pension fund of PURR become negative in year 2037 and the debts of the pension fund will accumulate to ¥8.8 trillion in 2050 and to ¥268 trillion in 2099, which accounts for 7% of GDP (Fig. 10.4).

If the government chooses to pay the debts of the pension schemes by increasing government expenditure on pension insurance, then this will put high pressure on the general government budget balance. The general government budget balance has been in deficit since 2012 and the share of the deficit over GDP has been maintained below 5%. The rapid accumulation of debts of the pension fund will cause the general government budget deficit to increase very fast. The share of the general government budget deficit over GDP will increase to 15% in 2050 and further to 22% by the

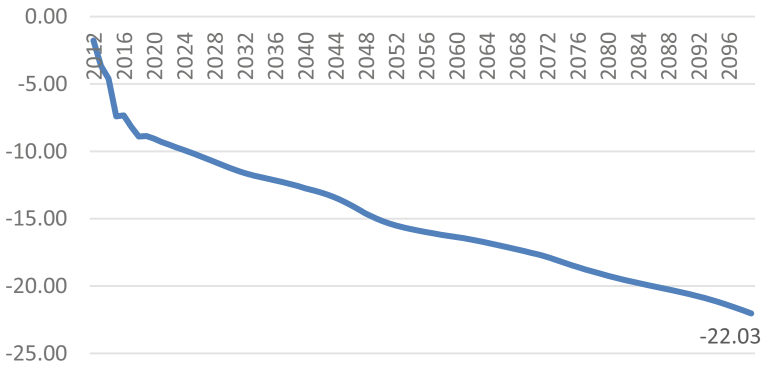

Fig. 10.5 General government budget deficit as share of GDP, 2012 to 2099 (%). *Source* baseline simulation results

end of the century (Fig. 10.5). To sustain economic growth, the Chinese government has to find ways to reform its current pension system. In this chapter, we investigate the impact on the economy and pension system of increasing the retirement age. In other words, we would like to know whether increasing the retirement age will help to reduce the pressure on the pension fund while stimulating economic growth given the rapid population ageing.

10.4 The Effects of Retirement Age Extension Policy

This section contains an analysis of the economic effects of raising the retirement age.

10.4.1 Retirement Age and Labour Force Participation Rate

Figure 10.6 displays the age-specific labour force participation rates (LFPR) in China in 2010. It was around 90% for the population aged 28 to 48. It declined to below 80% for the population aged 49. It was 65.3% and 54% for the population aged 58 and 60. The LFPR for the population aged 65 was only 41.8%. We notice that LFPRs for the population aged 50 and over have a very close relationship with the official retirement age. Currently, the retirement age is 60 for male employees, 55 for female officials and 50 for female workers. In most developed countries the retirement age is 65 for both men and women.

With the expected decline of the working age population in China, an increase in the retirement age would be an effective way to increase the LFPR.

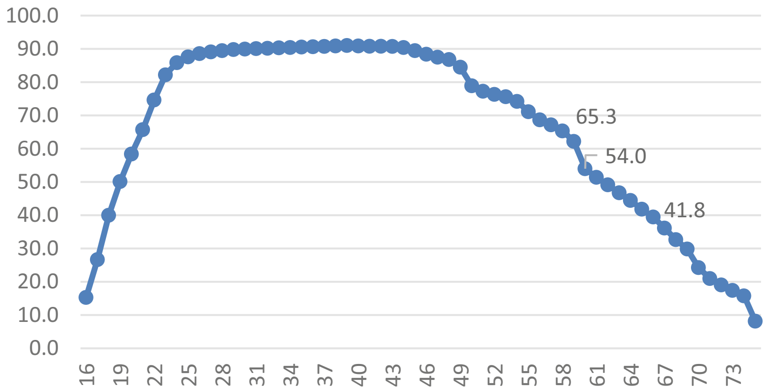

Fig. 10.6 Age-specific labour force participation rates in 2010 (%). *Source* Authors' calculated based on the Sixth Population Census data

In the policy scenario, we assume that the Chinese government will gradually increase both male and female workers' retirement age from 2020 onwards. We assume that in 2020, the average retirement age will increase to 59 years old. In 2022, it will further increase by one year to 60 years old. Following this pattern, it will be raised by one year every two years until 65 years old in 2032. It then remains at 65 years old from 2033 to 2100. The increase in retirement age will increase the LFPR. To our knowledge, there is no research on the precise extent to which a one-year increase in the retirement age increases the LFPR of the corresponding age group. Based on the corresponding age groups' LFPRs of Japan, Korea, G7 countries and OECD countries in 2016,[9] we assume that the LFPRs for the population aged 54 will increase from 74.21% to 75% in 2020 and remain at this level till the end of the century. For the detailed assumptions for the increases of the LFPRs for the population aged 55 to 65 please refer to Table 10.6 in the Annex.

Based on the above assumptions we calculate the corresponding shocks to the LFPRs of these age groups in the policy scenario. Meanwhile, we shock the retirement age which will affect the pension account. The new retirement age in the policy scenario becomes 59 in 2020, 60 in 2022, 61 in 2024, 62 in 2026, 63 in 2028, 64 in 2030 and 65 in 2032. These shocks mean that compared with the baseline scenario, in the policy scenario the labour force will be larger from 2020 and the contribution to the pension fund will increase. Meanwhile, the size of the retired population will be smaller.

[9] The LFPR for age group of 55 to 64 was 73.7% for Japan, 68% for Korea and 59.6% for OECD countries in 2016. For Japan, the LFPR for age group 55–59 was 83% and 68.1% for age group 60–64 and 45.3% for age group 64–69 in 2017.

10.4.2 *The Effects of Retirement Age Extension Policy on the Macro Economy*

10.4.2.1 The Effects on Real GDP

The increase in the retirement age will increase the labour force and boost China's economy. Figure 10.7 shows that real GDP will be 2.7% higher by the end of the simulation period than in the baseline scenario.

There are two reasons for the higher real GDP. First, the increase in the labour force as a result of the extension of the retirement age contributes to the growth of real GDP. Figure 10.7 shows that by the end of the simulation period the effective labour input (aggregate employment calculated using wage bill weights) will be 3.8% higher than in the baseline scenario.

Secondly, a growing capital stock contributes to higher GDP growth. In the long run the total capital stock will be 2.2% higher than in the baseline scenario (Fig. 10.7). The long-run increase in the capital stock relative to baseline is due to the increase in employment. We notice that the proportionate deviation of the capital stock from the baseline scenario is lower than that of labour input. The reason is that the increase in labour supply will reduce the growth rate of real wages. By the end of the simulation period, the real wage will be 3.2% lower than in the baseline scenario. The declining growth rate of real wages compared with the baseline scenario implies that labour is becoming cheaper and employers will have intention to substitute labour for capital, which will reduce the capital/labour ratio of the economy in the long run. The substitution between capital and labour will slow down the growth rate of the capital stock.

Please note that the shapes of deviations of GDP and capital stock from the baseline scenario are consistent with the growth of employment and labour supply of the age 54 to 65 cohorts in the policy scenario. Since we increased the LFPRs of the population aged 54 to 65 in the policy scenario, the increase of the labour force

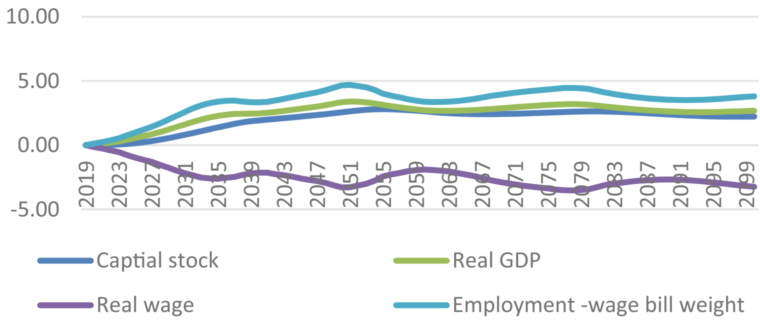

Fig. 10.7 The effects of later retirement policy on GDP and other macro variables—cumulative deviation from baseline scenario (%). *Source* Policy simulation results

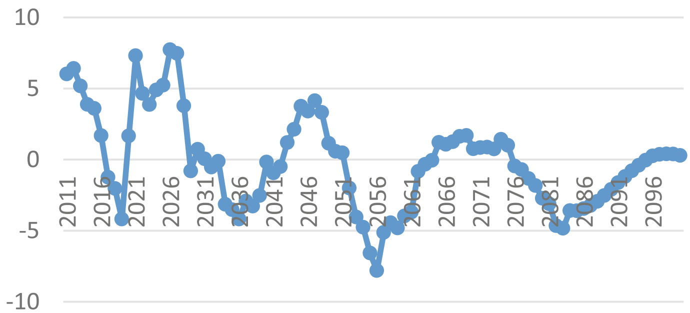

Fig. 10.8 Growth rate of the population aged 58–65 (%). *Source* Authors calculation from the medium variant population projection results

from these age groups continues through the whole policy simulation period from 2020 to 2100 (Fig. 10.8).

10.4.2.2 The Effects on the Expenditure Side of GDP

Due to the increase in the capital stock, i.e., aggregate investment, also increases relative to its baseline path (Fig. 10.9).

The increased labour supply also improves households' living standards measured by real consumption. As Fig. 10.9 shows, real household consumption will be 2.4%

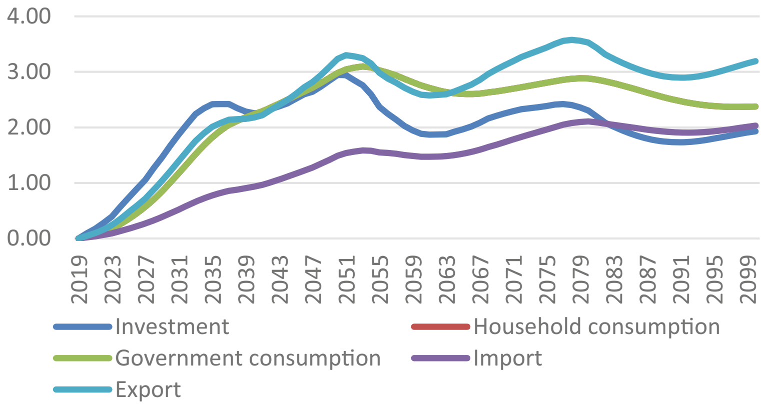

Fig. 10.9 The effects of retirement age extension on the expenditures side of GDP-cumulative deviation from baseline scenario (%). *Source* Policy simulation results. Please note household consumption and government consumption are overlapped

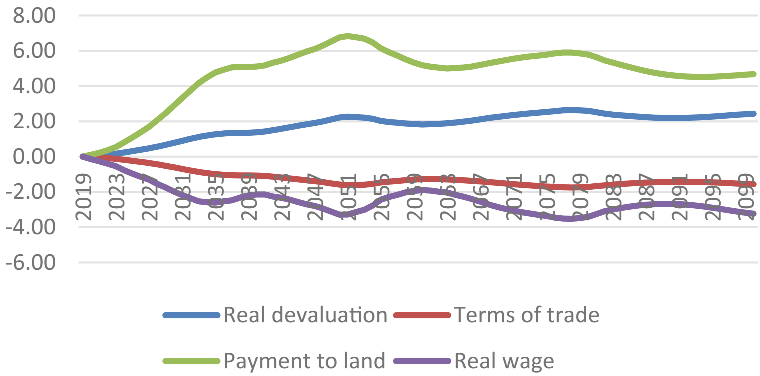

Fig. 10.10 The effects of retirement age extension on other macro variables: cumulative deviation from baseline scenario (%). *Source* Policy simulation results

higher than in the baseline scenario. We also notice that consumption increases less than real GDP. The reasons include:

- Firstly, the constant expansion of exports requires a deterioration of the terms of trade, which will affect the gains from a given volume of trade adversely. The retirement age extension policy will increase China's export (Fig. 10.9). The expansion of exports drives the terms of trade down because China is a "large country" in her export markets. The price of imports remains unaffected because we assume that China does not exert noticeable market power in her import markets. Figure 10.10 shows by the end of the simulation period the terms of trade will be 1.6% lower compared with the baseline case.
- Secondly, the larger labour force will reduce the per capita availability of the fixed factor (land). As labour supply increases in response to the increased retirement age, land becomes more scarce and expensive. Figure 10.10 illustrates that the payments to land will be 4.7% higher than in the baseline scenario. This dramatic increase in the price of land indicates the presence of diminishing returns to the extra labour and capital. This subdues the increase in income and consumption.

10.4.2.3 The Effects on Real Wage

Figure 10.10 shows that the real wage rate will be 3.2% lower at the end of the simulation period compared to the baseline scenario. There are two main reasons for the reduction of the real wage rate. First, the deterioration of the terms of trade together with the depreciation of the domestic currency[10] reduce the real wage rate as the retirement age increases. Secondly, the increase in the labour force reduces

[10] The expansion of exports requires a real devaluation of RMB relative to the exchange rate path of the baseline scenario. Figure 10.9 shows that the value of RMB is 2.4% lower than in the baseline case.

the relative availability of fixed resources, specifically land, and drives up its price as we discussed in the previous paragraph (Fig. 10.10). The increasing scarcity of land is associated with an increase in the labour intensity of production which in turn reduces the productivity of labour and, thus, depresses the wage rate.

10.4.3 The Effects of Retirement Age Extension Policy on the Pension Fund and Government Budget Balance

The increase in the retirement age will affect the pension fund and government budget balance dramatically.

10.4.3.1 *The Effects on the Pension Fund of Scheme 1*

Figure 10.11 displays the pension stock of Scheme 1 in the baseline and policy scenarios. In the baseline scenario, the pension fund will run out of money and turn negative in year 2025 while in the policy scenario it will turn negative in year 2028. By the end of the century, the accumulated debt of the pension fund of Scheme 1 in the policy scenario will be Y6190 trillion which is more than 160% of GDP (Fig. 10.12). Compared with the baseline scenario, the accumulated debts are 38% lower (Figs. 10.11 and 10.12).

The reasons for the reduction of the pension fund debts include:

- Firstly, increased contribution to the pension fund. The increased labour force as a result of the later retirement policy will increase contributions to the pension fund.

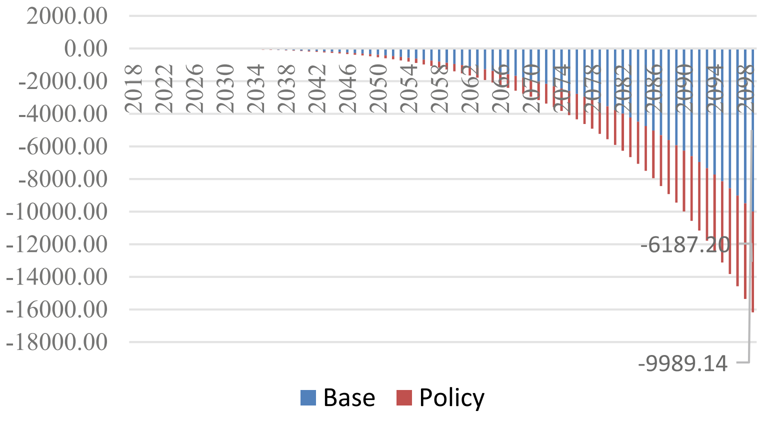

Fig. 10.11 The effects of retirement age extension–stocks of the pension fund, Scheme 1, baseline and policy scenarios (¥ trillion). *Source* Baseline and policy simulation results

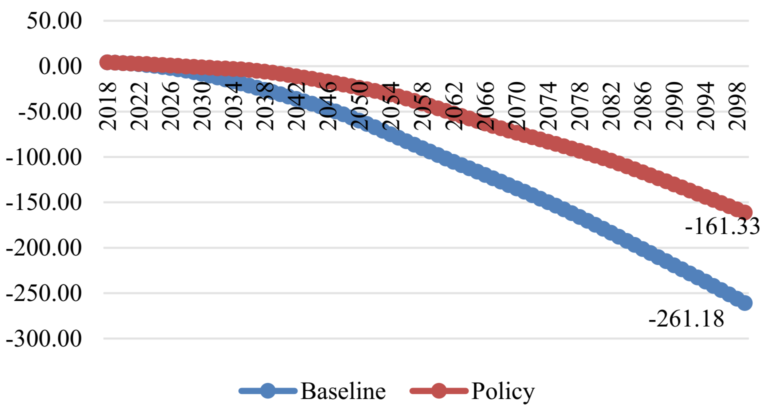

Fig. 10.12 The effects of retirement age extension–share of stocks of the pension fund over GDP, Scheme 1, baseline and policy scenarios (%). *Source* Baseline and policy simulation results

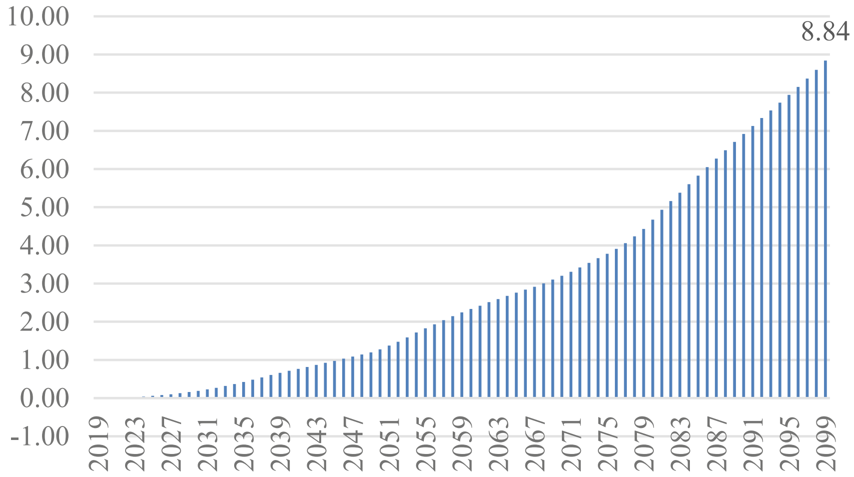

Fig. 10.13 Contribution to Scheme 1, cumulative deviation from the baseline (¥ trillion). *Source* policy simulation results

Figure 10.13 shows that by the end of the century, the accumulated contribution to the pension fund will be Y8.84 trillion higher than the baseline scenario.

- Secondly, reduction of expenditures from the pension fund. The smaller size of the retired population induced by the retirement age extension policy will reduce the total payment to pensioners. Figure 10.14 shows that by the end of the simulation period, the retired population receiving a pension from Scheme 1 will be 26.4 million smaller in the policy scenario than in the baseline scenario.

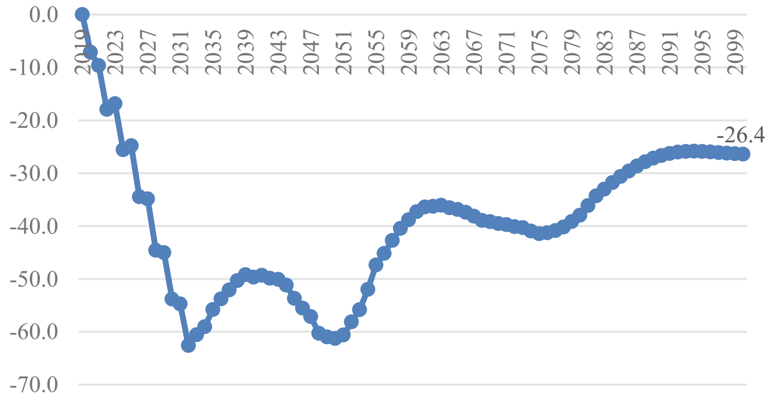

Fig. 10.14 The effects of retirement age extension on the size of the retiree population, Scheme 1, cumulative deviation from the baseline (million persons). *Source* policy simulation results

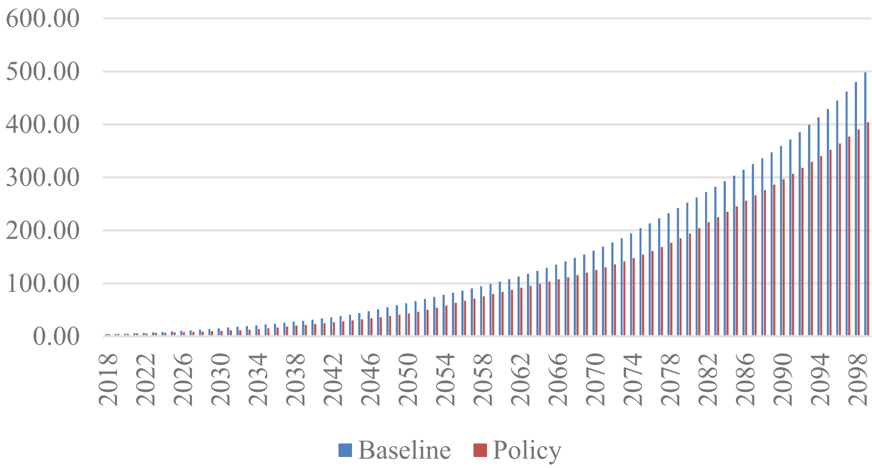

Fig. 10.15 Payment to the retirees, Scheme 1, baseline and policy scenarios (¥ trillion). *Source* Baseline and policy simulation results

Figure 10.15 shows that payments to eligible retired workers in 2020 amount to ¥5.01 trillion in the baseline compared to ¥4.66 trillion in the policy scenario. By the end of the century, pension payments decline to ¥498 trillion in the baseline scenario and to ¥404 trillion in the policy scenario, which is a 19% decrease.

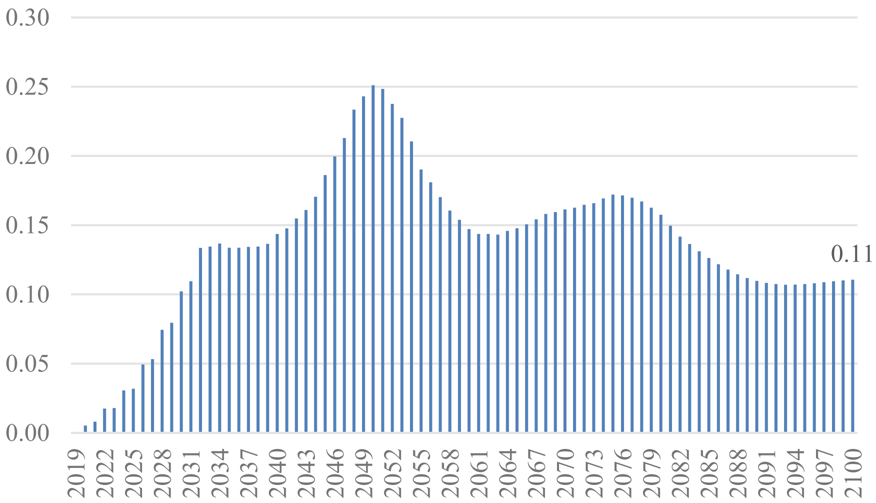

Fig. 10.16 The effects of retirement age extension on contribution, Scheme 2—cumulative deviation from the baseline (¥ trillion). *Source* Policy simulation results

10.4.3.2 The Effects of Retirement Age Extension Policy on the Pension Fund of Scheme 2

The retirement age extension policy will reduce the debts of the pension fund, Scheme 2 for reasons similar to Scheme 1: (1) increased contributions to the pension fund. By the end of the simulation period, the contribution will be 0.11 trillion higher than in the baseline scenario (Fig. 10.16); (2) lower pension payments. By the end of the simulation period, pension payment will be 2.5 trillion lower than in the baseline scenario (Fig. 10.17).

10.4.3.3 The Effects of Retirement Age Extension on the General Government Budget Balance

The decline of debts of both pension schemes with the implementation of the retirement age extension policy will improve the government budget balance. Figure 10.18 shows that the general government budget deficit will reduce dramatically. By the end of the simulation period, the general government budget deficit as a share of GDP will fall by 24%, from more than 22% (baseline scenario) to almost 17%. The improvement of the general government budget balance implies that there is less pressure to increase taxes or reduce government spending, and less crowding-out effect on investment.

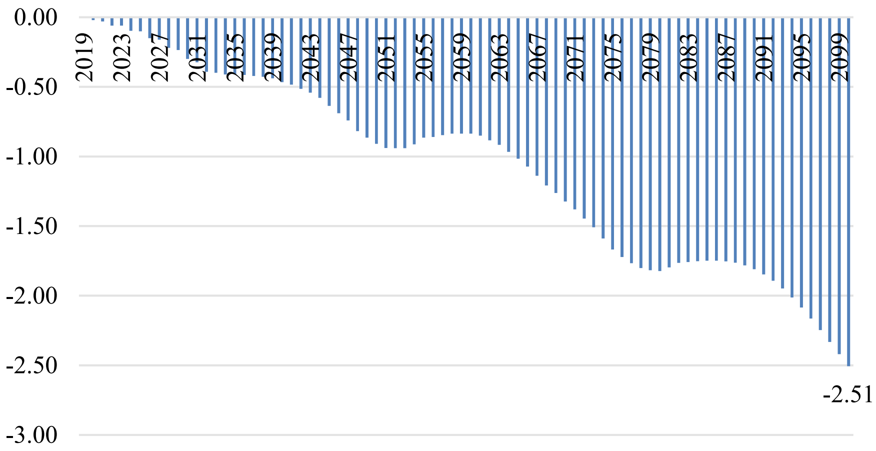

Fig. 10.17 The effects of retirement age extension on pension payment, Scheme 2—cumulative deviation from the baseline (¥ trillion). *Source* Baseline and policy simulation results

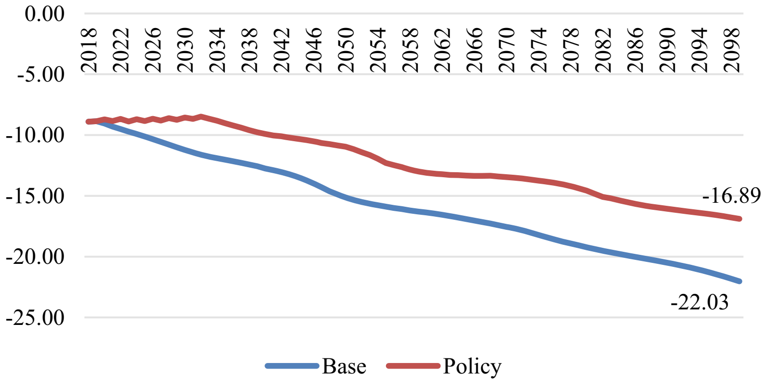

Fig. 10.18 General government budget deficit as share of GDP, baseline and policy scenarios (%). *Source* Baseline and policy simulation results

10.5 Conclusions and Policy Implications

China is experiencing rapid population ageing. Using a dynamic computable general equilibrium (CGE) model of the Chinese economy, we project China's economic performance over the period 2017 to 2100 against the background of rapid change in the population age structure. The simulation exercise reveals that the rapid population ageing will exert strong pressure on the current pension system and render the present growth of the economy unsustainable:

- China will experience a persistent labour force decline in the future. The labour force will decline at a rate of 0.33% in 2020 and 1.32% in 2050 and 0.92% at the end of the century.
- China has to rely on growth of the capital stock and total factor productivity to sustain its economic growth.
- The rapid increase of the old population and decline in the labour force will drive the pension funds into deficit, and the deficit will accumulate rapidly. By mid-century, China's pension deficit will exceed ¥520 trillion, which is equivalent to around 50% of that year's GDP. It will further accumulate to almost ¥10,000 trillion which is equivalent to 260% of GDP at the end of the century.
- The huge pension debt will put high pressure on China's general government budget balance. If the government choose to fund the deficits annually, it will increase the government budget deficit. By the end of the century, the general government deficit will account for more than 22% of GDP.

Thus, reforming the current pension system and finding ways to deal with the ageing problem become very urgent. Increasing the retirement age has been discussed among scholars and the Chinese government as a way to mitigate the negative effects of the ageing problem on the pension system and the macro economy. Applying a dynamic CGE modelling approach, we estimate the effects of raising the retirement age on China's macro economy and pension system through 2020 to 2100. We find out that raising the retirement age will.

- Boost China's economic growth by increasing employment and capital stock. By the end of the simulation period, real GDP will be 2.7% higher than in the baseline scenario;
- Improve households' living standard measured by real household consumption. By the end of the simulation period, real household consumption will be 2.4% higher than the baseline scenario;
- Improve the pension fund performance. By the end of the simulation period, the pension deficit will reduce from the baseline's ¥10,000 trillion to ¥6190 trillion, which is 38% lower than the baseline scenario.
- Improve the general government budget balance. The retirement age extension will bring the general government deficit back to around 17% of GDP.

In summary, retirement age extension is an effective policy. It will not only increase the labour force of the economy by increasing the labour force participation of the population, but also reduce the size of the retired working population receiving pensions at a given point of time by delaying their entry into the pool of pensioners. China's economy will benefit even more from this policy if the policy could be implemented soon.

The simulation results are very sensitive to the assumed increase of LFPRs of the population aged 54 to 65 when the government increase the retirement age. We know that increasing the retirement age will have positive effects on the LFPRs of the age groups which are affected. However, the extent to which the LFPRs will increase and how many workers will choose to stay in the labour force after the policy becomes effective really depend on how the policy is designed. Carefully designing the policy and implementing it with caution will help the country gain benefit from the policy.

We also notice that the gains from the policy will reach their highest point around the middle of the century, and will diminish thereafter. There are several reasons for the diminishing effects of the policy. First, this is due to the slowdown in the growth of the population aged 58–65 (Fig. 10.8). Later retirement, to a large extent, allows those aged 58 to 65 to increase the labour force and employment. The slower growth of these cohorts in the second half of this century will diminish such effects as compared with the baseline scenario. Secondly, the V shape of the change in the retired population. Fig. 10.14 shows the cumulative deviation of the retired population in the policy scenario from the baseline case. We notice that the fall in the number of retired workers will reach its highest point around the middle of the century. The number of retired workers will be around 61% lower than the baseline scenario in 2049. After 2049, even though the number of retired workers is still lower than in the baseline scenario, the reduction becomes smaller. By the end of the century, the retired working population is only 26% lower than in the baseline case. The effects of retirement age extension policy on the macro economy and pension funds are the combined results of these two factors. To sustain the effect of the policy, one feasible option is to further postpone the retirement age to 67 or even 70 after the middle of the century; this is the policy practice of some European countries nowadays.

Appendix

See Tables 10.4, 10.5 and 10.6.

Table 10.4 Revenues and expenditures of PUE, pillar one (¥ billion)

	Contribution	Government subsidy	Interest income and other	Total revenue	Total expenditure	Annual surplus	Accumulated surplus
	(1)	(2)	(3)	(4)	(5)	(6) = (5)−(4)	(7)
2012	1020.954	264.8	0	1285.754	1491.77	−206.0163	0
2013	1172.079	301.9	−12.3807	1461.598	1767.675	−306.078	−206.0163
2014	1286.924	359.368	−20.575	1625.717	2080.027	−454.3103	−512.0943
2015	1456.914	471.6	−32.97103	1895.542	2464.093	−568.5492	−966.4043
2016	1694.416	651.1	−48.15561	2297.358	3035.748	−738.3889	−1534.954

Source Authors' calculation based the Bulletin on the Development of Human Resources and Social Security in China, 2012 to 2015; Annual Report on the Development of Chinese Social Insurance, 2014 and 2016

Table 10.5 Revenues and expenditures of PUE, Pillar 2 (¥ billion)

	Contribution	Government subsidy	Interest income and other	Total revenue	Total expenditure	Annual surplus	Accumulated surplus
	(1)	(2)	(3)	(4)	(5)	(6) = (5)−(4)	(7)
2012	625.746	0	88.6	714.346	64.4283	649.9177	2394.1
2013	691.322	0	102.699	794.021	79.3258	714.6953	3044.018
2014	746.131	0	138.577	884.708	95.4734	789.2346	3758.713
2015	844.688	0	160.9	1005.587	117.2088	888.3792	4547.948
2016	982.387	0	177.9	1160.286	149.6526	1010.634	5436.328

Source Authors' calculation based the Bulletin on the Development of Human Resources and Social Security in China, 2012 to 2015; Annual Report on the Development of Chinese Social Insurance, 2014 and 2016

Table 10.6 Assumptions of labour force participation rates of population aged 54 to 65

Year	Age											
	54	55	56	57	58	59	60	61	62	63	64	65
2019	74.21	71.09	68.66	67.17	65.35	62.19	53.98	51.38	49.14	46.73	44.42	41.8
2020	**75**	**71.87**	**69.55**	**68.14**	**66.46**	62.19	53.98	51.38	49.14	46.73	44.42	41.8
2021	75	**72.66**	**70.44**	**69.11**	**67.56**	62.19	53.98	51.38	49.14	46.73	44.42	41.8
2022	75	**73.44**	**71.33**	**70.09**	**68.67**	**63.66**	53.98	51.38	49.14	46.73	44.42	41.8
2023	75	**74.22**	**72.22**	**71.06**	**69.78**	**65.13**	53.98	51.38	49.14	46.73	44.42	41.8
2024	75	**75**	**73.11**	**72.03**	**70.89**	**66.6**	**56.65**	51.38	49.14	46.73	44.42	41.8
2025	75	75	**74**	**73**	**72**	**68.06**	**59.32**	51.38	49.14	46.73	44.42	41.8
2026	75	75	74	73	72	**69.53**	**61.99**	**54.31**	49.14	46.73	44.42	41.8
2027	75	75	74	73	72	**71**	**64.66**	**57.25**	49.14	46.73	44.42	41.8
2028	75	75	74	73	72	71	**67.33**	**60.19**	**52.28**	46.73	44.42	41.8
2029	75	75	74	73	72	71	**70**	**63.13**	**55.43**	46.73	44.42	41.8
2030	75	75	74	73	72	71	70	**66.06**	**58.57**	**50.11**	44.42	41.8
2031	75	75	74	73	72	71	70	**69**	**61.71**	**53.49**	44.42	41.8
2032	75	75	74	73	72	71	70	**69**	**64.86**	**58.86**	**48.01**	42.33
2033	75	75	74	73	72	71	70	69	**68**	**60.24**	**51.61**	42.87
2034	75	75	74	73	72	71	70	69	68	**63.62**	**55.21**	43.4
2035	75	75	74	73	72	71	70	69	68	**67**	**58.81**	43.93
2036	75	75	74	73	72	71	70	69	68	67	**62.4**	44.47
2037	75	75	74	73	72	71	70	69	68	67	**66**	45
2038–2049	75	75	74	73	72	71	70	69	68	67	66	45
2050	75	75	74	73	72	71	70	69	68	67	66	45

Source The labour force participation rates in 2019 are the same as in 2010 which is from China Statistical Yearbook, 2017. Data from 2020 to 2050 are authors' assumptions

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Chapter 11
Financial CGE Model for China and Its Application

Jingliang Xiao

Abstract The increasing attention to the interactions of monetary and fiscal policies and their impact on macroeconomic dynamics has been devoted ever since the global financial crisis began in 2007. However, traditional CGE models, which mainly focus on real size of the economy, are inadequate to estimate monetary policy shocks. In this Chapter, we developed a recursive-dynamic general equilibrium model of the Chinese economy, which integrated detailed model of financial markets with core CGE models to explore the interactions between financial sectors and real side of the economy. By applying the financial CGE model of the Chinese economy, this chapter contributes to our understanding of China's economic recovery polices in the post-pandemic era and provides emerging economics with development experience in terms of the effectiveness of the different monetary-fiscal regimes.

Keywords Financial markets · Financial CGE model · China · Economic recovery polices

11.1 Introduction

The global financial crisis (GFC) that began in 2007 has undoubtedly been the most significant economic event in recent memory. The global economy has been experiencing a decade-long recovery since the GFC. However, the US-China trade war and the supply chain crisis triggered by the COVID-19 pandemics in the last several years disrupted the longest progression of globalization in the human history. The recent Russia's invasion of Ukraine fueled an already-hot commodities rally, which increased the risk of global stagflation. In an era of uncertainties, governments look for the best policies that could balance the economic growth and the foreign relationship with other nations.

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This chapter aims to find the most effective way in which China should address the above issues. We developed a recursive-dynamic general equilibrium model of the Chinese economy, referred to hereafter as the Financial Applied General Equilibrium (FAGE) model, which allows explicit policy analysis to be conducted on the financial sector. We believe that this model helps provide clarity and improve learning and understanding of the interaction of fiscal and monetary policies.

This chapter consists of seven sections. Section 11.2 reviews the literature of economic modelling on fiscal and monetary policies. Section 11.3 gives some explanation of the sources of the initial values for the model's key financial data. Section 11.4 describes the theory of the financial module of the FAGE model. Section 11.5 is concerned with the closure of the financial side of the model. Section 11.6 provides a simulation in which we explore the effects of the combination of monetary and fiscal policies on the economy. Section 11.7 concludes this chapter by highlighting the remarks.

11.2 Literature Review

There is a growing literature on the effectiveness of fiscal and monetary policy instruments on economic growth. Among them, vector autoregressive (VAR) models are widely used to measure the impact of monetary policy shocks on macroeconomic variables (Barakchian and Crowe 2013; Bernanke et al. 2005; Uhilg 2005). Similar to studies on monetary policy, a large body of literature focuses on the effect and mechanism of fiscal policy in stimulating economic growth. The findings of these studies are mixed, as the fiscal multipliers appear to depend heavily on countries-specific situations and the uses of multiple policy tools (Min et al. 2022). In reality, the combination of monetary and fiscal instruments ensures that authorities have adequate policy space to stabilize the economic cycle. Therefore, increasing attention to the interactions of monetary and fiscal policies and their impact on macroeconomic dynamics has been devoted in the recent literature. Related theoretical macroeconomic models have been established (Sargent and Wallace 1981; Leeper 1991). At the same time, a growing number of empirical studies have been conducted to testify these theoretical models. For example, Muscatelli et al. (2004) employ the New-Keynesian model and the US quarterly macroeconomic data to study the fiscal-monetary interactions. They find that the interactions are not consistent over time and policy shocks employed determine how the regimes work. In a similar vein, Reade (2011) uses the cointegrated VAR model to investigate the monetary-fiscal regime in the United States and finds that the two policy tools have different efficacies in the economic cycle. Fragetta and Kirsanova (2010) attempt to identify the policy instruments that dominate the monetary-fiscal policy regimes in the UK, the US and Sweden by specifying a small-scale, structural general equilibrium model.

Much works on the impacts of monetary-fiscal policies through the lens of structural models in advanced countries have been carried out. However, the instruments implemented in advanced economies are not necessarily applicable in emerging economies given their different economic characteristics and structural mechanisms. Against this background, some scholars pay more attention to the macroeconomic effects of evolving stabilizing policies in emerging economies, including China. Liu et al. (2021), for instance, construct a New Keynesian dynamic stochastic general equilibrium (DSGE) model with specified monetary and fiscal behavior to estimate the role of China's policy shocks in shaping the business cycle. They argue that a passive monetary and an active fiscal policy regime (PM/AF) is best-fitting regime in shaping China's macroeconomic dynamics. The study also sheds light on the transmission mechanisms of the regime and the driving force in output growth and inflation by focusing on the characteristics of emerging market economies. Luan et al. (2021) investigate the changes of China's monetary/fiscal policy mix in the three different periods from 1996 to 2020. Based on their findings, they argue that the control of debt and macro leverage are the key for the effectiveness of monetary/fiscal policies. Min et al. (2022) pay particular attention to the effectiveness of monetary/fiscal policy shocks on aggregate investments in China. Different policy shocks, that is, government spending, money and lending rate, and interest rate shocks, are investigated to assess policy stimulus on aggregate investment. The authors argue that both aggressive government spending policy and monetary policy are not necessarily a good choice to boost Chinese domestic investment and economic growth in the long run.

The findings of existing studies heavily depend on the choices of economic models and data. VAR models, which have been widely applied in existing studies, attempt to exploit the reduced-form correlations between macroeconomic variables. This approach is more flexible to estimate and generate out-of-sample forecasts. However, VAR models typically include a relatively small number of variables (Charles and Kuttner 1998). Moreover, due to the lack of structural modelling of complex economic behaviours, the VAR approach also has limitations in its ability to track the underlying structure of the economic system. In contrast, the DSGE modelling approach, a theory-based and structural approach, provides rich representation of the real economy. But forecasting accuracy of DSGE models heavily depend on assumptions and parameters modellers make. These types of models only allow for random variation to account for uncertainty and usually focus on the shorter-term impacts by capturing business cycle fluctuation.

Sharing some features with DSGE models, computable general equilibrium (CGE) models combine economic theory with detailed economic data (e.g., input–output data) to simulate impacts of policies or shocks on the economy. However, due to the lack of financial modules in standard CGE models, traditional CGE models are inadequate to estimate monetary policy shocks and their impacts on the real economy. The literature on financial CGE models and related empirical studies are scare. But on the other hand, the importance of understanding stabilizing policies is imperative within the context of global economic recovery in the post-pandemic era. In most recent decades, there have been emerging works on integrating detailed modelling of financial markets with core CGE models to explore the interactions between financial sectors and the real side of the economy. Xiao (2009) develops a detailed recursive-dynamic CGE model of the Chinese economy and uses the model to analyse fiscal-monetary policies under different exchange rate regimes. Building on a dynamic CGE model of the Australian economy evolved from the MONASH model, Dixon et al. (2015) incorporate detailed financial sector to examine the expansion of Australia's superannuation sector within an economy-wide setting. The treatment of modelling the financial sector includes embedding financial intermediaries and the agents, financial instruments describing assets and liabilities, the financial flows and rates of return on individual assets and liabilities in the financial module.

The development of the MONASH-style financial CGE model fills the gap between the real and monetary sides of the economy, laying the foundation for further empirical studies on particular countries' monetary policies. Following this approach, Dixon et al. (2014) add the financial module to a dynamic model for Papua New Guinea (PNG) and assess the impact of tighter monetary policy in the country. The work explains how increased interest rates stimulate foreign capital inflow which leads to real appreciation and deterioration in the trade balance. This approach rectifies the weakness in traditional CGE models that distort the stock/flow mechanism. Giesecke et al. (2017) and Rasyid et al. (2022) uses a financial CGE model of Indonesia (AMELA-F) to investigate the impact of increased bank capital adequacy requirements (CARs) on the emerging economy. They find that increase in CAR causes negative impacts on the country's industry and real investment. Galindev and Decaluwé (2020) construct a recursive dynamic CGE model of the Mongolian economy by introducing a Taylor-type interest rate rule to capture the central banks' stabilizing monetary policies.

In addition to the MONASH-based financial CGE model, Dixon et al. (2021) make an endeavor to introduce disaggregated, single-country financial modules into the multi-country CGE model, the well-known GTAP model. The financial modules are linked to core GTAP models by building around the asset-liability matrix through saving and investment behavior. This new model is used to simulate tit-for-tat situations of financial decoupling as well as trade decoupling between the U.S. and China, which sheds light on the growing tensions between the two countries and the impact on the global economic system.

The uneven post-pandemic recovery has caused an economic policy uncertainty to the Chinese government. Study on the effects of stabilizing monetary-fiscal policies on China's macroeconomics is of substantially importance for policymakers. As mentioned above, general economic models might not be applicable to capture China's distinct financial mechanism, policy environment and economic structure. By applying the financial CGE model of the Chinese economy, this paper contributes to our understanding of China's economic recovery polices in the post-pandemic era and provides emerging economics with development experience in terms of the effectiveness of the different monetary-fiscal regimes.

11.3 Data

There are six financial agents in FAGE. They are HouseHolds (HH), the Industries (IND), the Commercial Banks (Banks), the Central Bank (CBank), the Government (GOV), and the Rest Of the World (ROW). According to the double entry book-keeping method, Table 11.1 lists the balance sheets of each agent. The items on the left are assets and the items on the right are the liabilities.

As shown in the Table 11.1, the assets of households mainly include cash, personal deposits, government bonds, corporate bonds, equity issued by industries and commercial banks. And the liabilities of households are personal loans from commercial banks and foreign countries.

The assets of Industries mainly include its fixed assets, cash, corporate deposit, government bonds, corporate bonds, corporate equity and commercial bank equity, while the liabilities include loans from domestic commercial banks and foreign banks, the corporate bonds and equity they issued.

The assets of commercial banks include cash, commercial bank loans, reserves in the central bank, interbank lending and bonds issued by other commercial banks, treasury bonds, equity issued by other commercial banks, and bills from central bank. The liabilities of commercial banks include the deposits of households, industries and governments, discount loans applied to the central bank, interbank lending between commercial banks, financial bonds, and equity issued by commercial banks.

The financial assets held by the central bank mainly include foreign exchange reserves, discount loans, government bonds and financial bonds. The liabilities of the central bank include cash, Required reserves, excess reserves and central bank bills. The financial assets held by the government are only fiscal deposits (Public Finance-cash in Bank), and financial liabilities are mainly Government bonds.

We collected the related data in the Almanac of China's Finance and Banking (2018). In the official statement, there are more detailed classification. According to the characteristic of risk and return, we grouped the financial instruments in Table 11.1 into four types: Cash, DepositLoan, Bonds and Equity.

In CGE modelling, we assume that the economy in the base year is in equilibrium and the database has to follow some balancing conditions. In FAGE, we introduced the new database that describes the assets and liabilities of each financial agent. In order to be consistent with the existing database of the real CGE model, the financial database must satisfy the following conditions.

Firstly, each agent's savings or deficits derived from the real side of the economy should be consistent with its assets and liabilities at the beginning- and end-of-year in the financial database. Secondly, commercial banks should follow the zero profit condition and own zero net wealth, which is corresponding to the perfect competition assumption applied on firms in the standard CHINAGEM. Finally, the net financial assets (i.e., total assets minus total liabilities) of the whole economy should also be zero in both beginning- and end-of-year. However, as these data come from divers sources, it is inevitable to have some gaps between the real and the financial data.

Table 11.1 Agents' balance sheets

ASSETS	LIABILITIES
HouseHolds (HH)	
Cash	Commercial bank loans
Deposits	Foreign loans
Government bonds	
Corporate bonds	
Equity issued by industries	
Equity issued by commercial bank	
Industries (IND)	
Fixed assets	Commercial bank loans
Cash	Foreign loans
Corporate deposits	Corporate bonds
Government bonds	Equity issued by Industries
Corporate bonds	
Equity issued by industries	
Equity issued by commercial banks	
Commercial Banks (Banks)	
Cash	Deposits
Commercial bank loans	Discount loans
Required reserves & Excess reserves	Interbank borrowing
Financial bonds	Financial bonds
Interbank lending	Equity issued by Commercial Banks
Government bonds	
Equity issued by commercial banks	
Central bank bills	
Central Bank (CBank)	
Foreign exchange reserves	Cash
Discount loans	Required reserves & Excess reserves
Government bonds	Central bank bills
Financial bonds	
Government (Gov)	
Public finance-cash in bank	Government bonds
Rest of the world (ROW)	
Foreign loans	Foreign exchange reserves

Therefore, we applied a modified RAS program to create the database in the financial module that is consistent with the existing database of CHINAGEM.

11.4 Model Theory of FAGE

The modelling framework in the real side of the FAGE model used in this chapter is similar to the standard CHINAGEM described in Chap. 4 of this book. The theory of the financial side of the FAGE model is based on the work of Xiao (2009) and Dixon et al. (2015). In FAGE, each financial agent is simultaneously concerned with managing both the asset and liability sides of their balance sheets. Hereafter, when a financial agent is concerned with asset acquisition and disposal, we refer to them as "asset agents" (AA). When an agent is concerned with liability issuance and repayment, we refer to them as "liability agents" (LA). In their actions as both asset and liability agents, financial agents are assumed to behave as constrained optimisers.

There are three matrices used to parameterise the financial module. First, AT(s, f, d) is the beginning-of-year financial stock of the financial instrument f ϵ FI issued by liability agent s ϵ LA and held by asset agent d ϵ AA. Second, FLOW (s, f, d) describe the within-year flows of financial instrument f ϵ FI issued by s ϵ LA and held by asset agent d ϵ AA. Third, R (s, f, d) is the matrix of the power of the rate of return (one plus percentage rate of return) on financial instrument f ϵ FI issued by liability agent s ϵ LA and held by asset agent d ϵ AA.

In our model, the sets LA, FI, and AA are defined as follows:

AA	Households, industries, commercial banks, central bank, government, rest of the world
FI	Cash, deposit loan, bonds and equity
LA	Households, industries, commercial banks, central bank, government, rest of the world

11.4.1 Modelling Asset Allocation and Capital Structure Decisions

Asset agents are assumed to choose an allocation of their end-of-year portfolio across assets in order to maximise their utility—a constant elasticity of substitution (CES) function—in which the arguments are end-of-year asset allocations weighted by rates of return. This subjects to the amount of money available for agents to acquire new assets. Mathematically, this can be expressed as follows:

Maximize: $\mathbf{U}[\mathrm{AT1}(s, f, d) * \mathrm{R}(s, f, d)]$.

Subject to:

$$\sum_{s,f} \mathrm{AT1(s, f, d)} = \sum_{s,f} [\mathrm{AT0(s, f, d)} * \mathrm{V(s, f, d)} + \mathrm{FLOW(s, f, d)}]$$

$$\sum_{s,f} \mathrm{FLOW(s, f, d)} = \mathrm{NEWAACQ(d)}$$

where

R(s, f, d) is the power of the rate of return (e.g., a number like 1.05) earned by agent (d) on its holding of instrument (f) issued by agent (s);
AT1(s, f, d) is the end-of-year holding by agent (d) of instrument (f) issued by agent (d);
AT0(s, f, d) is the start-of-year holding by agent (d) of instrument (f) issued by agent (s);
V(s, f, d) is a valuation power term to capture the revelation of assets due to the fluctuations of the financial market and the foreign exchange market (e.g., in the absence of valuation effects, a number like 1);
FLOW(s, f, d) is net new acquisitions by agent (d) of instrument (f) issued by agent (s);
NEWAACQ(d) is agents' budget for net new acquisitions of financial instruments over the year.

For example, when the amount of available fund (NEWAACQ) increases, agents will acquire more all kinds of assets in their portfolio. If the interest rate on domestic bonds increases relative to the returns earned on other assets, Agents may want to hold more domestic bonds and less of the other assets. We assume that assets are imperfect substitutes in the CES framework. Given our previous example, it means that Agents will not invest only in domestic bonds, but they will also continue to spread their portfolio over various assets. They will increase their holding of domestic bonds relative to other assets.

Similarly, we define the optimal behaviour of the liability agents. They set their capital structure by minimizing a constant elasticity of transformation (CET) function of the weighted cost of financial capital. Subject to the need to raise a given level of new financial capital, liability agents decide the issuance of liability instruments held by different asset agents that minimizes the financial payment at the end of the year.

Minimize: $\mathbf{C}[\mathrm{AT1(s, f, d)} * \mathrm{R(s, f, d)}]$.

Subject to:

$$\sum_{f,d} \mathrm{AT1(s, f, d)} = \sum_{f,d} [\mathrm{AT0(s, f, d)} * \mathrm{V(s, f, d)} + \mathrm{FLOW(s, f, d)}]$$

$$\sum_{f,d} \mathrm{FLOW(s, f, d)} = \mathrm{NEWLACQ(s)}$$

where

NEWLACQ(s) is the new liabilities that must be raised by agent (s).

Again, we assume that liabilities are imperfect substitutes as well in the CET framework. That means agents will not rely solely on one source of funding even though the cost of borrowing of such source reduces. For example, corporate may increase the bond to equity ratio slightly but won't convert all of their fund raising from equity to bond when they see the bond marketing booming.

Agents' budget for net new acquisition of financial instruments depends on their saving (SAVE) and the accumulation of new liabilities (NEWLACQ) over the year.

$$\text{NEWAACQ(d)} = \text{SAVE(d)} + \text{NEWLACQ(d)} \tag{11.1}$$

The more saving or new fund raising will give more dry powder to acquire new financial assets.

11.4.2 Saving for Each Agent

Households

Households saving is the sum of the wage bills (V1LAB) and dividend from industries (0.2∗(V1CAP_I + V1LND_I)) minus the expenditure. We assume the payout ratio is 0.2. Industries will keep 80% of its earnings to reinvest.

$$\text{SAVE(“HH”)} = \text{V1LAB} + 0.2 * (\text{V1CAP} + \text{V1LND}) + \text{NET\_FINC} - \text{V3TOT} \tag{11.2}$$

Industries

The new liability issuance by industries depends on the nominal value of industry investment (excluding public investment, G_VINVEST) and the value of new purchases of financial assets by industries (NEWAACQ).

$$\text{SAVE(“IND”)} = 0.8*(\text{V1CAP} + \text{V1LND}) - (\text{V2TOT} - \text{G\_VINVEST}) \tag{11.3}$$

Normally, industries have negative saving (or deficit) due to the investment (V2TOT − G_VINVEST) exceeding the retain earning (0.8∗(V1CAP + V1LND)). Holding the new purchases of financial assets by industries constant, the greater the deficit (negative saving), the bigger amount of new liabilities will be. From Eqs. (11.1) and (11.3), we know that more investments by industries (V2TOT) require more funding raising (NEWLACQ).

Government

Government budget balance (i.e., its saving) are the sum of net tax revenue (NETTAX) and net transfers from overseas (NETTRNFGNC) minus its expenditure (V5TOT) and investment (G_VINVEST).

$$\text{SAVE(``GOV'')} = \text{NETTAX} + \text{NETTRNFGNC} - \text{V5TOT} - \text{G\_VINVEST} \tag{11.4}$$

From Eqs. (11.1) and (11.4), we know that more tax revenue could lead to more government saving and require less new liability issuance by the government.

Rest of the world

The saving of the rest of the world is the same as the current account deficit (CAD) of the home country, which can be expressed as follows:

$$\text{SAVE(``ROW'')} = \text{V0CIF\_C} - \text{V4TOT} + \text{NETTRNCFGN} \tag{11.5}$$

As shown in Eq. (11.1), the current account deficit of the home country must be financed by a rise in the nation's net foreign liability (i.e., NEWAACQ − NEWLACQ).

Commercial Banks

The saving for the Commercial Banks is equal to the sum of the total return of its assets minus the total cost of its liabilities, which should be equal to zero because of the zero pure profit condition in the private banking sector.

$$\begin{aligned} \text{SAVE(``Banks'')} &= \sum_{s,f}[\text{AT1(s, f, ``Banks'')} * (\text{R(s, f, ``Banks'')} - 1)] \\ &\quad - \sum_{f,d}[\text{AT1(``Banks'', f, d)} * (\text{R(``Banks'', f, d)} - 1)] \\ &= 0 \end{aligned} \tag{11.6}$$

Central Bank

Similar to the Commercial Banks, the saving of the Central Bank is equal to the return on its financial assets minus the cost of its borrowing. Different from the Commercial Banks, it is not necessarily equal to zero.

$$\begin{aligned} \text{SAVE(``CBank'')} &= \sum_{s,f}[\text{AT1(s, f, ``CBank'')} * (\text{R(s, f, ``CBank'')} - 1)] \\ &\quad - \sum_{f,d}[\text{AT1(``CBank'', f, d)} * (\text{R(``CBank'', f, d)} - 1)] \end{aligned} \tag{11.7}$$

11.4.3 Banking System, the Capital Adequacy Ratio and the Bank Reserve Ratio

In Sect. 11.4.1, we describe the general optimization settings for asset agents and liability agents. However, commercial banks face some additional constraints. Central banker can mitigate the risks in the banking system by changing the regulation on reserve and capital requirements.

Bank reserve ratio (BRR)

Money can't be created without limit. Central banker imposes the reserve requirements on the households' deposits in commercial banks. In addition to providing a buffer against bank runs and a layer of liquidity, such requirements are also used as a monetary tool by central banker. In our model, we can express this requirement by the following equation:

$$\begin{aligned}&\left[(\text{AT1}(\text{“CBank”}, \text{“Cash”}, \text{“Banks”}) + \text{AT1}(\text{“CBank”}, \text{“Deposit”}, \text{“Banks”})\right]\\&= \text{BRR} * \sum_{\text{d}}[\text{AT1}(\text{“Banks”}, \text{“Deposit”}, \text{d})]\end{aligned} \tag{11.8}$$

Capital adequacy ratio (CAR)

Another approach central banker controls money supply is through capital adequacy ratio. Following Dixon et al. (2015) and Giesecke et al. (2017), we introduced the capital adequacy ratio to the commercial banks' balance sheet, in which the equity capital of banks has to follow the regulatory capital requirement.

The capital adequacy ratio is the ratio of the sum of tier one and tier two capital to risk weighted assets. Broadly, tier one capital comprises those liabilities, such as ordinary equity, which can absorb losses without requiring the commercial bank to cease operations. Tier two capital comprises those liabilities that can absorb losses in a winding up, such as subordinated debt and hybrid securities, without threatening repayment of depositor liabilities. Risk weighted assets comprise the sum of commercial bank assets individually weighted by indices of asset-specific risk.

$$\text{RA\_BANK} = \sum_{(s,f)} \text{RISKWGT}(\text{s, f, “Banks”})*\text{AT}(\text{s, f, “Banks”}) \tag{11.9}$$

Following Dixon et al. (2015), we set the risk weights (RISKWGT) for cash as zero, deposits/loans and bonds as 0.4, and equity as 3.0 in our model.

By increasing the two ratios, the Federal Reserve is essentially taking money out of the money supply and increasing the cost of credit. Lowering them can lead to the increase of the money supply in the economy by giving banks excess reserves or equity, which promotes the expansion of bank credit and lowers rates.

Adjustments to the optimization settings in Sect. 11.4.1

Introducing the bank reserve ratio (BRR) requires us to deactivate that part of the bank's asset optimization problem related to decision marking over holding of cash and central bank deposits. The adjusted optimization behaviour of commercial banks on the asset side becomes:

Maximize: $\mathbf{U}[\text{NR\_AT1(s, f, “Banks”)} * \text{R(s, f, “Banks”)}]$.

Subject to:

$$\begin{aligned}\text{NR\_AT1(s, f, “Banks”)} = \;& \text{BIG\_BUD\_A(“Banks”)} \\ & - \text{AT1(“CBank”, “Cash”, “Banks”)} \\ & - \text{AT1(“CBank”, “Deposit”, “Banks”)}\end{aligned}$$

$$\begin{aligned}&\big[(\text{AT1(“CBank”, “Cash”, “Banks”)} + \text{AT1(“CBank”, “Deposit”, “Banks”)}\big] \\ &= \text{BRR} * \sum_{\text{d}} [\text{AT1(“Banks”, “Deposit”, d)}]\end{aligned}$$

where

NR_AT1(s, f, "Banks") is the end-of-year holding of non-reserves asset (f) by commercial banks issued by agent (s);

BIG_BUD_A("Banks") is the aggregate value of the portfolio available to commercial banks for asset purchases. It is the revalued start-of-year asset holdings plus the net new asset acquisitions during the year.

To activate the capital adequacy ratio (CAR) mechanism, we must provide for the non-equity component of bank financing to be determined outside of the usual liability optimization mechanism described in Sect. 11.4.1.

Minimize: $\mathbf{C}[\text{NE\_AT1(“Banks”, f, d)} * \text{R(“Banks”, f, d)}]$.

Subject to:

$$\text{NE\_AT1(“Banks”, f, d)} = \text{BIG\_BUD\_L(“Banks”)} - \text{AT1(“Banks”, “Equity”, d)}$$

$$\text{AT1(“Banks”, “Equity”, d)} = \text{CAR} * \text{RA\_BANK}$$

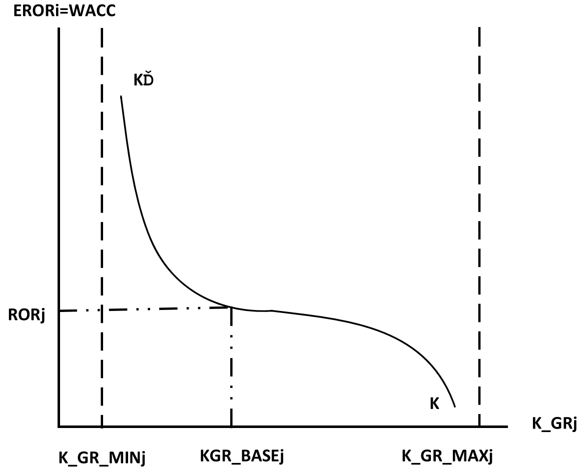
where

NE_AT1(s, f, "Banks") is the end-of-year non-equity liability (f) of commercial banks owned by agent (d);

BIG_BUD_L("Banks") is the total financing needs of commercial banks. It is the revalued start-of-year liabilities plus new net liabilities issued by commercial banks.

Corresponding to the zero-pure profit condition of the saving of commercial banks, the net worth of commercial banks should always be zero. That is, the total value of assets of commercial banks are equal to the total value of their liabilities.

Fig. 11.1 The relationship between capital growth rates and rates of return



11.4.4 *The Relationship Between Weighted Average Cost of Capital and Capital Growth Rates*

In CHINAGEM, the relationship between expected rate of return and capital growth rate is positive. Mathematically, it can be expressed as follows:

$$K\_GR_j = \psi_{KG}\left(EROR_j\right)$$
$$EROR_j = \psi_{EROR}\left(Q_j, PI_j\right)$$

where K_GR_j is the capital growth rate of industry (j); $EROR_j$ is the expected rate of return of industry (j); Q_j is the rental of capital in industry (j); PI_j is the replacement cost of capital in industry (j); ψ_{KG} and ψ_{EROR} are two monotonically increasing functions.

In FAGE, the Weighted Average Cost of Capital (WACC) is endogenized. Figure 11.1 shows the relationship between the WACC and the capital growth rate. A simplified representation of the functional relationship described in Fig. 11.1 is:

$$WACC_j = F\left(K\_GR_j\right) * ROR_j$$
$$ROR_j = \psi_{ROR}\left(Q_j, PI_j\right)$$

where WACCj is the weighted average cost of financial capital (i.e., the expected rate of return on physical capital[1]) in sector (j), K_GRj is sector (j)'s capital growth rate, RORj is the rate of return on sector (j)'s physical capital, and F(K_GRj) is a negative function of the capital growth rate with the logistic form described by K'K

[1] In equilibrium, capital creators will raise new liabilities and invest in physical capital up to the point where the expected rate of return on physical capital is equal to the weighted average cost of financial capital.

in Fig. 11.1. A decrease of the cost of capital (WACC) or an increase of the return on capital (ROR) will lead to a higher capital growth (K_GR).

F(K_GRj) is parameterised so that it has the value 1 when $K\_GR_j = KGR\_BASE_j$. Hence, when the capital growth rate is maintained at its level from the previous year (KGR_BASE_j), capital creators expecting new investments will generate the prevailing rate of return (RORj). Because F(.) is negatively-sloped, if capital growth exceeds KGR_BASE_j, then capital creators anticipate that new investment will generate lower rates of return than the current rate. $K\_GR\_MIN_j$ and $K\_GR\_MIN_j$ establish the minimum and maximum rates of annual capital growth in sector (i).

11.5 Closure of the Financial Side of FAGE

The closure assumptions we use in our model are similar to those in Dixon et al. (2015) with the following key elements:

(i) In line with the neo-classical framework, the real wage is sticky while the employment is flexible in the short run. The real wage adjusts over the medium to long run to ensure that the employment rate returns to the baseline forecast level in the long run.
(ii) The government consumption and household consumptions are linked to the Gross National Product (GNP). The government revenue is endogenously determined by tax rates and the economic activities. As consequence, the government budget deficits determine the new liability acquisition/new bond issuance.
(iii) Other GDP expenditures (investments, exports, import, and stocks) are endogenously determined by the model.
(iv) Capital stocks are prevented to move in the short run and adjust to respond the movement of the expected rate of return of industries over medium to long run.
(v) The central bank is treated exogenously. There is no Taylor rule [Taylor (1993); Rasyid et al. (2022)] applied to the policy rate in response to the employment rate and the inflation rate. In addition, the Chinese government adopts the managed floating exchange rate and strict capital control regime. So we set the nominal exchange rate exogenously and foreign reserves held by central bank as endogenously by default in the model.

11.6 Simulation

The war in Ukraine, sanctions on Russia, China's "zero COVID" policies, spiking inflation, and interest hikes by the Federal Reserve in U.S. are all set to dampen growth in 2022. Rescuing the economic growth without adding fuel on inflation is considered as the major issue for policy makers. In this section, we simulate three

Table 11.2 Tax and value of sales at basic price in 2022 (unit: 100 mn yuan)

	Firms	Investors	Households	Total
Tax	88,901	18,150	46,148	153,198
Value at basic price	1,603,371	432,968	397,465	2,433,805
Effective tax rate	5.5%	4.2%	11.6%	6.3%

Source China 2017 IO table and authors' estimates

hypothetical scenarios to evaluate the economic impacts of the policy packages. The Chinese government has unveiled bigger tax and fee cuts in 2022, with an attempt to reduce the burden on firms and encourage household spending as part of efforts to stimulate economic growth. Under this background, we examine the following three scenarios:

Scenario 1: Tax breaks and fee reduction: we cut taxes and fee on purchasing intermediate inputs, goods and services for investments and private consumption by 15% (equivalent to 2.3 trillion yuan tax breaks).
Scenario 2: On top of Scenario 1, we introduce a 2.0% cut in required reserve ratio (releasing about 5 trillion yuan in long-term liquidity).
Scenario 3: On top of Scenario 2, we enhance the flexibility of the exchange rate and let the yuan appreciate appropriately to stabilize the domestic price levels.

Table 11.2 shows the tax on the purchases of goods and services by different agents in China in 2022.[2] Firms purchase 160 trillion yuan intermediate inputs at basic price in 2022. Firms pay about 8.9 trillion yuan tax to the government. The effective tax rate is about 5.5%. For the 43 trillion of the capital formation, investors pay 1.8 trillion tax when they purchase machinery equipment and build their facilities. Private households pay 4.6 trillion tax on their consumption (39 trillion). That is, 11.6% of effective tax rate. On average the effective tax rate is 6.3% of the total purchases of goods and services at basis price by three agents.

In **Scenario 1**, we assume the tax reduction is 2.3 trillion yuan (about 15% of the 15.3 trillion). Simulation results in Table 11.3 show that the tax cut boosts the real GDP by 1.25%, investment by 2.23%, private and public spending by 0.96% in the short term (2022 column). At the same time, employment and real wage go up by 2% and 0.4%, respectively.

In the long term (in 2030), however, the gain of GDP drops to 0.59%, consumption to 0.22%. The investment even falls below the baseline by −0.39%. The weak domestic absorption (consumptions and investments) leads to the decline in imports (−0.63%), the jump in exports (by 4.88%) and the deterioration of terms of trade (−1.18%). The reason behind is that the tax reduction worsens the government budget balance. The new budget deficit caused by the 2.3 trillion tax reduction requires new issuance of government bonds, which leads to higher financing cost in the public and

[2] The original data is based on Chinese Input–output table in 2017. The data in 2022 is updated by the dynamic CGE model with macro inputs of the growths of employment, consumptions, investment, exports and imports etc.

Table 11.3 Macro results for three scenarios (% deviation from baseline)

	Scenario 1		Scenario 2		Scenario 3	
Unit: % deviation from baseline	2022	2030	2022	2030	2022	2030
Real GDP	1.25	0.59	1.79	1.55	1.61	1.62
Investment	2.23	−0.39	8.90	1.40	6.68	2.01
Household consumption	0.96	0.22	1.86	1.00	1.74	1.32
Government spending	0.96	0.22	1.86	1.00	1.74	1.32
Exports	0.18	4.88	−12.45	4.34	−8.75	1.91
Imports	1.79	−0.63	7.91	0.47	5.95	1.43
Capital stock	0.00	0.64	0.00	2.40	0.00	2.33
Employment	2.02	0.46	2.69	0.87	2.47	1.03
Real wage	0.40	2.37	0.54	3.64	0.50	3.54
Consumer price index (CPI)	−0.37	−1.90	4.50	−1.87	0.00	0.00
Nominal exchange rate	0.00	0.00	0.00	0.00	3.05	−1.14
Terms of trade	−0.04	−1.18	3.36	−1.08	2.31	−0.48
Capital rental price	4.79	0.10	11.59	−1.60	6.21	0.65
Investment price deflator	−0.87	−2.44	4.44	−2.48	−0.28	−0.59
Cost of financing (power of WACC)	−0.11	0.37	−1.53	0.26	−1.06	0.14
Required rate of reserve (RRR)	0.00	0.00	−2.00	−2.00	−2.00	−2.00
M1	0.30	0.11	2.56	1.30	1.10	0.81
M2	0.50	3.22	1.88	5.39	0.94	5.49
Current deficit to GDP ratio	0.00	−0.01	0.03	0.00	0.02	0.00
Government deficit to GDP ratio	0.02	0.02	0.01	0.02	0.02	0.02

Source authors' estimates
Note The year-on-year deviation from the baseline of the macro variables in Table 11.3 are charted in Appendix

drive down the investment in the long term. The cost of financing (power of weighted average cost of capital, WACC) will increase by 0.37% in 2030. The government deficit to GDP ratio increases by 0.02% and current deficit to GDP ratio drops by 0.01%.

In **Scenario 2**, we introduce the expansionary monetary policy to avoid the rise of financing cost. If central bank loosens the monetary policy by reducing the required reserve ratio (RRR) by 2.0% (i.e., 200 basis points, from the current 8.4% to 6.4%), the crowd-out effect on investment in Scenario 1 will be eliminated. The expansionary monetary policy induces an increase in M1 by 2.56% and M2 by 1.88% in 2022. In 2030, the increase in M1 falls to 1.3% while the increase in M2 approaches to 5.39% above the baseline.

Table 11.3 shows that the investment rises by 8.9% above the baseline in 2022 and remains at 1.4% above the baseline in 2030. The real GDP grows by 1.55% in 2030, which is similar to the level in 2022. The substantial expansion of the gross national expenditure (GNE), particularly investment, leads to the deterioration of the current account (e.g., exports decline by 12.5% and imports rise by on 7.9%) in 2022. In terms of the prices effect, this policy package is inflationary in the short run and deflationary in the long run. In particular, capital rental price jumps by 11.6%, investment price deflator by 4.4%, CPI by 4.5%, terms of trade by 3.4% in 2022. While in the long run (2030), capital rental price falls by 1.6%, investment price deflator by 2.5%, CPI by 1.87%, and terms of trade by 1.08% below the baseline. The deflationary effect in the long run is mainly coming from the lagging effect of the strong investment in the short run which boosts the production capacity in the later years. In the long term, current deficit to GDP ratio stays the same level as the baseline, and government deficit to GDP ratio goes up by 0.02% above the baseline. So, comparing to Scenario 1, the bonus of such policy package in Scenario 2 is that the current account surplus will not enlarge. In the context of China-US trade conflict in recent years, reducing trade surplus might be a welcoming idea.

Under the current inflationary environment in 2022 caused by the war in Ukraine, Russia sanctions and the disruption of the global supply chains, policy package in Scenario 2 could potentially exacerbate the already hot inflation pressures. Right now, keeping inflation under control without dampening the economy is the key concern of central bankers.

So, in **Scenario 3**, we propose an additional monetary policy to tame the short-term inflations induced by the policy package in Scenario 2. We assume that China would enhance the flexibility of the exchange rate and let the yuan appreciate appropriately to offset the effect of the short-term inflation. In the policy closure in Scenario 3, we swap the consumer price index (CPI) with the nominal exchange rate. Nominal exchange rate becomes endogenous to accommodate the pressure on domestic prices level. Table 11.3 shows that the short-term inflationary pressure can be eased by allowing the Chinese yuan to appreciate by 3% in 2022 to avoid the prices movement caused by tax cut and reduction of RRR in Scenario 2. In 2022, the capital rental price increases by only 6.2% in Scenario 3 instead of 11.6% in Scenario 2. Investment price deflator decreases slightly by 0.28% (instead of 4.4% in Scenario 2).

The GDP growth sustains at 1.6% above the baseline no matter in the short run or long run in Scenario 3. In terms of trade balance, this policy package creates less fluctuations compared to Scenario 2. The exports only decreases by 8.7% instead of 12.45% in 2022, and grows only 1.91% instead of 4.3% in 2030. The long-term employment expands by 1%, which is the largest gain comparing to the other two policy packages in Scenarios 1 and 2. The long-term real wage grows by 3.5% similar to Scenario 2.

11.7 Conclude Remarks

After the 2008 global financial crisis (GFC), the global economy has been experiencing a strong recovery. The momentum was disrupted by the US-China trade war, the global pandemics, the recent war in Ukraine and the following sanctions on Russia. In the situation of high inflation and low growth, policy makers look for effective solutions to prevent further economic slowdowns.

In the chapter, we built a Financial Applied General Equilibrium (FAGE) model based on Chinese data and used it to simulate the economic impacts of three sets of policy packages. Following the MONASH model by Dixon and Rimmer (2002), the core part of the model explains the real economy under the neoclassical theoretical framework. The financial module integrated the detailed financial agents with the real side economy following Dixon et al. (2015).

Our simulation in Scenario 1 shows that the 15% tax cut on the purchase of intermediate inputs, goods and services for investments and private consumptions boosts the GDP growth effectively in the short term. However, the gain diminishes quickly due to the tight capital market and rising cost of financing. If we impose a corresponding expansionary monetary policy along with this tax cut, the significant GDP growth can sustain in the long term. This brings us to the Scenario 2: reducing the required reserve ratio (RRR) by 200 bps on top of the tax cut in Scenario 1. This sustainable long-term growth comes at a cost. The drawback of such policy package is the high inflation pressure in the short term. In order to avoid adding more fuel to the already hot inflation caused by the war in Ukraine and sanctions on Russia, the Chinese government could embrace more flexibility of its currency and allow Chinese yuan to appreciate in the short run. The simulation results in Scenario 3 show that it requires about 3% of appreciation of Chinese yuan to offset the inflation pressure caused by policy package in Scenario 2. We found that the policy package in Scenario 3 has the least adverse effects on prices and current account, but the sustainable long-term growth in both GDP and employment. The only cost is the increase in the government debt level. History shows that it is the right thing for the government to do especially when the demand in the private sector is insufficient, as long as the debt is denominated in domestic (not foreign) currency.

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Appendix: The % Deviation from Baseline for Macro Variables

Scenario 1:

See Figs. 11.2, 11.3, 11.4, 11.5 and 11.6.

Scenario 2:

See Figs. 11.7, 11.8, 11.9, 11.10 and 11.11.

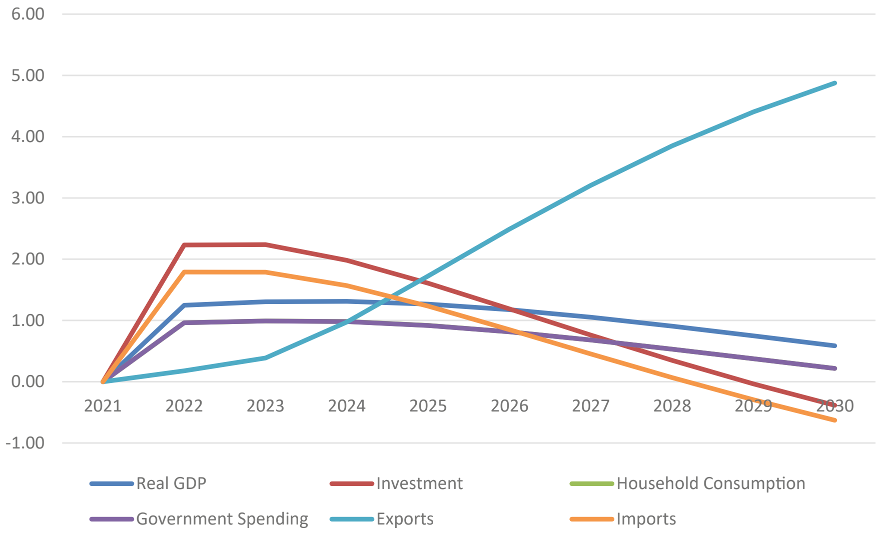

Fig. 11.2 Real GDP and its components (% deviation from baseline)

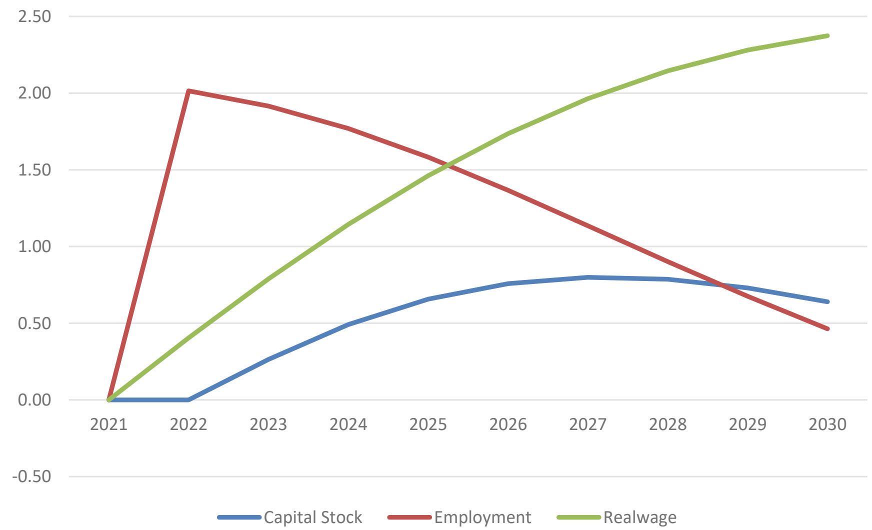

Fig. 11.3 Employment, capital stock, real wage (% deviation from baseline)

Scenario 3:

See Figs. 11.12, 11.13, 11.14, 11.15 and 11.16.

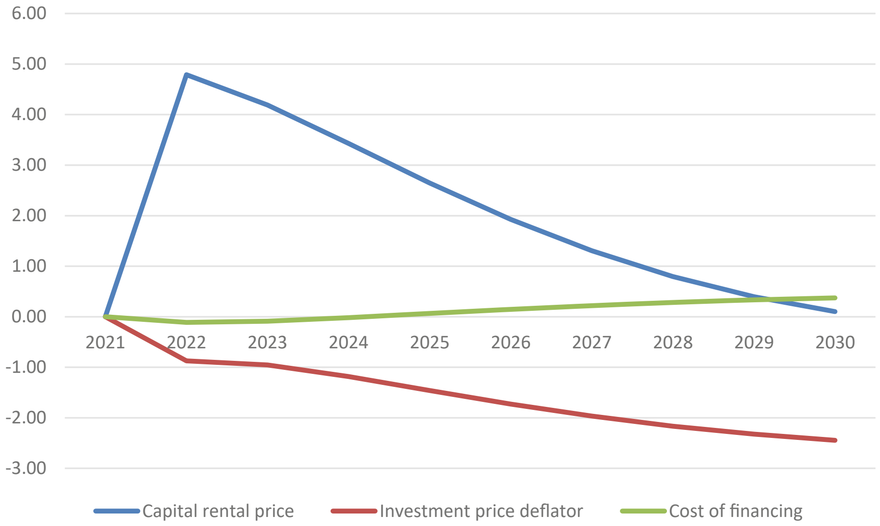

Fig. 11.4 Average capital rental price, investment price deflator, and cost of financing (% deviation from baseline)

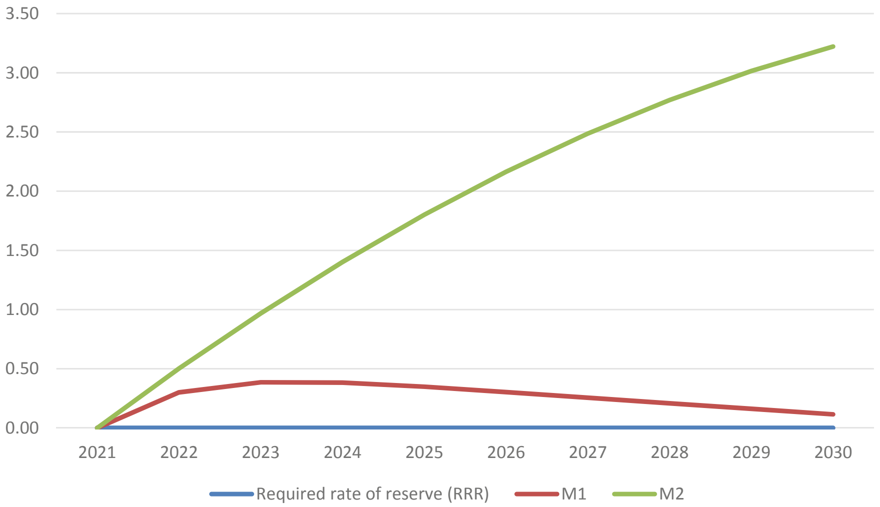

Fig. 11.5 M1, M2, and RRR (% deviation from baseline)

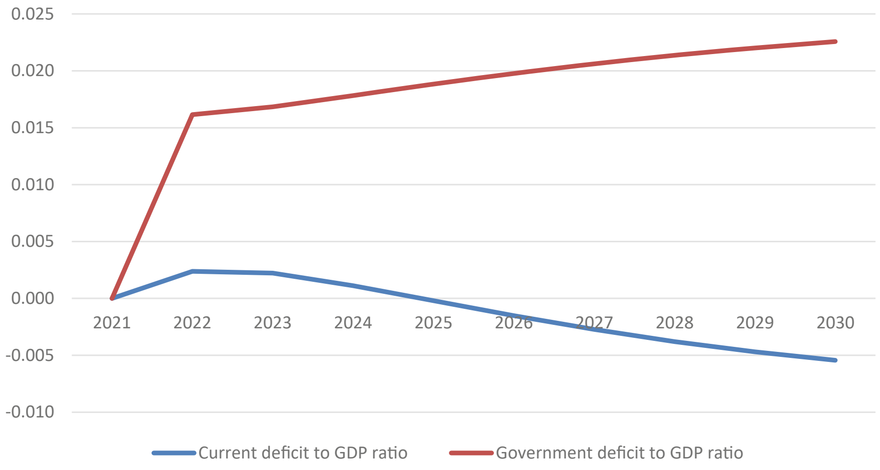

Fig. 11.6 Current deficit to GDP ratio, Government deficit to GDP ratio (% deviation from baseline)

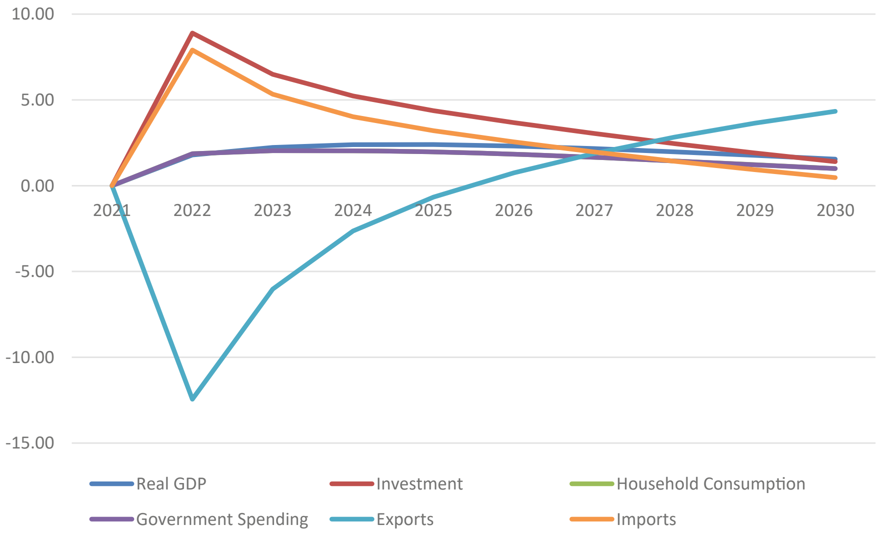

Fig. 11.7 Real GDP and its components (% deviation from baseline)

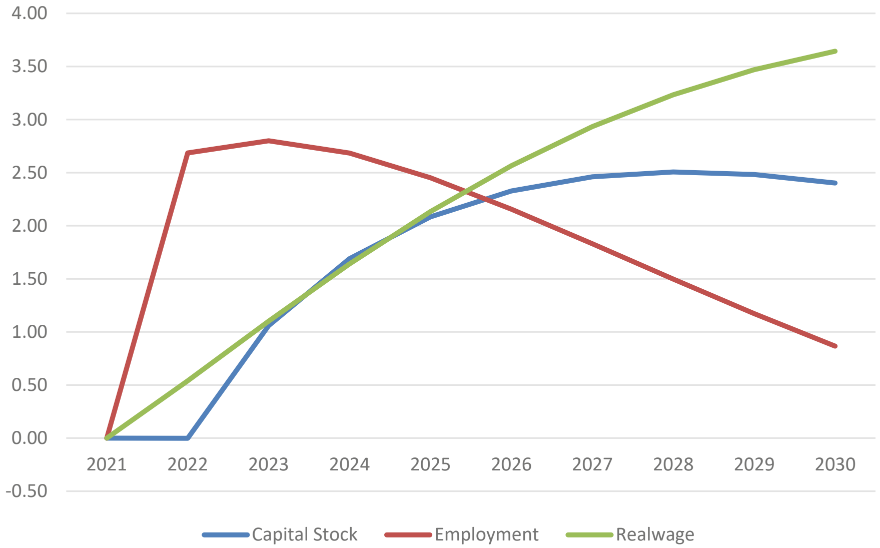

Fig. 11.8 Employment, capital stock, real wage (% deviation from baseline)

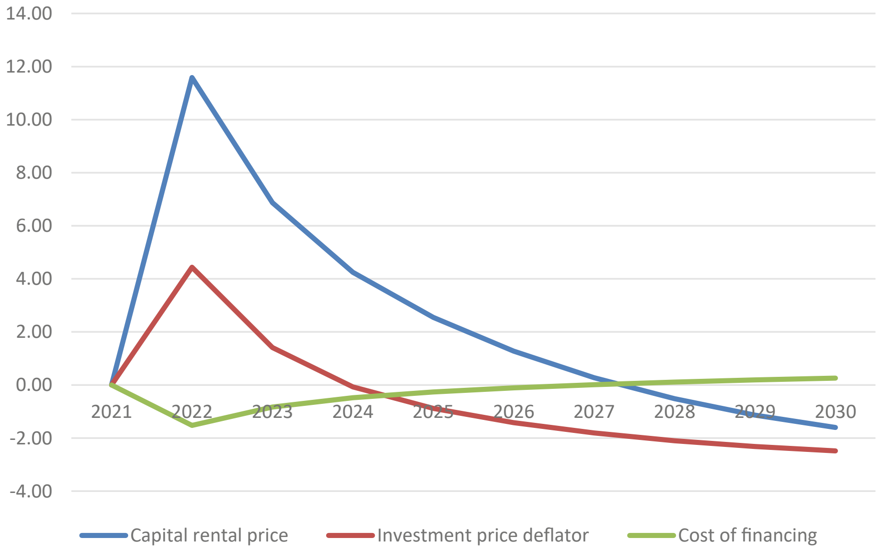

Fig. 11.9 Average capital rental price, investment price deflator, and cost of financing (% deviation from baseline)

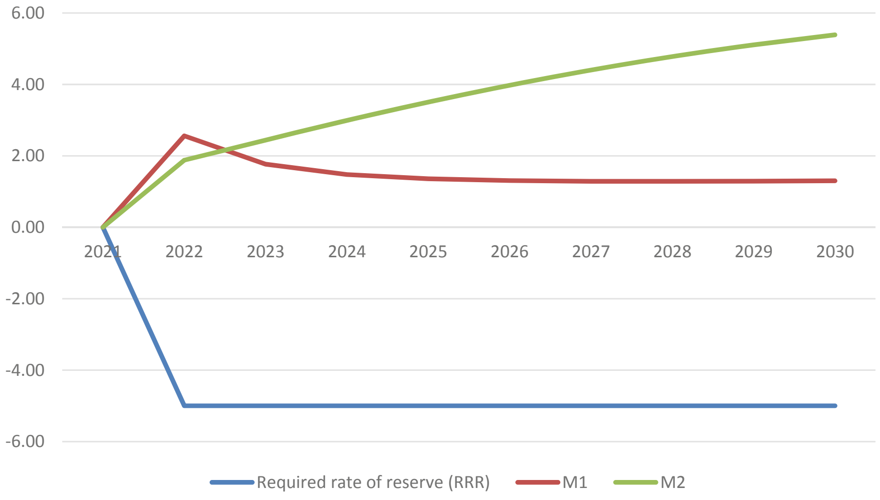

Fig. 11.10 M1, M2, and RRR (% deviation from baseline)

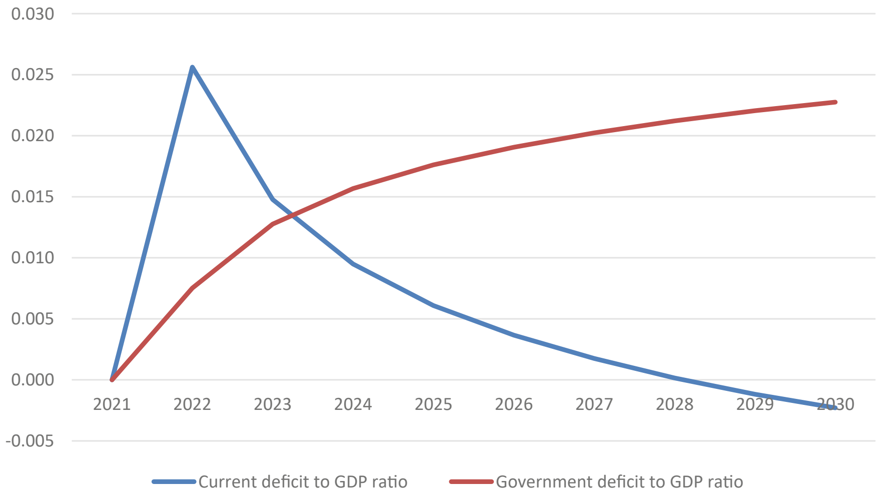

Fig. 11.11 Current deficit to GDP ratio, Government deficit to GDP ratio (% deviation from baseline)

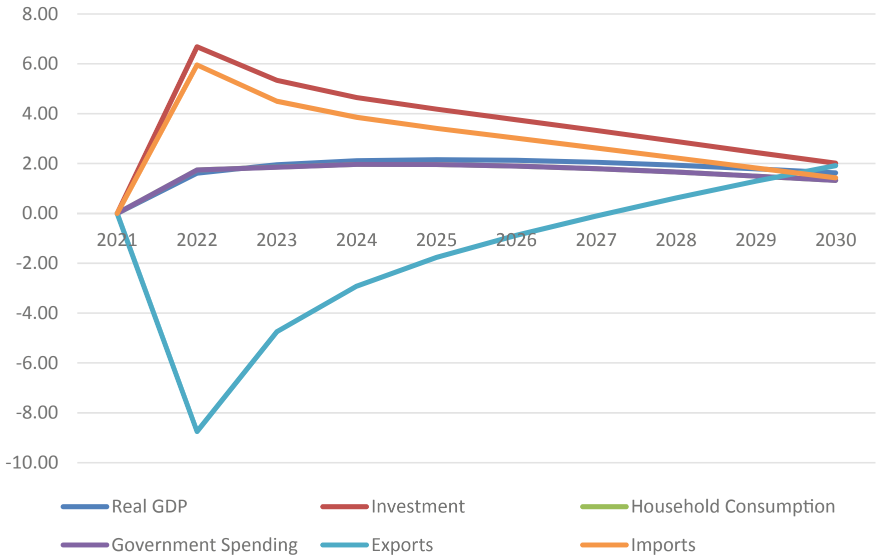

Fig. 11.12 Real GDP and its components (% deviation from baseline)

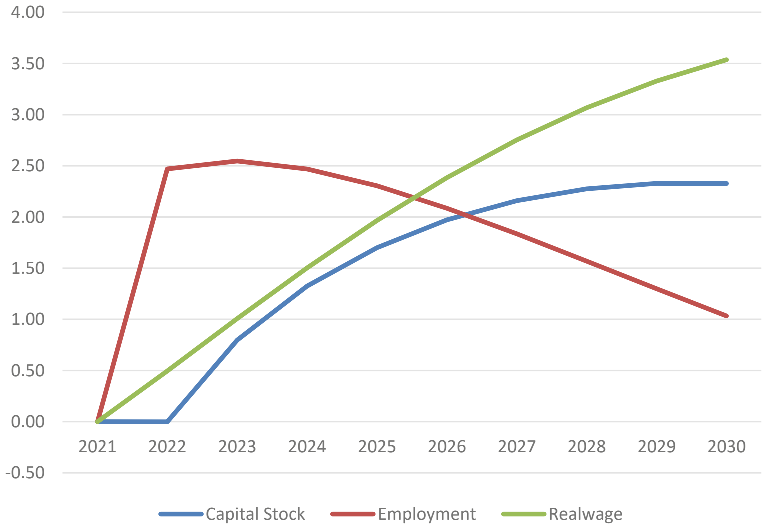

Fig. 11.13 Employment, capital stock, real wage (% deviation from baseline)

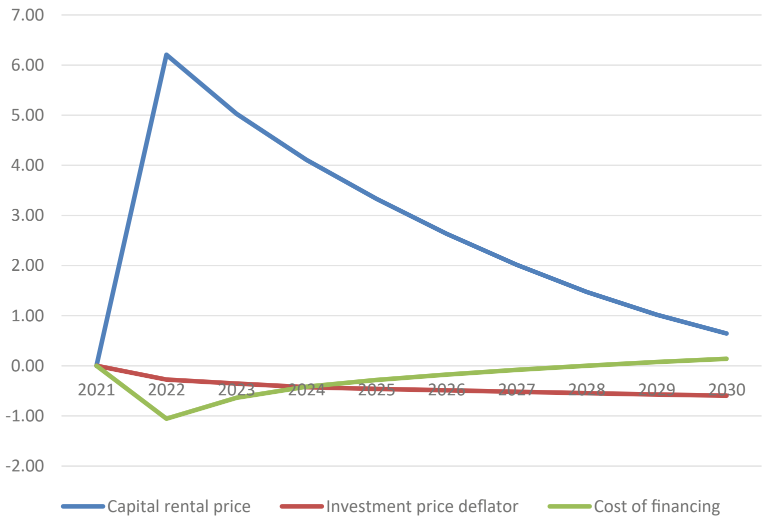

Fig. 11.14 Average capital rental price, investment price deflator, and cost of financing (% deviation from baseline)

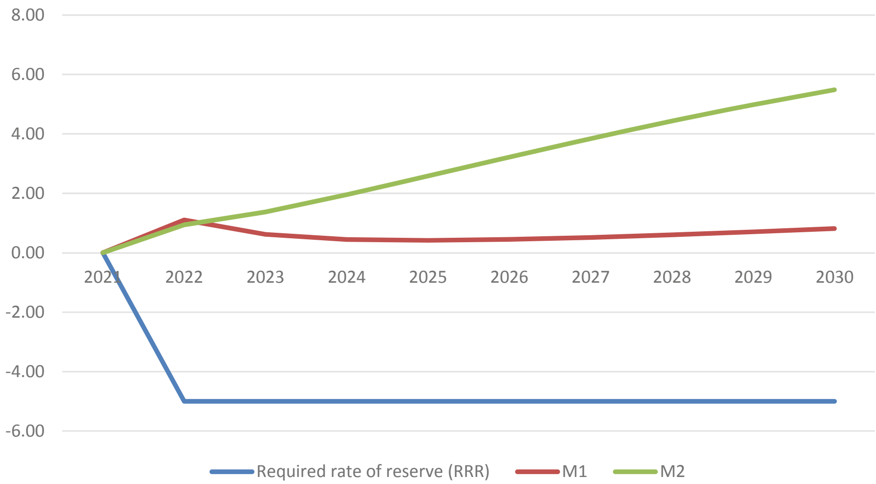

Fig. 11.15 M1, M2, and RRR (% deviation from baseline)

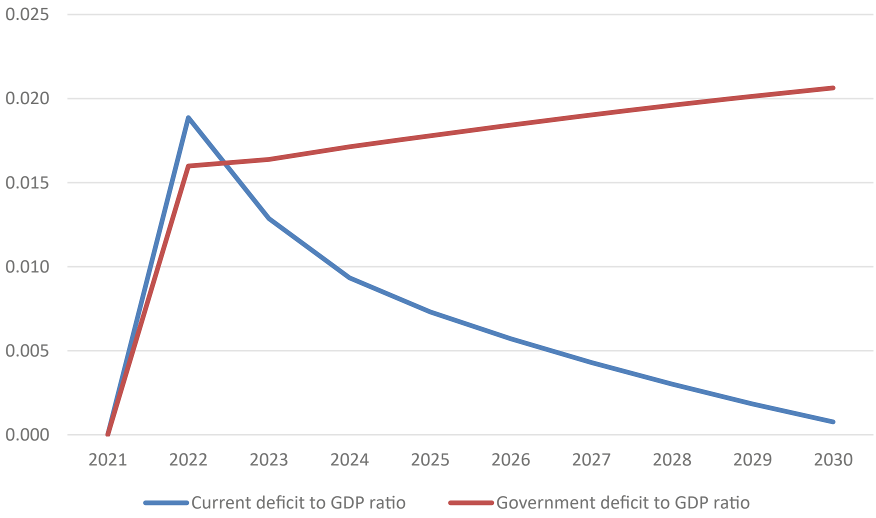

Fig. 11.16 Current deficit to GDP ratio, Government deficit to GDP ratio (% deviation from baseline)

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Chapter 12
Water Subdivision Module and Its Application—Impact of Water Price Reform on Water Conservation and Economic Growth in China

Jing Zhao, Hongzhen Ni, Xiujian Peng, Genfa Chen, Jifeng Li, and Jinhua Liu

Abstract Water pricing has been used as an effective way to conserve water and optimize water allocation. However, little is known about how to set a rational and efficient water price and how water pricing impacts economic growth. In this chapter we address this challenge using a dynamic general equilibrium model for China that is augmented by a total water constraint module. We also include a water subdivision module, allowing for substitution between various water sources. These extensions facilitate a comprehensive estimate of the impact that various water price reforms have on water conservation and economic growth. Modelling results confirm that an increase in the water price will lead to a decline in total water usage, a better water-use structure, and enhanced water use efficiency. We conclude with a comparison of multiple scenarios, which suggests an optimal water price system.

Keywords Water pricing · Water constraint · Water subdivision · Water conservation · Economic growth · China

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12.1 Introduction

China's burgeoning economic growth has been accompanied by soaring water use and has generated increasing excess demand for water resources (Huang et al. 2015). Efforts to address potential water scarcity problems have focused on the demand side of water management (He et al. 2007). Water managers and planners in China have given high priority to the allocation and development of water supply and the management of water prices, while the management of demand and improvement of water use patterns have received less attention (Jurian et al. 2013). The growing concern among researchers and policy makers with the continuous growth in global water demand has motivated some analysts, e.g., Calzadilla et al. (2007) and Louw and Kassier (2002), to embrace water demand management as a means of solving the current water crisis. Since the water price is one of the most effective tools to regulate water supply and demand, the Chinese government has continually attached great importance to water pricing (Jiang et al. 2014). However, problems associated with water pricing mechanisms in China still exist, including underpricing and nonstandard pricing in some regions. In addition, water endowments in some areas cannot adapt to economic development (Shen et al. 1999). Since water pricing in China is determined in some regions by top-down administrative commands rather than by a market, many water companies cannot recover their supply costs. The current pricing system is therefore unable to accurately account for the commodity attributes of water, so significant water pricing reform in China is necessary (Yu and Shen 2014).

Recognition of people's response to changes in the water price provides important information for those who are responsible for water policy formulation and water resource planning. However, assessment of the impact of revisions to China's water price policy has stagnated at the stage of qualitative description and rough estimation. Some research systematically investigated water price issues worldwide, but most work involved qualitative analyses (e.g., Eileen et al. 2013; Zuo et al. 2014). In contrast, Espey et al. (1997), Nauges and Thomas (2003) and Grafton et al. (2011) presented quantitative analyses using econometric methods. In general, Computable General Equilibrium (CGE) models have emerged as widely-applied and effective analytical tools in water pricing policy analysis. Since Berck's (1991) first application of a CGE model to water problems, CGE models for water have been continually refined and improved. For example, Chou et al. (2001) used a single-country water resources CGE model—WATERGEM—which included municipal water, surface water and ground water to investigate the double dividend effects of imposing water rights fees. Simulation results demonstrated that a double-dividend effect existed, and that its deduction from corporate taxes had an evident effect. The simulation results also showed that water demand decreased when water rights fees were imposed. Berrittella et al. (2007) developed a GTAP-W model to investigate the role of water resources and water scarcity resulting from reduced availability of groundwater, and identified regional winners and losers. Moreover, the water supply constraints were found to improve allocation and efficiency. Calzadilla et al. (2007) also used the

GTAP-W model to analyze the macroeconomic impacts of enhanced irrigation efficiency. The results indicated that global water conservation was achieved. For water-stressed regions, the effects on welfare and demand for water were generally positive, while for non-water scarce regions the results were mixed and mostly negative. Hassan et al. employed the TACOGE-W model which disaggregated agricultural and nonagricultural water use and contained detailed information on production, trade and consumption to examine the impacts of water-related policy reforms on water use and allocation, rural livelihoods, and the macro economy. The simulation results showed that allowing for water trade between irrigation and non-agricultural users lead to higher water shadow prices for irrigation water, with reduced income and employment benefits to rural households and increased gains for non-agricultural households. Wittwer et al. (2012) used the TERM-H2O model, a special version of the TERM model (The Enormous Regional Model), to analyze water policy issues in the Murray-Darling Basin in Australia. This model recognized 50 regions and 170 sectors. The results did not support the pessimistic view that buybacks worsened the plight of farmers. Conversely, buybacks were shown to increase economic activity, and were of benefit to farmers.

Existing research on the impact of water price reform on water usage and economic growth appears to pay little attention to: (1) Substitution between various types of water sources; (2) differentiated pricing of different types of water sources; and (3) the total water constraint. To fill this gap in this area we extended a dynamic CGE model—SICGE (State Information Centre General Equilibrium) model by introducing a total water constraint module and a water subdivision module with a substitution relationship between different water sources. To investigate the impact of water price reform on water usage among different users, in the water subdivision module, we divide water users into six categories based on the volume of water usage and sector classification. To further investigate the substitution relation between different water sources, water sources are divided into four categories. In this study, our baseline simulation spans a period of 14 years (2007–2020). We implement a water price policy change in 2011, with the resulting policy simulation analysis encompassing the period from 2011 to 2020. Crucial factors for designing pricing policies for water demand management include water conservation, water structure, water use efficiency and economic impact.

The paper is structured as follows. In Sect. 12.1, we provide some contextual background to the study by reviewing the pertinent literature. Section 12.2 outlines the modelling framework and data sources, while Sect. 12.3 describes the baseline scenario. We then discuss policy scenarios and the simulation results in Sect. 12.4, and present a summary of key findings and a discussion of future considerations and extensions in Sect. 12.5.

12.2 Modelling Framework

This study uses the SICGE model, a recursive dynamic CGE model of the Chinese economy. The SICGE model is based on China's 2007 Input–output table and has 42 sectors. As a classical CGE model applied to China, it was created for China's State Information Centre (SIC) by the Centre of Policy Studies (CoPS) in Australia (Li and Zhang 2012; Mai et al. 2014). The SICGE model is the earliest version of CHINAGEM model. The core CGE structure is based on ORANI, a static CGE model of the Australian economy (Dixon et al. 1982, 2005; Horridge et al. 2005; Dixon and Jorgenson 2013). The dynamic mechanism of SICGE is based on the MONASH model of the Australian economy (Dixon and Rimmer 2002; Panida et al. 2013; Khalid and Harald 2014).

12.2.1 SICGE Model

The SICGE model is a set of equations that describe supply–demand balance relations throughout the economic system. They are constrained by a series of optimizing conditions: optimization of producer profit, consumer benefit, import profit as well as export cost. The solution of the equation system yields a set of quantities and relative prices that correspond to an economy-wide general equilibrium. The model includes six economic agents: a single producer, investor, household, government, and foreign country agent (or rest of the world agent), along with an inventory agent/account. Each sector minimizes unit costs subject to given input prices and a constant-returns-to-scale (CRS) production function. Consumer demands are modelled via a representative utility maximizing household. Consumers get paid and use their income to consume goods and services. Subject to budget constraints, consumers achieve the highest possible benefit or utility by choosing the best combination of goods and services. Government revenues come from taxes and fees, while government spending includes various public undertakings, transfer payments and policy-oriented subsidies. The model assumes that the path of total government demand follows the path of household total consumption. The model also adopts flexible linkage mechanisms. A Constant Elasticity of Transformation (CET) Equation is usually adopted to describe the process of optimized allocation of output between domestic commodities, and between the domestic market and exports for ultimately optimizing profits. Imperfect substitutability between imported and domestic varieties of each commodity is modelled using the Armington constant-elasticity-of-substitution (CES) specification (Walras 1969; Johansen 1960; Dixon et al. 1982, 2005; Dixon and Rimmer 2002; Horridge et al. 2005).

There are three primary factors: land, labour and capital. Capital and labour are perfectly mobile domestically, and capital is also mobile internationally, i.e., between China and the rest of the world. In contrast, land is sector-specific. The value of the elasticity of substitution between factors is based on the findings of Burniaux and Truong (2002).

12.2.2 *The Extension of the SICGE Model*

The existing SICGE model has only one water sector. It does not consider different types of water sources with substitution relations. To achieve the objectives of this study, the China Institute of Water Resources and Hydropower Research (IWHR) and the State Information Center (SIC) have cooperated to develop a water pricing analysis model, which is based on the SICGE model and entitled the WPSICGE (Water pricing SICGE) model. This extended model combines the water subdivision module with the substitution relationship between different types of water sources and the total water constraint module. In WPSICGE, the water sector is subdivided into four sub-sectors; each sub-sector produces one of the four types of water commodities: raw water, tap water, recycled water and desalinated water. In this paper, raw water refers to water that is obtained directly from the surface or underground without disinfection treatment. Tap water refers to water that is produced by water works and needs to be purified and disinfected by successive procedures. Tap water is derived from raw water and must conform to relevant standards for human consumption and production. Recycled water refers to waste water and rain, which after appropriate treatment meets quality standards of recycled water. Desalinated water refers to fresh water generated from sea water. Recycled water and desalinated water are unconventional water sources. Conventional water supply (the total amount of raw water in this model) constitutes an important constraint variable.

Using the WPSICGE model, this study will contribute to several important topics including: (1) control of water consumption under the "red line"[1] by water pricing reform; (2) quantitative evaluation of water conservation and the economic impact of water pricing reform; and (3) recommendation of a more cost efficient water pricing system by comparing multiple scenarios, and indicating a water price reform direction.

(1) Water substitution modules

In order to reflect substitution relationships between different types of water sources, we set a hierarchical structure (from bottom-to-top) shown in Fig. 12.1 using a Constant Elasticity of Substitution (CES) production function to model the producer's decision regarding alternative water compositions in production.

We apply the CES function to reflect the substitution relationship between various types of water. Firstly, we consider raw water, which is composed of local water and

[1] "Red line" refers to the annual total raw water consumption control target set by the central government of China. It was first announced in the No. 1 Document in 2011 (Chinese State Council 2011, 2012). "Red line" was considered the most stringent water resources management system in China. The annual total raw water consumption in Tianjin must not exceed the "red line" which is 3100 million m^3.

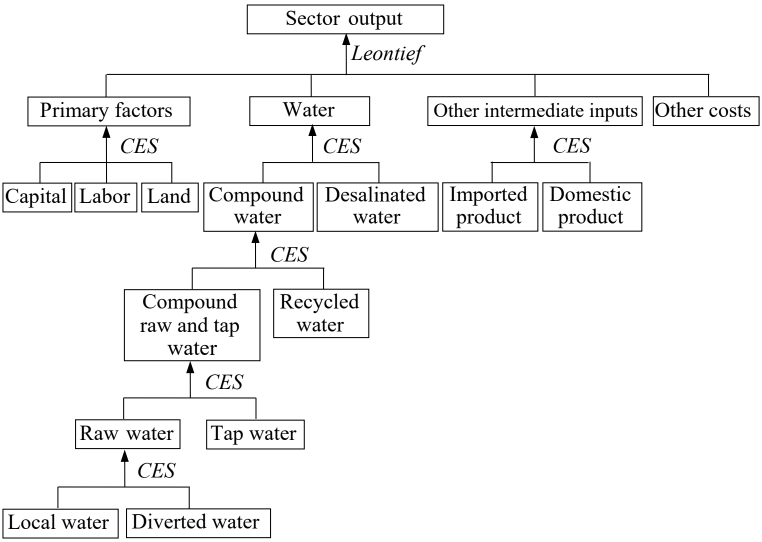

Fig. 12.1 The sectoral production structure in the water subdivision module

diverted water transferred from other regions, and can be represented in CES equation form as follows:

$$X^{(1)}_{raw,j} = CES\left\{\frac{X^{(1)}_{(raw,s),j}}{A^{(1)}_{(raw,s),j}};\ \rho^{(1)}_{raw,j},\ b^{(1)}_{(raw,s),j}\right\}(s = 1, 2; j = 1, \ldots, n) \tag{12.1}$$

Equation (12.1) shows that intermediate input raw water $X^{(1)}_{raw,j}$ used in sector j is the CES composite of local and diverted water, where $X^{(1)}_{(raw,s),j}$ represents the different sources of raw water used in sector j, and s represents the source (s = 1 is local products; s = 2 is diverted products). $A^{(1)}_{(raw,s),j}$ represents technological parameters, $b^{(1)}_{(raw,s),j}$ are the shares different raw water sources in sector j, and $\rho^{(1)}_{raw,j}$ is the constant elasticity of substitution between local water and diverted water.

We next examine the demand for the compound raw and tap water in sector j, $X^{(1)}_{raw\_tap,j}$ which is represented by the following CES equation:

$$X^{(1)}_{raw\_tap,j} = CES\left\{\frac{X^{(1)}_{(raw\_tap,s),j}}{A^{(1)}_{(raw\_tap,s),j}};\ \rho^{(1)}_{raw\_tap,j},\ b^{(1)}_{(raw\_tap,s),j}\right\}(s = 1, 2; j = 1, \ldots, n) \tag{12.2}$$

where $X^{(1)}_{(raw\_tap,s),j}$ is sector j's demand for compound water from sources of water (s = 1) and tap water (s = 2); $A^{(1)}_{(raw\_tap,s),j}$ are technological parameters of water sources (raw water and tap water); $b^{(1)}_{(raw\_tap,s),j}$ are the shares of raw water and tap water; and constant elasticity of substitution between raw and tap water. When compared with other sources, these two sours a strong substitutes, with an elasticity of substitution approximately 1 according to Tianjin Municipal Water Affairs Bureau.[2]

With the rapid development of recycled water, raw and tap water may be replaced by recycled water. The demand for composite water consisting of the compound raw-tap water from Eq. (12.2) and recycled water can be represented in CES equation form as follows.

$$X^{(1)}_{comp,j} = CES\left\{\frac{X^{(1)}_{(comp,s),j}}{A^{(1)}_{(comp,s),j}};\ \rho^{(1)}_{comp,j},\ b^{(1)}_{(comp,s),j}\right\}\quad (s = 1, 2; j = 1, \ldots, n) \tag{12.3}$$

where $X^{(1)}_{(comp,s),j}$ is the demand for compound raw-tap water ($s = 1$) and recycled water ($s = 2$) in sector j; $A^{(1)}_{(comp,s),j}$ represent technological parameters; $b^{(1)}_{(comp,s),j}$ are the shares of the compound raw-tap water and recycled water (respectively); and $\rho^{(1)}_{comp,j}$ is the constant elasticity of substitution between the compound raw-tap water and recycled water. The value of the elasticity of substitution $\rho^{(1)}_{comp,j}$ is approximately 0.5 according to Tianjin Municipal Water Affairs Bureau.

Desalinated water is generally regarded as being weakly substitutable with the aforementioned three water sources. The CES equation for water demand (the second highest level in Fig. 12.1) in sector j is as follows.

$$X^{(1)}_{water,j} = CES\left\{\frac{X^{(1)}_{(water,s),j}}{A^{(1)}_{(water,s),j}};\ \rho^{(1)}_{water,j},\ b^{(1)}_{(water,s),j}\right\}\quad (s = 1, 2; j = 1, \ldots, n) \tag{12.4}$$

where $X^{(1)}_{(water,s),j}$ is sector j's aggregate demand for the aforementioned three types of water ($s = 1$), and the demand for desalinated water ($s = 2$); $A^{(1)}_{(water,s),j}$ represent technological parameters of compound water and desalinated water; $b^{(1)}_{(water,s),j}$ are the shares of compound water and desalination water; and $\rho^{(1)}_{water,j}$ is the constant elasticity of substitution between the compound water and desalination water. This elasticity of substitution is approximately 0.2 according to Tianjin Municipal Water Affairs Bureau.

(2) Later constraints module

To meet the “red line” control target of total water utilization which is the most stringent water resources management in China, the total water constraints module is added to the SICGE model.

Water is used as both an intermediate input to production, and a final consumption good. The value of water use is calculated in the model by:

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[2] http://www.tjsw.gov.cn/pub/tjwcb/index.html.

$$V_w = X_w \times P_w \quad (12.5)$$

where V_w is water value, X_w is volume of water and P_w is the water price. In order to more conveniently simulate the impact of water price reform in the SICGE model, we need to transform the specific water tax, WTAX, which is levied on the volume of water, into an ad valorem tax, TAWP, which is based on the value of water.

$$WTAX^{(1)}_{s,j} \times QHY^{(1)}_{s,j} = TAWP^{(1)}_{s,j} \times \left(P^{(1)}_{HY,s,j} \times X^{(1)}_{HY,s,j}\right) \quad (12.6)$$

$$WTAX^{(3)}_{s} \times QHY^{(3)}_{s} = TAWP^{(3)}_{s} \times \left(P^{(3)}_{HY,s} \times X^{(3)}_{HY,s}\right) \quad (s = 1, 2, 3, 4) \quad (12.7)$$

In Eq. (12.6), $QHY^{(1)}_{s,j}$ represents the volume of water by source- s that is used as an intermediate input in production by sector j, where s. is used to distinguish between the various sources of water, e.g., $s = 1, 2, 3$ and 4 represent raw, tap, recycled and desalinated water, respectively; the superscript (1) indicates that this relationship is applied to producers; $WTAX^{(1)}_{s,j}$ indicates the tax levied per cubic meter of water by source and sector; $TAWP^{(1)}_{s,j}$ indicates the ad valorem tax levied by source and sector; $P^{(1)}_{HY,s,j}$ indicates the price of water from source- s used by sector j; and $X^{(1)}_{HY,s,j}$ indicates the amount of water used from source- s in sector j.

In Eq. (12.7), $QHY^{(3)}_{s}$ represents the volume of water from various sources consumed by households, with the superscript (3) indicating that this relationship applies to household consumption; $WTAX^{(3)}_{s}$ indicates the tax levied per cubic meter of water consumed by households; $TAWP^{(3)}_{s}$ indicates the ad valorem tax levied on source s by households; $P^{(3)}_{HY,s}$ indicates the price of water from different sources consumed by households; and $X^{(3)}_{HY,s}$ indicates the amount of water from different sources consumed by households.

In China, water control is applied only to raw water (tap water originates from raw water). Recycled and desalinated water are non-conventional water sources. The Chinese government encourages the use of these types of water by providing subsidies to water plants. The supply of recycled and desalinated water is limited only by production capacity, not by the total amount of water resources. The total amount of raw water consumed can be calculated as:

$$QHY = \sum_{raw,j} QHY^{(1)}_{raw,j} + QHY^{(3)}_{raw} \quad (j = 1, \ldots, n) \quad (12.8)$$

where QHY indicates the total amount of water consumption. It cannot exceed the “red line” control target of total water utilization.

12.2.3 Case Study Area

Tianjin was selected as the case study area. It is one of China's typical coastal municipalities with a comprehensive industrial base and trade center. Per capita GDP of Tianjin ranks third in China, trailing only Shanghai and Beijing. Due to pollution and climate change, Tianjin suffers from a severe water shortage, with its per capita water resources amounting to 160 m^3, only 6% of the national average. Even adding inflow and diverted water, its per capita water resources stand at only 370 m^3, the lowest level of any municipality in China. Rapid economic development, pollution and climate change have exacerbated Tianjin's water scarcity. Continuing growth in water demand is expected to impart severe constraints on the availability of water resources in Tianjin. This has driven several water conservation initiatives, and the expansion of unconventional water resource industries. As discussed, four distinct sources of water now exist in this region: raw, tap, recycled, and desalinated water. Nevertheless, water is still the binding constraint on economic growth in Tianjin.

The current level of water pricing in Tianjin is still relatively low. Price discrepancies between water users of the same type of water source and the relative prices of water from different types of water sources are too narrow. As a result, the current level of water pricing could not restrain the use of water in water-intensive sector and promote the usage of unconventional water.

12.3 Baseline Scenario

To analyze the economic effects of a policy change, we first develop a baseline scenario that represents business-as-usual without implementation of any water pricing policy reforms. Subsequent to this, we construct various policy scenarios to explore the impact of different policy settings on key measures of welfare. Specifically, the effects of these alternative policies are measured by the deviations of variables from their baseline levels.

12.3.1 Data Sources and Processing

For the baseline scenario, macroeconomic data is divided into two periods: an initial "historical" period from 2007 to 2010 and a second "planned" period from 2011 to 2020. For the first period, we provide realized values for key economic variables, e.g., real GDP growth, real consumption growth, real investment growth, employment, etc., as exogenous shocks to the model. Among these shocks are realized water usage figures for the various water users, and relative prices for the four types of water sources. To develop a suitable baseline forecast over the second period of the baseline simulation, exogenous shocks were developed using economic data from

Table 12.1 Economic growth in the baseline scenario in Tianjin at the basedate year price, 2007

Categories	2008 (%)	2009 (%)	2010 (%)	2011–2015 (%)	2016–2020 (%)
GDP	16	16	16	14	11
Employment	6	5	6	6	4
Household consumption	17	10	11	14	12
Government consumption	30	44	26	17	12
Capital	19	21	26	26	17

Source Authors' calculations based on the statistics yearbook and the "five-year" plan

the Tianjin "twelfth five-year plan and 2020 vision". In the twelfth five-year plan period, growth of GDP in Tianjin is expected to remain at 14.5% for five years, being driven primarily by investment. During this time, consumer spending is also expected to increase rapidly. The predictions for economic growth are displayed in Table 12.1.

Data used in the baseline scenario come from several sources. As with all CGE models, an initial solution is required. In the SICGE model, we use China's 2007 input–output table. The exogenous shocks for the historical period 2008–2011 are sourced from the China and Tianjin statistical yearbooks. Using the RAS (also called "biproportional scaling" method) method (Bacharach 1970) based on the initial 42 sectors in the input–output table, we obtain a 44-sector input–output table.[3] The classification of 42 sectors is based on the classification standards of Classification and Code National Economy Industry (GBT4754-2002) issued by the National Bureau of Statistics. The data for disaggregating water sectors into raw, tap, recycled and desalinated water are from the Tianjin Statistical Information Net[4] and Tianjin Municipal Water Affairs Bureau. In order to facilitate analysis of the impact of water pricing adjustments, the simulation results of 44 sectors are merged into 6 sectors according to water pricing classification, water use characteristics and industrial characteristics. These 6 sectors are listed in Table 12.2.

12.3.2 Parameters

(1) Water price

From 2007 to 2010, the prices of raw water used by the agriculture sector and desalinated water for all users did not change (Table 12.3). The price of raw water for all other users in 2008 was the same as in 2007. The price in 2009 increased by 0.02 RMB/m^3 compared with the preceding year. In 2010, the price increased by a

[3] Since values in the metal mining and dressing sector were all 0 we ignored this sector.

[4] http://www.stats-tj.gov.cn/.

Table 12.2 44 sectors merging into 6 sectors

6 sectors	42 sectors base on the National Economy Industry Classification
Agriculture	Agriculture, forestry, husbandry, subsidiary, fishery
General industry	Coal mining and washing sector; oil and gas sector; textile sector; textile clothing, shoes, hats; leather, down and their products; timber processing and furniture manufacturing; metal smelting and rolling processing sector; fabricated metal products; general and special equipment manufacturing; transportation equipment manufacturing; electric machinery and equipment manufacturing; telecommunications equipment; computers and other electronic equipment manufacturing; instrumentation and office machinery manufacturing; handicrafts and other manufacturing sector; gas production and supply sector; water production and supply sector
Water-intensive industry	Other non-metallic mineral ore mining; food production and tobacco processing; paper making or printing, stationery and sporting goods manufacturing sector; oil processing, coking and nuclear fuel processing sector; chemical sector; non-metallic mineral products; electric power; heat production and supply
Construction	Construction sector
General service	Accommodation and catering; household services and other services

further 0.03 RMB/m^3. For tap water, the price for all users in 2008 was the same as in 2007. In 2009, the price increased by 0.05 RMB/m^3. In 2010, the price increased by a further 0.5 RMB/m^3 to reach 7.2 RMB/m^3 for industry, construction and general service, 21.1 RMB/m^3 for water-intensive service, and 4.4 RMB/ m^3 for households. For recycled water, the price for all users in 2008 was the same as in 2007. In 2009 the price used in general industry and water-intensive industry increased by 1.9 RMB/ m^3 (Table 12.3). In the general service sector it increased by 1.5 RMB/m^3, while in the water-intensive service sector it increased by 2.2 RMB/m^3. The price for all users in 2010 was the same as in 2009.

In the forecast period of 2011–2020, we assume that water prices of all different types remain the same as in 2010.

(2) Water usage

Water usage for the first period is based on actual economic growth. Results are shown in Tables 12.4 and 12.5. The total amount of water usage was 2.33 billion m^3 in 2007. Due to the increase in water prices in the initial time period, which was discussed in the previous section, water usage declined. In 2010, total water usage was 2.13 billion m^3.

From Table 12.4, we can see that the agriculture sector only uses raw water. The industry sector uses water from all sources, while the service sector mainly use raw water, tap water and recycled water. The construction sector and households use only raw water and tap water. Table 12.5 shows that the share of the agricultural sector in total water usage was 60.24% in 2007, followed by water-intensive industry (14.48%) and households (13.54%). The water usage shares of the agriculture and

Table 12.3 Water pricing of Tianjin from 2007 to 2010 at the baseline year price (2007) (unit: RMB/m^3)

Years	Water source	Agriculture	General industry	Water-intensive industry	Construction	General service	Water-intensive service	Households
2007	Raw water	0.2	1.03	1.03	1.03	1.03	1.03	1.03
	Tap water	–	6.2	6.2	6.2	6.2	20.1	3.4
	Recycled water	–	1.2	1.2	–	1.5	1.8	–
	Desalinated water	–	4	4	–	–	–	–
2008	Raw water	0.2	1.03	1.03	1.03	1.03	1.03	1.03
	Tap water	–	6.2	6.2	6.2	6.2	20.1	3.4
	Recycled water	–	1.2	1.2	–	1.5	1.8	–
	Desalinated water	–	4	4	–	–	–	–
2009	Raw water	0.2	1.05	1.05	1.05	1.05	1.05	1.05
	Tap water	–	6.7	6.7	6.7	6.7	20.6	3.9
	Recycled water	–	3.1	3.1	–	3.1	4	–
	Desalinated water	–	4	4	–	–	–	–
2010	Raw water	0.2	1.08	1.08	1.08	1.08	1.08	1.08
	Tap water	–	7.2	7.2	7.2	7.2	21.1	4.4
	Recycled water	–	3.1	3.1	–	3.1	4	–
	Desalinated water	–	4	4	–	–	–	–

Source Tianjin Water Authority, Tianjin Water Resources communiqué

Table 12.4 The water usage in the baseline scenario in Tianjin (unit: million m^3)

User	Resources	2007	2010	2015	2020
Agriculture	Raw water	140,600.00	111,969.00	131,247.78	144,514.05
	Tap water	–	–	–	–
	Recycled water	–	–	–	–
	Desalinated water	–	–	–	–
General industry	Raw water	1310.00	1984.00	3268.61	5240.15
	Tap water	6746.00	12,716.00	20,921.03	33,646.01
	Recycled water	0	1.10	3.42	6.31
	Desalinated water	180.00	270.00	646.11	1324.04
Water-intensive industry	Raw water	18,563.00	19,909.00	26,355.56	33,764.48
	Tap water	14,111.00	12,547.00	14,477.23	16,412.68
	Recycled water	1070.00	801.00	1341.36	2103.44
	Desalinated water	20.00	30.00	52.79	85.53
Construction	Raw water	399.00	399.00	583.00	856.42
	Tap water	1501.00	2061.00	3019.32	4451.81
	Recycled water	–	–	–	–
	Desalinated water	–	–	–	–
General service	Raw water	1291.00	1639.00	3213.28	5737.67
	Tap water	7368.00	8753.00	18,199.02	34,697.49
	Recycled water	282.00	436.00	828.54	1353.85
	Desalinated water	–	–	–	–
Water-intensive service	Raw water	1810.00	1027.00	1387.43	1902.64
	Tap water	6567.00	3225.00	4585.98	6308.11
	Recycled water	0	0.29	0.41	0.58
	Desalinated water	–	–	–	–
Households	Raw water	14,500.00	12,300.00	12,853.05	13,285.96
	Tap water	17,100.00	22,600.00	29,320.85	37,601.42
	Recycled water	–	–	–	–
	Desalinated water	–	–	–	–
Total	Raw water	178,473.00	149,227.00	178,908.71	205,301.37
	Tap water	53,393.00	61,902.00	90,523.43	133,117.52
	Recycled water	1352.00	1238.39	2173.73	3464.18
	Desalinated water	200.00	300.00	698.90	1409.57
Total		233,418.00	212,667.39	272,304.77	343,292.64

Source Tianjin Water Authority, Tianjin Water Resources communiqué and development plan

Table 12.5 The shares of water usage by users in the baseline scenario in Tianjin

Water usage	2007 (%)	2008 (%)	2009 (%)	2010 (%)	2015 (%)	2020 (%)
Agriculture	60.24	62.87	58.71	52.66	48.20	42.07
General industry	3.51	4.90	5.39	7.05	9.10	11.73
Water-intensive Industry	14.48	11.14	14.17	15.66	15.52	15.25
Construction	0.81	0.86	1.13	1.18	1.32	1.54
General service	3.81	3.09	3.67	5.08	8.18	12.19
Water-intensive service	3.60	2.43	2.04	2.02	2.20	2.39%
Households	13.54	14.71	14.89	16.41	15.48	14.81%

Source Authors' calculations based on Tianjin Water Authority, Tianjin Water Resources communiqué and development plan

water-intensive service sectors have declined from 2007 to 2010, while the shares of the construction and general industry sectors have increased steadily (Table 12.5).

Table 12.6 shows the structure of water use by water source. The share of raw water in total water usage was 76.50% in 2007, followed by tap water (22.90%). The share of raw water decreased from 2007 to 2010 while the share of tap water increased.

The assumptions about water usage for the second period (2011–2020) are based on economic growth trends and the Twelfth Five-year Plan of Water Conservancy Development (Tianjin Water Authority). Results are shown in Tables 12.4 and 12.5. In the 12th five-year period, the annual growth rate of total water usage in Tianjin is forecast to be 5.1%. This rate is forecast to fall to 4.7% in the 13th five-year period (Table 12.7).

The growth in general service sector consumption is forecast to be the most rapid, followed by general industry and the construction sector. The agriculture sector will experience the slowest growth, due to forecast efficiency gains via advances in water-saving irrigation technology, e.g., trickle irrigation. As a result, the share of agriculture water usage will decrease. The shares of the general industry and the general service sectors show a faster rate of growth than the water-intensive industry and water-intensive service sectors (Table 12.5). Because of the assumption

Table 12.6 The shares of water usage from different sources in the baseline scenario in Tianjin

Usage structure	2007 (%)	2008 (%)	2009 (%)	2010 (%)	2015 (%)	2020 (%)
Raw water	76.50	73.50	73.40	69.80	65.70	59.80
Tap water	22.90	26.00	25.90	29.50	33.20	38.80
Recycled water	0.60	0.40	0.50	0.60	0.80	1.00
Desalinated water	0.10	0.10	0.10	0.10	0.30	0.40

Source Authors' calculations based on Tianjin Water Authority, Tianjin Water Resources communiqué and development plan

Table 12.7 The growth rate of water in the baseline scenario in Tianjin

Water usage	2008 (%)	2009 (%)	2010 (%)	Average annual growth rate 2011–2015 (%)	Average annual growth rate 2015–2020 (%)
Agriculture	−6.05	−1.82	−13.65	3.2	1.9
General industry	25.61	15.53	26.05	10.7	10.2
Water-intensive Industry	−30.77	33.76	6.39	4.9	4.4
Construction	−5.26	38.89	0.00	8.0	7.9
General service	−26.97	24.62	33.33	15.5	13.5
Water-intensive service	−39.29	−11.76	−4.44	7.1	6.6
Households	−2.22	6.47	6.08	3.9	3.8
Total	−9.98	5.14	−3.71	5.1	4.7

Source Authors' calculations based on Tianjin Water Authority, Tianjin Water Resources communiqué and development plan

of unchanged water prices from 2011 to 2020, water usage will continue to rise and the total amount of water usage will reach to 3.43 billion m^3 in 2020.

From Table 12.6, we can see that the share of raw water in total water usage will continue to decline to 59.80% in 2020, while the share of tap water will continue to rise, reaching 38.80% in 2020. The total usage of recycled water and desalinated water will increase from 2011 to 2020, to 1.0% and 0.4%, respectively.

(3) Other parameters

The labour demand elasticity for all sectors was 0.243 according to the Chinese Academy of Social Sciences (Zheng and Fan 2008). The consumer price elasticity was set at 4 according to the PRCGEM model data of the Chinese Academy of Social Sciences (Zheng and Fan 2008). Per capita income of Tianjin has reached the level of upper middle-income countries, so the Frisch parameter[5] in the Linear Expenditure System (LES) should be −2 (Dervis et al. 1982). The Armington elasticity is the elasticity of substitution between imports and native commodities. For the present study, its value of 2 was obtained from the Tianjin Statistical Information Net. The elasticity of substitution between primary factors in the CES production function is 0.5, derived from the Tianjin Statistical Information Net.

Values for the CET elasticity (substitution elasticity of domestic commodity exports and sale in domestic market), elasticity of households demand expenditure, etc. were obtained from the China Version of the ORANI-G model of CoPS at Victoria University (Horridge 2006).

[5] Frisch parameter $= -(\mathrm{x_{total}}/\mathrm{x_{luxuty}})$ in CGE model, where $\mathrm{x_{total}}$ indicates total household expenditure, x_{luxuty} indicates luxuty expenditure in total household expenditure.

12.3.3 Baseline Forecast Results

The baseline simulation results show that if the water price were to remain at the 2010 level, total water consumption would reach 3.433 billion m^3 in Tianjin by 2020 (Table 12.4). This projection is consistent with the estimate of 3.434 billion m^3 from water supply planning by the Tianjin Water Bureau. Meanwhile, consumption projections of raw, tap, recycled, and desalinated water are also similar to those of the Tianjin Water Bureau. The baseline scenario developed in this paper is therefore consistent with the forecasts generated by the Tianjin Water Bureau.

12.4 Policy Simulation Results and Discussions

Our policy scenarios focus upon exogenous shocks to the water price. The impact of the water price changes are subsequently measured via deviations of endogenous variables from their baseline levels. We use two main indicators to judge whether a water price system is rational: (1) Whether the amount of water usage is within the bearing capacity of water resources; and (2) Whether the water structure (the share of water used by sources and users) is optimized.

Since the sensitivity or responsiveness of different users to changes in the price of water is different, the effect of water price reform will differ across users and sources. In order to design an optimal water price policy, we first calculate the price elasticity of water demand.

12.4.1 Price Elasticity of Water Demand

Price elasticity of water demand is a measure used in economics to show the ceteris paribus responsiveness, or elasticity, of the quantity of water demanded to a change in the water price. More precisely, it gives the percentage change in quantity demanded in response to a one percent change in price.

Based on different water users, we set forty-nine policy scenarios. In these scenarios the water prices of different users using all water sources are increased by 40%, 50%, 60%, 70%, 80%, 90% and 100%, respectively, compared with baseline. The price elasticity of water demand is then calculated by running these policy simulations. The price elasticity of water demand by different users in Tianjin in 2020 is shown in Fig. 12.2. The price elasticity of household water demand is less than that of non-households. Among non-household water users, the water-intensive industry sector has the highest price elasticity of water demand, followed by the water-intensive service sector, the general industry sector, the general service sector and the construction sector. Since an increase in the price of water promotes water saving, price reform for water-intensive industry should be given top priority in order

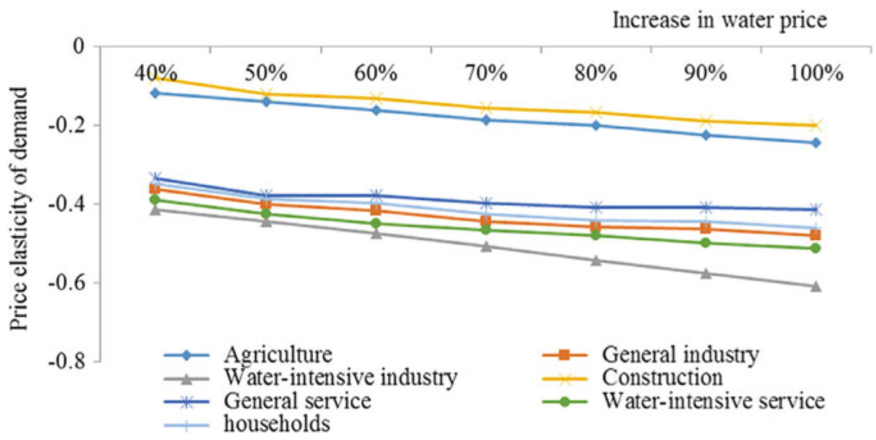

Fig. 12.2 The price elasticity of water demand of different users in 2020

to conserve more water, followed by the water-intensive service, general industry and general service sectors.

Based on different water sources, we set another twenty-eight policy scenarios. In each policy scenario, the water prices of different water types used by all users are increased by 40%, 50%, 60%, 70%, 80%, 90% and 100% relative to the baseline. The price elasticities of water demand by different water types are shown in Fig. 12.3. The price elasticities for recycled and desalinated water are quite low, around −0.1, which is highly inelastic. The government or administration encouraged consumers to use unconventional water such as recycled water or desalinated water to replace conventional water by applying a price advantage to unconventional water, which was supported by financial subsidies from government. Since the price elasticity of tap water is higher than raw water, the saving rate of tap water will be higher than that for raw water for a given price change. This means that price reform of tap water should be given top priority, followed by raw water.

The price elasticity of water demand is not uniform across price levels, but increases as prices rise. This implies that water pricing can directly promote water-saving. However, results show that even if the existing water price is doubled, the price elasticities of water demand of various users and water types still remain above −1, which means they are inelastic.

12.4.2 Optimal Scenarios

Based on the forty-nine policy scenarios of different users and twenty-eight policy scenarios of different water types, we obtain the price elasticities of water demand for different users and sources as discussed in the last section. From these elasticities, we conclude that increasing the price of tap water, especially in the water-intensive

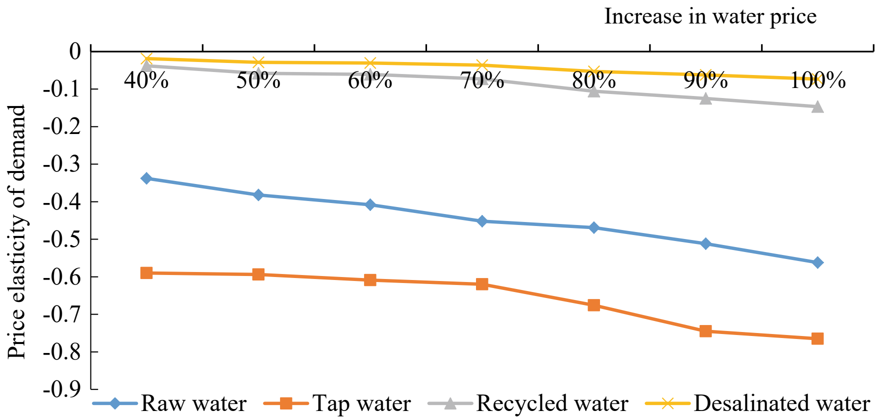

Fig. 12.3 The price elasticity of water demand of different sources in 2020

industry and water-intensive service sectors, should be given top priority when the government reforms the water price. We designed a series of scenarios from which we identified two optimal scenarios which conformed to the following goals: (1) constraints on water volume; (2) promote use of unconventional water, and optimize water structure. Scenario 1 assumes that the prices of recycled and desalinated water stay unchanged, and that by 2020, the raw water price for agricultural use will increase by 40%; prices for other industries will increase by 100%; tap water prices for households, general industry, construction and general service will also increase by 100%; tap water prices for water-intensive industry and service will increase by 200%. In scenario 2 we assume that the recycled water and desalinated water prices stay unchanged, and by 2020, the raw water price for all industries will increase by 100%; tap water prices for households, general industry, construction and general service will increase by 200%; tap water price for water-intensive industry and service will increase by 400% (Table 12.8).

12.4.3 Policy Results and Discussion

(1) Water conservation and utilization structure

The introduction of market-oriented pricing will reduce water wastage and the inefficient use of water. Both scenarios will produce tangible water saving results. The aggregated water saving rate will be 12.20% in scenario 1, or 420 million m^3. In scenario 2, the water saving rate is 16.30%, with 560 million m^3 of water conserved. In general, three factors initiated by water price adjustments contribute to overall water saving: first, the amount of water used decreases due to rising costs; second, all sectors adopt water-saving measures, therefore water use efficiency improves;

Table 12.8 Scenarios of water pricing reform (unit: RMB/m^3)

Scenario	Sources	Users						
		Agriculture	General industry	Water-intensive industry	Construction	General service	Water-intensive service	House-holds
Scenario 1	Raw water	0.28	2.16	2.16	2.16	2.16	2.16	2.16
	Tap water	–	15.00	30.00	15.00	15.00	87.60	8.80
	Recycled water	–	3.10	3.10	–	3.10	4.00	–
	Desalinated water	–	4.00	4.00	–	–	–	–
Scenario 2	Raw water	0.40	2.16	2.16	2.16	2.16	2.16	2.16
	Tap water	–	22.50	37.50	22.50	22.50	109.50	13.20
	Recycled water	–	3.10	3.10	–	3.10	4.00	–
	Desalinated water	–	4.00	4.00	–	–	–	–

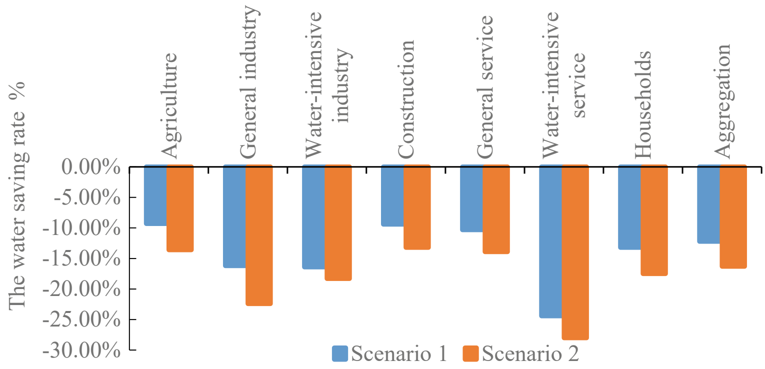

Fig. 12.4 The deviation of water usage by different users from the baseline scenario in 2020

third, the increase in the cost of water leads to industrial adjustment towards less intensive water use.

The adjustments on the demand side will differ across sectors. The water price for water-intensive services increases most, bringing the greatest proportionate decrease in water usage of circa 24% relative to baseline in scenario 1 (Fig. 12.4). The water usage by general industry in scenario 1 will be 16% lower than in the baseline scenario, since the tap water sector belongs to general industry. Water use by the general service industry and construction sector also declines (Fig. 12.4). The cost of water for households shows a continued increase, which enhances the motivation for water saving. In scenario 1, water used by households falls by 13% relative to the baseline scenario (Fig. 12.4).

Figure 12.5 shows that in scenario 1 the increase in the price of raw water reduces the demand for raw water by 9.60% by 2020 relative to the baseline scenario. There are two main reasons for this reduction. First, the increase in the price of water will reduce its demand. Second, because all tap water comes from raw water, the decline in tap water usage will lead to a decrease in raw water demand. In Scenario 1, the prices of recycled and desalinated water are assumed to remain unchanged. Their relative prices fall compared to raw and tap water, which drives a substitution towards these two types of water. The demand for recycled and desalinated water increases by 10.43% and 12.65%, respectively by 2020, relative to the baseline scenario. The shares of recycled and desalinated water in total water utilization increase by 0.6% and 0.3%, respectively, from the baseline in Scenario 1. The share of raw water is 1.7% higher than baseline while the share of tap water is 2.3% lower than baseline. This suggests that water price reform directed at the level and structure of relative water prices promotes the use of unconventional water and the conservation of conventional water. As a result, the water utilization structure is improved.

(2) Efficiency of water utilization

Water price reform has significant effects on efficiency of water utilization. As water prices increase, both water usage and sectoral output decrease because of the

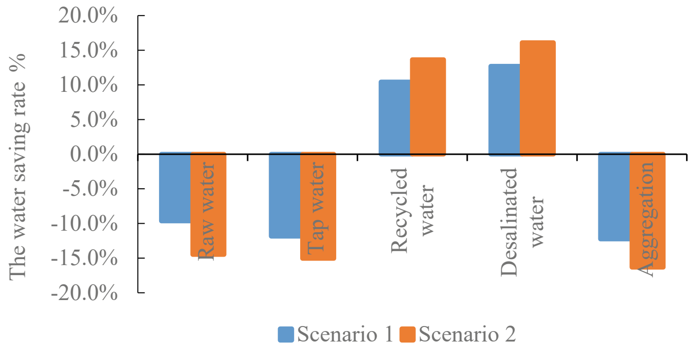

Fig. 12.5 The deviation of water supplied by different sources from the baseline scenario in 2020

increased cost. Since the proportionate decrease in water usage is greater than that of total output, water usage per 10,000 yuan of GDP declines. The water-intensive service sector shows the largest decrease. In 2020 water usage per 10,000 yuan of GDP is 32% lower in scenario 1 and 37% lower in scenario 2 than in the baseline scenario. In comparison, general industry and water-intensive industry also experience a reduction, though of smaller magnitude (Fig. 12.6). Additionally, aggregate water usage of 12.9 m^3/per 10,000 yuan of GDP in the baseline scenario falls by 14% to 11.1 m^3/per 10,000 yuan of GDP in scenario 1. In scenario 2, aggregate water usage falls by 16% to 10.6 m^3/per 10,000 yuan of GDP, in 2020. These adjustments confirm that an increase in the price of water causes a significant increase in the efficiency of water utilization.

Both scenarios 1 and 2 show that as the price of tap water increases, total water usage decreases. Specifically, total water usage in scenario 2 stands at 2,873 million m^3 by 2020, which implies that 140 million m^3 water is conserved compared with

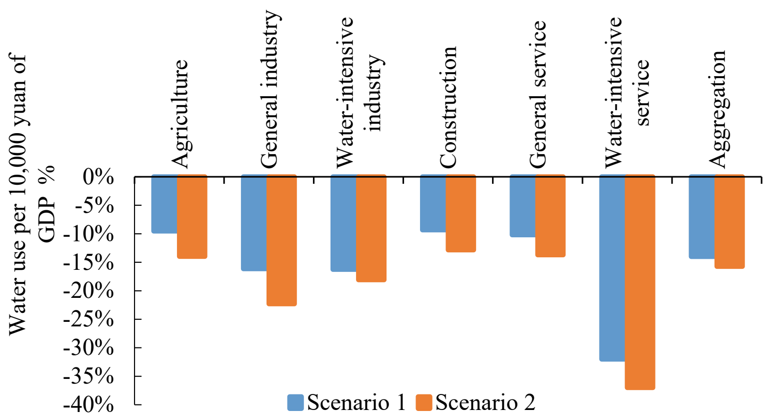

Fig. 12.6 The deviation of water usage per 10,000 yuan of GDP from the baseline scenario in 2020

scenario 1. The water-saving rate in scenario 2 is 16.3%, while in scenario 1 it is 12.1%. However, real GDP is 0.18% lower relative to baseline in scenario 1, while in scenario 2 it is 0.27% lower. Employment is 0.19% lower in scenario 1, while in scenario 2 it is 0.32% lower. Of the two scenarios presented, scenario 1 minimizes the impact of water price policy reform on GDP and unemployment, suggesting that scenario 1 is the better policy for economic outcomes. In the next section, we will focus our analysis on scenario 1. In scenario 1 the prices of tap, recycled and desalinated water are 27.35, 3.41 and 4.40 times higher than the price of raw water, respectively (Table 12.8).

(3) Economic impacts

Figure 12.7 shows the macroeconomic impacts of the water pricing reform captured in scenario 1. We can regard an increase in water prices here as being equivalent to a reduction in Government subsidies on water use, which flows through to producers and consumers as an increases in production costs and living expenses. All else being equal, we would therefore expect GDP to fall via a reduction in household consumption. We define GDP (Y) as a function of underlying technology A, capital K and labour L, $Y = \frac{1}{A}F(K,L)$. GDP in 2020 will be 0.18% lower than in the baseline scenario. This reduction reflects the combined effects of factor use and labour productivity adjustments (the percentage change in L is −0.194%, that in K is −0.31%). From the expenditure side of GDP, a higher water price will cause an increase in output prices. The CPI (consumer price index) will be 2.49% higher in 2020 than in baseline due to the effects of the water price increase. As a result, household real consumption will be 0.17% lower and investment will be 0.48% lower than in the baseline scenario in 2020.

A rational water price adjustment is regarded as one that minimizes the negative impact on the macro economy, causing small (if any) economic fluctuations and social instability. Water price adjustments will reduce water demand in water-intensive

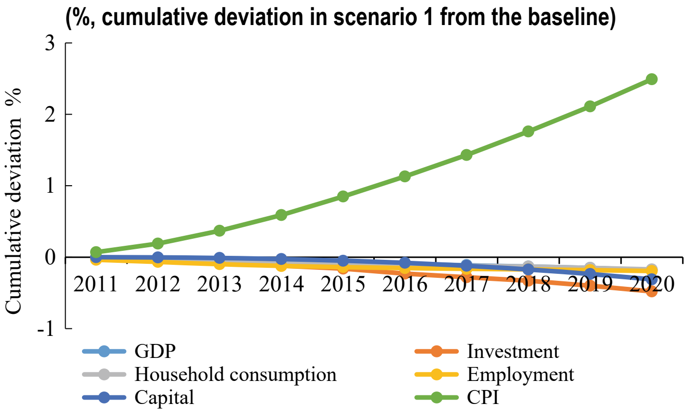

Fig. 12.7 The macroeconomic impact (%, cumulative deviation in scenario 1 from the baseline)

industries where output will decrease. Therefore, water resources will flow to sectors that use water relatively efficiently. These adjustments will lead to a better industrial structure and an improved efficiency of water utilization.

12.4.4 Application of This Study

Based on the findings of this study, the Tianjin government increased the water price in May 2015. Specifically, water prices for both general industry and service sectors were increased by 0.35 RMB/m^3, those for households were increased by 0.5 RMB/m^3, and those for water-intensive industry and service sectors by 1.15 RMB/m^3. The recycled water and desalinated water prices remained unchanged. Past and present water prices are shown in Table 12.9. By June and July total water consumption had fallen by 1.2% and 1.1%, respectively, compared to the same period in the preceding year. Water consumption of households decreased by 2.3% and 2.1%, respectively in June and July. The general industry and general service sectors showed a small decline, and water-intensive industry showed the biggest drop of 3.0% and 2.9% (according to Tianjin Water Authority). The recommended scenario which was applied in Tianjin has produced positive impacts on water conservation. Encouragingly, the practical application of the policy described herein drove changes in consumption patterns which were similar to those in the simulation results presented.

12.5 Conclusions

Many policy designers are afraid to implement reform of water pricing systems because of a perceived threat to social conditions. To date, the responses of people and the economy to changes in water pricing are unclear. Earlier studies using CGE water models did not distinguish between different water sources and different users. Therefore they could not analyze the effects of water price reform with sufficient granularity. Here, we present a computable general equilibrium model of the Chinese economy with raw water, tap water, recycled water and desalination water as independent sectors. This differentiation between four different types of water sources provides a deeper insight into the implications of different water policies and their respective economic implications.

The model used in this study captured the detailed characteristics of water users and water sources, and simulated the effect of water pricing reform. By looking at the impacts across different water users and sources, their different price responses could be explored. Among water users, we found that priority of water pricing reform should be given to water-intensive industry, followed by households and general industry and general service sectors. From the perspective of water sources, priority of water price reform should be given to tap water. We explored two specific pricing policy reforms. Our recommended policy was scenario one, in which the relative

Table 12.9 Past and present water pricing at the basedate year price (2007) (unit: RMB/m^3)

Years	Water source	Agriculture	General industry	Water-intensive industry	Construction	General service	Water-intensive service	Households
2007	Raw water	0.2	1.03	1.03	1.03	1.03	1.03	1.03
	Tap water	–	6.2	6.2	6.2	6.2	20.1	3.4
	Recycled water	–	1.2	1.2	–	1.5	1.8	–
	Desalinated water	–	4	4	–	–	–	–
2008	Raw water	0.2	1.03	1.03	1.03	1.03	1.03	1.03
	Tap water	–	6.2	6.2	6.2	6.2	20.1	3.4
	Recycled water	–	1.2	1.2	–	1.5	1.8	–
	Desalinated water	–	4	4	–	–	–	–
2009	Raw water	0.2	1.05	1.05	1.05	1.05	1.05	1.05
	Tap water	–	6.7	6.7	6.7	6.7	20.6	3.9
	Recycled water	–	3.1	3.1	–	3.1	4	–
	Desalinated water	–	4	4	–	–	–	–
2010	Raw water	0.2	1.08	1.08	1.08	1.08	1.08	1.08
	Tap water	–	7.2	7.2	7.2	7.2	21.1	4.4
	Recycled water	–	3.1	3.1	–	3.1	4	–
	Desalinated water	–	4	4	–	–	–	–
2015	Raw water	0.2	1.43	2.23	1.43	1.43	2.23	1.58
	Tap water		7.55	8.35	7.55	7.55	22.25	4.9
	Recycled water	–	3.1	3.1	–	3.1	4	–
	Desalinated water	–	4	4	–	–	–	–

Source Tianjin Water Authority, Tianjin Water Resources communiqué price in terms of raw water, tap water, recycled water and desalinated water was increased by 27.35, 3.41 and 4.40 times, respectively. In this scenario, an aggregate water saving rate of 12.20% was achieved. Water-intensive industry and service sectors showed the greatest decrease in water usage. The shares of recycled and desalinated water in total water utilization increased, while the share of tap water fell by 2.3%. The water pricing reform promoted the use of unconventional water and the conservation of conventional water, while improvements in water utilization structure were also observed. Water usage decreased proportionately more than total output, and water use per 10,000 yuan of GDP declined by 14%. This scenario had significant positive effects on water utilization efficiency, whilst driving smaller negative impacts on the level of economic activity than that observed in scenario two. The present investigation of water pricing reform has clearly demonstrated that pricing is an effective tool for policymakers to manage water consumption.

It should be noted that this study has several limitations. Specifically, a perfect water market was assumed, where various types of water could flow freely between various sectors. Additionally, we did not recognize differences in water quality between different water sources. We also assumed that water was used efficiently and no water was wasted. Nevertheless, the results of this study provide a promising start in the area of water pricing reform. The present limitations will be addressed in future investigations.

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Chapter 13
CHINAGEM-E: An Energy and Emissions Extension of CHINAGEM—And Its Application in the Context of Carbon Neutrality in China

Shenghao Feng, Xiujian Peng, and Philip Adams

Abstract This chapter introduces CHINAGEM-E, an energy and emissions extension of CHINAGEM. CHINAGEM-E has five major advancements from CHINAGEM, namely: (1) a finely disaggregated energy sector, (2) an advanced multi-layer fuel-factor nesting production structure, (3) a representation for specific carbon price, (4) physical quantitative accounts for energy consumption, electricity generation and CO_2 emissions, and (5) CCS mechanisms. We illustrate the use of CHINAGEM-E in analyzing the energy and economic implications of carbon neutrality in China. We design a base-case scenario (BCS) to serve as the benchmark to which results are compared. We design a main policy scenario, the carbon neutrality scenario (CNS), to investigate the energy and economic implications for China to reach carbon neutrality. We discuss in detail the assumptions used in these scenarios, including the macroeconomic closure, the energy efficiency and preference shocks and the carbon emissions pathways. Key results (GDP, employment, energy profile, CCS removals) in BCS and CNS are presented and analyzed.

Keywords Carbon neutrality · China · CGE · CCS · Power generation nesting · Energy consumption · Carbon price

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13.1 Introduction

CHINAGEM can be used to investigate energy related issues. The energy system is deeply embedded in the economic system. Formulating energy development plans, or analyzing impacts of energy policies, require understandings of the interactions between the energy and the economic system. CGE models are suitable to tackle such interactions (Fujimori et al. 2014; Otto et al. 2007; Bataille et al. 2006). This is because CGE models can channel the impacts of mitigation efforts through input–output linkages, and various price-, technology-, and/or preference-induced, behavioral changes throughout the entire economic system. Indeed, CGE models have been widely used in energy and climate policy analysis (Beckman et al. 2011; Böhringer and Löschel 2006; Hermeling et al. 2013; Allan et al. 2014; Babatunde et al. 2017).

CHINAGEM in its generic setup, however, is inadequate to deal with issues involving strong energy system transformations and deep decarbonization. There are five major limitations.

First, the generic setup is confined by its categorization of commodities/industries in the original input–output tables. China's IO tables to date do not distinguish between crude oil and oil, nor do they distinguish between different types of power generation technologies. Such categories miss out the possibility to replace carbon intensive fossil fuel with clean fuels, such as hydropower, solar power, and wind power.

Second, the generic model does not allow fuel-factor or inter-fuel substitutions. It treats energy inputs in the same way as they do other intermediate inputs—forming a Leontief aggregate, which, in turn, forms a Leontief combination with the factor aggregate. The model thus cannot facilitate price-induced substitutions between factor and energy, nor that among different power generation types.

Third, the generic model does not express carbon price as a *specific tax* (*i.e.*, ¥CNY per tonne of CO_2). Given the value-based IO table on which the generic model is based, a carbon price can only be implemented through ad valorem sales taxes (*i.e.* ¥CNY per¥CNY of sales of commodity '*i*'). This makes it hard for users to understand the level of a carbon price in *specific* terms as they are commonly expressed.

Fourth, there is a lack of physical accounts for energy and emissions. Incorporating physical quantity accounts for energy and emissions into conventional models is essential for the accurate and efficient CGE modelling of energy related issues.

Finally, our generic CHINAGEM does not have an explicit representation for the use of carbon capture and storage (CCS) technologies. Such technologies, however, are indispensable to deep decarbonization, especially in a coal-rich country like China. The lack of explicit representation of CCS could lead to misrepresentation of energy system structure, energy consumption levels, mitigation costs, and so on.

CHINAGEM-E therefore is developed to overcome these five limitations. It advances from CHINAGEM by:

(1) finely disaggregating energy sectors,
(2) developing an advanced, multi-level, fuel-factor production nesting structure,

(3) defining carbon price levels in specific terms,
(4) incorporating physical quantity accounts for energy consumption, electricity generation and carbon dioxide emissions, and
(5) building a CCS modelling mechanism.

Section 13.2 describes these five model developments of CHIANGEM-E in detail. Section 13.3 then illustrates an application of CHIANGEM-E by investigating carbon neutrality in China. Section 13.4 discusses the simulation results. Section 13.5 makes some final remarks.

13.2 Model Advancements

13.2.1 Disaggregation of Energy Sectors

We disaggregated the CrudeOilGas[1] and Electricity sectors[2] in the original database. Reaching carbon neutrality requires profound structural changes within the energy system. The composition between crude oil and gas, and more importantly, that between fossil fuel-based power and non-fossil fuel-base power, shall change. These two sectors are clearly inadequate to conduct such analysis.

The original CHINAGEM database has 149 sectors. Users can use database disaggregation facilities to disaggregate the sectors by providing key share informations. For this study, we disaggregated it into 157 commodities and 159 industries.[3,4] This allows the model to have more detailed energy types and therefore to do more detailed energy- and emissions-related analyses. Two original sectors are disaggregated, namely (1) Crude Oil and Gas, and (2) Electricity.

First, we split the old crude oil and gas (CrudeOilGas) sector into two separate ones, namely Crude Oil, and Gas. We use value shares to split both commodities and industries. The physical quantity data are obtained from China Energy Statistical Yearbook and the price data are deduced from the Chinese Custom (for import value) and China Energy Statistical Yearbook (for import quantity). Thus we use import prices as proxies for domestic prices of crude oil and gas. When splitting commodities, we also make two additional assumptions. On the one hand, we assume CrudeOil only sells to the Petroleum Refinery industry and no Gas is sold to Petroleum Refinery. On the other hand, we assume that only Gas is sold to users other than Petroleum Refinery. We then further disaggregate the gas industry into

[1] This is an abbreviation for a sector (Crude oil and gas) in the original input–output table.

[2] By 'sectors', we mean both commodities and industries, as the original IO table is symmetric.

[3] There is one more industry than commodity as commodity "wind power" is produced by two industries, namely "onshore wind power" and "offshore wind power".

[4] For comprehensive lists of industries and commodities of the current model database, please refer to Appendix 1 and Appendix 2 in Feng et al. (2021), respectively.

conventional and non-conventional gas industries. These two industries produce the same commodity-gas.

Second, we first separate electricity generation and distribution. We split electricity generation into eight commodities and nine industries. The eight commodities are coal-fired power, gas-fired power, nuclear power, hydropower, solar power, wind power, bioelectricity, and power generation & distribution. Each electricity commodity is produced by its corresponding industry, except wind power. The wind power industry is further disaggregated into onshore wind power and offshore wind power. They both produce the same commodity—wind power. We also use value shares to split both commodities and industries. The quantity data are obtained from China Electric Power Yearbook. The price data are provided by CHN Energy. When splitting commodities, we assume electricity generation outputs of all types are sold only to the power transmission & distribution industry.

13.2.2 Multi-level Fuel-Factor Production Nests with a New Power Generation Nesting Structure and Parameters

Existing CGE models, including CHINAGEM, still has some way to go to develop an appropriate fuel-factor nesting structure with related substitution parameters for CGE models of China. It has long been recognized that inter-fuel and inter-factor substitution parameters are important to CGE modelling results (Bhattacharyya 1996). It is only until recently that the literature began to investigate the implication of different nesting structures though. Zha and Zhou (2014) was the first attempt to find an appropriate top-level (the labor-capital-energy nesting level) fuel-factor nesting structure for China. Their work, however, does not employ a CGE model to test the implications of different nesting structures. Feng and Zhang (2018) was the first to do so. In addition, they propose a strategy to compare between different nesting structures. Yet, their work also remains at the top nesting level. Cui et al. (2020) extends these works by comparing two different nesting structures within the electricity generation nest. The current work extends the existing works by adding more lower-level nest in the electricity production nest. The purpose is to allow more targeted substitution between power generated from different fuels.

We create a new fuel-factor nesting structure to allow substitutions between production factors and different types of energy. More specifically, it has a new power generation nesting structure. The full nesting structure is shown in Fig. 13.1, and the values of the substitution parameters are shown in Table 13.1. Constant elasticity of substitution (CES) functions are used to construct our nesting structure. Equation 13.1 is an example of a typical, three-factor, nested production function:

$$Y = Ae^{\lambda}\Big[\beta\big(\alpha K^{-\rho_{KE}} + (1-\alpha)E^{-\rho_{KE}}\big)^{\rho_{KE\_L}/\rho_{KE}} + (1-\beta)L^{-\rho_{KE\_L}}\Big]^{-m/\rho_{KE\_L}} \tag{13.1}$$

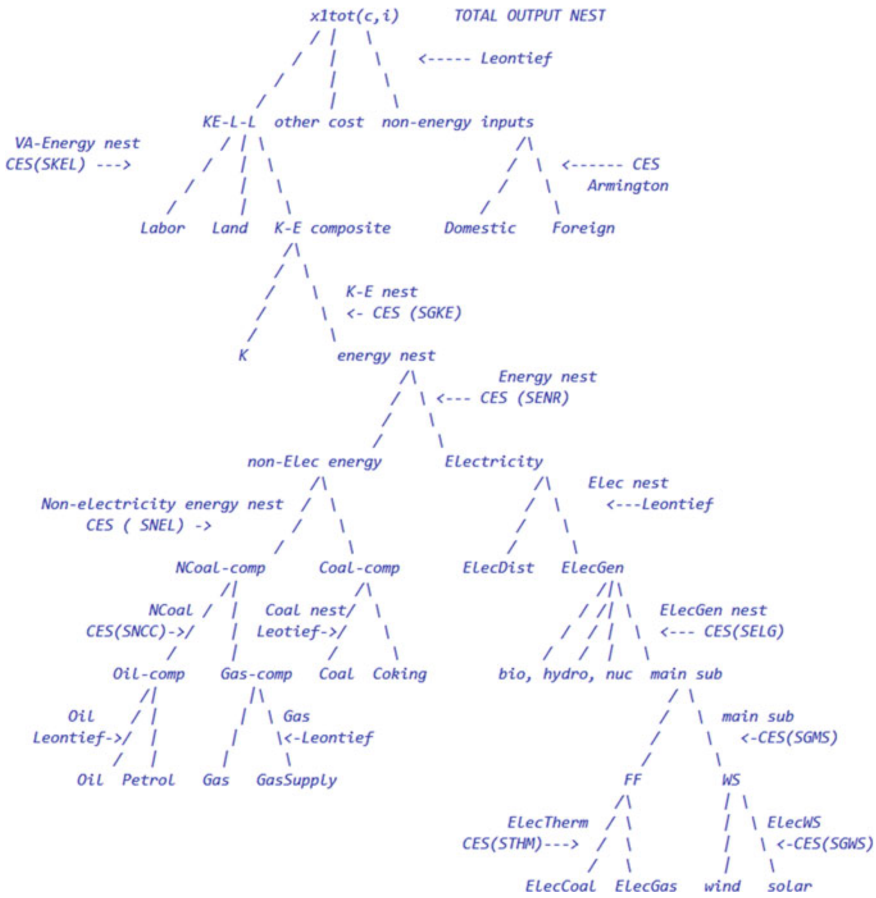


Fig. 13.1 Multi-level fuel-factor nesting structure in CHINAGEM-E

where Y is total output. K, L and E denote the total input of capital, labor, and energy, respectively. A and λ are an efficiency parameter and the rate of technological change, respectively, such that A, $\lambda \geq 0$. Share parameters α and β are input factor contributions to output, such that $0 < \alpha, \beta < 1$. ρ_{KE} and ρ_{KE_L} are inner and outer nested substitution parameters, respectively; m is the return to scale parameter, such that m = 1(>1, < 1) stands for constant (increasing, decreasing) return to scale. Equation (13.1) thus represents a nesting structure in which the upper level is a CES nest between labor and a capital-energy bundle, which, in turn, is formed by a lower level CES nest between capital and energy.

On the top level of the nesting structure in CHINAGEM-E, labor, land, and a capital-energy composite form a constant elasticity of substitution (CES) nest. Feng and Zhang (2018) found that a capital-energy CES composite is preferred to a capital-labor CES composite in the context of China. Using a consistent econometric

Table 13.1 CES parameter values in CHINAGEM-E

	Value for non-energy sectors	Values for energy sectors
STHM	2	2
SGWS	0.5	0.5
SGMS	1.5	1.5
SELG	0.5	0.5
SNCC	1	0
SNEL	0.5	0
SENR	1.85	0.5
SGKE	0.72	0.72
SKEL	0.78	0.78

framework and Chinese data, Feng and Zhang (2018) found that the CES parameter between labor and a capital-energy composite for China is 0.78. The capital-energy composite is a CES nest of capital and an energy composite. The corresponding CES parameter is 0.72 (Feng and Zhang 2018). The energy composite is a CES nest of an electricity nest and a non-electricity nest and the corresponding CES parameter for China is 1.85 (Feng et al. 2021).

The non-electricity nest is first a CES composite of a coal-composite and a non-coal-composite. The literature has not specifically measured this parameter for CGE models of China in a consistent nesting structure. We therefore borrow the corresponding CES parameter from GTAP-E, in which the value equals to 0.5. The non-coal composite is a CES composite of an oil-composite and a gas-composite. Similarly, in the absence of direct reference from the literature, we borrow the corresponding CES parameter from GTAP-E, in which the value equals to 1. The coal-composite is a Leontief composite of coal and coke, the oil-composite is a Leontief one of crude oil and petroleum products, and the gas-composite is a Leontief one of gas and gas supply.

Our electricity nesting structure is as the following. It is first a Leontief composite between power transmission and distribution and a power generation nest. This is a common setup as it is in GTAP-E. The power generation nest, however, is new in the literature. This is partly because we have different sector classifications to those in the literature and is partly because we try to reflect some special characteristics of China's power system. Since the nesting structure is new, we do not have the corresponding CES parameter values from the literature. The scope of the current study does not allow us to conduct a thorough analysis regarding the value either. We thus begin by assigning values to the CES parameters in the main simulation scenarios based on our judgements regarding the relative difficulties of substitution in each decision level. We will then perform sensitivity tests regarding our judged values in alternative scenarios.

The power generation nest is first a CES composite of four parallel inputs, namely bioelectricity, hydropower, nuclear power and a 'main substitution' composite. This level of nesting reflects the fact that substitution among these four types of power generation technologies is difficult. The development of hydropower and nuclear power, in particular, is subject to geological and political constraints. We thus begin by assigning a relatively small value (0.5) to this CES parameter in the main simulation scenarios.

The 'main substitution' nest is a CES composite between the fossil fuel power nest and the wind and solar power nest. Obviously, this is where strong changes must happen to allow solar and wind power to replace fossil fuel power in order to achieve carbon neutrality. In addition to price incentives, laws and policies will be developed and implemented to make such changes easier. We therefore assign a relatively large value (1.5) to the corresponding CES parameter.

At the bottom of the electricity generation nest are two CES composites. The fossil fuel power composite is a CES nest of coal-fired power and gas-fired power, with a CES parameter value equals to 2. This reflects the fact that it is easier to change between coal and gas than it is to change between thermal power and wind power or solar power. The wind-solar power composite is a CES nest of solar power and wind power. Here we give a relatively small CES value (0.5) to reflect the policy intension to dispatch solar and wind power as much as possible and that they do not become too competitive against each other.

13.2.3 Carbon Pricing Mechanism

A carbon price is a specific tax. It collects a given amount of monetary value from a given amount of physical CO_2 emissions. The I/O database is based on value. We need to translate the specific tax on CO_2 emissions into ad valorem tax that is consistent with the model database (in¥CNY 10 million). We apply the method used in Adams and Parmenter (2013) to implement carbon pricing mechanisms. This method has been widely applied in CGE modelling in China (e.g., Feng et al. 2018; Liu and Lu 2015). The method uses carbon pricing revenues to establish a link between an ad valorem tax (sales tax) and a specific tax (emissions tax), please see Eq. (13.2):

$$S \times Q \times I = \frac{P \times X \times V}{100} \tag{13.2}$$

The left-hand side (LSH) of Eq. (13.2) represents the carbon pricing revenues from a specific tax. S is the specific carbon price (¥CNY per tonne of CO_2), Q is the physical quantity of CO_2 emissions (in million tonnes), and I is a price index for preserving nominal homogeneity. The right-hand side (RHS) of Eq. (13.2) represents the carbon pricing revenues from an ad valorem tax. V is the (per cent) ad valorem tax rate and P × X is the basic value of the taxed flow (P and X denotes price and quantity, respectively). Since the monetary value in the model is in 10 million and emission is in millions, for LHS of Eq. (13.2) to be in 10 millions, I = 0.1 is needed.

The linearized forms of LHS and RHS of Eq. (13.2) are shown in Eqs. (13.3) and (13.4), respectively.

$$LHS = Q \times I \times delS + \frac{S \times Q \times I}{100} \times (q + i) \tag{13.3}$$

$$RHS = \frac{P \times X}{100} \times delV + \frac{P \times X \times V}{10,000} \times (p + x) \tag{13.4}$$

where *delS* and *delV* denote ordinary changes in *S* and *V*, respectively, and lower-case *q*, *i*, *p*, *x* denote percentage changes in their respective upper-case variables. Combining Eqs. (13.3) and (13.4) and solving for *delV* gives Eq. (13.5):

$$delV = \frac{S \times Q \times I}{P \times X} \times (q + i - p - x) + 100 \times \frac{Q \times I}{P \times X} \times delS \tag{13.5}$$

Ordinary changes in carbon pricing revenues (*delR*) can thus be expressed as Eq. (13.6):

$$delR = Q \times I \times delS + \frac{S \times Q \times I}{100}(q + i) \tag{13.6}$$

13.2.4 Energy and Emissions Accounts

The basic input–output database is a value database (i.e., price times quantities). To have standard energy or emissions quantities, we need to set up separate energy and emissions accounts and link them with real quantity variables in the CGE model. We added four separate energy and emissions accounts, they are:

(1) Primary energy consumption in 2017: we distinguish eight types of primary energy, namely coal, oil, gas, hydropower, nuclear power, wind power, solar power, and bioelectricity. The data is taken from China Energy Statistical Yearbook 2018, with the unit being 10,000 tons of standard coal equivalent (sce), using coal equivalent calculation (cec). We allocate the quantities of the eight types of primary energy to the 160 fuel users (159 industry users and 1 residential user) according to the input–output table sales structure of their corresponding energy commodities.

(2) Final energy consumption in 2017: we distinguish fourteen types of final energy, namely coal, oil, gas, petroleum, coke, coal-fired power, gas-fired power, hydropower, nuclear power, onshore wind power, offshore wind power, solar power and bioelectricity, and gas supply. They are allocated across the users in the same way as primary energy, using the same data source, the same energy unit, but are calculated by the coal calorific calculation (ccc) method.

(3) Electricity generation by fuel types in 2017: we distinguish seven power generation technologies, namely coal-fired power, gas-fired power, nuclear power, hydropower, solar power, wind power and bioelectricity. The data are taken from China Electric Power Yearbook. They are also allocated in the same way as primary energy. The energy unit is 100 mKWh.
(4) CO_2 emissions by fuel in 2020: we distinguish four types of gas emitting fuels, namely coal, gas, petroleum, and gas supply. We set the total level of carbon dioxide emissions in 2020 to be 9.88 billion tons. We allocate CO_2 emissions from each of these four types of fuel to each of the 160 fuel users based on their sales shares in the I/O table.

13.2.5 Carbon Capture and Storage (CCS) Mechanisms

CHINAGEM-E at adept at carbon neutrality analysis because it has an explicit account of CCS and BECCS (Bioenergy CCS) technologies. In our model, coal-fired power generators, for example, can adjust their output levels by comparing CCS costs against carbon prices. This feature is particularly relevant to carbon neutrality simulations—although carbon prices may not be very high now, they can become substantially higher than CCS costs as it gets closers to 2060. Our model allows a set of stationary emitters to cut costs by purchasing less emissions permits and investing more in CCS, and thereby maintain a relatively higher level of output. Vennemo et al. (2014) is the only attempt that has explicitly treated CCS in the CGE modelling in the context of China. They disaggregated coal-fired and gas-fired power generation sectors between ones with CCS and ones without CCS. They then put all different power generation types, including hydropower and nuclear, within a same power generation nest, and applying a constant elasticity of substitution parameter being 20. They estimated that a carbon price of 500 yuan/tCO_2 in 2050 is required to compensate the installation of 98% of the coal-fired units with CCS, and that this would reduce GDP by 4%. Their work however was done before the carbon neutrality target was announced and thus did not become part of the analysis in a carbon neutrality scenario. Moreover, they only considered coal-fired power CCS, but did not consider CCS application in other stationary point, such as steel or cement production. Likewise, some recent studies have also incorporated BECCS technologies (Weng et al. 2021; Huang et al. 2020), but did not combine all three of CCS, BECCS and DACCS to form a carbon neutrality scenario either. This study provides a carbon neutrality scenario considering the contribution from all three negative-emissions technologies.

We add carbon capture and storage mechanisms to this version of CHINAGEM-E. Reaching carbon neutrality without CCS would require carbon prices to be so high that fossil fuel use would become non-economically viable. With the help of CCS, however, the cost of reaching carbon neutrality would be significantly lower. We hence add two types of CCS mechanisms in this version of CHINAGEM-E, namely conventional CCS and BECCS (Bio-energy CCS). We identify four broad sectors, namely chemicals, cement, steel, and thermal power, to have conventional

CCS installations. Such installations can be further distinguished between coal-, oil- and gas-based facilities. BECCS are only installed on bio-electricity stations.

We do this by incorporating an explicit, endogenous mechanism of modelling carbon capture and storage is incorporated into CHINAGEM-E. We set up three new emissions accounts for CCS. They are: (1) FFCCS(f,i), denoting emissions extracted by sector 'i' from using fuel 'f', such that i ∈ [chemicals, cement, steel, thermal power}, and f ∈ [coal, oil, gas}; (2) BECCS, denoting emissions capture by bioelectricity; and (3) DACCS, where emissions are not earmarked to any specific industry. Net carbon dioxide emission ($NetCO_2$) is thus shown in Eq. (13.7), such that:

$$NetCO_2 = \sum_{f,i} CO_2(f,i) + \sum_{f,i} FFCCS(f,i) + BECCS + DACCS \quad (13.7)$$

Our fossil fuel-based CCS and BECCS mechanisms do not require the disaggregation of existing sectors. This spares the need to specify the cost structure for CCS technologies, which can be (1) difficult to come by and/or, (2) changing rapidly. Instead, we assume a given proportion of emissions from a given industry is removed by CCS technologies, and this proportion is defined as the fossil fuel CCS coverage rate (FFCOV) and BECCS coverage rate (BECOV), as shown in Eqs. (13.8) and (13.9), respectively:

$$FFCOV(f,i) = -\frac{FFCCS(f,i)}{CO_2(f,i)} \quad (13.8)$$

$$BECOV = -\frac{BESSC}{CO_2(bioelec)} \quad (13.9)$$

At the same time, we assign a given cost of CCS for per unit of CO_2 removed. This cost is registered as an 'Other cost ticket' in the model and is not directly related to any specific intermediate or factor costs. Through such cost tickets, users can exogenously impose the cost of removing a unit of emissions by a particular user using a particular CCS technology.

13.3 Investigating Carbon Neutrality in China

China aims to reach carbon neutrality before 2060.We use CHIANGEM-E to investigate the energy and economic implications of reaching carbon in China in 2060. We set two main scenarios, namely the base-case scenario (BCS) and the carbon neutrality scenario (CNS). The BCS illustrates a likely economic development path before the carbon neutrality target was announced. It runs between 2017 and 2060. The BCS can serve as a benchmark to which results from the CNS are compared. The CNS illustrates a likely economic development path that would lead to carbon neutrality in China in 2060. It runs between 2021 and 2060. The deviations in results from BCS to CNS are thus the impacts of carbon neutrality efforts.

We give seven sets of assumptions in these two scenarios, they are:

(1) Macroeconomic
(2) Energy production, consumption, and trade
(3) Carbon price levels
(4) Energy efficiency
(5) Energy preference
(6) CCS penetration rates and costs
(7) A CO_2 emissions path

In BCS, we give assumptions to sets (1) to (4). In CNS, we give assumptions (4) to (7). Although both BCS and CNS are given set (4) assumptions, some shocks are of different sizes between the two scenarios. This section describes the assumptions used in both scenarios. In Sect. 13.5, we will also show and discuss the design and results of some additional, comparative scenarios.

13.3.1 Base-Case Scenario (BCS)

13.3.1.1 Macroeconomic Assumptions in the BCS

We give exogenous, specific growth rates to selected macroeconomic variables in the BCS. The following principles are used in setting the macroeconomic shocks.

(1) Using IMF's world Economic Forecast, the Chinese economy (real GDP) will grow at 1.85% in 2020 because of the impacts of COVID-19. Followed by a strong recovery in 2021 the economy will grow at a rate of 8.25%, then returns to its normal growth trend from 2022: real GDP will continue to grow strongly, but overall growth will slowly diminish.
(2) The pattern of growth will favor consumption and consumption-related industries at the expense of investment and investment-related industries;
(3) Import growth will exceed export growth; and
(4) Growth in the service sector will exceed growth in the industrial sector and
(5) Growth in the industrial sector will be higher than that in the agricultural sector.

The upper part of Table 13.2 shows the assumed growth rates of the real GDP, employment[5] and GDP components. These numbers are used as shocks to CHINAGEM-E under the forecast closure. The lower part Table 13.2 shows the endogenously generated macroeconomic results of the BCS, including the growths

[5] The growth rate of the exogenous variable employment is calculated based on the growth rate of working-age population and the aggregate labour force participation rate. In the baseline scenario, we assume that the aggregate labour force participation rate will remain at their 2015 levels until 2060. The growth rate of working-age population is from the medium variant of population projection conducted by Zuo et. al. (2020).

Table 13.2 Base-case scenario: growth rate of real GDP, employment, GDP components and other variables (%, selected years)

Exogenously specified variables	2020	2021	2025	2030	2040	2050	2060
Real GDP	1.85	8.24	5.49	4.03	3.16	2.87	2.60
Employed persons	−0.39	−0.26	0.04	−0.81	−1.11	−1.26	−1.21
Household consumption	2.61	8.96	6.14	4.59	3.65	3.31	3.00
Investment	1.96	8.37	5.68	4.29	3.57	3.08	2.60
Exports	2.45	8.81	5.92	4.28	3.06	2.63	2.30
Model generated results							
TFP	−0.82	5.29	2.67	2.02	1.94	2.08	2.06
Capital stock	6.58	6.05	6.18	5.63	4.28	3.62	3.11
Imports	4.86	10.9	8.07	6.32	5.18	4.17	3.20
Agriculture	−0.40	4.98	2.52	1.17	0.56	0.65	0.90
Industry	0.62	6.88	4.26	3.05	2.36	2.18	2.07
Services	2.27	8.78	6.01	4.57	3.65	3.29	2.95

GDP = gross domestic product; TFP = total factor productivity
Sources Growth of real GDP 2018–2019 from NBS; 2020–2025 from IMF World Economic Outlook; 2026–2040 referring IEA's World Energy Outlook. 2041–2060 are authors' assumptions. Employment data from Zuo et al. (2020). Growth of household consumption, investment and exports are authors' assumptions

of total factor productivity (TFP), capital stock, import and the growth of three macro sectors. Table 13.2 shows that with the declining employment because of rapid population aging, China relies on capital growth and total factor productivity improvement to sustain its economic growth.

13.3.1.2 Energy Production, Consumption, and Trade Assumptions in the BCS

We give exogenous shocks to four sets of energy-related variables in the BCS, including:

(1) consumption of primary energy,
(2) consumption of final energy,
(3) production of electricity generation, and
(4) energy import–quantity and price.

We consult IEA (2020) to formulate forecast assumptions for these four sets of exogenous shocks. For primary energy, we shock consumption of coal, oil, and gas. For final energy, we shock consumption of petrol, coke, and gas-supply. For electricity generation, we shock production of all eight types of power output. For energy import quantity and price, we shock coal and oil. These variables are chosen to be shocked annually due to the availability of forecasts for years between 2020 and 2040, in IEA (2020). IEA (2020) does not, however, have forecasts for years after 2040. The authors extrapolate based on trends.

Figures 13.2, 13.3, 13.4, and 13.5 show base-case primary energy consumption, final energy consumption, electricity generation and energy trade, respectively. In our base-case scenario, total energy consumption increases gradually from 2020 (4875 mtce) to 2040 (6071 mtce) and increases only slightly afterwards. By 2060, total primary energy consumption is 6171 mtce.

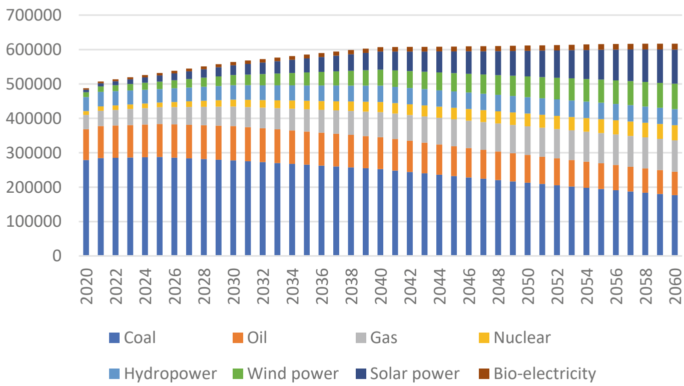


Fig. 13.2 Primary energy consumption in BCS (10,000 tce, coal-equivalent calculation). *Source* IEA (2020) for years 2021–2040, authors' assumptions for years 2041–2060

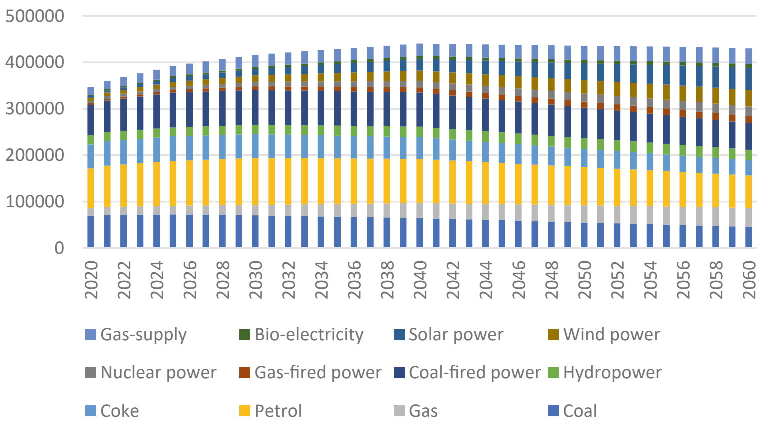


Fig. 13.3 Final energy consumption in BCS (10,000 tce, coal-calorific calculation). *Source* IEA (2020) for years 2021–2040, authors' assumptions for years 2041–2060

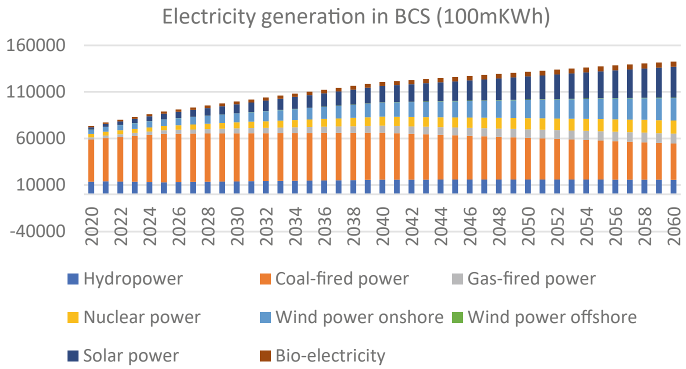


Fig. 13.4 Electricity generation in BCS (100 mKWh). *Source* IEA (2020) for years 2021–2040, authors' assumptions for years 2041–2060

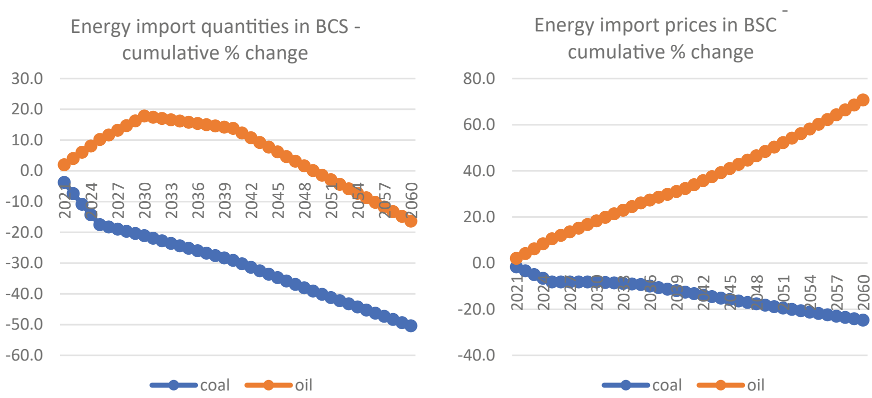


Fig. 13.5 Coal and oil import quantity and price changes in BCS. *Source* IEA (2020) for years 2021–2040, authors' assumptions for years 2041–2060

13.3.1.3 Carbon Price Assumptions in the BCS

We set carbon price levels for different years in the BCS. We consult IEA (2020) for years between 2020 and 2040, and we make our own assumptions for years between 2041 and 2060. Figure 13.6 shows carbon price levels in the BCS.

13.3.1.4 Energy Efficiency Assumptions in the BCS

Three sets of energy efficiency assumptions are given to the BCS, including:

(1) Improvement in capital-using efficiency in renewable power generation.
(2) Changes in renewable power generation costs supplied to the grid.

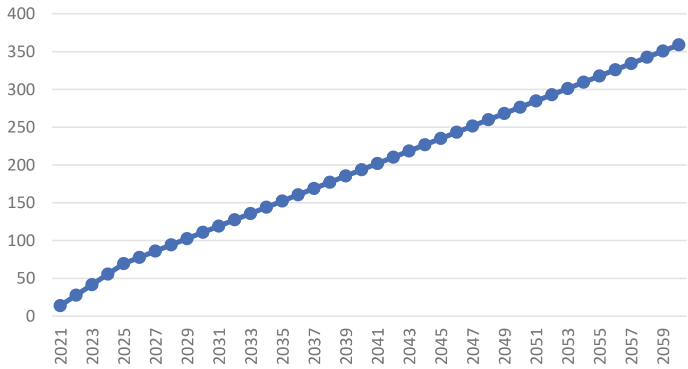


Fig. 13.6 Carbon price levels in BCS (y/tCO_2). *Source* IEA (2020) for years 2021–2040, authors' assumptions for years 2041–2060

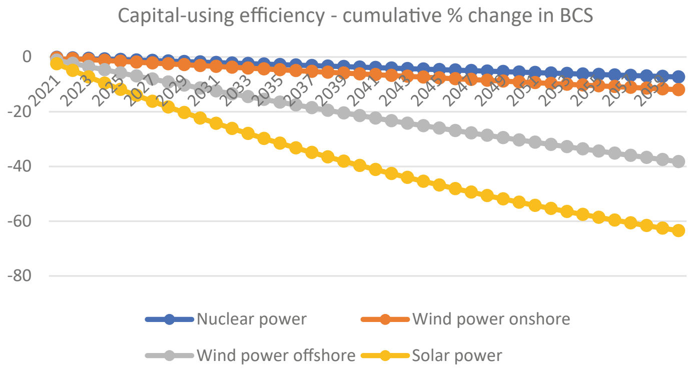


Fig. 13.7 Capital-using efficiency in BCS—cumulative % change (negative numbers denote efficiency improvement). *Source* IEA (2020) for years 2021–2040, authors' assumptions for years 2041–2060

(3) Energy-using efficiency improvement.

Similar to our previous assumptions, we rely on IEA (2020) to formulate our shock sizes. The cos-neutrality condition is enabled in our energy efficiency shocks. Figures 13.7, 13.8, and 13.9 show the levels of the shocks.

13.3.1.5 Emissions Results in the BCS

Our base-case simulations can already produce some interesting results. The most important ones are CO_2 emissions. Figure 13.10 shows that the absolute peak of CO_2 emission occurs in 2025 at 10.5 btCO_2. However, we can consider emissions reaches a plateau, or a 'flat peak' at 10.5 billion tonnes of CO_2 (btCO_2) between 2025 and

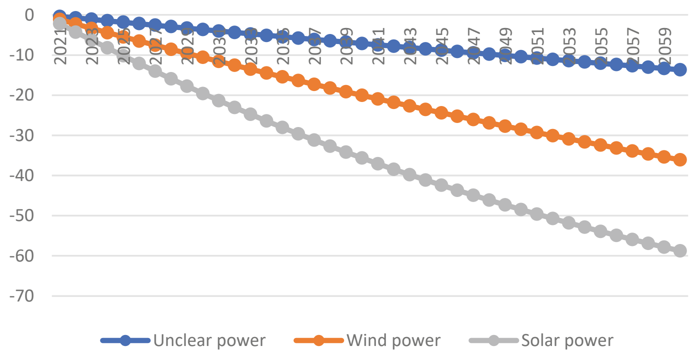


Fig. 13.8 Unit electricity costs supplied to the grid in BCS—cumulative % change. *Source* IEA (2020) for years 2021–2040, authors' assumptions for years 2041–2060

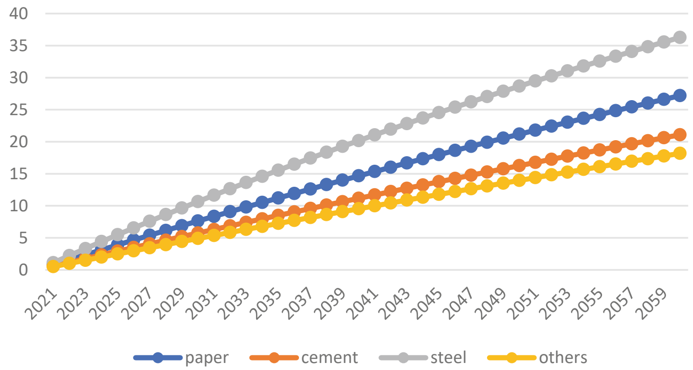


Fig. 13.9 Cumulative % energy efficiency improvement in BCS. *Source* IEA (2020) for years 2021–2040, authors' assumptions for years 2041–2060

2030. Total emissions fall to 7.5 btCO_2 in 2060. Clearly it requires a significant effort to reduce this to zero. The cumulative emissions in the base-case between 2020 and 2060 are 387 btCO_2.

13.3.2 Carbon Neutrality Scenario (CNS)

In the carbon neutrality scenario (CNS), we make macroeconomic variables, energy production, energy consumption, energy trade and carbon price endogenous. We give extra energy efficiency shocks, energy preference shocks, and CCS shocks to the CNS. At the same time, we impose a path of carbon neutrality in this scenario. These settings would lead to higher carbon prices in the CNS than those in the BCS and put downward pressure to economic growth.

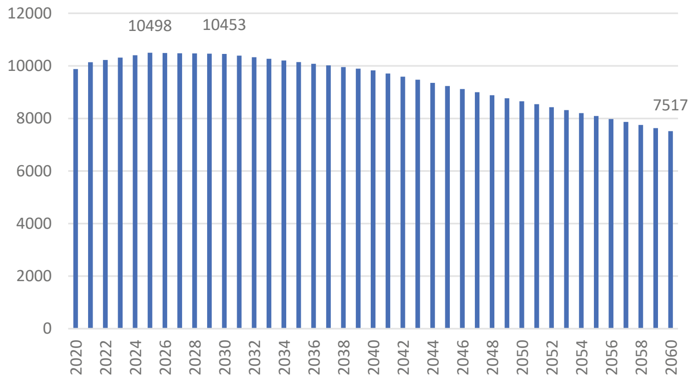


Fig. 13.10 CO_2 emissions endogenously generated in BCS ($mtCO_2$). *Source* Authors' simulation using CHINAGEM-E

We also set some common macroeconomic assumptions. First, real wage is sticky in the short-run and becomes flexible in the long-run. Employment in the policy case can deviate from the base-case in the short-run but gradually gets back towards the base-case level in the long-run because of the lagged wage adjustment mechanism (Dixon and Rimmer 2002). Second, capital stock is fixed in the short-run and is flexible in the long-run. Third, aggregate consumption follows household disposable income. Fourth, government expenditure moves together with aggregated consumption. Fifth, investment is a function of expected rate of return on capital. Sixth, export faces a downward-sloping demand curve. Seventh, import price is assumed to be fixed. Eighth, trade balance as a share of GDP is assumed to be fixed at the BCS level. Ninth, carbon pricing revenues are recycled as a lump-sum transfer to households. Tenth, the nominal exchange rate is set as the numeraire.

This subsection shows the extra, energy-related assumptions imposed in the CNS.

13.3.2.1 Energy Efficiency Assumptions in the CNS

We give additional energy efficiency improvement in the CNS than they were in the BCS (Fig. 13.11). The additional energy efficiency improvement kicks in from 2030 and gradually accelerates. The acceleration reflects the gradual increase in carbon prices, which stimulate the improvement of the energy efficiency. Energy efficiency improvements are unlikely to be cost-free. We, however, do not have specific information regarding the related costs. We thus assume energy efficiency improvements are 'cost-neutral'. The cost-neutrality condition is achieved by increasing other input costs across the board so that total costs are unaffected.

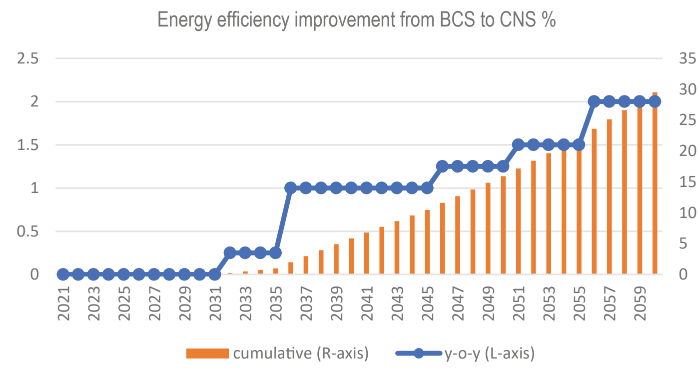


Fig. 13.11 Energy efficiency improvement in CNS. *Source* Authors' assumption

13.3.2.2 Energy Preference Assumptions in the CNS

We explicitly model six types of energy preference change, namely:

A. households using electricity to replace fossil fuel,
B. buildings using gas to replace coal,
C. the transportation sector using electricity to replace petrol,
D. energy intensive industries using electricity to replace fossil fuel,
E. the grid using wind and solar to replace thermal power, and
F. the grid using gas-fired power to replace coal-fired power.

The shock levels resemble the reduction in demand for the fuels that are being replaced due to preference changes. Similar to cost-neutrality, energy preference shocks are assumed to be 'energy neutral', so that fuel replacements do not affect total energy use in energy units. Figure 13.12 shows the levels of the shocks. Notice that shocks (A), (D) and (F) were given the same shock values and therefore only appear as a single (green) line in Fig. 13.12.

13.3.2.3 CCS Assumptions in the CNS

We explicitly model three types of CCS, namely fossil-fuel based CCS, bioenergy CCS (BECCS), and direct air CCS (DACCS). Fossil-fuel based CCS are utilized by four broad sectors, including chemical, cement, steel, and thermal power. Fossil-fuel based CCS are also distinguished by three fuel types: coal, oil, and gas. BECCS is only employed in the bio-electricity sector.

We choose to control the coverage rate of CCS facilities. This would leave the amount of carbon dioxide emissions released by the five sectors to be endogenous. The actual amount of carbon dioxide emissions that are absorbed by CCS thus depends on the coverage rate times the amount emissions before entering CCS.

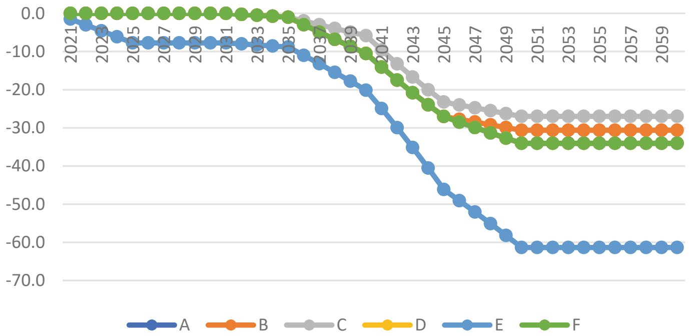


Fig. 13.12 Energy preference assumption in CNS—cumulative % change. *Source* Authors' assumptions. Please note lines A, D and F are overlapped

Figure 13.13 shows the CCS coverage rate assumptions. We assume coal-based CCS are utilized at large-scale from 2031. We set the penetration rate for coal-based CCS through our contacts from CHN Energy—an energy enterprise. The coverage rate increases relatively quickly till 2050, when a large number of coal-based power generation stations reach their life-expectancy. The rates increase only slowly from 2051 and reaches 90% in 2060.

Oil- and gas-based CCS are assumed to be utilized in large scale from 2041. Their coverage rates increase by a fixed annual rate that will lead it to reach 90% in 2060.

BECCS is also assumed to be employed in large-scale from 2041. Its coverage rate also increases by a fixed annual rate—one that will lead to be 80% in 2060. Notice that bio-electricity is not associated with any emissions in our database. In reality, however, BECCS do capture and store emissions. We use the level of bioelectricity

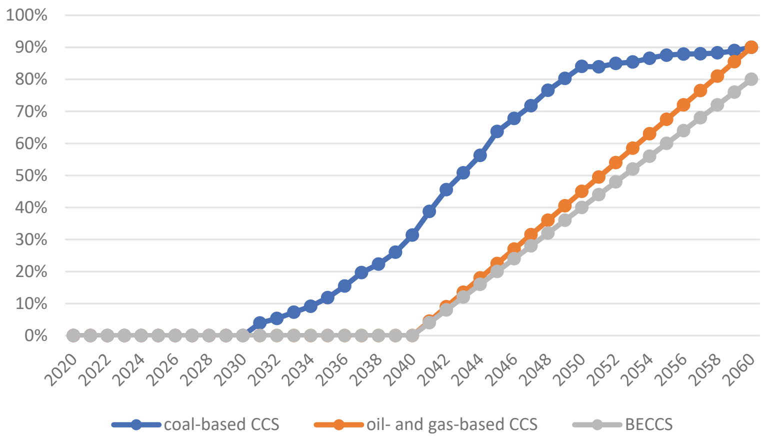


Fig. 13.13 CCS coverage rate assumptions in the CNS. *Source* Authors' assumptions

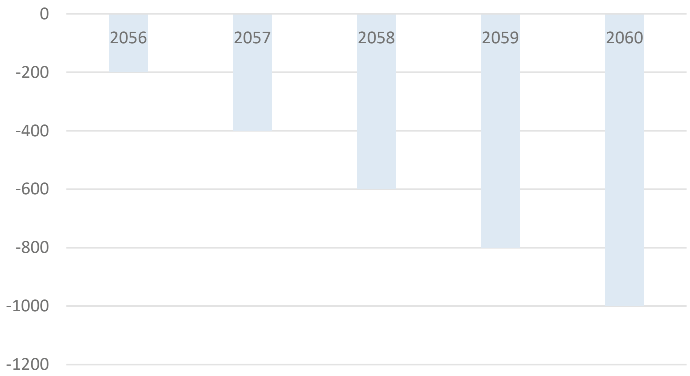


Fig. 13.14 CO_2 emissions reduction by DACCS ($mtCO_2$)

to calculate the equivalent CO_2 emissions from coal-fired power generation. We use this amount of CO_2 emissions, together with our BECCS coverage rate assumptions, as the basis to calculate the amount of emissions reduced by BECCS.

We also model the costs of employing fossil-fuel based CCS explicitly. We do this by assuming a fixed unit cost of 400 yuan per ton of CO_2 emissions captured and stored by fossil-fuel based CCS. We do not model the cost of BECCS explicitly. We, instead, assume that the gain in selling CO_2 permits offsets the costs of BECCS.

We assume DACCS becomes available in large scale from 2056. We exogenously set the amount of CO_2 emissions that are taken by DACCS (see Fig. 13.14). We also assume DACCS costs are fully compensated by its permits income.

13.3.2.4 The Carbon Neutrality Path in the CNS

We impose a carbon neutrality path in the CNS that will lead total carbon dioxide emissions from fuel combustion to zero in 2060 (see Fig. 13.15).

In this scenario, total CO_2 emissions reaches its absolute peak in 2025 at 10.2 $btCO_2$. Year-on-year emissions levels remain above 10 $btCO_2$ in the 2020s. China aims to peak emissions before 2030. It seems an emissions peaking is indeed highly likely to happen before 2030. Peaking is of great significance to China as it marks a reverse in trend. In terms of total cumulative emissions in the long term, however, the actual year of peaking hardly matters—whether it is 2027 or 2029, the total emissions will be similar. In CNS, total cumulative emissions between 2020 and 2060 is 250 $btCO_2$. This is 65% of total cumulative emissions in the BCS.

Emissions begin to fall noticeably in 2031. Average annual emissions reduction rate between 2030 and 2035 is 2.5%. The fall accelerates from 2035. Average annual emissions reduction rate between 2035 and 2040 is 5.0%. It further accelerates in the 2040s, averaging 9.6% per annum. The 2040 is the fastest decade of emissions reduction largely due to contributions from fossil-fuel based CCS and BECCS. Although

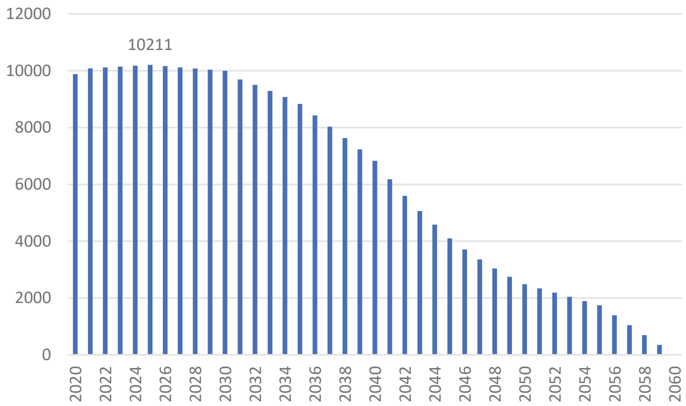


Fig. 13.15 CO_2 emissions in CNS ($mtCO_2$)

it slows down in the early 2050s, the reduction rate increases again in 2056 given large-scale adoption of DACCS.

13.4 Simulation Results

We show key macroeconomic and energy results in this section. For detailed sector-level results, and energy intensity results, please consult Feng et al. (2021).

13.4.1 Economic Results

13.4.1.1 Carbon Price

We show levels of carbon price in Fig. 13.16. In CNS, carbon price levels are slightly higher than those in BCS till mid-2030s. Before mid-2030s, extra abatements in CNS are mostly achieved by changes in energy efficiency and preference. After mid-2030s, carbon price levels begin to increase faster in CNS. The acceleration is mainly due to the faster fall of total emissions in this period (see Fig. 13.17).

Carbon price increases even faster after mid-2050s. Although the absolute levels of emissions reduction are smaller comparing with earlier years, the rate of emissions reduction are much faster in this period. Moreover, there are much less room for emissions reduction in the later years. The increase in CCS penetration rate also decelerates in the 2050s. These make marginal abatement costs to increase faster. By 2060, carbon price level reaches 1614 y/tCO_2 in CNS.

Carbon price levels in CNS imply the level of efforts needed to achieve our carbon neutrality path. By 'imply', it shows that the carbon price levels are results

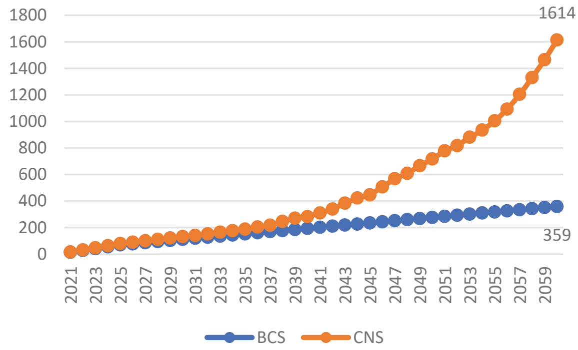


Fig. 13.16 Carbon price levels (y/tCO_2)

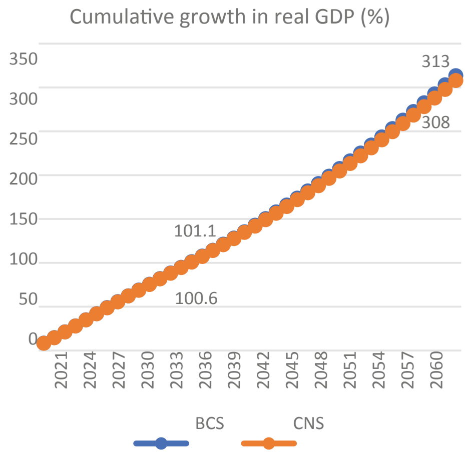


Fig. 13.17 Real GDP results: growth rates

endogenously generated in CNS. By 'efforts', we mean that they indicate the levels of price incentives for restriction on economic activities and motivation for fuel switch. Obviously, the higher the carbon price are, the lower the incentive to engage in energy-intensive activities and the higher the incentive to switch to cleaner energy sources. These levels of efforts themselves are not enough to achieve the carbon neutrality path though, they must work together with our energy efficiency, energy preference and other assumptions in the CNS.

Carbon price levels are results of the main shocks in CNS. They will increase the overall costs of the economy and especially the emissions-intensive industries.

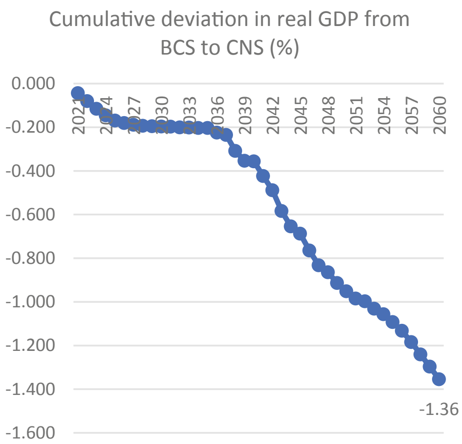


Fig. 13.18 Real GDP results: deviations

13.4.1.2 Real GDP—Supply Side

Real GDP

Real GDP growth rates are close between BCS and CNS (Fig. 13.18). Between 2020 and 2060, real GDP grow by 313% and 308% in BCS and CNS, respectively. In 2060, real GDP in CNS will be 1.36% lower than it is in BCS (Fig. 13.18). Notice that in CNS, in year 2035, real GDP will be 100.6% higher than it is in 2020. This suggests that China can achieve the target of doubling GDP between 2020 and 2035 and reaching carbon neutrality in 2060 at the same time.

Real GDP in CNS falls further below its BCS levels from late 2030s. This is the result of faster carbon prices increase in CNS. As we explained before, carbon price is a form of indirect tax that increases general costs of the economy and puts downward pressure on economic growth.

Employment

Employment in CNS measured in wage bill weights are below the BCS levels (see Fig. 13.19). They are, however, not far below. This is because of the lagged wage adjustment mechanism in the policy simulation. Employment levels in the policy case (CNS) tend to return to their base-case (BCS) levels. This assumption is consistent with the non-accelerated inflation rate of unemployment (NAIRU) equilibrium state in the long run. Under downward pressure of increasing carbon prices, in the CNS, employment declines to below BCS level. However, the lagged wage adjustment mechanism makes the real wage levels in CNS keep falling below BCS levels. The falling real wage helps employment levels in CNS to move towards their BCS levels. By 2060, employment (measured in wage bill weights) is 0.1% lower than its BCS level, and real wage is 0.6% lower.

Figure 13.20 shows the number of employed persons at the national level. The difference in total number of employed persons between BCS and CNS is small.

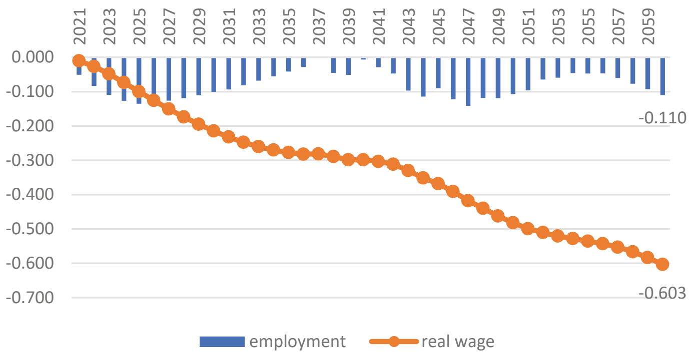


Fig. 13.19 CNS employment (wage bill weighted) and real wage cumulative deviation from BCS (%)

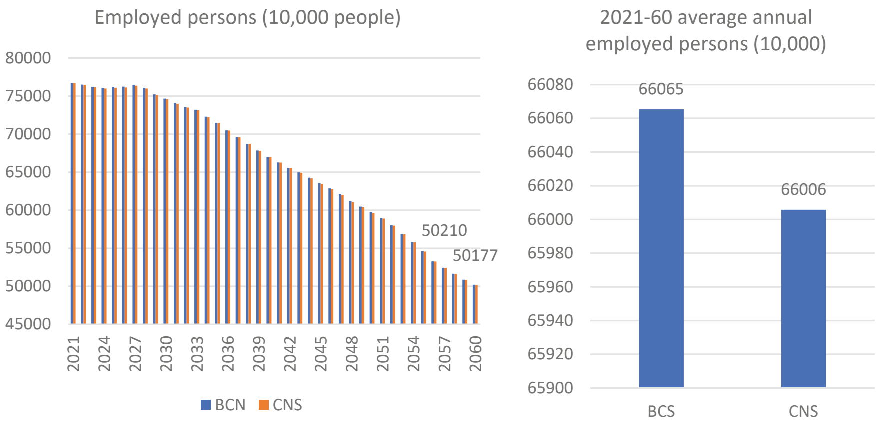


Fig. 13.20 Employed persons—national results

This is consistent with employment deviations measured in wage-bill weights. By 2060, the total number of employed persons are 502.1 million and 501.8 million in BCS and CNS, respectively. Carbon neutrality results in approximately 330,000 job loss in 2060 in CNS than in BCS. This is a big number, but in an economy with more than 500 million employed persons, it only represents a reduction of 0.066% (=−100*(501.77–502.10)/502.1). Between 2021 and 2060, on average, the number of persons employed per annum are 660.7 million and 660.1 million in BCS and CNS, respectively. Hence the annual average number of unemployed persons that are attributed to CNS is 600,000, which, again, is a small proportion in China's total employment.

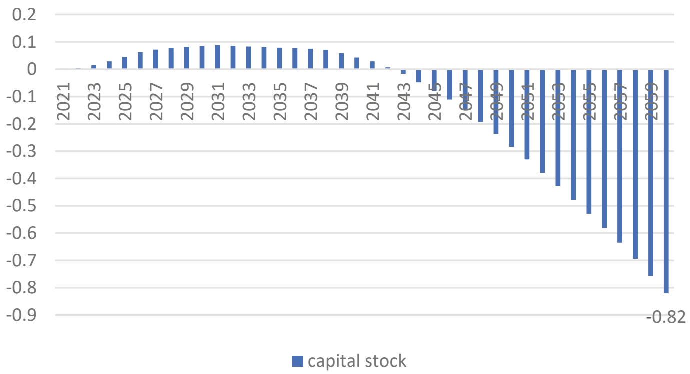


Fig. 13.21 Capital stock and real return to capital in CNS—cumulative deviation from BCS (%)

Capital

Figure 13.21 displays the capital stock changes. Capital stock movements are affected by output effects and substitution effects. The demand of the capital-energy bundle determines the output effect and the relative costs between capital and energy determines the substitution effect. In the early years, when carbon prices are low, the substitution effects dominate as overall demand for the capital-energy bundle are relatively less affected. In this phase, the contract in real GDP is small, and so are the contraction for the capital-energy bundle.

In addition, energy composition effects also help capital stock to be higher in the initial years. Recall that in BCS, the capital-using efficiency of nuclear power, onshore wind power, offshore wind power and solar power all improve. In the CNS, as the share of these energy outputs increase, the increase in capital-using efficiency has a higher contribution in enhancing overall capital-using efficiency and thus increase capital demand.

In the later years of the simulation (since late-2030s) output effects become dominate. Carbon price increases faster in late-2030s and real GDP falls faster during the same period. Fall in demand for the capital-energy bundle become dominate. In 2060, capital stock in CNS is 0.82% lower than it is in BCS.

Supply side decomposition

Decomposition of real GDP deviations on the supply side is shown in Fig. 13.22. From late 2030s, as carbon price levels increase, indirect taxes become the largest contributor to reduction in real GDP on the supply side. This is consistent with the simulation design, as carbon price changes are the main drivers to facilitate emissions abatement towards carbon neutrality.

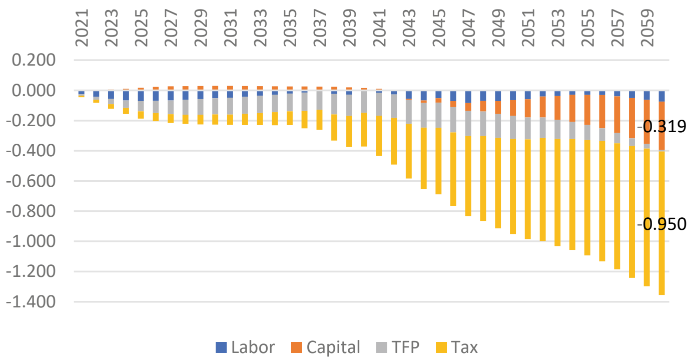


Fig. 13.22 Real GDP deviations—a decomposition on the supply side

13.4.2 Primary Energy Consumption and Composition

Total energy consumption continues to rise in CNS from 2020 (see Fig. 13.23). It begins to plateau in 2035 and peaks near 5800 mtce in 2040. It falls to just above 5500 mtce in late 2040s and stays near that level till 2060. Total energy consumption in CNS in 2060 is still higher than it is in 2020. This means it is possible to decouple energy consumption and CO_2 emissions.

Total energy consumption in CNS between 2020 and 2060 is 228 btce—95% of its BCS level. Hence, although the total energy consumption path is lower in CNS, cumulative energy consumption, as a percentage share, is not far below its BCS level. Nevertheless, the energy saving in absolute term, which mounts to 12 btce over 41 years, or 294 mtce per annum, is large.

China aims to increase non-fossil fuel share in total energy consumption (NFF/E) to 25% in 2030. In BCS this share is only 23% (see Fig. 13.24). In the CNS, however, the share just reaches this level. It shows that 25% target is consistent with

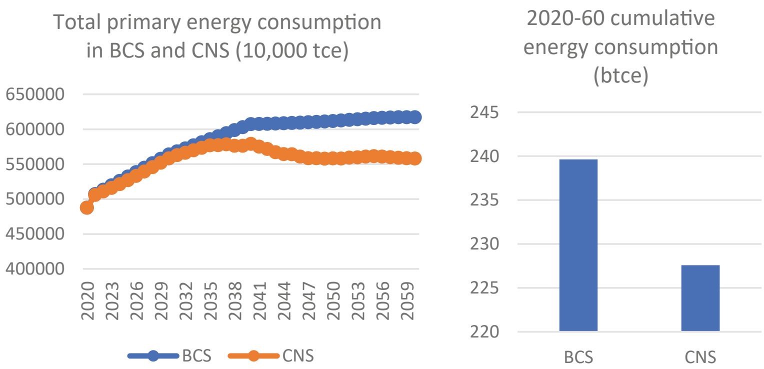


Fig. 13.23 Total primary energy consumption. *Source* Authors' simulation with CHINAGEM-E

a path towards carbon neutrality in 2060. That said, it is a challenge as it requires more mitigation efforts than those already exist in the base-case.

In CNS, NFF/E increases from 16% in 2020 to 73% in 2060. It is a significant 1.4 percentage points increase per annum. The share of cumulative non-fossil fuel in total energy consumption over the 41 years in BCS and CNS are 31% and 42%, respectively.

We show primary energy consumption by fuel types in CNS in Fig. 13.25. Coal dominates the energy composition in 2020. It takes 30 years from 2020 for solar power to overtake coal and become the largest primary energy source in 2050. Only 4 years later, in 2054, wind power output also exceeds coal. Solar and wind power contribute the most to total energy use in 2060, accounting for 31% and 22%, respectively. Coal's share falls to 12%. In 2060, solar power and wind power output levels are not only higher than coal, but are also higher than their respective BCS levels, despite lower total energy consumption.

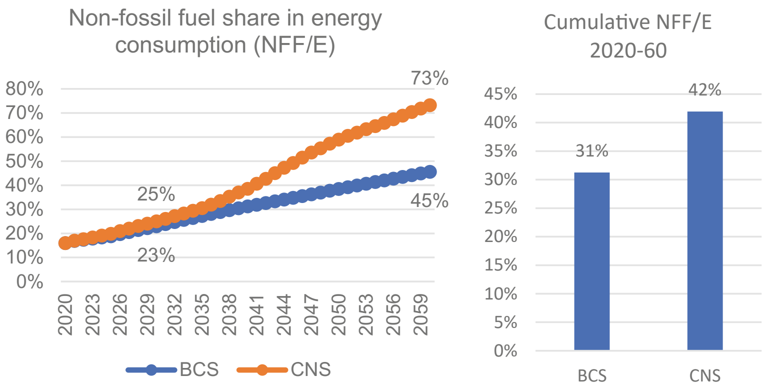


Fig. 13.24 Non-fossil fuel share in energy consumption (NFF/E)

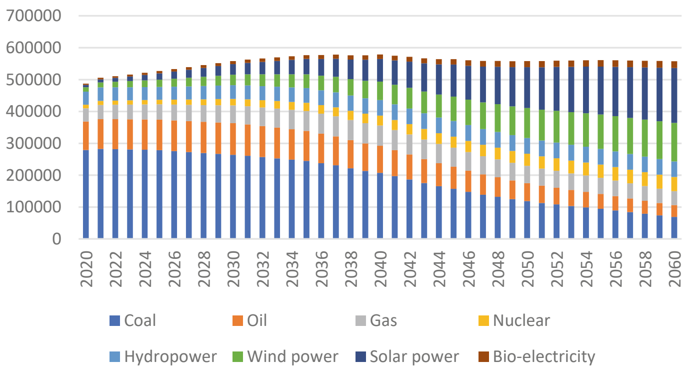


Fig. 13.25 Primary energy consumption by fuel type in CNS (10,000 tce)

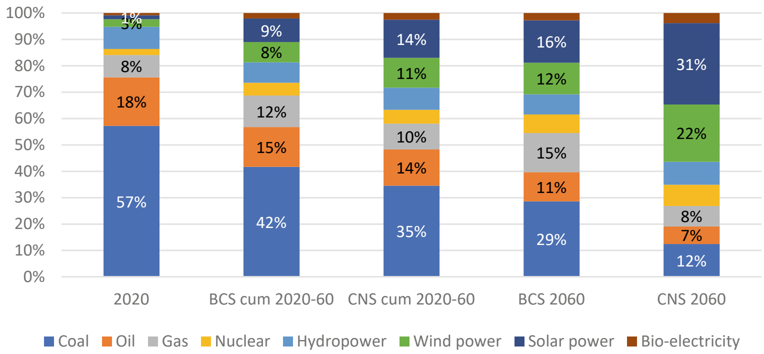


Fig. 13.26 Primary energy composition—a comparison between BCS and CNS

Figure 13.26 shows cumulative primary energy composition between 2020 and 2060. Coal is the largest primary energy source in cumulative term in both BCS and CNS. Adding energy consumption over the 41 years, coal accounts for 42% and 35% in BCS and CNS, respectively. In BCS, oil and gas are the second and third largest energy sources cumulatively, accounting for 15% and 12%, respectively. In CNS, solar power become the second largest, accounting for 14.5%. Oil is the third by 13.7%. Wind's share is still lower than oil's and is the fourth largest, accounting for 11%. Gas' share falls to the fifth, accounting for 10%.

13.4.3 Electricity Generation and Composition

We compare total electricity generation in BCS and CNS in Fig. 13.27. Electricity generation in CNS grows at a nearly constant rate over years, whereas it grows at a lower rate from early 2040s in the BCS. Hence electricity generation in CNS becomes noticeably higher than it is in the BCS from early 2040s and the gap expands afterwards. In 2060, electricity generation in CNS is 15.8 petawatt-hour (PWh)—1.6 PWh more than it is in BCS. Cumulative electricity generation between 2021 and 2060 in BCS and CNS are 458 PWh and 477 PWh, respectively. Our simulations thus show that carbon neutrality could lead to higher electricity consumption because of the higher rate of energy preference.

Electricity share in total final energy consumption (Elc/FE) keeps increasing in both BCS and CNS (Fig. 13.28). The share of electricity in final energy increases at a roughly constant rate in BCS and reaches 48% in 2060. The share in CNS increases at a similar rate as it in BCS till mid-2030s and then increases faster in CNS. By 2060, electricity accounts for 68% of total final energy consumption in CNS, this is 20 percentage points higher than it in BCS. Comparing with 2020, in CNS, the share of electricity in final energy increases 0.9 percentage points per annum. Cumulatively, Elc/FF is 40% and 46% in BCS and CNS, respectively.

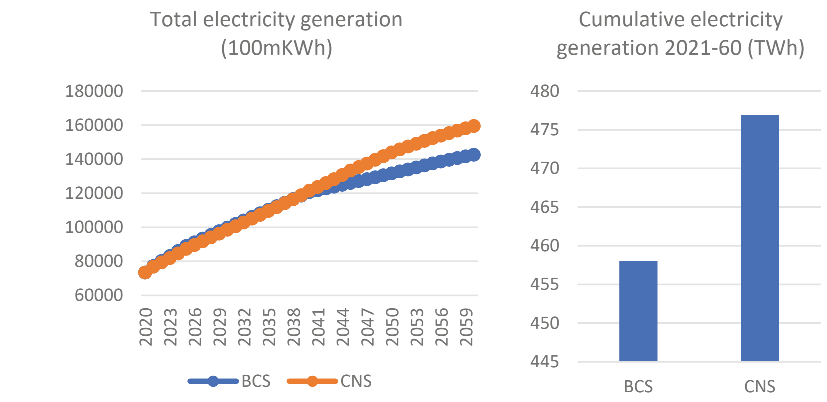


Fig. 13.27 Total electricity generation

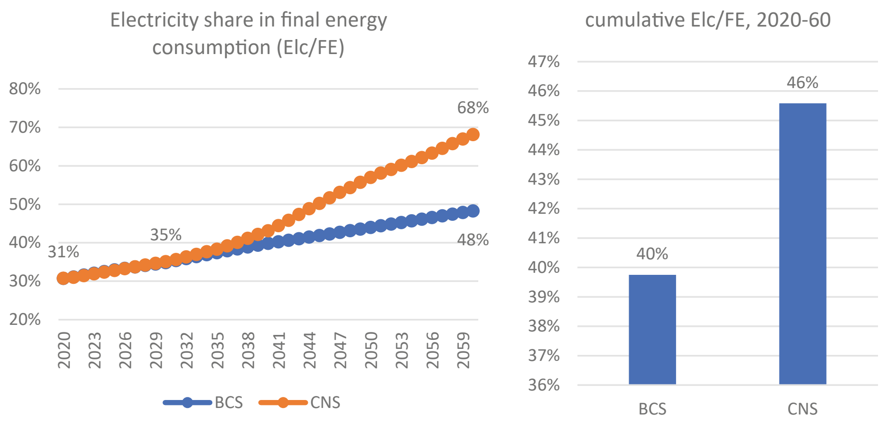
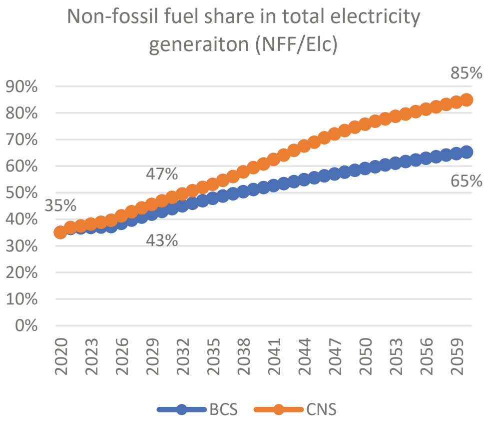


Fig. 13.28 Electricity share in final energy consumption

The share of non fossil fuel based electricity generation in total electricity generation (NFF/Elc) increases in both BCS and CNS (Fig. 13.29). From the beginning of the policy simulation, NFF/Elc increases faster in CSN than in BCS. By 2060, it reaches 65% and 85% in BCS and CNS, respectively. Between 2020 and 2060, in CNS, NFF/Elc increases by 1.2 percentage points per annum. Cumulatively, NFF/Elc is 40% and 51% in BCS and CNS, respectively.

We show electricity generation by fuel types under CNS in Fig. 13.30. Coal-fired power dominates in 2020. 62% of total power output is from coal-fired power generation in 2020. It takes 26 years from 2020 for solar power to overtake coal and become the largest source of electricity generation in 2046. Only 4 years later, in 2050, wind power output also exceeds coal-fired power. Solar and wind power contribute the most to total power generation in 2060, accounting for 36% and 25%, respectively. Coal-fired power's share falls to 11%.



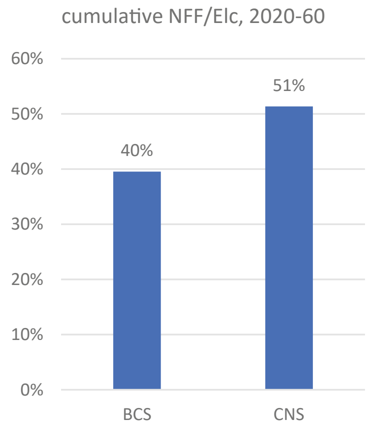


Fig. 13.29 Non-fossil fuel share in total electricity generation

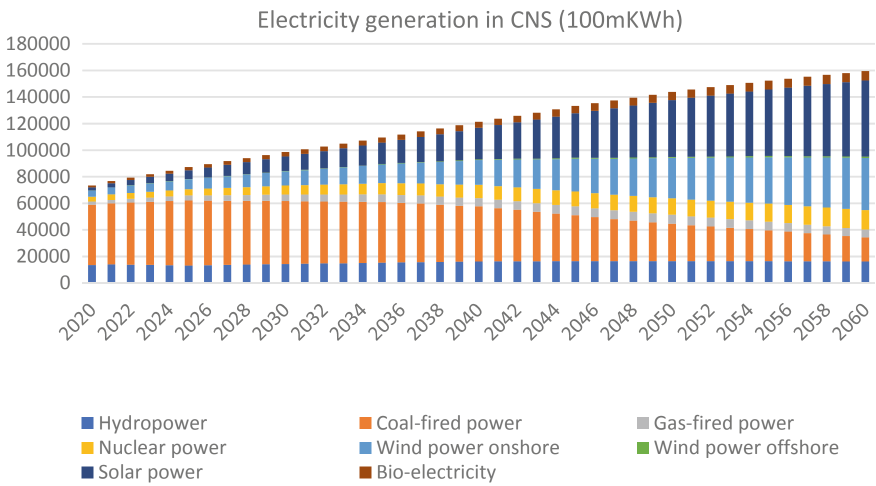


Fig. 13.30 Electricity generation by fuel type in CNS (100 mKWh)

Figure 13.31 shows cumulative electricity composition between 2020 and 2060. Coal is the largest primary energy source in cumulative term in both BCS and CNS. Summing electricity generation over the 41 years, coal-fired power accounts for 41% and 31% in BCS and CNS, respectively. Solar power is the second largest power source in both BCS and CNS cumulatively, accounting for 15% and 22% of total power output, respectively. In BCS, wind power and hydropower are equal third largest power sources, accounting for 13% to cumulative generation each. In CNS, though, wind power and hydropower account for 17% and 13%, and become the third and fourth largest power sources, respectively.

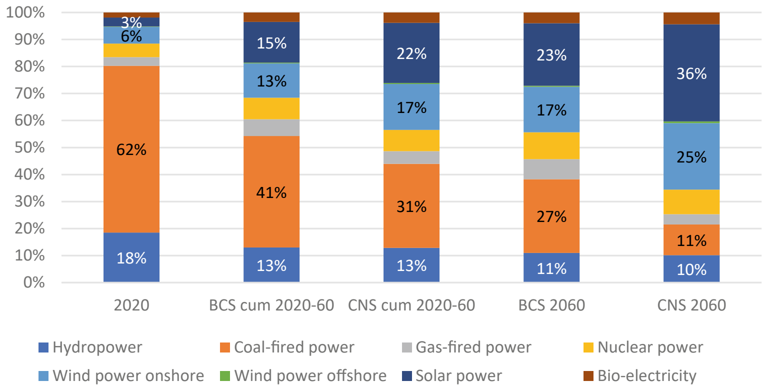


Fig. 13.31 Electricity generation composition

13.4.4 CCS-Related Results

Annual CCS and CO_2 emissions results are displayed in Fig. 13.32. Our simulations show that it is possible to achieve carbon neutrality while still having 3200 mtCO_2 emission in 2060. CCS, BECCS and DACCS will capture and store 1650 mtCO_2, 550 mtCO_2 and 1000 mtCO_2, respectively.

The amount of CO_2 emissions captured and stored by CCS peaks in 2048 at 2377 mtCO_2, and then gradually falls. This is because there are less emissions to be captured by CCS facilities from fossil-fuel burners, especially those from coal-fired power generation.

Figure 13.33 shows the cumulative emissions and emissions reduced by CCS between 2020 and 2060. Over the simulation years, CCS, BECCS and DACCS reduced emissions by 49 btCO_2, 5 btCO_2 and 3 btCO_2, respectively. These are equivalent to 17%, 2% and 1% of total emissions before being sequestrated by CCS,

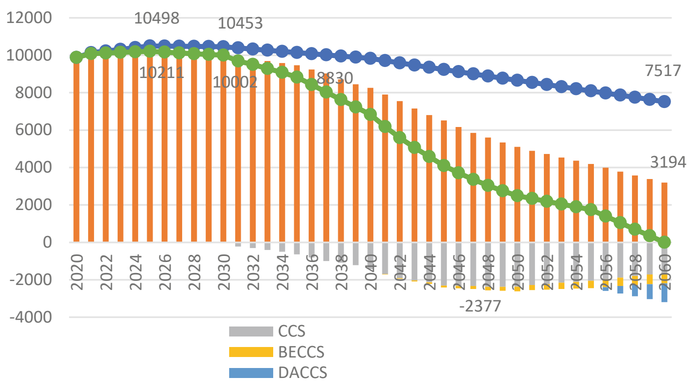


Fig. 13.32 Carbon dioxide emissions and CCS in CNS (mtCO_2)

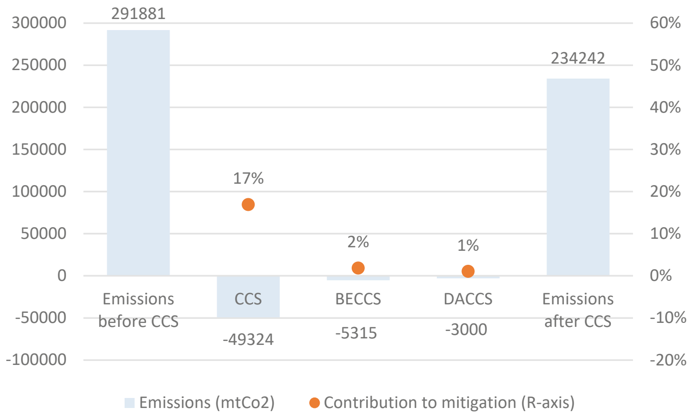


Fig. 13.33 Cumulative emissions and CCS in CNS, 2020–2060

respectively. Our simulations thus show that CCS would help to reduce cumulative emissions by 20% (58 btCO_2) over the simulation years.

13.5 Final Remarks

CHINAGEM-E has five major advancements from CHINAGEM, namely: (1) a finely disaggregated energy sector, (2) an advanced multi-layer fuel-factor nesting production structure, (3) a representation for specific carbon price, (4) physical quantitative accounts for energy consumption, electricity generation and CO_2 emissions, and (5) CCS mechanisms.

We illustrate the use of CHINAGEM-E in analyzing the energy and economic implications of carbon neutrality in China. We design a base-case scenario (BCS) to serve as the benchmark to which results are compared. We design a main policy scenario, the carbon neutrality scenario (CNS), to investigate the economic implications for China to reach carbon neutrality. We discuss in detail the assumptions used in these scenarios, including the macroeconomic closure, the energy efficiency and preference shocks and the carbon emissions pathways.

The following policy implications can be drawn from our analysis.

(1) China can reach its carbon neutrality target in 2060 meanwhile achieving its target to double GDP between 2020 and 2035. Real GDP in our main carbon neutrality scenario is 1.36% lower than it was in the base-case scenario, in 2060. Our results are consistent with the general results in the literature, that strong mitigation efforts do not necessarily derail economic development in the long-term, even before taking into the consideration of positive social benefits.
(2) The effect of carbon neutrality efforts on employment is very small. The employment in the carbon neutrality scenario is only 0.066% lower than it is in the base

case scenario in 2060. Clean energy sectors employ more persons, and this compensates job losses from fossil fuel-related sectors.

(3) Carbon neutrality efforts will reduce energy consumption. Under CNS, total primary energy consumption will likely to 'flat peak' in late 2030s, fall gradually, and stabilize at a lower level afterwards. Hence, despite continued economic growth, CNS could help China to decouple GDP growth and energy consumption growth.

(4) Non fossil fuel share in total energy consumption need to rise. China aims to increase non-fossil fuel share in total energy consumption to 25% in 2030. In BCS this share is only 23%. In the CNS, however, the share just reaches the target level. It shows that the 25% target is consistent with the carbon neutrality target. By 2060, it will reach 73% in CNS.

(5) Electricity consumption will continue to increase. Electricity consumption, which will be composed of more clean energy, will increase to levels above the BCS ones, despite total energy consumption is going to be lower than those in the BCS.

(6) CCS technologies are indispensable to carbon neutrality efforts. CCS, including fossil fuel-based CCS, BECCS and DACCS, could help to reduce total emissions between 2020 and 2060 by 20%. Fossil fuel-based CCS could reach a peak of almost 2400 mtCO_2 captured and stored in late 2040s.

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Chapter 14
Regional Extension and Its Application—The Regional Economic Implications of Carbon Neutrality in China

James Giesecke, Xiujian Peng, and Glyn Wittwer

Abstract We examine the regional economic consequences of the Chinese central government's proposal to limit China's peak carbon emissions before 2030 and to achieve carbon neutrality by 2060. This is done in two stages. First, we draw on detailed simulations at the national level of the economic consequences of China's net zero transition plan. These simulations are discussed in Chap. 13 herein (see Feng et al. in CHINAGEM-E: an energy and emissions extension of CHINAGEM—and its application in the context of carbon neutrality in China. Springer, 2023). Second, we develop a top-down regional model of the Chinese economy that distinguishes 31 regions. By inputting to this regional model the national results from the simulations reported in (Feng et al. in CHINAGEM-E: an energy and emissions extension of CHINAGEM—and its application in the context of carbon neutrality in China. Springer, 2023), we are able to trace the economic consequences of China's net zero plan for 31 regions.

Keywords China · Carbon neutrality · Regional CGE model · Top-down model

14.1 Introduction

Following the Chinese government's announcement of peaking carbon emissions before 2030 and achieving carbon neutrality before 2060, widespread attention has been devoted to exploring pathways for achieving these goals and their possible

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energy and economic implications for China. As the world's largest carbon dioxide emitter, reaching net zero carbon emissions in less than four decades requires substantial energy and economic structural change (Feng et al. 2023) This will impose significant challenges not only for the national economy but also for regional economies given the vast differences in the natural resource endowments and economic growth disparities between regions. Thus, investigating the implications of achieving the "two-carbon" goals for China's regional economies will provide quantitative support for the policy formation for both national and regional governments.

Though CHINAGEM is a large-scale economic-wide CGE model of the national economy, its flexibility allows us to decompose the national results to the regional level by incorporating a regional extension system into the core model. Using the top-down regional theory of Dixon and Rimmer (2007), this chapter will illustrate how the CHINAGEM model can be extended to estimate the regional consequences of national policies or shocks. We use the national carbon neutrality scenario as an example.

This chapter is organized as follows: in Sect. 14.2, we briefly summarize the national results of the carbon neutrality simulation. An explanation of the top-down regional model is provided in Sect. 14.3. In Sect. 14.4, we explain how to use the databases of the CHINAGEM and SinoTERM (a multiregional model of the Chinese economy with 365 regions) to develop the data needed for the top-down regional model. The regional results are discussed in Sect. 14.5. Conclusions and avenues for further study are discussed in Sect. 14.6.

14.2 Overview of the National Results

As discussed in Feng et al. (2023) (Chap. 13 herein), the CHINAGEM-E model is used to simulate the economic implications of China's decarbonisation efforts over the period of 2020–2060 at the national level. CHINAGEM-E is an extension of the CHINAGEM model. It was developed for the purpose of analysing energy and climate change related issues. It features disaggregated energy sectors, a detailed and updated database, a new power generation nesting structure, energy and carbon emission accounts, carbon tax, and carbon capture and storage (CCS) mechanism.

To investigate the economic effects of China's carbon neutrality efforts, Feng et al. (2023) first designed a business-as-usual base-case scenario (BCS) to serve as the benchmark against which policy results are compared, and a core policy scenario, the carbon neutrality scenario (CNS). Feng et al. discuss in detail the assumptions used in these scenarios, including the macroeconomic closure, the energy efficiency and preference shocks, the CCS assumptions, and the carbon emissions pathways. Feng et al.'s simulation results show that carbon neutrality will change China's energy structure significantly. Coal's share in primary energy consumption will decline from 57% in 2020 to 12.5% in 2060, while the share of non-fossil fuels will nearly quadruple, reaching 74%. Among the non-fossil fuel, solar and wind power will increase the most. Their shares will increase sharply from less than 1% and 3% in 2020, to 31%

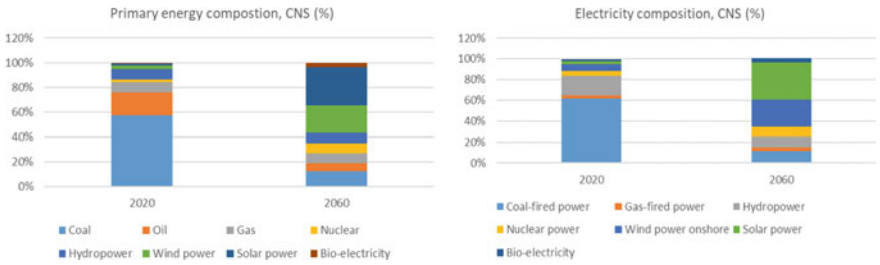

Fig. 14.1 China's changing energy structure in CNS. *Source* CHINAGEM-E carbon neutrality simulation results

and 22%, respectively in 2060. Meanwhile, the penetration of electricity into the economy is projected to increase strongly, with the share of electricity in final energy more than doubling between 2020 (31%) and 2060 (68%). Much of the additional electricity use will be clean. For instance, 62% of total electricity is from coal-fired power generation in 2020. This share will fall to 11% while the contribution of solar and wind power generation will increase to 36% and 25% respectively by 2060. The share of bioenergy will also double, from 2 to 4%. The rest of the clean electricity will come from traditional hydropower and nuclear power (Fig. 14.1).

The dramatic change in China's energy structure will no doubt cause a significant change in its economic structure. Fossil fuel and energy intensive sectors will contract considerably, while non-fossil fuel sectors will boom. While Feng et al.'s simulations project significant structural change, the effects of carbon neutrality on the macro economy are mild. By 2060 real GDP will be approximately 1.4% lower than in the baseline scenario. To put it another way, from 2020 to 2060, with climate action China's real GDP will grow at 3.56% per year compared to 3.61% per annum without action. The carbon neutrality action will affect capital mildly, with a 0.82% lower capital stock in 2060 compared with the base case scenario. The effect on national employment is also small. By 2060, employment (measured in wage bill weights) is 0.1% lower than its BCS level, and the real wage is 0.6% lower.

While the economic effects of decarbonization at the national level are small, we expect a different story at the regional level, especially for those regions that rely heavily on fossil fuel mining and extraction, and those regions with significant activity by energy-intensive industries. At the same time, we would expect that regions concentrating on the development of non-fossil fuel and related industries will experience relative expansion during China's net zero transition.

As we shall discuss in Sect. 14.5, the effects on regional economic outcomes of China's net zero transition depend on prospects for certain industries that are projected to be either adversely or positively affected by net zero policies. To facilitate the discussion in Sect. 14.5, we reproduce in Table 14.1, from Feng et al.'s (2023) simulation, the output deviation results by industry for the top eleven and bottom eleven industries ranked by 2060 output deviation.

As is clear from Table 14.1, the sectors that are most adversely affected by the transition to net-zero emissions are those that are related to the mining and extraction of fossil fuel primary resources (*Coal mining*, *Crude oil extraction*, *Gas extraction*,

Table 14.1 Output of top- and bottom-ranked industries by 2060 output deviation (percent deviation from baseline)

	2020	2030	2040	2050	2060
Bottom-ranked sectors					
Coal mining	0.0	– 4.8	– 17.2	– 42.9	– 58.7
Coal-fired electricity	0.0	– 8.1	– 17.8	– 37.0	– 53.8
Production and distribution of gas	0.0	– 1.1	– 8.8	– 31.2	– 46.0
Gas-fired electricity	0.0	– 7.1	– 18.4	– 28.1	– 45.6
Petroleum refining	0.0	– 0.7	– 7.1	– 26.0	– 38.9
Processed coal	0.0	– 0.7	– 8.5	– 27.7	– 35.1
Pipeline transportation	0.0	– 0.7	– 7.2	– 24.6	– 33.7
Conventional gas extraction	0.0	– 0.5	– 3.7	– 16.1	– 30.2
Non-conventional gas extraction	0.0	– 0.5	– 3.7	– 16.1	– 30.2
Crude oil extraction	0.0	– 0.3	– 4.0	– 17.1	– 29.2
Mining services	0.0	– 0.6	– 3.4	– 12.8	– 21.2
Top-ranked sectors					
Manufacture of measuring equipment	0.0	0.0	0.7	2.1	2.5
Machinery and equipment repair	0.0	0.0	0.7	2.1	2.6
Nuclear power generation	0.0	3.6	3.8	3.1	2.6
Water management services	0.0	0.0	1.0	3.0	3.5
Hydro-generated electricity	0.0	3.0	3.6	3.6	3.7
Elec. transmission and distribution equipment manuf.	0.0	0.5	2.2	6.0	6.5
Electricity distribution	0.0	– 1.2	0.7	9.4	11.7
Bio-energy generation	0.0	4.4	11.4	25.5	24.2
Wind-powered generation (on-shore)	0.0	11.4	25.1	57.7	65.7
Solar-powered electricity generation	0.0	16.2	35.8	75.4	76.6
Wind-powered generation (off-shore)	0.0	13.1	32.0	74.4	77.5

Source CHINAGEM-E carbon neutrality simulation results

Mining services), the processing and transportation of these resources (*Gas production and distribution*, *Petroleum refining*, *Processed coal manufacturing*, *Pipeline transportation*), and the burning of fossil fuels to generate electricity (*Coal-fired electricity generation*, *Gas-fired electricity generation*). The sectors that are positively affected by the transition to net zero emissions are non-fossil fuel electricity generators (*Wind-power*, *Solar-power*, *Bio-energy*, *Hydroelectricity*, *Nuclear power*) and sectors that benefit from the electrification of energy-using activities (*Manufacture of measuring equipment*, *Machinery and equipment repair*, *Power transmission and distribution equipment manufacturing*, *Electricity generation*). In Sect. 14.5, we will refer back to the outcomes for these industries in explaining the relative economic prospects for China's provinces under the net zero transition policy.

14.3 Overview of the Top-Down Regional Model

As discussed in Sect. 14.1, we use the top-down regional theory of Dixon and Rimmer (2007) to explore the regional consequences of the national carbon policy scenario investigated in Chap. 13 herein (Feng et al. 2023). Here, we summarise the regional model's core equations via Eqs. (14.1)–(14.14) (see Sect. 1.1 in Appendix 1 to this Chapter).[1] Section 1.4 in Appendix 1 describes the model's core coefficients. These are evaluated using a SinoTERM database for the Chinese economy (see Sect. 14.3).[2]

Equations (14.1)–(14.3) in Appendix 1 are the core of the top-down system. Equation (14.2) calculates the demand in region *r* (each of 31 Chinese regions) for commodity *c* (each of 157 commodities) from source *s* (China or foreign). Equation (14.1) determines which regions satisfy those demands. Satisfaction of supplies of domestic commodity *i* by region *r* determines output for industry *i* in region *r* via Eq. (14.3). The remaining equations of the model largely relate to the determination of the variables on the right-hand-side of Eq. (14.2), namely, commodity demands by each economic agent within each region. We expand on the structure of the model below.

Each of the model's 157 commodities is associated with one of two sources: domestic (that is, Chinese) and foreign. Equation (14.1) defines the percentage change in total supply of source-specific commodity *i*, *s* from domestic region *r* as the (share weighted) sum of percentage changes in demand for *i*, *s* from *r* across all demanding regions.

Equation (14.2) calculates total demand for commodity *i* from source *s* for each region, *r*. The percentage change in demand for commodity *i*, *s* by agents in region *r* is the share-weighted sum across agents of percentage changes in agent-specific demands for *i*, *s* within region *r*.

Equation (14.3) determines the percentage change in the output of industry j in region r ($z_{j,r}$). The possibility for multi-production (that is, commodity *i* being produced by multiple industries, *j*) is recognised by the coefficient SHCI(i, j), which records the SinoTERM (see Wittwer and Horridge 2018) value for the share of industry *j*'s output represented by output of commodity *i*, essentially as the percentage change in supply of domestic commodity *j* by region *r* ($x0CSR_{j,dom,r}$). Equation (14.3) provides output of industry *j* in region *r* to move in proportion with the CHINAGEM-E result for national output of industry *j*, unless the top-down regional model calculates that region *r* is being called upon (via Eq. 14.1) to supply output to a greater (lesser) degree than the national average, in which case output of industry *j* in region *r* will expand by more (less) than the national average expansion in *j* as given by CHINAGEM-E.

[1] Equations (14.1)–(14.14) simplify the presentation of the top-down theory by describing margin demands as being exogenous. In the full theory, both as described in Dixon and Rimmer (2007), and as implemented in the model underpinning the simulations presented in this paper, margin demands are endogenous and linked to trade flows within and between regions. Readers interested in more details of the regional theory are referred to Dixon and Rimmer (2007).

[2] See Horridge et al. (2005) for a discussion of the TERM model and its parameterization.

Equation (14.2) introduces source-specific commodity demands by each agent in region r. Equations (14.4)–(14.10) define these demands. As Dixon and Rimmer (2007) describe, these, and a number of other equations in the model describing regional activity variables, have the form:

$$reg_{x,r} = chinagem_x + (relevant_r - \sum\nolimits_{k \in REG} \mathrm{SH_{x,k}} \times relevant_k)$$

where,

$reg_{x,r}$	is the percentage change in variable x in region r.
$chinagem_x$	is the percentage change in variable x at the national level, as calculated in CHINAGEM-E. Since the regional model is top-down, the value for $chinagem_x$ is imposed exogenously and set at its corresponding CHINAGEM-E value for each year of the regional model simulation.
$relevant_r$	is the percentage change in some variable at the regional level that is relevant to the determination of the value for variable x in region r.
$\mathrm{SH_{x,k}}$	is the share of the national level of x that takes place in region r.

This formulation says that the regional result for variable x will move with the national result for variable x, unless the value for some regional variable relevant to the determination of the regional value of x rises or falls relative to the economy-wide average value for that relevant variable. Since $\sum_{\mathrm{k}} \mathrm{SH_{x,k}} = 1$, this formulation ensures that the regional results for $reg_{x,r}$ accord with the economy-wide result for x, that is: $\sum_{k \in REG} \mathrm{SH_{x,k}} \times reg_{x,k} = chinagem_x$. Equations (14.4)–(14.9) are each built around this basic form. Equation (14.4) says that demand for commodity i from source s for use as an intermediate input by industry j in region d ($x1r_{i,s,j,d}$) moves in proportion with the CHINAGEM-E value for intermediate input demand for commodity i, s by national industry j ($x1csi^{(C)}_{i,s,j}$) unless movement in the output of j in region d ($x0IR_{j,d}$) deviates from the economy-wide average output of j. Equation (14.5) applies the same form to demand for source specific commodity i, s by regional industry j, d for capital formation. Equation (14.6) applies the specification to regional household demands for source-specific commodities, using regional household disposable income (yr_d) as the "relevant" variable.

Equation (14.7) calculates household disposable income, relating the deviation in regional household disposable income (yr_r) from the economy-wide average ($y^{(C)}$) to the deviation in regional employment ($empr_r$) from the economy-wide average ($emp^{(C)}$).

In general, exports of commodity i from region d move with national exports of commodity i (Eq. 14.8), unless a change occurs in the share of national exports of commodity i originating from region d ($reg4_{i,d}$).

In the absence of changes in the sourcing of government demands ($reg5_d$) Eq. (14.9) calculates the percentage change in government demand for commodity i, s in region d via an indexing relationship with the corresponding national variable. Equation (14.10) allocates national inventory demand across regions on the basis of fixed shares.

Equations (14.11) and (14.12) calculate real regional GDP at factor cost (14.11) and market prices (14.12). Equation (14.11) is a production-based calculation of real regional GDP at factor cost, where $VASHJ_{j,r}$ is the share of region *r*'s value added represented by value added in industry *j*. Equation (14.12) uses the national/relevant variable scheme to calculate real gross regional product at market prices.

Equations (14.13) and (14.14) calculate regional employment. Equation (14.13) calculates regional employment ($empr_r$) using the national/relevant pattern. Equation (14.14) defines the "relevant" variable for regional employment determination ($relemp_r$).

14.4 Using CHINAGEM-E and SinoTERM Data to Parameterise the Top-Down Model

Table 14.3 documents the coefficients of the regional model. As is clear from Table 14.3, the regional model's coefficients are evaluated using a mix of national and regional data. The former are sourced from the CHIANGEM-E database, and we refer the reader to Chap. 13 for more information on the compilation of these data. The latter are sourced from the regional CGE model SinoTERM (Wittwer and Horridge 2018). We refer the reader to Wittwer and Horridge (2018) for more details on SinoTERM and the compilation of its data, but provide below a summary of the key ideas.

As documented in Table 14.3, the initial evaluation of the coefficients of the regional model draws on the full details of a disaggregated multi-regional input-output table. In describing the data inputs in Table 14.3, we use the SinoTERM naming conventions in describing relevant elements of the input output table. To be precise, the initial solution to SinoTERM requires regional data describing:

- The structure and composition of the use of commodities for production, investment, private consumption, public consumption and export within each region (given by the SinoTERM coefficient $USE_{(i,s,u,r)}$, describing the value of purchases of commodity *i* from source *s* by agent *u* in region *r*.
- Labour costs, $VLAB_{(j,r)}$, describing the payments for labour inputs by industry *j* in region *r*.
- Primary factor payments, $PRIM_{(j,r)}$, describing the total value of payments for primary factors (labour, capital and land) by industry *j* in region *r*.
- Investment activity, $INVEST_{(j,r)}$, describing the value of gross fixed capital formation in industry *j* in region *r*.
- Inter-regional trade flows, TRADE(i,s,q,r), describing the value of purchases by agents in region r of commodity *i* from source *s* satisfied by supplies from region *q*.

These data are sourced from the SinoTERM model. Broadly, the SinoTERM database, based on the 2012 national input-output table prepared by the National

Bureau of Statistics in Beijing, uses regional shares data compiled from China Data Center, University of Michigan (accessed via the National Library of Australia). In particular, the site provided access to provincial statistical yearbooks. Although the University of Michigan's resource is no longer accessible (Leung 2018), the data are now available at a new site (see https://chinadatacenter.net/). The regional shares were prepared at the prefectural level (365 regions). The provincial statistical yearbooks accessed via the China Data Center contained data from a combination of the 2005 census and 2014 provincial national accounts. Data of variable quality covered agricultural, manufacturing and services output. Table 14.2 of Wittwer and Horridge (2018) contains details of data coverage. SinoTERM is disaggregated into different types of electricity generation. Data on power plant capacity, type of generation and location were available at the now inoperative carma.org website.[3] If available, international trade data at the port level are used to provide regional shares of international merchandise trade. SinoTERM international merchandise trade share estimates are sourced from various websites outlining the activities of international ports. The regional output, investment, consumption and trade shares from SinoTERM are aggregated to the provincial level for the present application.

The TRADE matrix estimated in SinoTERM is based on a modified gravity assumption as outlined in Horridge (2012). Some sectors, such as dwellings services, are designated as non-tradable between regions. Hence, regional output must equal regional demand, with no off-diagonal elements in the TRADE matrix. For relatively tradable commodities, estimates of regional supplies and regional demands provide a starting point for estimating trade. However, even if a region's production and demands for a given commodity are equal, there is still trade with other regions. If a commodity is tradable, trade is distributed using the gravity assumption, in which trade values are inversely proportional to distance.

14.5 Regional Results

Table 14.2 reports the real regional GDP deviations for each province from the base case scenario (BCS). For comparison, we also include the real national GDP deviation (the last row). While the model is dynamic and traces annual time paths for variables, in Table 14.2 we simplify the presentation by presenting deviation results at the end of each decade. By 2060, real GDP at the national level with carbon neutrality action will be nearly 1.4% lower than in the BCS while the effects on each region varies considerably. We discuss below the results for the highest and lowest ranked provinces in terms of 2060 real GDP deviations. The lowest ranked regions in 2060 are Shaanxi (− 3.6%), Shanxi (− 3.3%), Heilongjiang (− 2.2%), Shanghai (− 2.1%), Tianjin (− 2.1%) and Henan (− 2.1%). The highest ranked regions in

[3] Global data on power plants are now downloadable at https://github.com/wri/global-power-plant-database.

Table 14.2 Provincial real GDP (percent deviation from baseline)

	2020	2030	2040	2050	2060
1. Beijing	0.00	− 0.24	− 0.48	− 1.21	− 1.73
2. Tianjin	**0.00**	**− 0.29**	**− 0.64**	**− 1.64**	**− 2.07**
3. Hebei	0.00	− 0.11	− 0.13	− 0.44	− 0.85
4. Shanxi	**0.00**	**− 0.83**	**− 1.90**	**− 3.17**	**− 3.31**
5. Inner Mongolia	*0.00*	*− 0.31*	*− 0.37*	*0.22*	*0.31*
6. Liaoning	0.00	− 0.20	− 0.43	− 1.19	− 1.64
7. Jilin	0.00	− 0.19	− 0.47	− 1.33	− 1.85
8. Heilongjiang	**0.00**	**− 0.23**	**− 0.60**	**− 1.62**	**− 2.16**
9. Shanghai	**0.00**	**− 0.26**	**− 0.61**	**− 1.63**	**− 2.14**
10. Jiangsu	0.00	− 0.23	− 0.50	− 1.37	− 1.88
11. Zhejiang	0.00	− 0.23	− 0.38	− 0.99	− 1.41
12. Anhui	0.00	− 0.23	− 0.41	− 0.98	− 1.45
13. Fujian	0.00	− 0.13	− 0.22	− 0.63	− 1.02
14. Jiangxi	0.00	− 0.20	− 0.36	− 1.00	− 1.38
15. Shandong	0.00	− 0.22	− 0.41	− 1.08	− 1.46
16. Henan	**0.00**	**− 0.29**	**− 0.66**	**− 1.63**	**− 2.06**
17. Hubei	0.00	− 0.18	− 0.36	− 1.10	− 1.56
18. Hunan	0.00	− 0.22	− 0.51	− 1.50	− 1.95
19. Guangdong	0.00	− 0.19	− 0.39	− 1.02	− 1.35
20. Guangxi	0.00	− 0.18	− 0.35	− 1.03	− 1.40
21. Hainan	0.00	− 0.14	− 0.25	− 0.76	− 1.16
22. Chongqing	0.00	− 0.24	− 0.55	− 1.49	− 1.98
23. Sichuan	0.00	− 0.12	− 0.32	− 1.19	− 1.81
24. Guizhou	0.00	− 0.40	− 0.77	− 1.48	− 1.77
25. Yunnan	*0.00*	*0.23*	*0.68*	*1.17*	*0.82*
26. Tibet	0.00	0.06	0.27	0.21	− 0.25
27. Shaanxi	**0.00**	**− 0.57**	**− 1.48**	**− 3.06**	**− 3.60**
28. Gansu	*0.00*	*0.72*	*2.15*	*4.37*	*4.07*
29. Qinghai	*0.00*	*3.50*	*10.30*	*21.32*	*21.36*
30. Ningxia	*0.00*	*1.17*	*3.87*	*9.03*	*9.18*
31. Xinjiang	*0.00*	*0.50*	*1.72*	*3.57*	*3.29*
National					− 1.36

Source CHINAGEM-E with regional extension simulation results
Note: The highest and lowest ranked provinces in terms of 2060 real GDP deviations are denoted in italic and bold font respectively

2060 are Inner Mongolia (0.31%), Yunnan (0.82%), Xinjiang (3.3%), Gansu (4.1%), Ningxia (9.2%) and Qinghai (23%).

While the regional outcomes are influenced by local multiplier and inter-regional trade effects, the dominant factor determining regional economic outcomes are the relative importance of particular industries within each regional economy. As such, in the discussion that follows, we focus on the relative importance to each regional economy (in terms of value added share) of those industries (as reported in Table 14.1) that are projected to be either adversely or positively affected by policies aimed at transitioning China's economy to net zero emissions by 2060. In general, a regional economy's real GDP deviation ranking is buoyed by having: (i) a relatively high share of its regional activity in sectors that are positively affected by the net zero transition; and or (ii) a relatively low share of its regional activity in sectors that are negatively affected by the net zero transition. The corollary also holds: a regional economy's real GDP deviation will tend to be lowered by having: (i) a relatively high share of its regional activity in sectors that are adversely affected by the net zero transition; and/or (ii) a relatively low share of its regional activity in sectors that are favourably affected by the net zero transition.

We begin by discussing the outcomes for the regions that are most adversely affected by the transition to net zero emissions, beginning with Shaanxi, the lowest-ranked province in terms of 2060 real gross regional product deviation (− 3.6%, see Table 14.2). While Shaanxi has an above average share of its regional GDP in the *Solar-powered electricity generation sector,* this is not sufficient to compensate for its comparatively high exposure to fossil fuel sectors. Relative to the national average, Shaanxi has above average shares of its regional value added in sectors that are adversely affected by the net zero transition, in particular *Coal mining, Crude oil extraction, Gas extraction, Mining services* and *Coal-fired electricity generation.*

Shanxi is the second lowest ranked province in terms of 2060 real gross regional product deviation (− 3.3%, see Table 14.2). Like Shaanxi, Shanxi has above average shares of its regional GDP in selected renewable generation sectors (Wind- and Solar-powered electricity generation), but not sufficient to compensate for relatively high regional value added shares in a number of fossil fuel sectors. In particular, Shanxi's baseline economic activity is over-represented (relative to the national average) by *Coal mining*, *Coal-fired electricity generation, Mining services,* and *Gas-fired electricity generation.* At the same time, a number of sectors that benefit from the net zero transition are under-represented in Shanxi's economy relative to the national average, in particular: *Electricity transmission and distribution equipment manufacturing,* and *Hydro-generated electricity.*

The third lowest ranked province in terms of 2060 real gross regional product deviation is Heilongjiang (− 2.2%, see Table 14.2). Heilongjiang's ranking suffers from the high share of its regional economic activity in the *Crude oil extraction* and *Mining services* sectors. At the same time, Heilongjiang's regional economy is under-represented in a number of sectors that are favourably affected by the transition to net zero emissions, in particular *Solar-powered electricity generation*, *Electricity transmission and distribution equipment manufacturing, Electricity distribution* and *Electronic parts manufacturing.*

Shanghai is the fourth lowest ranked province in terms of 2060 real gross regional product deviation (− 2.1%, see Table 14.2). Shanghai's low real GDP ranking is largely attributable to the under-representation in its regional economic structure of a number of sectors that are favourably affected by the net zero transition, in particular *Wind-powered generation, Solar-powered electricity generation,* and *Electricity distribution.*

Tianjin is the fifth lowest ranked province in terms of 2060 real gross regional product deviation (− 2.1%, see Table 14.2). This is largely due to the comparatively high share of Tianjin's regional economic activity attributable to *Crude oil extraction,* and *Mining services*, two sectors which are adversely affected the net zero transition. At the same time, Tianjin has comparatively low shares of its regional economic activity in sectors that are favourably affected by the net zero transition, in particular: *Wind-powered electricity generation*, *Solar-powered electricity generation*, *Electricity transmission and distribution equipment manufacturing,* and *Bio-energy generation.*

The sixth lowest ranked province in terms of 2060 real gross regional product deviation is Henan (− 2.1%, see Table 14.2). Economic activity in Henan's regional economy is over-representation by a number of adversely affected sectors (in particular *Petroleum refining*, *Processed coal*, and *Coal-fired electricity generation*). At the same time, a number of sectors that are favourably affected by the net zero transition represent below-average shares of Henan's regional economic activity, in particular: *Wind-powered electricity generation*, *Electricity transmission and distribution equipment manufacturing,* and *Solar-powered electricity generation.*

We turn now to discuss the regions that are favourably affected by the transition to net zero emissions. We begin with Inner Mongolia, which is the sixth-ranked province in terms of 2060 real gross regional product deviation (0.3%, see Table 14.2). At one level, the finding that Inner Mongolia's economy is a relative beneficiary of China's carbon neutrality action is somewhat unexpected, given its rich fossil fuel resources and relatively heavily energy-based industrial structure. For instance, Inner Mongolia has comparatively high shares of its local activity in *Coal mining* and *Mining services*, which are relatively adversely affected sectors. This acts to damp Inner Mongolia's real GDP deviation relative to other regions. However, this relative handicap is more than offset by Inner Mongolia also having relatively high shares of its activity in sectors that are favourably affected by the transition to net-zero, in particular: *Wind-powered generation*, *Solar-powered generation*, and *Electricity distribution.* Its unique geographical location and extensive prairies are the reasons for the rapid development of wind-powered generation and solar-powered generation. Transmitting and distributing its electricity to the advanced eastern and southern regions also promote its electricity distribution industry. Furthermore, Inner Mongolia's real gross regional product ranking is also aided by it having comparatively low shares, relative to the national average, in a number of sectors that are adversely affected by the net-zero transition, in particular *Petroleum refining*, *Gas supply*, *Crude oil extraction* and *Gas extraction.*

Yunnan is the fifth ranked province in terms of 2060 real gross regional product deviation (0.8%, see Table 14.2). Yunnan benefits from having a relatively low share of its regional economic activity in a number of sectors that are adversely affected by the net zero transition. In particular *Coal mining*, *Crude oil extraction*, *Gas extraction*, *Gas supply*, *Coal-fired electricity generation* and *Gas-fired electricity generation.* At the same time, the region begins with, and continues to have in the baseline forecast, comparatively high shares of its economic activity in a number of sectors that benefit from the net zero transition, in particular: *Hydro-generated electricity* and *Wind-generated electricity.*

Xinjiang is the fourth ranked province in terms of 2060 real gross regional product deviation (3.3%, see Table 14.2). This is despite Xinjiang having a comparatively high share of its economic activity in sectors that are adversely affected by the transition to net zero emissions (in particular, *Coal mining*, *Crude oil extraction*, *Gas extraction*, *Coal-fired electricity generation*, and *Gas-fired electricity generation*). Similar to Inner Mongolia, the adverse impact on Xinjiang's real GDP deviation of the relatively high shares of its economic activity in these sectors is more than offset by the region also having relatively high shares of its activity in a number of energy sectors that expand rapidly because of the net zero transition, in particular *Wind-generated electricity* and *Solar-generated electricity*. The region also benefits from a relatively high share of its activity in *Crops*, a sector that expands relative to the baseline scenario.

Gansu is the third ranked province in terms of 2060 real gross regional product deviation (4.1%, see Table 14.2). Gansu's real GDP ranking is buoyed by the growth in *Wind-powered generation*, *Solar-powered generation*, *Hydro-generation* and *Electricity distribution*; sectors which represent relatively high shares of Gansu's economic activity, compared to the national average.

Ningxia is the second ranked province in terms of 2060 real gross regional product deviation (9.2%, see Table 14.2). This is despite Ningxia having a higher share than the national average of its gross regional product in the baseline accounted for by *Coal mining* and *Coal-fired generation.* The negative impact on Ningxia's potential real GDP ranking of the adverse impact of the net zero transition on these sectors is more than offset by the positive impact on *Wind-generated electricity*, *Solar-generated electricity* and *Electricity distribution*; sectors that represent a relatively high share of Ningxia's economic activity relative to the national average.

Qinghai is the top-ranked region in terms of 2060 real gross regional product deviation. Its long sunshine hours (3100–3600 h annually), and extensive and sparsely populated area, are ideal for building large-scale photovoltaic grid-connected power plants. The rapid development of *Solar-powered electricity generation* makes the most contribution to its relative expansion under the nation's carbon neutrality action. The development of *Hydro-powered electricity generation* is the other reason for its higher real gross regional product deviation by 2060.

14.6 Conclusions

Using the national carbon neutrality scenario as an example, this chapter demonstrates how the CHIANGEM model can be extended to estimate the regional consequences of national policies or shocks through a top-down disaggregation system. Though achieving carbon neutrality by 2060 requires significant changes in China's energy and economic structure, the effects of decarbonisation efforts on the national economy are mild. Consistent with the outcomes at the national level, most regions experience small negative GDP deviations relative to baseline. Only the regions which heavily rely on fossil fuel mining and extraction experience comparatively larger negative real GDP deviations, for example, Shaanxi, Shanxi, Heilongjia and Henan. Regions that have more abundant cleaner energy sources experience gains relative to other regions during China's net-zero emission transition. Interestingly, those regions that gain the most are currently economically underdeveloped areas. They are located either in the northwest (Inner Mongolia, Xinjiang, Gansu, Ningxia and Qinghai), or southwest (Yunnan), far from high-tech and high-growth Eastern and Southern regions. Carbon neutrality action potentially offers these less developed areas opportunities for economic growth, which could help China narrow regional economic disparities, especially between the western and eastern regions.

We would like to mention that the results in this chapter are generated in a purely top-down way. What this means is that in the policy scenario, the effects of the national industrial development outcomes for key industries (like those in the renewable energy sector) are disaggregated into regions according to the base case regional industry shares. The central government's Great Western Development Strategy, which was implemented at the beginning of this century, appears to favour those western regions. In our base case, these regions already have high shares of renewable energy production and distribution, and so our model results capture the idea that a high share of future growth in these sectors will occur in these regions. Following China's 2060 carbon neutrality pledge, the latest Five Year Plan for social and economic development which was released in March 2022 includes detailed policies to achieve neutrality. Each region is in the process of forming its own net zero emission strategies. In future work, we will refine the regional results by adding specific regional shocks based on the detailed national and regional plans.

In this chapter we have focussed on presenting a discussion of the real GDP results. In future work, we would like to expand this to analyse regional household income and consumption. The regional distribution of results for these variables could differ from the regional distribution of real GDP results reported in this chapter. Renewable energy generation and distribution is capital intensive. Capital owners may live outside the regions of generation. As such, the income generated by the renewable generation activities will likely flow to wealthier regions with high concentrations of capital owners.

Appendix 1: Core Equations, Variables, Coefficients and Parameters of the Regional Model

1.1 Equations

$$\mathrm{TOTSUPREG}_{\mathrm{i,s,r}} \times x0CSR_{i,s,r} = \sum_{\mathrm{g \in REG}} [\mathrm{SHIN}_{\mathrm{i,s,r,g}} \times \mathrm{TOTDEMREG}_{\mathrm{i,s,g}}] \times demCSR_{i,s,g} \quad (i \in \mathrm{COM}, s \in \mathrm{SRC}, r \in \mathrm{REG}) \tag{14.1}$$

$$\begin{aligned}
&\mathrm{TOTDEMREG}_{\mathrm{i,s,d}} \times demCSR_{i,s,d} \\
&= \sum_{\mathrm{j \in IND}} [\mathrm{REGSHR1}_{\mathrm{j,d}} \times \mathrm{BAS1}_{\mathrm{i,s,j}}] \times x1r_{i,s,j,d} \\
&\quad \sum_{\mathrm{j \in IND}} [\mathrm{REGSHR2}_{\mathrm{j,d}} \times \mathrm{BAS2}_{\mathrm{i,s,j}}] \times x2r_{i,s,j,d} \\
&\quad + [\mathrm{REGSHR3}_{\mathrm{i,s,d}} \times \mathrm{BAS3}_{\mathrm{i,s}}] \times x3r_{i,s,d} \\
&\quad + [\mathrm{REGSHR5}_{\mathrm{i,s,d}} \times \mathrm{BAS5}_{\mathrm{i,s}}] \times x5r_{i,s,d} \\
&\quad + [\mathrm{SRCDOM}_{\mathrm{s}} \times 100] \times \Delta \mathrm{X6R}_{i,s,d} \\
&\quad + [\mathrm{SRCDOM}_{\mathrm{s}} \times \mathrm{REGSHR4}_{\mathrm{i,d}} \times \mathrm{BAS4}_{\mathrm{i}}] \times x4r_{i,d} \\
&\quad + [\mathrm{SRCDOM}_{\mathrm{s}} \times \mathrm{DMCR}_{\mathrm{i,d}}] \times xmar_{i,d} \\
&\qquad (i \in \mathrm{COM}, s \in \mathrm{SRC}, d \in \mathrm{REG})
\end{aligned} \tag{14.2}$$

$$\begin{aligned}
z_{j,r} &= z_j^{(C)} + \sum_{i \in COM} \mathrm{SHCJ}_{\mathrm{i,j}} \\
&\quad \times \left[x0CSR_{i,dom,r} - \sum_{g \in REG} \mathrm{REGSHR1}_{j,g} \times x0CSR_{i,dom,g} \right] \\
&\qquad (j \in \mathrm{IND}, r \in \mathrm{REG})
\end{aligned} \tag{14.3}$$

$$\begin{aligned}
x1r_{i,s,j,d} &= x1csi^{(C)}_{i,s,j} + z_{j,d} \\
&\quad - \sum_{k \in REG} \mathrm{REGSHR1}_{j,k} \times z_{j,k} \\
&\qquad (i \in \mathrm{COM}, s \in \mathrm{SRC}, j \in \mathrm{IND}, d \in \mathrm{REG})
\end{aligned} \tag{14.4}$$

$$\begin{aligned}
x2r_{i,s,j,d} &= x2csi^{(C)}_{i,s,j} + z_{j,d} \\
&\quad - \sum_{k \in REG} \mathrm{REGSHR2}_{\mathrm{j,k}} \times z_{j,k} \\
&\qquad (i \in \mathrm{COM}, s \in \mathrm{SRC}, j \in \mathrm{IND}, d \in \mathrm{REG})
\end{aligned} \tag{14.5}$$

$$x3r_{i,s,d} = x3_{i,s}^{(C)} + yr_d - \sum_{\mathrm{k \in REG}} \mathrm{REGSHR3_{i,s,k}} \times yr_k \quad (i \in \mathrm{COM}, s \in \mathrm{SRC}, d \in \mathrm{REG}) \tag{14.6}$$

$$yr_r = y^{(C)} + empr_r - emp^{(C)} \quad (r \in \mathrm{REG}) \tag{14.7}$$

$$x4r_{i,d} = x4_i^{(C)} + reg4_{i,d} - \sum_{\mathrm{k \in REG}} \mathrm{REGSHR4_{i,k}} \times reg4_{i,k} \quad (i \in \mathrm{COM}, d \in \mathrm{REG}) \tag{14.8}$$

$$x5r_{i,s,d} = x5_{i,s}^{(C)} + reg5_{i,s,d} - \sum_{k \in REG} \mathrm{REGSHR5_{i,s,k}} \times reg5_{i,s,k} \quad (i \in \mathrm{COM}, s \in \mathrm{SRC}, d \in \mathrm{REG}) \tag{14.9}$$

$$\Delta \mathrm{X6R_{i,s,r}} = \mathrm{REGSHR6_{i,s,r}} \times \Delta \mathrm{X6_{i,s}^{(C)}} \quad (i \in \mathrm{COM}, s \in \mathrm{SRC}, r \in \mathrm{REG}) \tag{14.10}$$

$$grpfc_r = \sum_{\mathrm{j \in IND}} \mathrm{VASHJ_{j,r}} \times z_{j,r} \quad (r \in \mathrm{REG}) \tag{14.11}$$

$$grpmp_r = gdpreal^{(C)} + grpfc_r - \sum_{\mathrm{k \in REG}} \mathrm{VASHR_k} \times grpfc_k \quad (r \in \mathrm{REG}) \tag{14.12}$$

$$empr_r = emp^{(C)} + relemp_r - \sum_{\mathrm{k \in REG}} \mathrm{LABSHR_k} \times relemp_k \quad (r \in \mathrm{REG}) \tag{14.13}$$

$$relemp_r = \sum_{j \in IND} \mathrm{LABSHJ_{j,r}} \times (labind_j^{(C)} + z_{j,r} - z_j^{(C)}) \quad (r \in \mathrm{REG}) \tag{14.14}$$

1.2 Set Definitions

IND: {j1 – j159} Set of all industries.

REG: {r1 – r31} Set of all regions.

SRC: {s1 – s2} Sources of commodities: $s1$ (domestic) and $s2$ (foreign).

COM: {c1 – c157} Set of all commodities.

1.3 Variables

Variable	Closure	Set range	Description
$demCSR_{i,s,r}$	endog	$i \in$ COM $s \in$ SRC $r \in$ REG	Percentage change in demand for commodity i, s within region r
$empr_r$	endog	$r \in$ REG	Percentage change in regional employment
$emp^{(C)}$	exog		Percentage change in national employment. Input from CHINAGEM
$grpfc_r$	endog	$r \in$ REG	Percentage change in real gross regional product (at factor cost) for region r
$grpmp_r$	endog	$r \in$ REG	Percentage change in real gross regional product (at market prices) for region r
$gdpreal^{(C)}$	exog		Percentage change in real GDP (at market prices). Input from CHINAGEM
$labind_j^{(C)}$	exog	$j \in$ IND	Percentage change in national employment in industry j. Input from CHINAGEM
$reg4_{i,r}$	exog	$i \in$ COM $r \in$ REG	Percentage change in share of exports of i leaving China from region r
$reg5_{i,s,r}$	exog	$i \in$ COM $s \in$ SRC $r \in$ REG	Percentage change in share of economy-wide public consumption demands for i, s accounted for by government demand in region d
$relemp_r$	endog	$r \in$ REG	Used for calculating the deviation in region r's employment from national employment
$x0CSR_{i,s,r}$	endog	$i \in$ COM $s \in$ SRC $r \in$ REG	Percentage change in supply of commodity i, s from region r
$x1r_{i,s,j,r}$	endog	$i \in$ COM $s \in$ SRC $j \in$ IND $r \in$ REG	Percentage change in demand for good i from source s by industry j in region d for input to current production

(continued)

(continued)

Variable	Closure	Set range	Description
$x1csi^{(C)}_{i,s,j}$	exog	$i \in$ COM $s \in$ SRC $j \in$ IND	Percentage change in demand for commodity *i* from source *s* by industry *j* for input to current production. Input from CHINAGEM
$x2r_{i,s,j,r}$	endog	$i \in$ COM $s \in$ SRC $j \in$ IND $r \in$ REG	Percentage change in demand for good *i* from source *s* by industry *j* in region *r* for input to capital formation
$x2csi^{(C)}_{i,s,j}$	exog	$i \in$ COM $s \in$ SRC $j \in$ IND	Percentage change in demand for commodity *i* from source *s* by industry *j* for input to capital formation. Input from CHINAGEM
$x3r_{i,s,r}$	endog	$i \in$ COM $s \in$ SRC $r \in$ REG	Percentage change in demand for commodity *i*, *s* by households in region *r*
$x3^{(C)}_{i,s}$	exog	$i \in$ COM $s \in$ SRC	Percentage change in household demand for source-specific commodity *i*, *s*. Input from CHINAGEM
$x4r_{i,r}$	endog	$i \in$ COM $r \in$ REG	Percentage change in demand for exports of *i* via a port in region *r*
$x4^{(C)}_{i}$	exog	$i \in$ COM	Percentage change in national exports of commodity *i*. Input from CHINAGEM
$x5r_{i,s,r}$	endog	$i \in$ COM $s \in$ SRC $r \in$ REG	Percentage change in demand for commodity (*i*, *s*) by government in region *r*
$x5^{(C)}_{i,s}$	exog	$i \in$ COM $s \in$ SRC	Percentage change in government demands for *i*, *s* at the national level. Input from CHINAGEM
$\Delta X6R_{i,s,r}$	endog	$i \in$ COM $s \in$ SRC $r \in$ REG	Change in demand for (*i*, *s*) for addition to inventories in region *r*
$\Delta X6^{(C)}_{i,s}$	exog	$i \in$ COM $s \in$ SRC	Change in national demand for commodity *i* from source *s* for addition to stocks. Input from CHINAGEM
$xmar_{i,r}$	exog[a]	$i \in$ COM $r \in$ REG	Percentage change in demand for commodity *i* for use as a margin service to facilitate commodity flows to/within region *r*
$y^{(C)}$	exog		Percentage change in national household disposable income. Input from CHINAGEM
yr_r	endog	$r \in$ REG	Percentage change in regional household disposable income
$z^{(C)}_{j}$	exog	$j \in$ IND	Percentage change in activity level of industry *j*. Input from CHINAGEM
$z_{j,r}$	endog	$j \in$ IND $r \in$ REG	Percentage change in output of regional industry *j*, *r*

[a] Exogenous in this description of the core equations, but endogenously related to trade flows in the implementation of the full model. See discussion in Sect. 14.3.

1.4 Coefficients and Parameters

See Table 14.3.

Table 14.3 .

$BAS1_{i,s,j}$	$i \in$ COM $s \in$ SRC $j \in$ IND	Basic value of national usage of good *i* from source *s* by industry *j* for input to current production. Sourced from the CHINAGEM-E database (see Chap. 13 herein)
$BAS2_{i,s,j}$	$i \in$ COM $s \in$ SRC $j \in$ IND	Basic value of national usage of good *i* from source *s* by industry *j* for input to capital formation. Sourced from the CHINAGEM-E database (op. cit.)
$BAS3_{i,s}$	$i \in$ COM $s \in$ SRC	Basic value of national private consumption of good *i* from source *s*. Sourced from the CHINAGEM-E database (op. cit.)
$BAS4_{i}$	$i \in$ COM	Basic value of national exports of *i*. Sourced from the CHINAGEM-E database (op. cit.)
$BAS5_{i,s}$	$i \in$ COM $s \in$ SRC	Basic value of national use of commodity *i* from source *s* for government consumption. Sourced from the CHINAGEM-E database (op. cit.)
$BAS6_{i,s}$	$i \in$ COM $s \in$ SRC	Basic value of national use of commodity *i* from source *s* for addition to inventories. Used in calculation of TOTDEMREG below. Sourced from the CHINAGEM-E database (op. cit.)
$DMCR_{i,r}$	$i \in$ COM $r \in$ REG	Total demand within region *r* for commodity *i* for use as a margin. Sourced from the SINOTERM database (Wittwer and Horridge 2018)
$LABSHJ_{j,r}$	$j \in$ IND $r \in$ REG	Share in region's *r*'s total wage bill represented by wages paid by industry *j, r*. Calculated via: $LABSHJ_{j,r} = \frac{VLAB_{j,r}}{\sum_{k \in IND} VLAB_{k,r}}$, where $VLAB_{j,r}$ is the SINOTERM (op. cit.) value of payments to labour by industry j in region r
$LABSHR_{r}$	$r \in$ REG	Share of economy-wide wagebill accounted for by payments to labour in region *r*. Calculated via: $LABSHR_{r} = \frac{\sum_{j \in IND} VLAB_{j,r}}{\sum_{k \in IND} \sum_{t \in REG} VLAB_{k,t}}$, where $VLAB_{j,r}$ is the SINOTERM (op. cit.) value of payments to labour by industry j in region r
$REGSHR1_{j,r}$	$j \in$ IND $r \in$ REG	Share of national activity of industry *j* accounted for by activity of *j* in region *r*. Calculated via $REGSHR1_{j,r} = PRIM_{j,r} / \sum_{k \in REG} PRIM_{j,k}$, where $PRIM_{j,r}$ is the SINOTERM (op. cit.) value for primary factor payments in industry *j* in region *r*

(continued)

Table 14.3 (continued)

$REGSHR2_{j,r}$	$j \in IND$ $r \in REG$	Share of national investment in industry *j* accounted for by investment in *j* in region *r*. Calculated via $REGSHR2_{j,r} = INVEST_{j,r} / \sum_{k \in REG} INVEST_{j,k}$, where $INVEST_{j,r}$ is the SINOTERM (op. cit.) value for the value of gross fixed capital formation in industry *j* in region *r*
$REGSHR3_{i,s,r}$	$i \in COM$ $s \in SRC$ $r \in REG$	Share of national private consumption of *i*, *s* accounted for by consumption of *i*, *s* in region *r*. Calculated via $REGSHR3_{i,s,r} = USE_{i,s,Hou,r} / \sum_{k \in REG} USE_{i,s,Hou,k}$, where $USE_{i,s,Hou,r}$ is the SINOTERM (op. cit.) value for private consumption of commodity *i* from source *s* in region *r*
$REGSHR4_{i,r}$	$i \in COM$ $r \in REG$	Share of national exports of commodity *i* accounted for by exports of *i* from *r*. Calculated via $REGSHR4_{i,s,r} = USE_{i,Dom,Exp,r} / \sum_{k \in REG} USE_{i,Dom,Exp,k}$, where $USE_{i,Dom,Exp,r}$ is the SINOTERM (op. cit.) value for international exports of commodity *i* from region *r*
$REGSHR5_{i,s,r}$	$i \in COM$ $s \in SRC$ $r \in REG$	Share of the economy-wide usage of good *i* from source *s* by government accounted for by government usage in region *r*. Calculated via $REGSHR5_{i,s,r} = USE_{i,s,Gov,r} / \sum_{k \in REG} USE_{i,s,Gov,k}$, where $USE_{i,s,Gov,r}$ is the SINOTERM (op. cit.) value for public consumption of commodity *i* from source *s* in region *r*
$REGSHR6_{i,s,r}$	$i \in COM$ $s \in SRC$ $r \in REG$	Share of the economy-wide inventory demand for good (*i*, *s*) accounted for by region *r*. SINOTERM does not include inventory demands. Hence, estimated from SINOTERM (op. cit.) commodity demands via: $REGSHR6_{i,s,r} = \frac{\sum_{t \in USER} USE_{i,s,t,r}}{\sum_{j \in USER} \sum_{k \in REG} USE_{i,s,j,k}}$
$SHCJ_{i,j}$	$i \in COM$ $j \in IND$	Share of commodity *i* in total output of industry *j*. Calculated from CHINAGEM-E (op. cit.) data via: $SHCJ_{i,j} = MAKE_{i,j} / \sum_{t \in COM} MAKE_{t,j}$, where $MAKE_{i,j}$ is the value, at the national level, of production of commodity *i* by industry *j*
$SHIN_{i,s,q,r}$	$i \in COM$ $s \in SRC$ $q \in REG$ $r \in REG$	Share of region *r*'s demand for commodity *i*, *s* that is satisfied by supply from region *q*. Calculated from SINOTERM data (op. cit.) via: $SHIN_{i,s,q,r} = \frac{TRADE_{i,s,q,r}}{\sum_k TRADE_{i,s,k,r}}$, where $TRADE_{i,s,q,r}$ is the SINOTERM value for trade in commodity (*i*, *s*) from region *q* to region *r*
$SRCDOM_s$	$s \in SRC$	Dummy variable, equal to 1 if source is domestic, equal to 0 if source is imported

(continued)

Table 14.3 (continued)

$TOTDEMREG_{i,s,r}$	$i \in COM$ $s \in SRC$ $r \in REG$	Total demand for commodity (i, s) within region r $= \sum_{j \in IND} REGSHR1_{j,d} \times BAS1_{i,s,j} +$ $\sum_{j \in IND} REGSHR2_{j,d} \times BAS2_{i,s,j} +$ $REGSHR3_{i,s,d} \times BAS3_{i,s} +$ $REGSHR5_{i,s,d} \times BAS5_{i,s} +$ $SRCDOM_s \times BAS6_{i,s} +$ $SRCDOM_s \times REGSHR4_{i,d} \times BAS4_i +$ $SRCDOM_s \times DMCR_{i,d}$
$TOTSUPREG_{i,s,r}$	$i \in COM$ $s \in SRC$ $r \in REG$	Supply of commodity i, s by region r to the domestic (Chinese) market $= \sum_{g \in REG} SHIN_{i,s,r,g} \times TOTDEMREG_{i,s,g}$
$VASHJ_{j,r}$	$j \in IND$ $r \in REG$	Share of region r's total value added accounted for by value added in industry j. Calculated from SINOTERM data (op. cit.) via: $VASHJ_{j,r} = \frac{PRIM_{j,r}}{\sum_{t \in IND} PRIM_{t,r}}$, where $PRIM_{j,r}$ is the SINOTERM value of payments to primary factors by industry j in region r
$VASHR_r$	$r \in REG$	Share of national value added accounted for by value added in region k. Calculated from SINOTERM (op. cit.) data via: $VASHR_r = \frac{\sum_{j \in IND} PRIM_{j,r}}{\sum_{t \in IND} \sum_{k \in REG} PRIM_{t,k}}$, where $PRIM_{j,r}$ is the SINOTERM value of payments to primary factors by industry j in region r

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