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Green Transformation:

A System Dynamics Model on Endowment, Investment and Employment

Yan Wang, Hefeng Tong and Jiajun Xu[1]

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Abstract

Structural transformation is critical to attaining improvements in productivity and employment generation. However, it is imperative that any structural transformation undertaken should take a green approach as the international community have placed great emphasis on achieving Sustainable Development Goals (SDGs) by 2030. Given the importance of green structural transformation, this paper attempts to explore a ***system dynamics (SD) model*** to analyze and simulate three policy options to achieve transformation to a green economy in an effort to shed new lights onto the claimed tradeoff between competitiveness and greenness. Consistent with the New Structural Economics (Lin 2010, 2011), our main analytic approach starts from the structure of endowment (stocks), followed by investment (flows) in green sectors and lastly the structure of employment and changes in labor productivity. The key findings from our simulation results are as follows: first, although there is a short run negative impact on GDP growth, the long run benefits outweigh the short run cost; secondly, green sectors will expand rapidly generating significant number of jobs; and lastly, as pollutant emissions fall along with a decline in pollutant intensity, labor force becomes healthier and more resilient thus contributing to a rise in productivity in the economy.

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[1]Respectively, Senior visiting fellow at the Institute of New Structural Economics (INSE), Researcher at Institute of Scientific and Technical Information (ISTIC), and Assistant Professor and Executive Deputy Dean, at INSE, Peking University. The authors thank Justin Yifu Lin, John D. Shilling, Weishuang Qu, Vinod Thomas, Hua Wang, Yong Wang and Xin Wang for advice; Ji Qi for pollution data sources, and participants at Institute of New Structural Economics Peking University for comments and suggestions. Comments and suggestions may be sent to Yan Wang at wangyan@nsd.pku.edu.cn.

1. Introduction

Confronted by severe challenges of environmental degradation and climate change, policy makers have been working towards achieving the 17 Sustainable Development Goals (SDGs) by 2030. Structural transformation is an effective way to achieve these goals, as historical trends since the industrial revolution show that transformation from primary activities of resource extraction and agriculture to manufacturing activities and then to services is crucial for productivity growth, job creation, and poverty reduction. The New Structural Economics, proposed by Professor Justin Yifu Lin (2010, 2011) and his colleagues (Ju, Lin and Wang 2015) postulates that modern economic development is a process of continuous structural change in technology, industry, and hard and soft infrastructure. These changes make a continuous increase in labor productivity and per capita income possible.

China's economic growth and development over the past 40 years has been remarkable, lifting over 600 million people out of poverty. However, this growth has come with a cost on the environment and a resultant loss in productivity. It is estimated that the costs of these externalities could be as high as 9 percent of China's gross national income. Of these costs, it was estimated that energy and mineral depletion amount to 3.1 percent of gross national income, air and water pollution damages to 3.8 percent, soil depletion to 1 percent, and carbon dioxide damages to 1.1 percent (World Bank 2015a; World Bank and DRC 2012). Deteriorating urban air quality in particular exposes people at higher risks of cardiovascular and acute respiratory diseases. ***According to estimates, pursuing greener growth could result in a net improvement of 2.7 percent in gross national income by offsetting some of the effects of environmental depletion and degradation by 2030*** (World Bank 2015a; World Bank and DRC 2012). Tremendous progress has been made in deploying renewable energy in China, allowing it to become the largest renewable energy producer in the world. However, China has a long way to go before greening the industrial structure and dealing with the cumulative effects of many years of pollution. President Xi Jinping recently reiterated the importance of ecological and environmental protection, specified six principles for ecological green development, and set the aim to completely realize the goal of "A beautiful China" by 2035 (Xi 2018)

It is imperative that China's structural transformation is **green** in nature, consistent with the SDGs. Therefore, this inter-disciplinary paper attempts to apply a system dynamic (SD) model to **analyze the various policy options to achieve the structural transformation from the status quo to a green economy.** Using a framework that is consistent with the New Structural Economics (Lin 2010, 2011) the paper is exploratory in nature, aiming to introduce an SD model commonly used in engineering, projects and business decision-making to lay a basic foundation for future research. Questions to be investigated include:

- Can the green transformation as we defined provide a higher quality growth and enhance people's welfare?
- How much extra investment is needed for green transformation as compared to the baseline scenario?
- Would targeted investment in green sectors accelerate green transformation?

The paper proceeds as follows. After a brief literature review and discussion on definition in Section 2, Section 3 presents an analytical framework that is consistent with the New Structural Economics (Lin 2010, 2011) and discusses the empirical methodology of SD model Section 4 discusses various scenario designs, Section 5 explains the simulation results and implications, and finally Section 6 concludes.

2. Links between three bodies of literature

The development community over the years have been trying to broaden the traditional definition of GDP growth and development to cover poverty and welfare.[2] In the 1970-90s the emphasis was on economic growth, but the quality of growth was largely neglected. From the 1990s to 2015, the broad objective was achieving the Millennium Development Goals. The quality of growth was brought to the forefront of development agenda since the 2000s (Thomas et al 2000) and now the focus is placed on the challenges of achieving the 17 Sustainable Development Goals by 2030. Beyond household or individual income, welfare includes, but is not limited to: distribution of **opportunities**, and improvements in health, education, poverty reduction, jobs and income generation. It also includes **sustainability**, as represented by the protection of the environment, natural resources, biodiversity, and reduction of pollutants and CO2 emissions to combat climate change.

2.1 Three bodies of literature

This paper aims to enrich the New Structural Economics by engaging with environmental economics, using the empirical method of system dynamics for policy simulation. The paper is exploratory and inter-disciplinary in nature. The following strands of literature are most relevant to our study:

a) The New Structural Economics (Lin 2010, 2011; Ju, Lin and Wang 2015);

b) The framework of the quality of growth which stresses the role of three types of

[2]Many earlier studies have addressed the multidimensional view of development objectives, among them: Dasgupta 1990, 1993; Hicks and Streeten 1979; Lewis 1955; Nordhaus and Tobin 1972. Hamilton 2010 on genuine savings and efforts to measure Green GDP. Patil 2012; Stiglitz, Sen and Fitoussi 2009 on the quality of life, World Bank 2011, Large, Wodon and Carey 2018 on “the Changing Wealth of Nations”.

endowments: human capital, natural capital, and physical /financial capital (Lopez, Thomas and Wang 2008).

c) The application of system dynamics models in environmental issues in China and other countries (UNEP study on Green Economy in China, T21 model developed by the Millennium Institute, and others).

We attempt to narrow down our scope by providing a bridge linking the three bodies of literature on New Structural Economics, the quality of growth, and system dynamic models for pollution control. Due to limited space and capacity, this short paper will not be able to address the vast literature on development strategy, the environmental Kuznets curve, or climate change.

In a recent and important paper, Justin Yifu Lin and his coauthors proposed a theoretical hypothesis of a "new structural environmental economics". This theoretical hypothesis postulates that countries or regions in different stages of development are constrained by their different industrial structure which are dependent on their respective endowment structure, and thus have different emission densities and different pollution problems. If the government chooses the catching-up strategy which entails focusing on heavy industries defying the country's comparative advantages (CAD), it may have to distort the prices of energy and other resources in order to protect non-viable enterprises – leading to excessive resource use and pollution. On the other hand, if the country adopts the strategy of following comparative advantage, the distortion of prices and resources will not occur. In addition, with the "advantage of backwardness", governments of developing countries can play a positive role in promoting the use of clean energy technologies resulting in lower levels of pollution. The paper presented empirical analysis using panel data from global cross-border and Chinese provincial and city level, which supports the main theoretical hypothesis. Finally, the paper argues that the solution to the problem of environmental pollution is to enter the high-income-stage dominated by the service sector via a Comparative Advantage-Following (CAF) development strategy (Fu, Zheng and Lin 2017).

2.2 System Dynamic Model and New Structure Economics

The New Structural Economics stresses the importance of endowments (stocks) and their changing structure, which affects the comparative advantage of an economy. Justin Yifu Lin considers that, "The optimal industrial structure in an economy at a specific time is endogenous to its comparative advantage, which in turn is determined by the economy's given endowment structure at that time" (Lin 2011). Lin considers investment (flow) as the main instrument for changing the factor endowment (stock): "With capital accumulation, the economy's factor endowment structure evolves, pushing its industrial structure to deviate from the optimal determined by its previous level. If the economy follows its comparative advantage in developing its industries, these industries will have the lowest possible factor costs of production and thus be most competitive in domestic and world markets. As a result, they will gain the largest possible market share and generate potentially the largest surplus (Lin 2011; Ju, Lin and Wang 2015).

Consistent with the NSE, in this paper, a country has at least three types of assets that matter for production and welfare: **physical capital, K; human capital, H; and natural capital, N.**[3] These assets are factor endowments that are necessary for production and welfare at any point in time. Technological progress and the policy environment affecting the use of these assets matter as well. In the past, much attention has traditionally been given to the accumulation of physical and financial capital. However, for poverty reduction and human welfare, the areas that deserve greater attention are other key assets such as human capital (including health and education levels), as well as natural capital (including ecological environment), because these are primary assets that poor countries possess. Physical capital contributes to welfare through economic growth. Human (and social) capital and natural (and ecological/environmental) capital in addition to contributing to growth are direct components of human welfare. Human capital (H) and natural capital (N) also help to increase investment returns, thereby attracting more physical/financial capital and making the investment more productive. Accumulation of all three types of capital (stock) through investment (flows) and other policy measures (such as taxes and subsidies) are crucial for balanced and sustainable growth (Thomas et al 2000; Lopez, Thomas and Wang 2008).

Market failures usually lead to underinvestment in human capital and overexploitation of natural capital. In many countries, governments have failed to offset market failures by adequately providing basic services, especially healthcare and education for the poor. Meanwhile, for the same market failures, the governments often do not have the political incentive to protect natural resources and regulate pollution, leading to over-exploitation of natural capital, depletion of resources and environmental degradation (Lopez, Thomas and Wang 2008). There are also government failures such as corruption and vested interest groups "capturing" policies.

System dynamics is an approach that links endowments (stocks) and investments (flows) while providing a policy simulation tool for the New Structural Economics, incorporating "policy delays" or "change resistance" without relying on the strong assumptions in general equilibrium models (CGE models). System dynamics (SD) is a modeling tool to understand and simulate the nonlinear behavior of complex systems over time, using stocks, flows,

[3] These assets are well defined as in the World Bank's *Changing Wealth of Nations 2011*, and Lange, Wodon, and Carey 2018.

internal feedback loops, and time delays. Created in the 1950s by MIT professor Jay Forrester and further developed in the 1990s, SD is now widely used by the public and private sectors for policy analysis and simulation (Forrester 1961; Sterman 2000, 2001). SD has been used to investigate resource dependencies and constraints, CO2 emissions, and climate change (for example, UNEP 2014[4]; Tong 2014; El Sawah et al 2012). SD also has macroeconomic applications: a system dynamic model known as *Minsky* has been developed by Steve Keen and has successfully modelled macroeconomic events from the Great Moderation to the unexpected financial crisis of 2007-08.[5]

We think that system dynamics is a suitable tool for New Structural Economics because of its emphasis on the causal structure among factors and sectors, on endowment (stocks) and investment (flows), and on "everything links to everything" in a complex world. "In system dynamics, the fundamental premise is that the dynamic behavior over time is ***endogenously*** generated from the "systemic structure" or the network of interactions that bind system components together."[6] Moreover, in the SD model, market and government failures can be considered as "policy delays" or "change resistance". Therefore, the role of government and the possibility of its policy delays is one of the underlying assumptions of this study. General equilibrium models (such as CGE) often ignore these policy delays, change resistance, and non-clearance of markets.

To develop a numerical SD model, the modeler converts the dynamic hypothesis into a "stock and flow" representation. Stocks (also known as accumulators, levels, or endowment in our model) represents the system state (Sterman, 2000a, p.199). Flows (also known as rates) are the processes that influence change in the stock levels such as investment by sector in our model. Next, differential equations are used to numerically show the rate of change in stocks. A simulation engine is used to run the numerical model, and simulate the change in the values of stocks and flows over time.

Thus, this SD model aligns well with NSE which stresses the structure of endowments

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[4] Tong, Hefeng, China Green Economy Prospect.

[5] "Steve Keen developed the dynamic disequilibrium models of monetary production that fulfils these conditions using a technique that combines double entry book-keeping with **systems dynamics**." (page 16, Steve Keen 2011). Steve Keen, 2011. "A Monetary Minsky Model of the Great Moderation and the Great Depression," 2011, available at https://www.aeaweb.org/conference/2011/retrieve.php?pdfid=185.

[6] ElSawah et al 2012. "Using system dynamics for environmental modelling: Lessons learnt from six case studies".

(human capital, natural capital and physical capital) that determine the comparative advantages, and consequently the industrial structure. Investments, like taxation, are government intervention tools which can change the structure of endowments as well as its comparative advantages and subsequent industrial structure. Therefore, we think this SD model is consistent with the theoretical foundation of NSE and also suitable to simulate results of industrial policies.

3. The framework of simulation – a system dynamic tool for Green Transformation

This section first provides a working definition of green transformation, introduces the System Dynamic (SD) Model, illustrates the process of building a SD model, and finally presents the initial input data.

3.1 Define green transformation

What is "green transformation"? We define green transformation as a **process of upgrading the current industrial structure, moving towards sectors that have low "pollution intensity"** with low emission of pollutants in which production is carried out using clean technology or renewable energy. In other words, it is a process that is more people friendly and environmentally sustainable. In order to operationalize, we focus here on the emission of only 7 pollutants by subsectors due to data constraints.[7] To identify "green sectors" and non-green sectors, these 7 pollutants include gas pollutants, water pollutants and solid pollutants of which time series data is easy to obtain in statistical yearbooks. In the empirical part, we use a "Borda ranking technique" to build a composite index of "pollution intensity" and to rank 44 subsectors based on 7 pollutants (see Appendix I for "A Composite Index of Pollution Intensity by Sectors"). We will then merge these 44 subsectors into 10 sectors for further analysis using the SD model: the primary sector, the secondary sector which comprises of the construction, labor intensive manufacturing (such as garment, footwear and toys), capital intensive manufacturing(such as automobile), natural gas, oil, electricity, ferrous metal(including steel), nonmetallic mineral products (including cement), and the tertiary sector (10 sectors). Obviously, the second industry is divided into more detailed sectors, the green transformation mainly refers to the transformation of the secondary sector.

[7] Data on pollutants by 44 subsectors were provided by Dr. Ji Qi, for the year 2014. The seven pollutants included COD, Oil, Ammonium-Ammonia (NH_4^+ and NH_3), SO_2, Smoke and Dust, NOX; and Solid Waste.

3.2 Introduction to the System Dynamic Model

System dynamics (SD) was initiated during the mid-1950s by Professor Jay Forrester of the Massachusetts Institute of Technology (Forrester 1958). Initially the model was intended to help corporate managers improve their understanding of industrial processes, and now it is being used throughout the public and private sector for policy analysis and simulation (Forrester 1964, 1968, 1969). In the 1970s, J.W. Forrester was invited by the Club of Rome to use SD in analyzing the relationship between population, resources, industrial development and environmental pollution, the published report is titled *The Limit of Growth* (Meadows 1972). In the early 1990s, the authors added updated data of over 20 years, and utilized again the SD model called the World3 model and published another report –*Beyond the Limits* (Meadows 1992). This report enhanced the conclusion of the previous report as it contended that some resources and pollutants has gone beyond the limits that can be sustained, thus pointing to the need to establish a "sustainable development society".

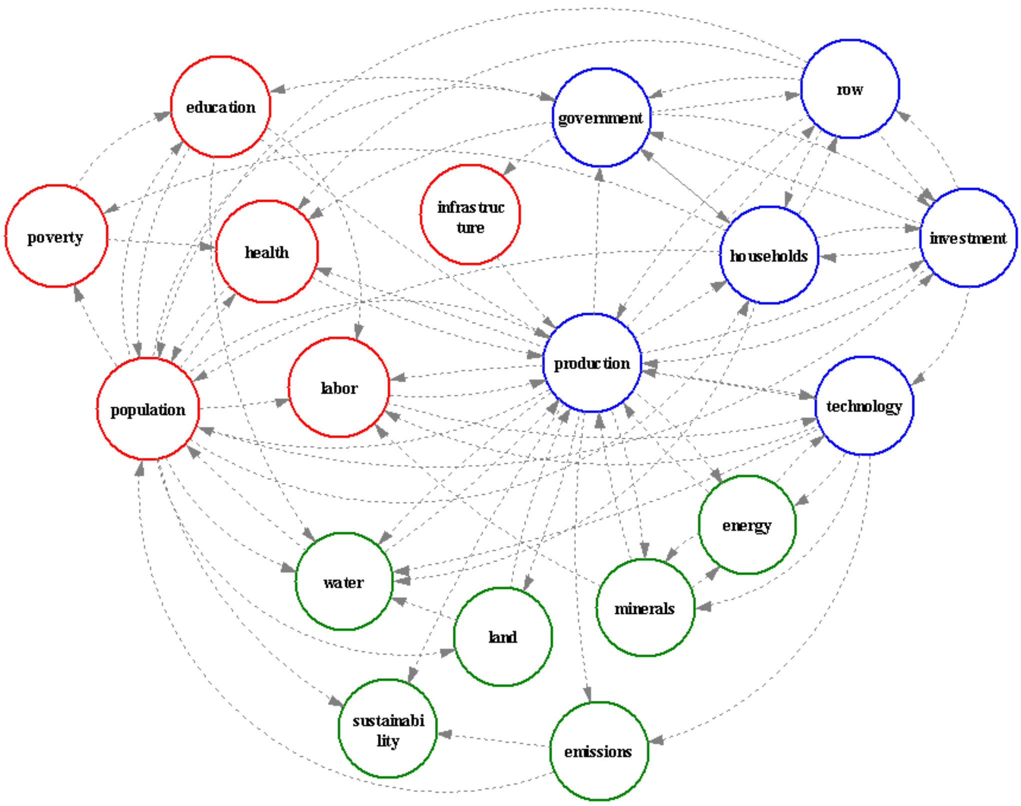
System dynamics emphasizes the views that all problems are in a complex system and should be viewed holistically because various parts are interconnected, dynamic and co-dependent. It is suitable to deal with long-term, cyclical, and nonlinear issues (Sterman 2000; Forrester 1993; Mosekilde 2007; Winz 2008; El Sawah 2012). Since the 1980s, Systematic Dynamics has been gradually refined and applied to almost every academic field. However, it is mainly applied in the broad areas of economics, social science, environmental sustainability and other related fields. UNEP published in 2011 a report entitled ***Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication,*** which indicates that if 2% of global output can be invested in 10 major economic sectors, the global economy can move toward a low carbon and green economic path. This quantitative analysis was also the conclusion of a system dynamic model.

The System Dynamic model in this study is developed and revised based on the Millennium Institute T21 Threshold Framework. T21 has been applied to multiple fields in more than 20 countries (Barney 1999, 2009, 2010; Qu 2000, 2005). One of principal authors of this study, Hefeng Tong, conducted a series of research on the Chinese green economy, energy consumption in agriculture, cement, iron, transportation industries and carbon emission based on the Chinese sustainable development SD model (Tong 2009, 2010, 2015a, 2015b, Yang 2013a, 2013b).

When building a System Dynamic model, the researchers integrate the **economic, sociological and environmental systems** in a holistic way and effectively incorporate the feedback loops in the three systems. For instance, the environmental system not only provides water, energy, biology and material inputs to the social system, it also absorbs and degenerates the pollutants and other wastes emitted from the human system activities. Energy utilization and pollutant emission are constantly changing the environmental system, and at the same time, they feedback to the humans causing severe consequences, impact human health, welfare, economic growth, and development. SD can effectively incorporate such two-way feedback impacts.

When building a SD model, we also divide each of the main modules into different sectors in sub-modules. For example, the social system includes interlinked submodules of population, labor, education, poverty, infrastructure, health and so on. Based on various theoretical models, the SD model uses the simplest and most direct way to link the function relationship between the dependents and independent variables. Its sub-modules are connected but also independent respectively, as shown by Figure 1. If one module is linked by an arrow to another module it indicates that the starting module will impact the ending module.

Figure 1. Relationships and Effects among Different Sectors/Modules



The SD model we use are based on sectoral models with a small three-sector core of CGE model developed at the World Bank, with added the social and environmental pillars. The social pillar would cover population, health, education, with its population module is based on the UN's population projection model. In terms of education, it would track the impacts of government expenditure on education on the changes in literacy /education attainment by age cohort and sex. The increased education feeds back into the production functions increasing the productivity of the labor force over time. Thus it shows both the impacts on economic growth as well as the impacts on human development indicators. Similarly with health programs, where levels of government expenditures would not only change health indicators, but the impact of morbidity on the labor force, and productivity.

When compared with CGE models, SD models have relaxed some strong and unrealistic assumptions regarding general equilibrium, and market clearance. Our SD model incorporates features of an open economy consistent with a Social Accounting Matrix (SAM) but it does not require market clearance. It combines advantages of CGE model to design a balance sheet of five agents as the center of economic model. We make sure that the data of every year are consistently fit into a balance sheet. Our SD model is calibrated against historical data from 1990-2014 before simulating to the future. It contains highly aggregated economic sectors (10 sectors in our paper) and integrate more social (populations, education, health care, and employment), and environmental (land, water, air, fossil fuels and minerals) sectors, which cannot be achieved by CGE models. This user-friendly model has been used by Chinese researchers for long term (5-20 years) policy analysis, especially in sustainable development policies (Tong Hefeng 2009, 2011 2015, UNEP 2011).

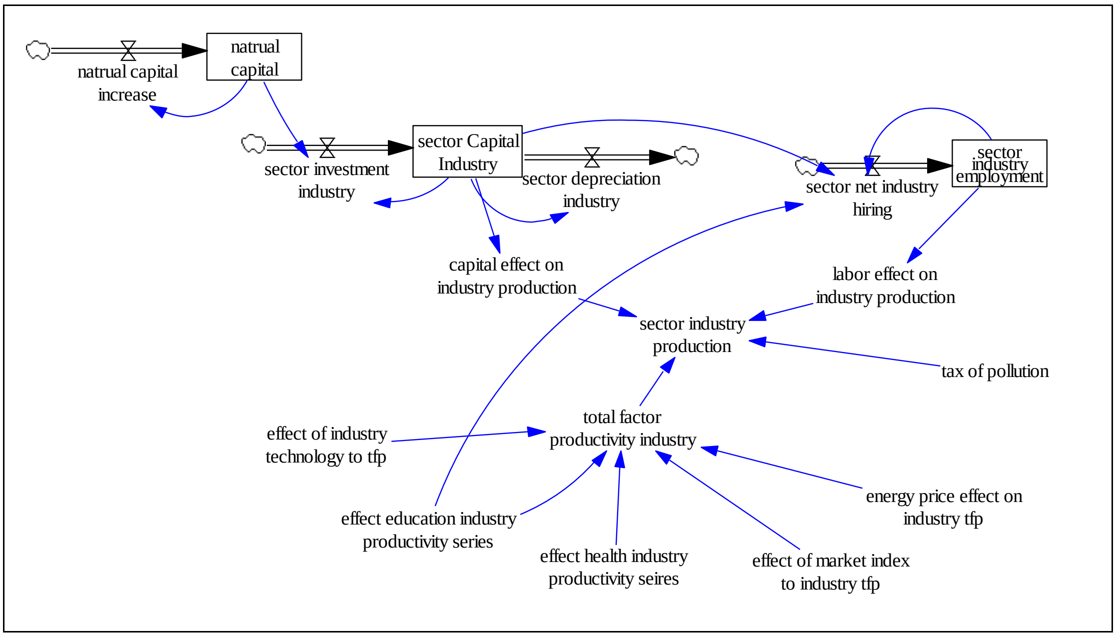
3.3 Building the system dynamic model

The process of building a SD model involves several stages including: framing the problem, building a conceptual model, conducting a simulation experiment, converting the model into mathematical equations, and assessing and analyzing policy. SD starts with the targeted problem and conducts an analysis on the targeted system in details. It can abstract and simplify the realistic system and obtain the outline from it. SD models analyzes and calculates through simulation experiment to present nonlinear behavior of different variables that change over time in the future.

Since green transformation is a long-term task, it requires complex coordination among each sub-system in order to achieve sustainable growth and maximum efficiency of the economic-social-environmental systems. Green transformation study is based on the systematic thinking that “an integrated system is greater than the sum of individuals”.

As we mentioned previously, Physical capital (K), Human capital (H) and Natural capital (R) are defined as the “stock” in SD. SD is centered around the stock variables and driven by flows. It takes flows as a tool to influence stock. Policy uses flows as forces to change the amount of stock. These three capitals affect and correlate with each other, together they can determine the increment and total value of an economy (as shown below in Figure 2).

Figure 2. the relationship of Physical capital (K), Human capital (H) and Natural capital (R) in the model



Source: Authors.

From the supply-side perspective, Brock and Taylor (2005) summarized three factors that affect pollution: gross size of the economy, industrial structure and technological level. The total pollution of an economy E is:

$$E = \sum_{i=1}^{n} E_i = \sum_{i=1}^{n} a_i s_i Y$$

E_i represents the pollutant emission of industry i, S_i is the share of industry i in GDP, i indicates pollution per unit of GDP generated by industry I (which can reflect energy efficiency or technical progress), and Y represents GDP. By differentiating this equation with respect to time we can divide the growth rate of pollution into three effects:

$$\frac{\dot{E}}{E} = \sum_{i=1}^{n} \frac{E_i}{E}\left(\frac{\dot{\alpha}_i}{\alpha_i} + \frac{\dot{s}_i}{s_i}\right) + \frac{\dot{Y}}{Y}$$

$\frac{\dot{\alpha}_i}{\alpha_i}$ represents technical progress effect, $\frac{\dot{s}_i}{s_i}$ represents industrial structural effect, and $\frac{\dot{Y}}{Y}$ represents economic growth effect. Therefore, with other variables being constant, technical progress that reduces emission per unit of GDP and increases the share of low pollution industries, can reduce pollution while economic growth will increase pollution. Justin Yifu Lin and his coauthors (1994, 1996, 1998, 1999, 2002，2017) described this problem from the aspect of the basic logical relationship among economic growth, technological progress and industrial structural change. The government can increase or decrease pollution by adjusting green investment, technological progress, environmental regulation, industrial structure, and economic growth.

3.4 Initial input data

The simulated time period in this model is 2000-2030; data in 2000 are imported as the initial data, and data in 2000-2015 are used as a historical standard to adjust the model. If not specified, the default price is based on data in 2000. During 2000-2015, there was some variation in industrial classification, industrial indicator statistic standard and financial expenditure standard. We use studies of Shiyi Chen (2011), Jun Zhang (2009), Harry X. Wu (2013) and others as references to organize data of industrial added value, capital stock, total investment in fixed assets (Since data of Chinese industrial fixed capital formation is insufficient, we use total investment in fixed assets instead), employment and waste disposal.

By comparing Annex table 2 with the rest of data, we find that according to the yearbook the real GDP of 2000 is 10,028.01 billion yuan, slightly higher than the value in the model. According to the estimation by Youchun Tian (2016), the capital stock of 2000 is 18,1746.4 billion yuan, slightly lower than the value in the model. The employment of 2000 in the yearbook is 720.85 million people, also lower than the value in the model.

In terms of the capital investment, Juhuang He (1992) used productive capital accumulation and nonproductive capital accumulation as the total investment. Qianli Xie and others (1995) used investment in new fixed asset deducted by housing investment and nonproductive capital. Meng Lian and Xiao Lu Wang (2000) used total investment in fixed assets multiplied by the application rate of invested fund as the fixed capital formation before 1980, and they used fixed capital formation as data after 1980. He Feng (2003) and Jun Zhang (2004) also used fixed capital formation. Yongfeng Huang (2009), Yixuan Wang and You Wu (2003) used data of industrial fixed capital formation, while Yong Chen and Xiaoping Li (2009) believed this method calls for too much estimation and the standard error is unpredictable. Yong Chen and Xiaoping Li (2009) used net added value of fixed assets in two sequential years as the total investment. Shiyi Chen (2011) framed total investment in two ways: one is taking the difference of fixed assets cost, and the other way is taking the total new fixed assets of infrastructure and betterment investment. However, China Statistical Yearbook has stopped releasing fixed assets costs data in 2008. Therefore, using it to frame data requires extra assumptions. This study takes industrial investment in fixed assets as the total investment, which is mainly used for solving output elasticities of capital and labor as well as variations of investment proportions in 10 industries.

This study sets up an exogenous relationship between pollution emission and average life expectancy. We first select soot and dust emission, COD emission and solid waste emission to represent atmosphere, water and solid pollution respectively. Subsequently, we create a pollution emission index and set up the relationship between the index and average lifetime. Although there is no specific empirical evidence, it is widely known in the academic field that pollution can cause disease and reduce life expectancy.

Pollution emission is significantly related to public health. In 2015, *The Lancet* released statistics about global life expectancy and reasons of death in 1980-2015, showing that in 2015 air pollution caused 21 percent of deaths from cardiovascular diseases，25 percent of deaths from coronary artery diseases and, 24 percent of deaths from cerebrovascular incidents (Kassebaum 2015). In 2013, *Proceedings of the National Academy of Sciences of the United States of America* released a study that was accomplished jointly by scholars from Israel, China and America (Chena 2013). This study shows that life expectancy of northern China is lower than southern China because of smog. Life expectancy of residents in northern China is reduced by more than 5.5 years. This result is estimated by the statistical model on difference of total suspended particulate (TSP)[8] across the Huaihe river and the mortality rate of cardiovascular disease (See Chen et al 2013; Ebenstein et al, 2015; and Cai et al 2015). A study by *The New England Journal of Medicine* showed that in the U.S. if the radius of PM 2.5 is reduced by 10 ug/m3, the average life expectancy will increase by around 0.61±0.20 years. To measure the effect of pollutants on public health, we need a large amount of information including exposure level and time, population, pollution source and influence of exposure to chemical per unit. However, some data are unavailable. The World Health Organization (WHO) is now studying the global disease burden caused by these factors. Other researchers have also been trying to calculate the disease burden caused by exposure to chemicals. The standard of disease burden is *Disability-Adjusted Life Year*, *DALY* proposed by the WHO. It measures the difference between life expectancy under current public health condition and optimal public health condition. This method is applied to measure the impact of disease and compare impact levels among different diseases and negative factors. Although the study is still at the initial stage, the result will provide an analysis on reasons, characteristics and effects of certain diseases in the future.

3.5 Calibration and Selection

In our SD model, we set up exogenous parameters mainly based on three types of resources. The first group includes the future industrial development plans released by the Chinese government, such as the 13th five-year plan, China's future vision for 2020 and so on; the second group includes related studies by research institutions and scholars, such as *China 2030*, which is a joint project of World Bank and Development Research Center of the State

[8] TSP is total suspended particulate, which refers to particulate with a diameter smaller than $100\mu m$. TSP with a diameter smaller than $10\mu m$ is PM10, and same applies to PM2.5.

Council; *China 2030 to a shared prosperity* by Angang Hu and others in School of Public Policy & Management of Tsinghua University; *China in 2050 Low-carbon Development Path* by 2050 China energy and carbon research group; and *China Energy 2030 Outlook* by China energy research *World Energy Outlook* by International Energy Agency. The third group includes data sources such as Chinese Statistics Yearbook, industrial statistical yearbooks, World United Nations Population Division and World Bank Open Data.

SD models do not require data accuracy to the same extent as many econometric models. Therefore, there is no strict requirement about the initial value or constant. If some variables cannot be obtained from currently available sources, we can infer them according to logic and past experience/studies. Parameters of Systematic Dynamics include the initial value, constant, tabulated functions and so on. To simplify parameters, SD models assume variables that do not change significantly over time to be constant. SD models use tabulated functions to effectively solve nonlinear problems. For those variables that lack reliable resources, this study either assume them to be the initial value or imply a reasonable value according to past experience. When adjusting the model, this study will compare simulated results with historical data to adjust parameters and calculate the optimal value of endogenous variables. Only those that match best with historical data can be selected into the model.

This model mainly focuses on the influence of structural change in the secondary industry on green transformation. The following part explains the calculation of parameters using the added value of the secondary industry as an example.

The model employs the C-D production function:

$$Y_t = AK_t^{\alpha} L_t^{\beta} \quad (1)$$

Y_t represents real production, L_t represents labor input, K_t represents capital stock, α, β represent capital elasticity and labor elasticity respectively.

Taking natural log on both sides of the production function to estimate shares of average capital production and average labor production:

$$\ln(Y_t) = \ln(A) + \alpha \ln(K_t) + \beta \ln(L_t) + \varepsilon_t \quad (2)$$

Assuming constant return to scale: i.e. $\alpha + \beta = 1$:

$$\ln(Y_t / L_t) = \ln(A) + \alpha \ln(K_t / L_t) + \varepsilon_t \quad (3)$$

We can get capital production elasticity and labor production elasticity from added value, investment and employment of secondary industry in 2000-2015 by doing multiple regressions on time series data. The financial crisis in 2008 had a dramatic effect on the global and Chinese economy. Chinese capital production elasticity declined after 2008. Therefore, we calculate Chinese capital production elasticity during 2000-2008 and 2009-2015 separately, and we get α =0.7, 0.5 respectively.

As for the total factor productivity, with the assumption of constant return to scale, and technology neutrality, the growth rate of total factor productivity is:

$$\frac{\Delta A}{A}=\frac{\Delta Y}{Y}-\alpha\frac{\Delta L}{L}-(1-\alpha)\frac{\Delta K}{K} \tag{4}$$

After determining the value of α, we solve for annual growth rates of actual production, employment and capital accumulation, and plug them into function (4), so we can get the total factor productivity in 2000-2015. Nevertheless, to calculate total factor productivity, the initial total factor productivity in 2000 should be assumed as 1. Total factor productivity is the sum of all components that contribute to economic growth except capital input and labor input. The sources of aggregation include technical progress, efficiency improvement of resource allocation (mainly reflected by structural improvement), random aspects and so on. Therefore, our theoretical total productivity factor mainly includes two aspects: technical progress and structural improvement (mainly economic structural improvement). Overall our model considers technical progress, labor force educational level, labor force health condition, market index and energy price as factors that significantly influence total factor productivity.

Technical progress is an endogenous factor that is influenced by investment, capital stock and growth rate of technical advance. Labor force educational level is represented by average years of schooling. Labor health condition is represented by average population lifetime. Study results and the calculation methodology of Fan Gang (2003) and others are chosen as market index. Energy price is represented by fossil energy price index from the Chinese Green Economy model created by Hefeng Tong for UNEP. This index is generated by weighing prices of coal, petroleum and natural gas. All factors have the identical effect except the eight sectors of secondary industry which have different technical progress. By doing multiple regression on time series data, we can obtain the elasticity of these five factors.

4. Scenarios analysis

Policy is an important tool to control and adjust social economic systems. Each system has several action points, which means policy decisions are always anchored to a few factors. As long as we figure out these factors, we can observe their consequences (Xu Li 2009). Policy in SD is the behavior of single or multiple variables. The current system varies with variable change as a result of policy adjustment.

There are three scenarios in this paper:

1. The baseline scenario
2. The Green Future scenario
3. The Tax-Future scenario, which utilizes tax proceeds in green investment

4.1 Major Simulated Results Under the baseline scenario

There are different methods that can be used to achieve green transformation, the scenario presented by this model is only one of them. The model gives a feasible plan rather than a prediction: it can present different future views based on different scenarios. Any variable change can cause a new simulation and therefore generate a different scenario. The critical time points are set at 2020 and 2030. Setting values of selected variables at 2020 and 2030 refers to related policy plans, research results and common sense. The collection of these values is the baseline scenario. The comparison between data of the baseline scenario and the rest of the scenarios will be further explained in other scenarios.

To make sure that the model is accurate, we compare the simulated data with historical data with respect to population, GDP, added value of secondary industry and employment of secondary industry. The maximum standard error between the simulated value and the historical value is below 6%.

Under the baseline scenario, year 2020 and 2030, simulated results of Chinese economic, social and environmental indexes are shown as follows:

Table 4.1. Simulated Results: Chinese Economic, Social and Environmental Indexes

Indicators	2020	2030
Population (Million)	1420	1435
Fraction of pop 60 and over (%)	18.37	26.62
Real GDP (2000 price, Trillion)	56.90	99.73
The proportion of the service industry (%)	54.94	65.17
Industrial COD (Million Tons)	2.74	3.38
Industrial soot and dust (Million Tons)	6.83	7.89

Source: simulation results of base line scenario, authors.

4.2 Green scenario

A main task of this model is to simulate related policies as well as their impact on green economy transformation. In this study, the government is the major driving force of green transformation. In the baseline scenario, the future investment ratio of the related industries is unchanged from 2015. Firstly, by changing the orientation of green investment, physical capital in the future (2016-2030) will raise the share of investment in green industries. Secondly, by changing government behavior towards supporting the green economy, more fiscal investment will be used on education and public health to increase human capital accumulation. Thirdly, government will impose environmental tax on pollutant discharge to reduce the endowment on pollution. Adjusting expenditure orientation of tax income can generate different policy effects.

4.2.1 Green Investment

In terms of investment, the first step is to change the investment orientation of three sectors: the primary, secondary and tertiary. In the future, there should be more investment in green primary industry and tertiary industry. However, to maintain a balanced industrial structure, we need to keep a certain share of investment in the secondary sector especially in those subsectors with low pollution intensity. See table 4.2 for more details.

Table 4.2. Shares of Investment in Primary, Secondary and Tertiary Industries (%)

	2010	2011	2012	2013	2014	2015	2020	2030
The primary industry	3.1	2.8	2.9	3.0	3.2	3.7	3.7 (4.5)	3.7 (5)
The secondary industry	46.9	42.5	42.2	41.6	40.7	40.0	40.0 (36)	40.0 (33)
The tertiary industry	49.9	54.7	54.8	55.4	56.0	56.2	56.2 (59.5)	56.2 (62)

Note: Values of green scenarios are in brackets. Source: Authors.

Next, investment in secondary sector should also focus on green subsectors. However, we still need to consider the realistic development situation of each industry at the same time. Chinese cement demand has been declining after hitting a peak in 2015, and it will hardly increase in the future. Hence investment on Non-metal Mineral Product Industry will decrease rapidly. The production of Ferrous Metal Melting and Rolling Industry has been shrinking, although the investment in this industry will not drop dramatically until 2020 since Chinese iron demand will be maintained at a stable level during this time. While the construction industry should be considered as a green industry with regards to emissions, related industries such as cement and iron are high pollutant industries. Therefore, future investment in construction should be maintained at a stable level. In the electricity, heat production and supply industry, renewable energy power has a relatively high potential development and large investment demand, so the share of investment will increase. The natural gas production and supply industry is a dirty sector according to the results of Borda ranking, but it is cleaner than coal and oil as fossil energy, so in the future this industry should maintain steady.

Table 4.3 Shares of Investment in Sub-sectors of Secondary Industry (%)

	2010	2011	2012	2013	2014	2015	2020	2030
Construction	2.2	2.5	2.3	1.9	1.9	2.1	2.1 (2.1)	2.1 (2.1)
Ferrous metal melting and rolling	3.3	3.9	3.3	2.8	2.3	1.9	1.9 (1.5)	1.9 (1)
Nonmetallic mineral products	7.8	7.8	7.6	7.4	7.6	7.5	7.5 (5)	7.5 (2)
Electricity,heat production and supply	11.2	8.8	8.2	7.9	8.4	9	9 (12)	9 (15)
Petroleum processing, coking and nuclear fuel processing	4.9	4.0	3.5	3.7	3.4	2.7	2.7 (2)	2.7 (2)
Natural gas production and supply	1.0	0.9	1.0	1.2	1.1	1	1 (1)	1 (1)
Labor intensive industry	16.8	17.4	18.3	15.9	16.5	20	20 (18)	20 (16)
Capital intensive industry	52.7	54.7	55.7	59.2	58.9	55.9	55.9 (60.5)	55.9 (63)

Source: Authors with simulation results.

4.2.2 Expenditure on Education and Public Health

Most studies show that education expenditure of government is significantly related to average years at school, and health care expenditure is significantly related to average life expectancy. In the green scenario, government will expand the expenditure on education and health care, thereby increasing labor capital accumulation and labor productivity. In 2007, Chinese government Bureau of Statistics changed accounting methods. To stay consistent, this model divides government expenditure into five categories: education expenditure, health care expenditure, infrastructure, public service and other expenditure. Except expenditure on education and health care, the rest of social expenditure mainly belongs to other expenditure. Table 4.4 below indicates that although Chinese expenditure on education and public health keeps increasing, its share in total expenditure has been fluctuating, especially the share of education expenditure. The proportion of other expenditure, which includes social welfare expenditure, remains unchanged. However, the proportion of poverty reduction expenditure will increase, and it is an important goal to reduce the development gap and the Gini coefficient.

Table 4.4 Financial Expenditure on Education and Public Health

	Financial Expenditure on Education	Share in Total Financial Expenditure	Financial Expenditure on Public Health	Share in Total Financial Expenditure
2000	2847	17.92%	709.52	4.47%
2001	3498	18.51%	800.61	4.24%
2002	4103	18.61%	908.51	4.12%
2003	4455	18.07%	1116.94	4.53%
2004	4461	15.66%	1293.58	4.54%
2005	5197	15.32%	1552.53	4.58%
2006	6511	16.11%	1778.86	4.40%
2007	7122.32	14.31%	1989.96	4.00%
2008	9010.21	14.39%	2757.04	4.40%
2009	10437.54	13.68%	3994.19	5.23%
2010	12550.02	13.96%	4804.18	5.35%
2011	16497.33	15.10%	6429.51	5.89%
2012	21242.1	16.87%	7245.11	5.75%
2013	22001.76	15.69%	8279.9	5.91%
2014	23041.7	15.18%	10176.8	6.70%
2020	/	16%(17%)	/	8%(9%)
2030	/	18%(20%)	/	9%(11%)

Source: China financial statistics yearbook, and authors.

4.2.3 Environmental Protection Taxation

Environmental Taxation is an economic approach that internalizes the cost of environmental pollution and ecological destruction into production cost and market price， and then allocates environmental resources through a market mechanism. The purpose of imposing environmental taxation is to reduce pollutant discharge. Environmental taxation will definitely increase the tax burden and change the cost-benefit ratio of polluting companies, thereby forcing them to re-estimate their resource allocation effectiveness. At the same time, environmental taxation will influence economic decisions and behavior of other companies. Imposing an environmental tax will also change the financial expenditure of Chinese government.

At the end of 2016, the Standing Committee adopted *Environmental Protection Tax Law of the People's Republic of China*, which shall come into force on January 1, 2018. This law coverts the original pollution discharge fee into an environmental tax and uses the current pollution discharge fee standard as the lower boundary of the environmental tax. From 2003 to 2015, the accumulated pollution charge in China was 211.599 billion yuan. In 2015, the total pollution discharge fee was 17.3 billion yuan. Since it was the first time that government imposed an environmental tax, the tax rate was relatively low. If the optimal tax rate cannot be achieved, a relatively low environmental tax is also a fair option. According to the law, tax on atmospheric pollutant ranges between 1.2 yuan and 12 yuan per unit, water pollutant ranges between 1.4 yuan and 14 yuan, tax on solid waste varies between 5 yuan to 1000 yuan per ton based on types, and the tax on excessive noise is charged by excessive decibel of the noise, the amount ranges between 350 yuan and 11200 yuan each month.

This study will simulate the future influence of the upper limit of the environmental tax. In the baseline scenario of the model, since the current tax burden is equivalent to the original discharge fee, we do not consider environmental tax in this case. In a green scenario, the environmental tax rate will be higher than the tax rate regulated by *Environmental Protection Tax Law*. The environmental tax income will be accounted in government total tax income, and it will be expended into different fields according to the original ratio. In addition, there are different types of pollutants. This model selects soot and dust, COD and solid waste. Besides, the model assumes that the tax is imposed in 2016 rather than 2018 to estimate the effect of this policy approximately.

4.3 Tax-revenue Allocation Scenarios

Each country has its own policy on the secondary allocation of environmental tax revenue. For example, the environmental tax in the U.S. is collected by the Internal Revenue Service and stocked in the Treasury Department. The Treasury Department is responsible for allocating the tax income into the general fund budget and the trust fund. The Superfund is a trust fund, and it is administrated by the U.S. Environmental Protection Agency. The Superfund is mainly used for specific environmental protection projects. The environmental tax in France is collected and allocated jointly by central government and local government, and it is all invested in environmental protection. Tax income collected from local pollution projects by local government is directly invested in reducing pollution of these projects.

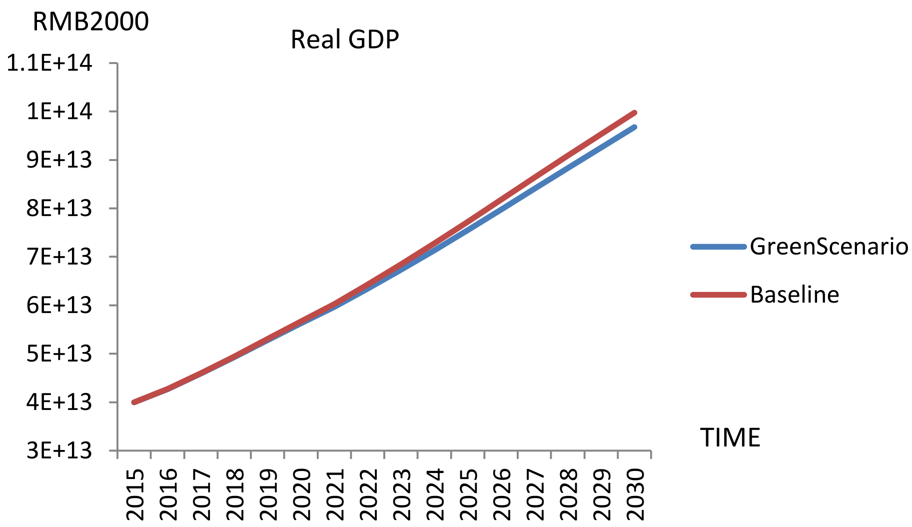
In order to distinguish different effects generated by different orientations to use environmental tax income, we add a tax scenario, which is investing all the environmental tax income into green industries. In this case, we assume the environmental tax income to be invested in the capital-intensive industry. The capital-intensive industry is the industry in which the unit labor occupies the higher capital, the amount of investment needs is relatively large, and the investment cycle is long, but very important to improve the labor productivity of a country. "Made in China 2025" is an initiative to comprehensively upgrade Chinese industry and particularly to support "Strategic Emerging Industries". Clear goals of this plan are to make Chinese companies more competitive across the board, to have Chinese firms move up the value-added chain in production and innovation networks, and to achieve much greater international brand recognition. In addition, the plan calls for the Chinese government and firms to ramp up their efforts to invest. If all the extra environmental tax income is invested in capital intensive industry, the future influence is still unknown.

5. Results from Different Scenarios, and Interpretation of results

5.1 Comparison of simulation results

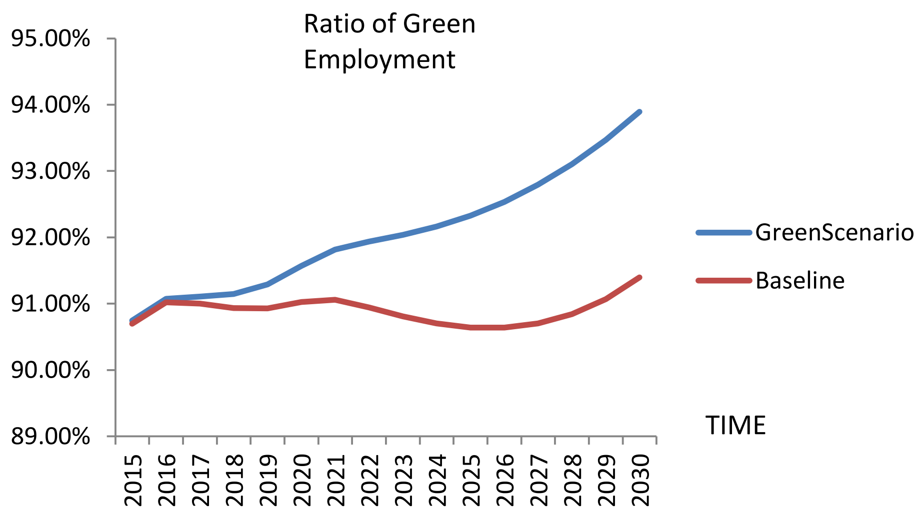
Moving towards a green development path will not cause huge negative shocks for China's future economy. The real GDP growth rate will fall by 0.1 to 0.3 percentage points, but if we take into account the effect of pollution on GDP, it would be a positive effect (See Figure 3). First, the policy change will not have a large immediate impact, and in the later period, the productivity of the secondary industry will be higher than the baseline scenario, making it more competitive. Second, our model predicts that the share of green sectors in the economy will rise significantly, in terms of both the ratios of green employment as well as the green sectors in the economy (see Figure 4).

Figure 3. Comparison of Real GDP of the Green Transformation scenario and base line scenario



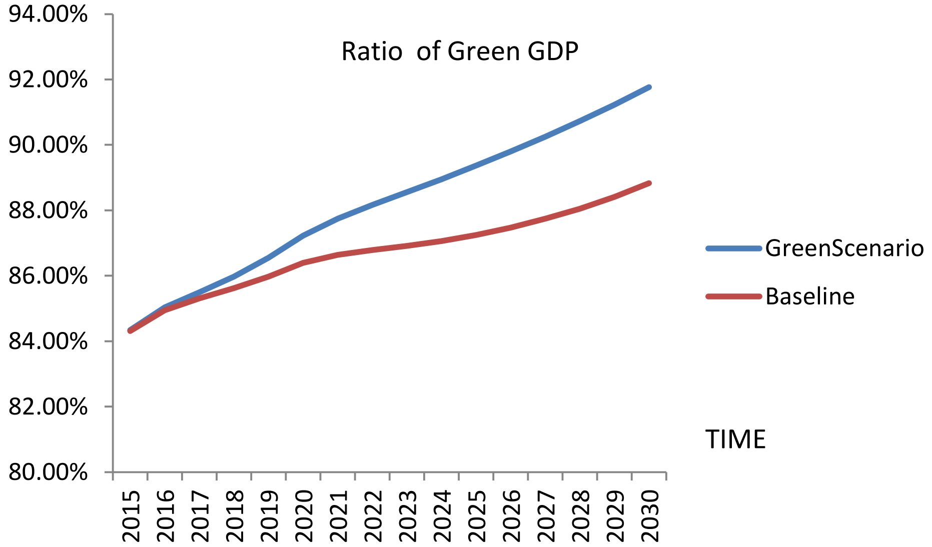
Source: Authors, based on simulation results.

Figure 4 Comparison of Ratio of Green Employment of the Green Transformation scenario and baseline scenario



Source: Authors

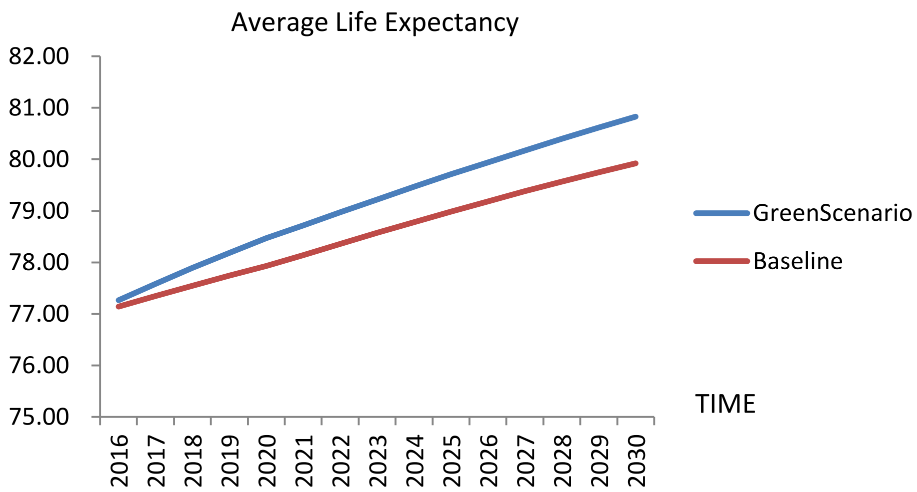
Figure 5. Comparison of Ratio of green GDP of the Green Transformation scenario and base line scenario



Source: Authors

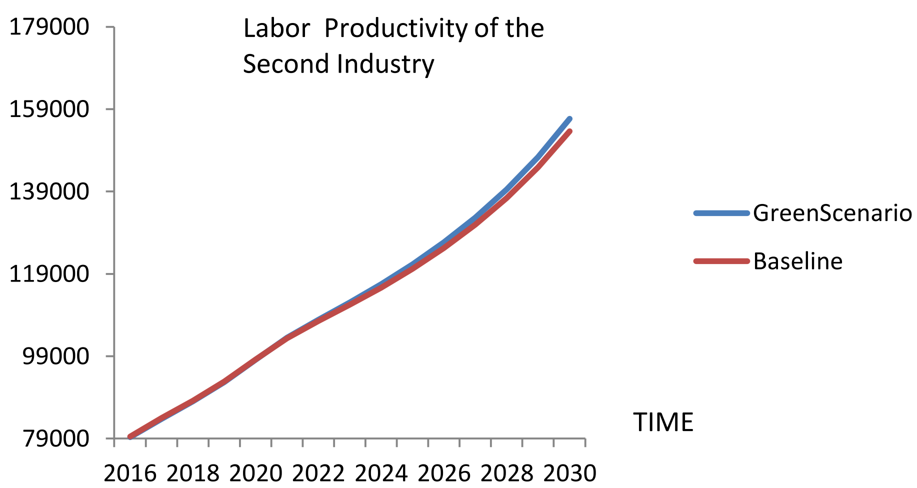
The green scenario enhances people's welfare, even though the GDP growth rate declines moderately. People's life expectancy has been improved, and this effect is becoming more and more obvious. In 2030, it will be 0.91 years higher than the baseline scenario (see Figure 6 below). The number of poverty is reduced, as measured by the 2300-yuan poverty line set in 2011 by Chinese government, although the per capita income is slightly lower than the baseline scenario, the number of poverty in the green scene is less in most years. The labor productivity of the second industry has been improved, although the labor productivity of some non-green industries has fallen, but the labor productivity of the whole second industry has not been negatively affected. Under green scenario, the emission of industrial pollutants can be controlled effectively. The cumulative reduction of industrial solid waste discharge would be 1.1 billion tons from 2016 to 2030, industrial smoke and dust 13 million tons and industrial COD emissions 5 million tons. After the reduction of pollutant emission, along with the pollution intensity decline, the negative impact on people's life expectancy is reduced, and therefore, the labor force becomes healthier and more resilient, contributing to rising productivity (See Figure 7 and summary table 6.1).

Figure 6. Comparison of Average Life Expectancy of the Green scenario and baseline scenario



Source: Authors

Figure 7. Comparison of Labor Productivity of the Second Industry of the Green scenario and baseline scenario

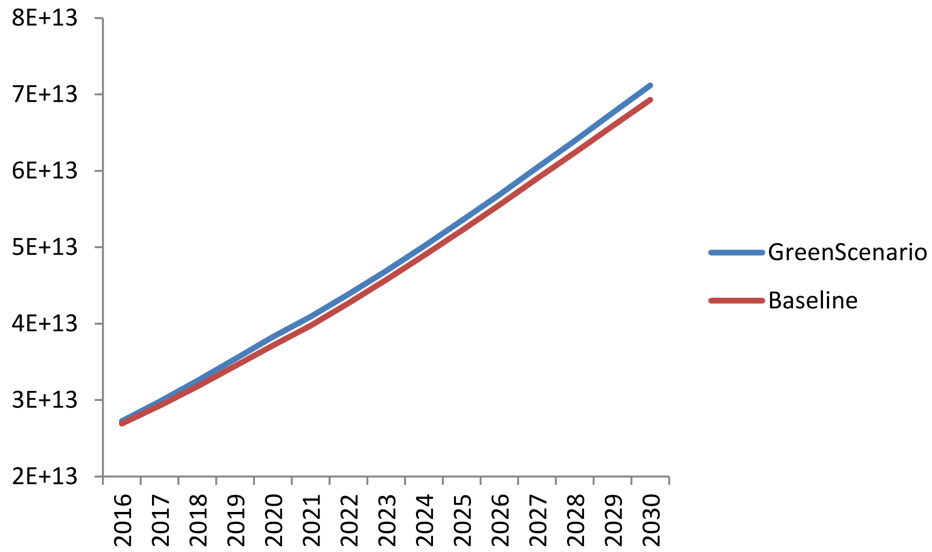


Source: Authors.

5.2 On Green Investment

The total green investment in green scenario is higher than the baseline scenario. The cumulative additional green investment would be 1.8 trillion yuan from 2016 to 2030. As the dirty investment would be fallen a lot, making it possible to invest more on green industry (see Figure 8).

Figure 8. Comparison of Green Investment of the Green Transformation scenario and base line scenario



Source: Authors

Table 5.1 below summarizes the important results from simulations, most of which were discussed above. There are three scenarios: the Baseline, the Green Scenario, and the Tax scenario. Compared with the green scenario, the tax scenario only adjusts the way environmental tax expenditure is allocated, so the impact of simulation results on GDP and social welfare is very small. Although the investment in capital intensive industries has increased, it does not have much influence on the output value of the whole industry, and the labor productivity has not been improved. Thus, this shows that the way of government investment is less effective.

Table 5.1 Summery Results: comparison of main simulation results in 2030 in three scenarios

Index	Unit	Baseline	Green	Tax
Total Pop	Billion	1.44	1.44	1.44
Real GDP	Trillion	9.97	9.67	9.67

	RMB 2000			
Value added of the secondary Ind.	Trillion RMB 2000	2.95	2.49	2.49
Productivity of the secondary Ind.	RMB 2000/person/year	153660	156636	156665
Value added of capital intensive Ind.	Trillion RMB 2000	1.48	1.37	1.37
Productivity of capital intensive Ind.	RMB 2000/person/year	183692	183961	183960
COD emissions of the secondary Ind.	Million tons	3.38	2.67	2.67
Smoke and dust emissions of the secondary Ind.	Million tons	7.89	5.97	5.96
Solid waste discharge of the secondary Ind.	Billion tons	2.14	1.98	1.98

Source: Authors. Note: “RMB 2000” means RMB at the year 2000 constant price.

6. Conclusion

This paper deploys a ***system dynamics (SD) model*** to analyze and simulate three policy options to achieve the transformation to a green economy. Consistent with the New Structural Economics (Lin 2010, 2011), our approach starts from the structure of endowment (stocks), and then moves to investment (flows), the structure of employment and changes in labor productivity.

Our simulation results are as follows: First, moving towards a green development path will significantly improve people’s welfare including reduced pollution and extended life expectancy. In 2030, average life expectancy will extend by 0.91 years, and poverty incidence will decline. Moving towards a green development path will not cause huge negative shocks for China’s future economy. The policy change will not have a large immediate impact, rather, it will promote economic development in the later period. Second, our model predicts that the share of green sectors in the economy will rise significantly, in terms of both the ratios of green employment as well as the green sectors in the economy. Third, as pollutant emission fall along with the pollutant intensity decline, the labor force becomes healthier and more resilient, contributing to a rise in productivity in the economy.

Governments are able to influence the level of pollution via active taxation and expenditure policies, as well as industrial structural reforms. Based on our SD model simulation, under the green transformation scenario, the emission of industrial pollutants can be controlled effectively. From the perspective of pollutant emission, the industrial soot dust and solid waste emission in the green scenario are lower than the baseline scenario, indicating that green transformation is also good for air pollution control.

A relatively modest policy on the environmental tax will not have a large negative impact on the Chinese economy. Chinese current tax rate is adopted mainly based on a tax base characterized by cost-benefit of emission. An ideal environmental tax should induce a change in the behaviors of enterprises and those of consumers, through tax basis and tax rate. In the future, the government may adjust gradually the tax base and tax rate, in order to optimize the tax system so that the environmental taxation rate can reach its optimal level without heavily influencing the market equilibrium.

Similar to many economic models including the CGE models, the system dynamic model deployed in this study is based on some assumptions (albeit not as strong as in CGE models), and then numerical simulations were done based on these assumptions. The theoretic foundation for such assumptions still needs in-depth analysis. In future research, we need to make clear what transmission channels can be utilized for industrial policy to play a better role in green transformation. The cross-sector effect of clean technology on green transformation is not included in the current version of the model. In the future, the role of cleaner technology, innovations such as shared ride, shared space and shared economy as a whole should be investigated.

Appendix:

Appendix I: A Composite Index of Pollution Intensity by Sectors

This model mainly simulates the influences among these three types of capitals and the effect of the investment from government and society on the industrial structure. In order to have an idea about the pollution levels of each industry, we need to first organize the discharge of seven types of pollutants per unit of value-added in the primary industry, tertiary industry, construction industry and 41 other industrial sectors (using data of 2014). We rank the data of

7 pollutants by Borda ranking method[9] to construct a composite index of pollution intensity, and thereby identifying "green" and "nongreen" sectors. The secondary industry is divided into construction, gas production and supply, petroleum processing, coking and nuclear fuel processing, ferrous metal melting and rolling, nonmetallic mineral products, electricity, heat, gas production and supply, labor intensive industry and capital intensive industry. In electricity, heat, gas production and supply industry, there are two ways to supply electricity: thermal power and non-thermal power. According to Chinese industrial statistics, high-energy consuming industries mainly include the following six categories: electricity, heat, gas production and supply, petroleum processing, coking and nuclear fuel processing, manufacturing of chemical raw materials and chemical products, non-ferrous metal melting and rolling, ferrous metal melting and rolling, nonmetallic mineral products. Combing the result of Borda ranking and Chinese classification of sectors, we consider the following sectors as **non-green industries**: petroleum processing, coking and nuclear fuel processing, ferrous metal melting and rolling, nonmetallic mineral products, gas production and supply, thermal power and labor-intensive industry. The rest, the primary industry, tertiary industry, construction industry, renewable energy power and capital-intensive industry are classified as **green industries.**

Green Transformation needs to be achieved by changing the orientation of investment. First, the private sector in responding to changes in consumer demand will increase the share of investment on green industry in the near future (2016-2030). Secondly, Government will increase fiscal investment on education and health care to improve human capital accumulation, and also improve the investment on poverty reduction. At the same time, government should impose differentiated environmental tax on each industry according to their pollution intensity, which will influence the production of each industry and increase tax income. Allocating tax income into different sectors can generate different regulation consequences. For example, government can utilize the environmental tax proceeds in either

[9]Borda ranking method is based on public choice theory and has been used in evaluating welfare across countries. The Borda rule provides a method of rank-order scoring that allows policy indicators to be aggregated even though they were originally measured in different units. We first rank each country/sector for each criterion (pollutant, in this case). The rank order points are then added for each country/sector to obtain its aggregate score. Then the countries/sectors are re-ranked on the basis of their total scores. In the Quality of Growth, we used the Borda ranking method to construct two composite indexes, one for human development, the other for environmental sustainability, each consisting of three indicators. For details See Fine and Fine (1974), Nitzan and Rubinstein (1981), and Thomas and Wang (1996). See also https://en.wikipedia.org/wiki/Borda_count

green industrial development or in public health.

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