Advances in Management & Applied Economics, vol. 8, no. 2, 2018, 33-59
ISSN: 1792-7544 (print version), 1792-7552(online)
Scienpress Ltd, 2018

Sources of China's Economic Growth: A Case for Green Accounting

Wanping Yang* and Jinkai Zhao

Abstract

Based on the Solow growth model and the concept of sustainable development, we decomposed the sources of China's economic growth into total factor productivity, physical capital, human capital, energy consumption and the environmental loss, utilizing data 1981-2012 in China. The contribution of each of the five aspects on China's economic growth and the impact on China's economic growth fluctuations were measured, and results revealed that investment in physical capital is the main driving force for China's economic growth at the present stage. The energy consumption accounts for 24.8% of China's economic growth. The economic growth rate related to the environment is -1.14%, showing that environmental loss has become an obstacle to economic growth in China. Economic growth fluctuations and TFP fluctuations also showed a more consistent trend. As a whole, China's economy presents an extensive development, characterized by "high input, high consumption, high emission and low efficiency". Therefore, the key for China to achieve sustainable economic development is changing their economic growth model and impelling total factor productivity to be the main motivating force and source, instead of physical capital and energy consumption.

JEL classification numbers: 011
Keywords: Sources of economic growth, total factor productivity, human capital stock, resources restriction, environmental restriction

---

* School of Economics and Finance of Xi'an Jiaotong University, China

Article Info: *Received*: January 10, 2018. *Revised:* February 3, 2018
Published online: March 1, 2018

1 Introduction

Since China launched their market-oriented reform and open-door policies in 1978, China’s economic growth has been remarkable. However, this rapid growth has highlighted the economy’s extensive features, which include "high input, high consumption, high emission and low efficiency", and have attracted increased attention to China’s approach to economic development. Large-scale energy mining and coal usage have caused damages to the ecological environment, bringing serious environmental pollution to China. Therefore, it is crucial to re-examine the sources of economic growth in China, and the main factors affecting economic growth fluctuation. What is China’s source of economic growth? Is it efficiency, factor inputs or ecological loss? What are the main factors affecting fluctuations in China's economic growth?

This paper investigates the determinants of China’s growth over the period of 1981–2012, using a simple growth-accounting framework that incorporates human capital stock, energy consumption and environmental loss. By introducing human capital stock, energy consumption and environment loss into the Cobb-Douglas production function and decomposing sources of China’s economic growth, we attempt to shed light on the relative importance of factor accumulation (physical capital, human capital, and environment loss) and total factor productivity (TFP). We also analyze China’s economic development process over the past few decades to provide a reference for achieving a well-off society.

When it comes to economic growth sources, it is widely acknowledged that energy consumption is a crucially important factor. Energy consumption is often considered part of the intermediate inputs, however, it is difficult to record emissions in production costs, due to the lack of market pricing and environmental taxation policies for pollution. This paper regards energy consumption and environmental loss as the ecological loss, avoiding the difficulty that pollution losses are hard to measure. Under the green economic growth accounting framework that considers energy consumption and environmental loss, we explore the sources of economic growth.

The rest of this paper is organized as follows: part two reviews relevant literature, part three introduces methods and data sources, and part four analyzes the power sources of economic growth between 1981 and 2012, utilizing Solow growth model. The fifth part studies the contribution of each sources of economic growth to China's economic growth fluctuation, and part six is a conclusion and policy recommendations. Supplementary material is provided in the appendix.

2 Literature Review

Since Solow proposed total factor productivity in 1957 [1], it has been widely used in growth accounting framework, and has become an important indicator of economic growth. If total factor productivity holds the majority of shares in a country's economic growth, then that country's economy is considered sustainable; however, if factor input holds the majority, the country's economy is considered unsustainable. Therefore, most Chinese scholars (see [2,3,4,5,6]) study sources of China's economic growth on the basis of total factor productivity.

Guo et al. (2005) [2] found that the contribution of total factor productivity growth to China's economic growth was lower during the 1979 to 2004 period, and with the average contribution rate 9.46%; and the average contribution of factor inputs 90.54%. This reveals that China's economic growth primarily depends on factor inputs, which is a kind of typical input type. Li et al. (2013) [3] studied the sources of China's economic growth from 1978 to 2010 using the Solow residual method, and found that the average annual economic contribution of investment in physical capital, labor input, productivity were 56.72%, 8.82%, and 34.46%. As a result, investment in physical capital was the most important source of China's economic growth from 1978 to 2010. The performance proved that China's economic growth is unsustainable, and China will face greater downward pressure on their economic growth due to capital investment contracting, which has appeared for nearly two years. Wu (2013) [4], Dong and Liang (2013) [5] and Jiang et al. (2014) [6] all found that capital investment was the main source of China's economic growth from 1978 to 2010.

However, the above researchers did not consider the contribution of quality of labor on economic growth. Therefore, some researchers (for example [7,8,9,10,11]) studied China's economic growth based on the difference between labor's quantity and quality. Wang (2000) [7] used the production function method to estimate the growth rate of total factor productivity, concluding that the contribution to economic growth of total factor productivity, capital, labor and human capital were 15.21%, 53.13%, 8.44% and 9.69% from 1979 to 1999, respectively. Hu (2003) [8] found that from 1978 to 1998, the contribution of capital, labor, and human capital expressed as average years of the education were 43.3%, 7.8%, and 6.7%, respectively. Consistent with the above findings, Xu et al. (2006) [9] found that the main driver of China's economy from 1987 to 2003 was the increase of fixed capital stock, and that the driver accounted for 67.23%. Fan et al. (2011) [10] used the production function method to estimate the contribution of total factor productivity to China's GDP growth rate from 1997 to 2007. They found that the contribution of total factor productivity, physical capital, labor and human capital were 32.06%,59.19%, 3.21%, and 5.55%, respectively. Zhou (2013) [11] decomposed the sources of economic growth from 1978 to 2009, revealing that the contribution of capital input, labor and human capital, TFP to GDP growth were 39.95%, 10.92% and 15.50%, respectively. This demonstrated that physical capital accumulation was the main source of economic growth and TFP was the second largest source, while the contribution of human capital was minimal. In these studies, although human capital played a positive role in promoting growth, its contribution was less. This shows that China's economic growth still strongly depended on factor input. The contributions of human capital and technological innovation should further improve.

Most studies, however, did not consider the ecological loss caused by China's economic growth, which may bring certain deviations to the measurement of the sources of economic growth. Further, this may cause conclusions and policy suggestions to have a negative effect on sustainable economic development. When it comes to economic growth sources, it is widely acknowledged that the energy factor is crucially important for economic growth. The processing of energy variables is identical, and they are regarded as an input factor. However, it is difficult to reckon the pollution discharged by production, due to the lack of market pricing and pollution-related tax policies. Therefore, there are two primary ways to process environmental variables when studying sources of economic growth. One is by introducing emissions as the undesired output into the function; the other is by regarding environmental pollution and energy uniformly as new inputs, which are unpaid input factors ([13, 27,28,29,30,31,32]).

Shi (2013) [14] chose physical capital stock and human capital stock as inputs. In addition to considering GDP as a desired output, he selected sulfur dioxide (SO_2) and chemical oxygen demand (COD) as the undesired output indexes to decompose outputs by green technological progress. He found that green total factor productivity accounted for 63.04% of the growth rate of output per worker, while the contribution of physical capital and human capital were 34.92% and 21.66%, respectively. This showed that green TFP plays an important role in the rate of growth of output per worker. On the basis of environmental loss, Liu (2014) [15] found that the environment as a whole pays a certain price for high economic growth, and that the environment was not a key factor in China's economic growth, compared with the factors such as physical capital, labor and productivity. Yang (2010) [16] regarded energy and material capital synthetically as composite physical inputs. Together with human capital stock and GDP, which were a factor input and an output variable, respectively, he decomposed the average output per worker in the western region of China. He found that total factor productivity accounted for about 54.48% of the growth rate of average output per worker, while the contribution of capital and human capital stock were 15.11% and 30.21%, respectively.

In addition to Chinese scholars, foreign economic scholars have also studied the sources of China's economy. Some scholars believe that the key driving force behind China's economic miracle is the use of soaring inputs, and that the contribution of productivity growth is limited. Chow (1993) [17] showed that from 1952 to 1980 China's economic growth was mainly due to the accumulation of capital. Krugman (1994) [18] argued that China would eventually face a limit on growth, since the economy depended heavily on a massive increase in input with only small improvements in productivity, as in the case of East Asian economies. His view caused a wide range of international influence. Based on an analysis of Chow, Hu and Khan (1997) [19] pointed out that capital accumulation was a major factor for economic growth from 1952 to 1994. However, China's TFP grew by about 4% from 1979 to 1994, and its contribution to China's economic growth was over 40%. Chow and Liu (2002) [20] used data from 1978 to 1998 to estimate the contribution of physical capital, labor and TFP on economic growth. They found that the contribution of physical capital was 66.34%, while the contribution of labor and TFP were 5.7% and 27.59%, respectively. Young (2003) [21] points out that the TFP growth rates in China are lower than 1.5%, and their contribution to economic growth is less than 20%, arguing that the main contributors to growth is the soaring increases in inputs, such as labor and capital. By considering the stage characteristics of China's economy, Maddison (2007) [22] studied the long-term economic performance, and made a continuous analysis and inference on China's economic growth.

Aoki (2011) [23] identified five phases of economic development that are common to China, Japan, and Korea: M (Malthusian), G (government-led), K (*à la* Kuznets), H (human capital based) and PD (post demographic-transition). In the different phases of economic development, China has had different sources of growth. Recently, Krugman (2013) [24] argued that China was experiencing a plummeting investment-income trend, that no matter what the government did, investments would fall sharply, and dramatic spending would be required to take the place of investing. However, China's consumption growth was too slow, it was not enough to avoid severe economic downturn. Naminse et al. (2015) [25] investigated the relationship among energy consumption, carbon emissions and economic growth in China from 1952 to 2012, conducting static and dynamic regression analyses on the determinants of carbon emissions and economic growth. They found that coal has a dominant impact on economic growth and carbon emissions, and GDP has a bi-directional relationship with carbon dioxide emissions, coal, gas, and electricity consumption. Jiang (2015) [26] investigated the linkage between China's output growth and its pollution emissions and found that the growth of total factor productivity in the Chinese provinces from 1997–2011 was accompanied by increasing pollution emissions.

In previous studies, we can hardly find one paper that considers both energy and environmental factors in the study of China's economic growth momentum. Sources of China's economic growth are calculated by regarding just physical capital and labor as inputs into the production function, neglecting the energy inputs that are required for economic growth and their environmental impacts. This neglect diminishes the relevance of this literature for assessing the true sustainability of China's evolving growth model. In this paper, we add energy and environmental factors to the economic growth model, and review the source of China's economic growth from an ecological civilization perspective. We view ecological destruction in the form of environmental pollution and energy consumption as the price paid in the process of human development, rather than the undesired output of human production activities. For these reasons, factor inputs (physical capital and human capital), total factor productivity and ecological loss (including energy and the environment) are included in the production function. The three terms can be considered as three drivers of economic growth. In addition, most researchers have chosen a single or multiple-single index to represent the environmental factor, causing difficulties and biases in expressing environmental stress. In this paper, we select emissions of industrial waste water, industrial waste gas (including sulfur dioxide and smoke dust [powder]) and industrial solid waste as indexes, and we use an objective evaluation method to account pollution index, which accurately represents China's overall environmental factor. For details, see Appendix B. This paper found that economic growth fluctuations and TFP fluctuations showed a more consistent trend. As a whole, China's economy presents an extensive development, characterized by "high input, high consumption, high emission and low efficiency".

3 Research methods and data sources

3.1 Research method

Following ideas that appeared in Denison (1962), Tyteca (1997), Brock and Taylor (2005), Tzouvelekas (2006), Dasgupta and Mäler (2000) and Xepapadeas (2005) that regard environmental pollution and energy consumption as new inputs. We construct the following Cobb-Douglas production function:

$$Y = AK^{\alpha}H^{\beta}N^{\theta}P^{\varphi} \tag{1}$$

Where Y is aggregate output, A is the total factor productivity, K is the physical capital investment, and H is the stock of human capital. N is the energy consumption and P is the environmental loss. α , β , θ , and φ represent the elasticity of physical capital, human capital, energy consumption and environmental loss, respectively. Taking the logarithm on both sides of the equal (1), we have:

$$\ln Y = \ln A + \alpha \ln K + \beta \ln H + \theta \ln N + \varphi \ln P \tag{2}$$

Differentiating (2) with respect to time produces:

$$dY / Y = dA / A + \alpha dK / K + \beta dH / H + \theta dN / N + \varphi dP / P \tag{3}$$

When the time precision is very short, we can use the difference instead of the differential. Then, equation (3) becomes the following：

$$\Delta Y / Y = \Delta A / A + \alpha \Delta K / K + \beta \Delta H / H + \theta \Delta N / N + \varphi \Delta P / P \tag{4}$$

By transforming equation (3) to (4), equation (3) was transformed from a continuous state to a discontinuous state. Utilizing this approach, we can obtain a plurality of variance and co-variance.

We obtain $g_Y = g_A + \alpha g_K + \beta g_H + \theta g_N + \varphi g_P$ (g denotes the growth rate of the corresponding variable), which means that the growth rate of economic output is expressed as the linear summation of total factor productivity and input growth rates. The contributions of various inputs to the output growth rate were $\alpha g_K / g_Y$、$\beta g_H / g_Y$、$\theta g_N / g_Y$、$\varphi g_P / g_Y$, respectively.

The contribution of total factor productivity to economic growth is

$$g_A / g_Y = 1 - \alpha g_K / g_Y - \beta g_H / g_Y - \theta g_N / g_Y - \varphi g_P / g_Y \tag{5}$$

Every country inevitably encounters fluctuations in economic development. So, which factors play the key role in economic growth rate fluctuations? Is it input factors, total factor productivity, energy consumption or environment loss? In order to answer this question, we decomposed the economic growth rate into parts related to total factor productivity, factor inputs and environmental loss. Further, the variance decomposition of (4) is expressed as follow:

$$Var(g_Y)=\mathrm{cov}(g_Y,g_A)+\mathrm{cov}(g_Y,\alpha g_K)+\mathrm{cov}(g_Y,\beta g_H)+\mathrm{cov}(g_Y,\theta g_N)+\mathrm{cov}(g_Y,\varphi g_P) \quad (6)$$

In the above formula, the left side represents the economic growth of the variance, used to represent the fluctuating level of economic growth. The right side is the sum of the co-variances of economic growth with growth sources. If the co-variance of the economic growth rate and one growth source is larger, then the source has a greater contribution to economic growth fluctuations; otherwise, the source has smaller contribution. In this article, the period from 1981 to 2012 was divided into six stages, based on the five-year plan formulated by the Chinese government. We calculated the contributions of each source to China's economic growth rate fluctuations in each stage, and found the sources of fluctuations.

3.2 Data sources

This paper utilizes China’s time series data between 1981 and 2012, from the "China Statistical Yearbook," "60 Years of New China Compendium of Statistics," "China Industrial Economy Statistics," and the web site of China’s Bureau of Statistics. The variables are described as follows:

1. The physical capital K (one hundred million Yuan). As China has no official statistical data of physical capital stock available, we used perpetual inventory method to form an estimation. We chose gross fixed capital formation as the investment in each year. Meanwhile, we used fixed the capital formation in 1978 that divided by 10% to be the base of physical capital stock, and chose 9.6% as the depreciation rate. Then, we inferred the implicit deflator of investment from 1981 to 1991 based on 1978, according to the fixed capital formation total price index, provided by "China's GDP accounted for historical data (1952 to 2004)". Together with the price index of investment in fixed assets provided by the "China Statistical Yearbook" from 1992 to 2012, the implicit deflator of investment was used to represent the price index of investment in each year.
2. The stock of human capital H (ten thousand years). In order to simultaneously consider the quantity and quality of labor input, stock of human capital is represented by the product of the number of average effective years of schooling per person in the 14–65 age group and the total employment number. Employment statistics came from the "China Statistical Yearbook". We calculated average education years by the method of Lu et al. (2009) [10].

3. The output Y (one hundred million Yuan). We calculated the real GDP of 1981-2012, based on 1978. The original data is from "China Statistical Yearbook".
4. Ecological loss. In this article, ecological loss is divided into two parts: energy consumption and environmental loss. Energy consumption is measured in tons of standard coal, and the data is from "China Statistical Yearbook". Environmental loss is estimated by the method of our published paper. We selected emissions of industrial waste water, industrial waste gas, and industrial solid waste as indexes, and used an objective evaluation method to estimate the pollution index (for details, see Appendix B). The data was from "China Statistical Yearbook" and "China Environment Statistical Yearbook."

4 Empirical analysis

4.1 Unit root test and co-integration test

To avoid spurious regression, we used the unit root test to check the stationarity of each variable. The results are shown in Table 1, which are significant at a 10% confidence level. We observe that LnY, LnK, LnH, LnN, LnN, and LnP are integrated as the first order. Carrying out the co-integration test for each time series using Johansen eigenvalue root tracing statistics, we chose 2 as the optimal lag order.

Table 1：Results of co-integration test

Hypothesized No.Of(CEs)	Eigenvalue	Trace Statistic	5%Critical Value	Prob.
None*	0.987537	307.1853	88.80380	0.0000
At most 1*	0.923347	184.4060	63.87610	0.0000
At most 2*	0.837767	112.4891	42.91525	0.0000
At most 3*	0.750146	61.56487	25.87211	0.0000
At most 4*	0.555972	22.73230	12.51798	0.0007

Note：“*”denotes rejection of the hypothesis (there is no co-integration) at the 5% level.

From the results of the Johansen co-integration test, we observed that the five variables exist in a co-integration relationship. Thus, a long-term equilibrium model could be established, which includes physical capital, human capital, energy consumption, environmental loss and economic output (t values are shown in brackets)

Table 2: Results of regression and counterfactual tests

Explanatory variables	M1	M2	M3	M4
K	0.5782*** (19.3924)	0.5840*** (52.4426)	0.4722*** (7.4628)	0.5701*** (18.0082)
L	1.0384*** (12.2156)	0.6411*** (18.9412)	0.9916*** (10.7294)	1.0640*** (11.7541)
N		0.4243*** (22.6231)	0.2195* (1.8164)	-0.0109 (-0.9353)
P		-0.3125*** (-38.1423)	-0.0054 (-0.7161)	-0.0047 (-0.5908)
c	-9.6459*** (-12.0040)	-9.1431*** (-23.6416)	-10.5120*** (-11.6012)	-9.7551*** (-11.5502)
R^2	0.9972	0.9982	0.9975	0.9973
Adjusted R^2	0.9970	0.9979	0.9972	0.9969
P value	0.000000	0.000000	0.000000	0.000000

(Note: Figures in parentheses are t-statistics of estimated coefficients, ***, **, * represent significance level at 1%, 5%, 10%)

M1 are the regression results without energy consumption and environmental loss. We can observe that the variables and the linear relationship are significant. M2 are the regression results with energy consumption and environmental loss. The variables and the linear relationship are also significant. During 1981-2012, 99.7% of China's economic changes can be represented by changes in K, H, N and P. The elasticity of physical capital was 0.58, indicating that when the other elements remained constant, as physical capital increased by 1%, China's economy increased by an average of 0.58%. The elasticity of human capital was 0.64, and the elasticity of energy consumption is 0.42. However, the elasticity of the environment is negative, indicating that when other factors remain unchanged, environmental loss will hinder China's economic development.

Comparing M1 and M2, we can find that the elasticity of physical capital is the same, while the estimators of elasticity of human capital have huge differences. In our opinions, the estimator of M1 is higher than the elasticity of M2 due to lack of attention to ecological loss. Chow [20] estimated that the elasticity of physical capital was 0.7741 and the elasticity of labor was 0.6353 for the period of 1952 to

1998. The elasticity of physical capital is higher than the 0.58 that we estimated, while the elasticity of labor is approximately equal to our estimation. Compared with the regression results of Lv [7], which considered the quantity and quality of labor, the elasticity of physical capital was 0.5, the elasticity of labor was 0.3, and the elasticity of human capital was 0.2. Results from Lv imply that faster capital formation has made an important contribution to the growth, however, he assumed constant returns to scale and did not consider energy and environmental factors, which may have led to underestimation of the output elasticity and an overestimation of the TFP.

M3 and M4 are counterfactual tests. In M3, we randomly generated a string of numbers whose size was the same as that of K, and we use the numbers to substitute P. In M4, we randomly generated another a string of numbers to replace N. From the results, we can observe that the coefficients of energy consumption and environment are close to zero, and that they are both not significant. The counterfactual tests demonstrate that ecological factors do play a role in China's economic development.

4.2 Comprehensive analysis of economic growth

In this subsection, China's economic growth is decomposed into traditional inputs (including physical capital and human capital), energy consumption, environmental loss and total factor productivity. Together with the elasticity coefficient of each variable from the above established long-term equilibrium model, China's economic growth rate and its source decomposition were obtained, which is available in Table 2 of Appendix A. Table 3 is the decomposition comparison, based on models with and without ecological factors. The time series pattern of the decomposition results in Table 2 are drawn in three figures. Figure 1 is China's economic growth rate and its source from TFP. Figure 2 shows China's economic growth rate and its source from factor inputs. Figure 3 shows China's economic growth rate and its source from ecological loss.

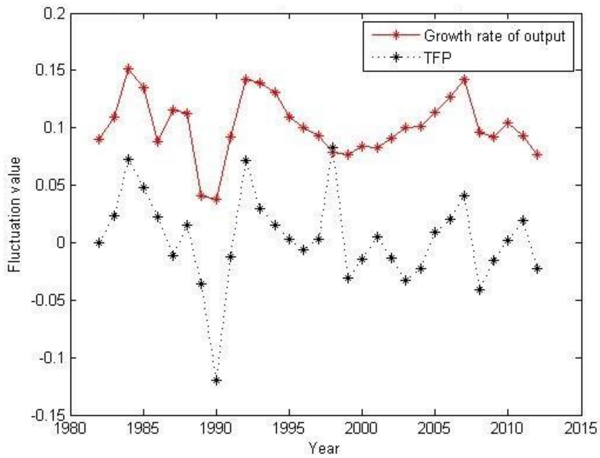

Figure 1: China's economic growth rate and its decomposition of TFP

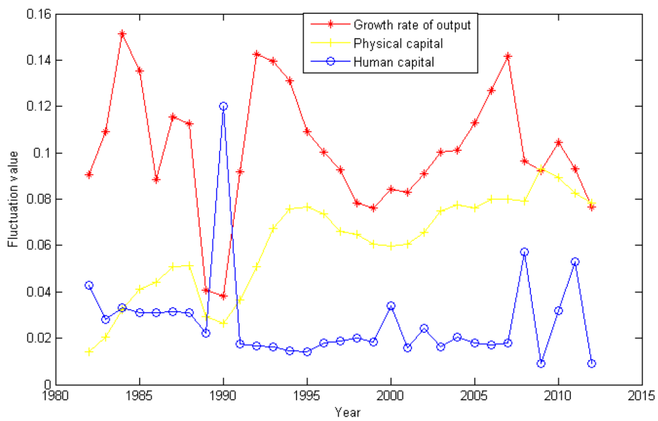

Figure 2: China's economic growth rate and its decomposition of factor inputs

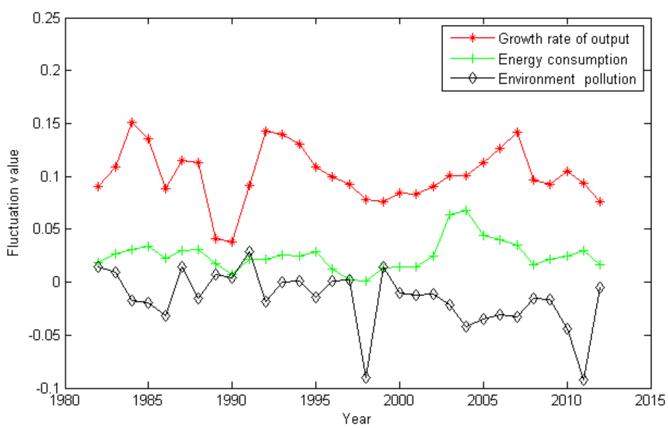

Figure 3: China's economic growth rate and its decomposition of ecological loss

Between 1981 and 2012, China's average economic growth rate was 10.12%. The economic growth rate driven by physical capital was 6.03%, contributing to 59.59% of economic growth, which plays a vital role in the process of China's economic development. The economic growth rate associated with human capital was 2.71%, its contribution close to 26.76%. Ecological loss contributed 10.67% to economic growth, among which energy input accounted for 2.51%. As shown in Table 3, disregarding ecological factors, the economic growth rate driven by physical capital was 10.49%, which is more than that of the model with ecological factors. The economic growth rate associated with human capital is 3.74%, its contribution close to 36.96%. TFP was 0.2%, which is lower than the TFP of the model with ecological factors. This fully shows that physical capital investment is the main driving force for China's economic growth at the present stage. Wang [33] found that the accumulation of human capital was quite rapid and contributed significantly to growth, and that total factor productivity played a positive role in GDP growth in the reform period. These results are different from our results. The studies may have overestimated the TFP growth due to the absence of energy consumption and environmental loss in their growth-accounting framework. TFP growth has not emerged as one of the most important sources of China's rapid growth.

In reality, China's economy is developing, but its environment is deteriorating. Then, there is a question worth exploring: is China's main source of economic growth efficiency, factor inputs or ecological loss? The model without ecological factors cannot provide the answer. However, introducing energy consumption and environmental loss, as inputs into the Solow growth model allow us to compare their contribution to economic growth, to identify the main source.

From Table 2, we can observe that, nowadays, China's economic development partly depends on energy consumption. The economic growth rate related to the environmental level is -1.43%, suggesting that environmental loss has halted to China's economic growth to a certain extent within the inspection period. In order to promote efficient development of China's economy, the quality of the environment should be ameliorated and the contribution of the quality of the environment on China's economic growth should improve. From contributions of each source on economic growth, China's economic growth mainly relies on the inputs, and the current economic development pattern is extensive and unsustainable. In this paper, economic growth rates related to total factor productivity are low, just 0.30%. This indicates that China should continue to absorb foreign advanced technology, to improve the utilization efficiency of enterprises and enhance innovation abilities. In this case, total factor productivity would be the main source of China's economic growth.

Observing Figure 1, we find that economic growth fluctuations and TFP fluctuations follow a more consistent trend. However, from Figure 2 and Figure 3, fluctuations of the factor inputs and ecological losses don't have the same changes as economic growth fluctuations.

Now, we discuss the contribution of energy and environmental factors in China's economic growth. Figure 3 shows the contribution of environmental loss as a factor in China's economic growth. Throughout the study period, the fluctuations in energy consumption were relatively stable, while those in environment loss were more acute. Fluctuations of energy provide positive effects for fluctuations in the growth rate of the economy, while fluctuations of environmental loss provided negative contributions. Figure 3 reveals that economic growth and energy consumption are growing, while environmental loss is intensified. Those performances indicate that China's economic growth is based on energy consumption, with serious damage to the environment. China's economy has been in a phase, and such a stage is unsustainable. Thus, a conversion about economic development is imperative, and the current high-carbon and high-energy way is no longer suitable for China's development. Since 2010, China's economic growth rate has declined, and economic development has entered a new normal stage. Though the energy consumption is relatively stable, the environment has suffered further damage. China's resources have reached unbearable proportions to support "extensive" economic and social development. A model with low value and high pollution production makes China face the embarrassing plight that the country is not rich, while its resources are bone-dry.

Next, we will analyze the dynamic economic growth in China from the period of 1991 to 2012, and which we divided into three parts (1991-1997, 1997-2002 and 2002-2012) based on major economic events that happened in China. The decomposition of our study of China's economic growth in these three periods is as follows:

(1) 1991-1997. The economic growth rate in 1991 was 9.19%, and then rapidly increased to 14.24% in 1992. Though there were drops in next few years, they remained higher than the level of 1991. In combination with international and domestic environments, we found that China's readjustments of economic order were basically completed in 1992, which promoted the looser environment for

reforms. Under this background, Deng Xiaoping inspected the South and published the famous southern conversation, which greatly promoted the process of reform and opening-up policies, pulled the economic growth rate to its peak in 1992. In the meantime, the economic growth rate related to investment in physical capital, human capital, and energy inputs were 6.84%, 1.64%, and 1.93%, respectively. The economic growth rate related to total factor productivity was 1.93%, while that related to the environment is 0.43%. This shows that between 1991 and 1997, the main power to promote growth in China's economy was physical capital. Total factor productivity, energy input and human capital also played roles. However, during this time, China's environment began to deteriorate along with economic growth.

(2) 1997-2002. Due to the impact of the Asian financial crisis, China's economy fluctuated during this period. Its economic growth rate fell from 9.3% in 1996 to 7.8% in 1998. In this period, the average growth rate of China's economy was 8.25%, and capital input was still the main power driver of economic growth, which accounted for 61.48%. Human capital's contribution to economic growth increased to 22.14% during this time. And the contribution of energy input was 13.44%. This suggests that China's popularization of education obtained certain achievements, and investment in physical capital was adopted primarily to get out of the shadow of the financial crisis. The economic growth rate related to the environment was -1.48%, indicating that environmental conditions did not improve with China's economic development. The economic growth rate related to total factor productivity growth was 0.44%, a significant decline. The environmental loss index achieved an increase in 1998 compared with 1997. In our opinion, the devastating floods in 1998 may have more an impact than economic growth.

(3) 2002-2012. In this period, the average growth rate of China's GDP was 10.44%. China's accession to the WTO in 2001 increased integration into the global economy. China's economic growth rate was 11.64% from 2002-2007. It dropped to 9.25% from 2008 to 2012 with the spread of the sub-prime crisis of the United States.

In the period between China's participation in the WTO and the outbreak of the sub-prime crisis, the economic growth rate related to capital was 7.78%, with contribution of 76.86%. The contribution of energy consumption and human capital were 49.56% and 17.64%, respectively. After accession to the WTO, China's most important driver of economic growth was capital investment, then energy inputs and human capital. The economic growth rate related to the environment was -3.22%, and that related to total factor productivity was 0.29%. China's environmental situation continued to deteriorate during this time, and had a trend of aggravation. Improving total factor productivity was still a necessary prescription.

After the outbreak of the sub-prime crisis in 2008, the Chinese government implemented a proactive fiscal policy, based on the downturn of China’s economy. Because of this, the contribution of physical capital investment on economic growth increased to 83.51%, while the energy contribution rate fell to 21.62%. The economic growth rate associated with human capital increased by 1.39% compared with 3.17% of last period. Total factor productivity contributed to about -1.25% of the economic growth rate. The environmental problem was serious, and its corresponding economic growth rate was -3.31%.

During this period, the Chinese government realized the importance of sustainable development, implemented energy-saving and emission-reducing policies and carried out binding targets of environmental standards. For some reasons, such as companies adopting trade policies of high energy-consumption and high emissions, some local governments launched projects with heavy environment losses for excellent performance and so on, with still no significant improvement in the environmental level. What’s more, due to proactive fiscal policy, China's economic growth has relied on large amounts of capital, energy and other input factors, which is an extensive development pattern.

5 Effects of growth sources on fluctuations of economic growth rate

In order to consider the contribution of various sources on China's economic growth fluctuation, this article used the variance of economic growth to represent economic growth fluctuation. For the period of China's Five-Year Plan, the variance of economic growth was decomposed into the following: co-variance of economic growth and physical capital, co-variance of economic growth and human capital, co-variance of economic growth and energy, co-variance of economic growth and total factor productivity and co-variance of economic growth and the environment. Results are shown in Figure 4.

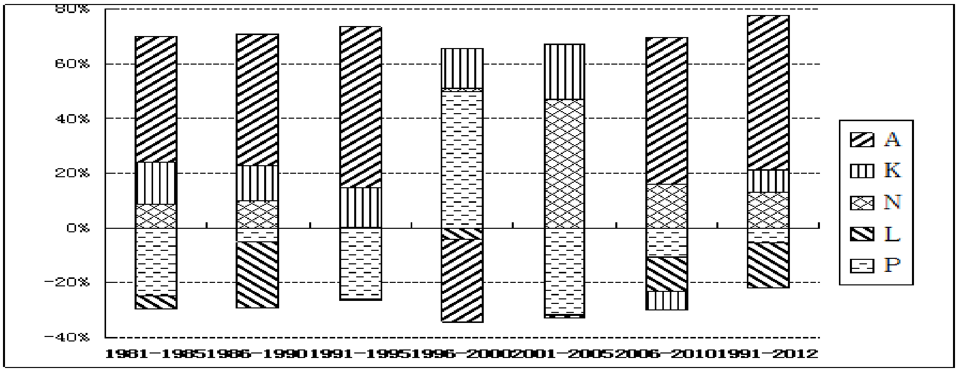

Figure 4：Impact that each source of growth on fluctuations in economic growth

In terms of the global observing period, we found that the greatest contribution to economic growth fluctuations was given by total factor productivity, which was followed by human capital, energy consumption, physical capital and the environmental loss. However, in a former part of this article, we mentioned that each source's contribution to economic growth, from high to low, was physical capital, human capital, energy consumption, total factor productivity and the environment. The two results are obviously in contrast. This shows that China's economic growth is mainly influenced by factors such as investment in physical capital, but the fluctuations in China's economic growth are in conformity with that of total factor productivity.

As for these conclusions, we consider that, they have some association with the measurement of TFP. In this paper, the total factor productivity was not directly obtained by the Solow model, but rather by a margin, or 'Solow residual'. TFP was obtained under the processions of input-out data by the use of Solow model, and the inputs can't be accurately measured. We only considered the physical capital and human capital stock, but the efficient-use of physical capital, the efficiency of working hours and the working efficiency of human capital were not considered. Thus, during the economic boom years, as the efficiency of physical capital and working time or strength of labor increased, the input was underestimated and the total factor productivity was overestimated. During the recession, the utilization rate of physical capital and labor working time or intensity reduced, which leaded to an overestimation of inputs and an underestimation of total factor productivity.

Meanwhile, as China is a country with a large of population, economic growth is important for it, so the Chinese government actively promotes policies to maintain a steady growth. Since the TFP is vulnerable to external shocks, naturally increasing the input should become a top priority for the government in selecting sources to support China's economic growth. When the financial crisis in 1998 and the sub-prime crisis in 2008 happened, China adopted proactive fiscal policies. Large amounts of money were invested into infrastructure, to ensure China's economic growth rates. Thus, factor inputs became the main tool for the government to smooth the economic cycle. This is the reason that total factor productivity contributes more to economic growth fluctuations than other sources. Environmental consumption is a by-product, which is brought by social production and business operation activities, so the environmental loss index increased with the speeding up of economic growth. Also, the coefficient in the production function is negative, thus, there is a negative correlation between environmental consumption and economic growth fluctuations. Figure 4 indicates that the contribution of human capital on economic growth fluctuations is negative. For such results, this paper argues that, with the development of education and the weakening of the demographic divide in China, human capital maintains growing trend every year. However, its growth rate shows a tendency of decline, and economic growth fluctuation expressed by the variances of the GDP growth rate are positive. Therefore, the human capital and economic growth fluctuations present a negative correlation relationship.

Results of the decomposition of economic growth fluctuations of every five years are different from that of the entire study period. Among the four periods of "Sixth Five-Year" (1981-1985), "Seventh Five-Year" (1986-1990), "Eighth Five-Year" (1991-1995) and "Eleventh Five-Year" (2006-2010), the most important factor that influenced the fluctuations in economic growth was the total factor productivity. In "Ninth Five-Year" (1996-2000) and "Tenth Five-Year" (2001-2005) periods, the main factors were environmental loss and energy consumption. In the "Ninth Five-Year" period, the environmental loss index raised from 2.12 in 1997 to 2.73 in 1998, which may be related to the adverse influence the flood in 1998 had on China’s ecological environment. The increased environmental loss index is also related to a sudden increase in the TFP. Thereby, the increase in the co-variance of growth of the environmental index and economic growth influence the increase of the contribution of environmental factors on fluctuations in economic growth.

A negative correlation appeared between TFP and economic growth fluctuation. During the "Tenth Five-Year" period, energy consumption rapidly increased, its growth rate rising from 6% in 2002, to 15% in 2003, to 16% in 2004, to 11% in 2005, which is related to China's excessive industrialization during that time. The proportion of secondary industry rose from 50.4% in 2002 to 52.2% in 2003, and correspondingly, the total industrial energy consumption rose from 96,864 billion tons of standard coal in 2002 to 123,122 billion tons in 2003, to 143,607 billion tons in 2004. Growing energy consumption widens the co-variance between it and economic growth rates, which is a reason why energy factor is the main factor affecting economic growth fluctuations in the "Tenth Five-Year" period.

In "Eleventh Five-Year" period, there was a negative correlation between physical capital and economic growth fluctuations. The reason is that China's economic growth continued to the decline under the influence of the sub-prime crisis in 2008, and the Chinese government adopted a proactive fiscal policy to end the economic decline, leading to the constant increase of investment in physical capital in this period. What is different from sub-prime crisis in 2008 is that, although the economic growth rate declined and the total investment in physical capital increased, the growth of investment in physical capital was lower in 1998. Thus, the correlation between physical capital and fluctuations in economic growth is positive.

6 Conclusions and Recommendations

This paper aimed at formulating a new approach for exploring the sources of China's economic growth at a macroeconomic level, which considered energy consumption and environmental loss. That was a case for green accounting of China's economy. Based on the Solow Growth Model, China's economic growth was decomposed into five aspects including physical capital, human capital, total factor productivity, energy consumption and environmental loss, using data from 1981 to 2012. In some of the five-year plan periods, the factors affecting China's economic growth fluctuation were explored. The study shows that investment in physical capital is the main motivating power for China's economic growth, followed by human capital and energy consumption, while continuation of total factor productivity is the least. The economic growth rate related to the environment is -1.14%, which shows that environmental loss has become an obstacle to economic growth in China. Over the entire study period, the main driving force of China's economic growth, investment in physical capital, made unnoticeable contributions to China's economic growth fluctuations, while total factor productivity as the Solow residual was the main factor of economic growth fluctuations.

The results reveal that economic growth rates associated with total factor productivity are slowly decreasing and becoming negative, while the dependence of China's economy on investment in physical capital is gradually increasing, and the environmental loss is having increasingly hindering effects on China's economy. The Chinese economy as a whole presents an extensive development characterized by "high input, high consumption, high emission and low efficiency". Therefore, the key for China to achieve sustainable economic development is to change the economic growth mode and impel total factor productivity as the main motivating force and source, instead of physical capital and energy consumption. For the above conclusion, this paper puts forward some suggestions as follows:

(1) Persevere in opening-up policies and deepen reforms. An analysis of the results indicates that the economic growth rate brought on by total factor productivity from 1991 to 1997 was 1.93%. While, in the following two stages, the contributions from TFP dropped obviously, the main reasons for the increasing productivity during this time were due to a series of systemic changes under the policies of reform and opening-up in China. However, in the following progressions, invested factors like capital became the main power of economic growth, caused by a drop in increases from productivity, due to the explosion of the economic crisis and the decrease of the bonus from reforms. Thus, in order to maintain a good and steady momentum of economic growth, China must deepen their reforms, overcome all-around difficulties, and make a breakthrough in solving profound problems. This will ultimately provide power and safeguard for the changing pattern of economic growth.

(2) Maintain a stable and high economic growth rate, in the single digits. Results indicate that, since opening up, China’s economic growth is primarily driven by high investment of material and natural resource consumption. China’s total economic increases are due to high-speed development, but an extensive development mode that merely depends on high investment in material resources and natural resources consumption is unsustainable. In this case, China’s economic growth will show a certain degree of deceleration. Meanwhile, China’s economic structure is seeking to transition, and is in a transition period, during which a new way of growing power is yet to be trained as the old growth power weakens. To avoid economic hard landing and to achieve steady growth, China can reduce economic growth under the conditions that China's per capital income continues to improve. The measure can provide sufficient buffer time for the adjustment of structure and transformation of economic growth, which also can lay a solid foundation for economic development, which is characterized by higher quality, lower pollution and resource saving.

(3) Change the status of energy consumption heavily. Economic growth is inseparable from energy consumption. Therefore, maintaining a rapid level of growth for China's economy requires energy inputs. Heavy energy inputs pose a threat to sustainable development, while at the same time causes greater pollution to the environment. With the high frequency of energy-shortage crises and increased global attention to environmental protection, exploiting renewable energy sources to replace non-renewable energy sources has become a main direction of focus for energy development. At the present stage, non-renewable energy occupies a leading position, so China should accelerate the transformation of energy production and energy structures, improve energy efficiency, control total energy consumption, strengthen domestic exploration and development, and actively develop renewable resources, such as wind energy, biomass energy, solar energy and so on. The government should also formulate a corresponding development plan, to guide the development of renewable energy, support the renewable energy industry, and gradually form an energy consumption structure that mainly relies on renewable energy.

ACKNOWLEDGEMENTS
The authors need to acknowledge the National Social Sciences Fund (17BJL043).

References

[1] Solow R M. Technical Change and the Aggregate Production Function [J]. Review of Economics and Statistic, 1957, 39(3):312-320. (in Chinese)
[2] Guo Q.W. Jia J.X. Estimating Total Factor Productivity in China: 1979—2004[J]. Economic Research, 2005(6):51-60. (in Chinese)
[3] Li P. Zhong X.Y. Wang H.W. Zheng S.L. Productivity Change and the source of Economic Growth in China[J].The Journal of Quantitative and Technical Economics,2013(1):3-21. (in Chinese)
[4] Wu P. The Propulsion Transform of China's Economic Growth since Reform [J]. China Industrial Economics, 2013(2):5-17. (in Chinese)
[5] Dong M.J. Liang Y.M. The Sources of China's Economic Growth from 1978 to 2010: A Non-parameter Framework [J].Economic Research, 2013(5):17-32. (in Chinese)
[6] Jiang F.T. Wu P. Li X.P. The Dynamic Mechanism Transform of China's Industrial Economic Growth [J]. China Industrial Economics, 2014(5):5-17. (in Chinese)
[7] Wang X.L. Sustainability of China's Economic Growth and Institutional

Changes [J]. Economic Research, 2000(7):3-15. (in Chinese)
[8] Hu Y.Y. The Human Capital and Economic Growth: an Empirical Analysis [J].Economic Science, 2003(1):54-60. (in Chinese)
[9] Xu Y. Chen X.S. Liu F.L. Estimating and Decomposing the Contribution of Technical Change in China [J].Economic Research, 2006(8):93-103,128. (in Chinese)
[10] Fan G.Wang X.L. Ma G.R. Contribution of Marketization to China's Economic Growth [J]. Economic Research, 2011(9):4-16. (in Chinese)
[11] Zhou C.Y. Factor inputs, TFP, Human capital? Source Analysis of the Regional Economic Growth [J].Northwest Population, 2012,33(5):84-89.Fiance and Trade Research, 2013(1):32-39. (in Chinese)
[12] Liu R.X. Search for the Source of Economic Growth in China: Inputs, Productivity and Environmental Cost [J].The Journal of World Economy, 2013(10):123-141.
[13] Yang W.P. Sources of Economic Growth in China's Weston Regions [J]. East China Economic Management, 2014,28(1):30-35. (in Chinese)
[14] Shi F.G. Analysis of Convergence Mechanism of Economic Growth Source in Chinese Provinces Under the Binding of Environment [J].Finance and Trade Research, 2013(1):32-39. (in Chinese)
[15] Zhang J.Wu G.Y. Zhang J.P. The Estimation of China's provincial capital stock: 1952-2000 [J].Economic Research, 2003(10):35-44. (in Chinese)
[16] Yang W.P. Dynamic Comprehensive Evaluation of China's Provincial Pollution and Research on Influencing Factors [J]. Economic Management, 2010(8):159-165. (in Chinese)
[17] Chow G C. Capital formation and economic growth in China [J]. The Quarterly Journal of Economics, 1993: 809-842.
[18] Krugman, P. (1994, December). The myth of Asia's miracle. Foreign Affairs, 73, 62–78.
[19] Hu Z F, Khan M S. Why is China growing so fast? [J]. Staff Papers-International Monetary Fund, 1997: 103-131.
[20] Chow G C, Li K W. China's Economic Growth: 1952–2010[J]. Economic Development and Cultural Change, 2002, 51(1): 247-256.
[21] Young, A. (2003). Gold into base metals: Productivity growth in the People's Republic of China during the reform period. [J] Journal of Political Economy, 111(6), 1220–1261.
[22] Maddison A. Chinese Economic Performance in the Long Run [J]. Edition, Deve, 2007.
[23] Aoki M. The five phases of economic development and institutional evolution in China, Japan, and Korea [M] Institutions and Comparative Economic

Development. Palgrave Macmillan UK, 2012: 13-47.
[24] Krugman P. Hitting China's wall [J]. The New York Times, 2013, 18.
[25] Long X, Naminse E Y, Du J, et al. Nonrenewable energy, renewable energy, carbon dioxide emissions and economic growth in China from 1952 to 2012 [J]. Renewable and Sustainable Energy Reviews, 2015, 52: 680-688.
[26] Jiang Y. Total factor productivity, pollution and 'green' economic growth in China [J]. Journal of International Development, 2015, 27(4): 504-515.
[27] Tyteca D. Linear programming models for the measurement of environmental performance of firms—concepts and empirical results [J]. Journal of productivity analysis, 1997, 8(2): 183-197.
[28] Brock,W. and Taylor,M.S. Economic Growth and the Environment [M] in Aghion,P.and Durlauff,S.eds., Handbook of Economic Growth Ⅱ.Chap.28,Elsevier,2005,1749-1821
[29] Tzouvelekas E, Vouvaki D, Xepapadeas A. Total factor productivity growth and the environment: a case for green growth accounting [M]. Beijer International Institute of Ecological Economics, 2006.
[30] P.S. Dasgupta and K.-G. Mäler, Net national product, wealth and social well-being, Environment. [J] Develop. Economic 5 , 69-93 (2000).
[31] E. F. Denison, "The Sources of Economic Growth in the United States and the Alternatives Before, Us", Washington DC: Committee for Economic Development (1962).
[32] A. Xepapadeas, Economic Growth and the Environment in the "Handbook of Environmental Economics", Economy wide and International Environmental Issues, (Mäler K.-G., and J. Vincent, Eds), a volume in the series Handbooks in Economics, edited by, Kenneth Arrow and Michael D. Intrilligator, Elsevier Publishers (2005).
[33] Yan W, Yudong Y. Sources of China's economic growth 1952–1999: incorporating human capital accumulation [J]. China Economic Review, 2003, 14(1): 32-52.

Appendix A:

Table 2: Decomposition of China's economic growth rate

Year	Growth rate of output	TFP	Factor input		Ecological loss	
			Physical capital	Human capital	Energy consumption	Environment pollution
1981-1982	0.0904	0.0002	0.0141	0.0430	0.0185	0.0146
1982-1983	0.109	0.0239	0.0206	0.0280	0.0268	0.0097
1983-1984	0.1514	0.0724	0.0324	0.0332	0.0309	-0.0175
1984-1985	0.1353	0.048	0.0412	0.0310	0.0342	-0.0191
1985-1986	0.0883	0.0224	0.0442	0.0309	0.0228	-0.0319
1986-1987	0.1155	-0.0113	0.0509	0.0313	0.0300	0.0146
1987-1988	0.1127	0.0154	0.0511	0.0312	0.0308	-0.0158
1988-1989	0.0407	-0.0356	0.0294	0.0223	0.0177	0.0068
1989-1990	0.0383	-0.1195	0.0262	0.1202	0.0076	0.0038
1990-1991	0.0919	-0.0119	0.0364	0.0176	0.0216	0.0283
1991-1992	0.1424	0.0714	0.0507	0.0165	0.0218	-0.0179
1992-1993	0.1394	0.0295	0.0675	0.0162	0.0262	0.0001
1993-1994	0.1309	0.0148	0.0758	0.0147	0.0244	0.0011
1994-1995	0.1093	0.0034	0.0768	0.0142	0.0288	-0.0139
1995-1996	0.1001	-0.0059	0.0737	0.0179	0.0128	0.0016
1996-1997	0.0928	0.0032	0.0662	0.0186	0.0022	0.0025
1997-1998	0.0783	0.0824	0.0650	0.0202	0.0008	-0.0901
1998-1999	0.0763	-0.0306	0.0604	0.0182	0.0135	0.0148
1999-2000	0.0842	-0.014	0.0596	0.0339	0.0148	-0.0101
2000-2001	0.083	0.0052	0.0605	0.0159	0.0140	-0.0126
2001-2002	0.0909	-0.0129	0.0656	0.0241	0.0252	-0.011
2002-2003	0.1002	-0.0332	0.0749	0.0161	0.0640	-0.0216
2003-2004	0.1009	-0.0227	0.0775	0.0205	0.0677	-0.0421
2004-2005	0.1131	0.0092	0.0761	0.0178	0.0443	-0.0344
2005-2006	0.1267	0.0203	0.0802	0.0170	0.0403	-0.0311
2006-2007	0.1417	0.0407	0.0801	0.0178	0.0354	-0.0323
2007-2008	0.0963	-0.0409	0.0792	0.0572	0.0163	-0.0155

2008-2009	0.0922	-0.0153	0.093	0.0089	0.0219	-0.0163
2009-2010	0.1044	0.002	0.0892	0.0320	0.0250	-0.0439
2010-2011	0.0930	0.0196	0.0826	0.0531	0.0298	-0.0921
2011-2012	0.0765	-0.0227	0.0785	0.0090	0.0165	-0.0048
Average	**0.1012**	**0.003**	**0.0603**	**0.0271**	**0.0251**	**-0.0143**

Note: The "Average" in the last row is the value of all the numbers above in the same column

Table3: Decomposition comparison based on models with and without ecological factors

Year	TFP		Physical capital		Human capital	
	without	with	without	with	without	with
1981-1982	0.0071	0.0002	0.0245	0.0141	0.0667	0.0430
1982-1983	0.0435	0.0239	0.0356	0.0206	0.0434	0.0280
1983-1984	0.0655	0.0724	0.0561	0.0324	0.0515	0.0332
1984-1985	0.0442	0.0480	0.0713	0.0412	0.0481	0.0310
1985-1986	-0.0055	0.0224	0.0764	0.0442	0.0479	0.0309
1986-1987	0.0142	-0.0113	0.0882	0.0509	0.0486	0.0313
1987-1988	0.0114	0.0154	0.0885	0.0511	0.0483	0.0312
1988-1989	-0.0247	-0.0356	0.0508	0.0294	0.0347	0.0223
1989-1990	-0.0199	-0.1195	0.0453	0.0262	0.0310	0.1202
1990-1991	0.0273	-0.0119	0.0630	0.0364	0.0272	0.0176
1991-1992	0.0652	0.0714	0.0877	0.0507	0.0256	0.0165
1992-1993	0.0458	0.0295	0.1168	0.0675	0.0252	0.0162
1993-1994	0.0313	0.0148	0.1312	0.0758	0.0228	0.0147
1994-1995	0.0096	0.0034	0.1330	0.0768	0.0220	0.0142
1995-1996	-0.0023	-0.0059	0.1275	0.0737	0.0277	0.0179
1996-1997	-0.0034	0.0032	0.1146	0.0662	0.0289	0.0186
1997-1998	-0.0191	0.0824	0.1124	0.0650	0.0313	0.0202
1998-1999	-0.0133	-0.0306	0.1045	0.0604	0.0282	0.0182
1999-2000	-0.0299	-0.0140	0.1031	0.0596	0.0525	0.0339
2000-2001	-0.0031	0.0052	0.1046	0.0605	0.0247	0.0159
2001-2002	-0.0134	-0.0129	0.1135	0.0656	0.0373	0.0241
2002-2003	-0.0006	-0.0332	0.1296	0.0749	0.0250	0.0161
2003-2004	-0.0096	-0.0227	0.1341	0.0775	0.0318	0.0205
2004-2005	0.0083	0.0092	0.1317	0.0761	0.0277	0.0178
2005-2006	0.0191	0.0203	0.1388	0.0802	0.0264	0.0170
2006-2007	0.0330	0.0407	0.1386	0.0801	0.0275	0.0178
2007-2008	-0.0749	-0.0409	0.1371	0.0792	0.0887	0.0572

2008-2009	-0.0152	-0.0153	0.1609	0.0930	0.0138	0.0089
2009-2010	-0.0363	0.0020	0.1544	0.0892	0.0497	0.0320
2010-2011	-0.0751	0.0196	0.1430	0.0826	0.0824	0.0531
2011-2012	-0.0164	-0.0227	0.1358	0.0785	0.0139	0.0090
Average	**0.002**	**0.0030**	**0.1049**	**0.0603**	**0.0374**	**0.0271**

Note: The “Average” in the last row is the value of all the numbers above in the same column.

Appendix B:

In order to obtain integrated environmental pollution index that can reflect the pollution levels, we ultimately select industrial waste water, industrial waste gas and industrial solid waste as factors for environmental pollution index. Data from "China Statistical Yearbook" and "China Environment Statistical Yearbook." Evaluation method of pollution index can be described as followings:

1. Data normalization

The step is to eliminate the difference of dimensions and dimensional units, which may bring incommensurability.

Assuming $\left\{x_{ij}(\mathrm{t_k})\right\}$ $(\mathrm{i}=1,2,\cdots,\mathrm{m};\ \mathrm{j}=1,2,\cdots,n; k=1,2,\cdots,T)$ denote value of j factor of sample i at time t. We have

$$x_{ij}^{'}(\mathrm{t_k})=\frac{x_{ij}(\mathrm{t_k})-\overline{x_j(\mathrm{t_k})}}{s_j(\mathrm{t_k})} \quad ,$$

where $x_{ij}^{'}(\mathrm{t_k})$ is normalized value of $x_{ij}(\mathrm{t_k})$, $\overline{x_j(\mathrm{t_k})}$ is the mean of $\{x_j(\mathrm{t_k})\}$, and $s_j(\mathrm{t_k})$ is the standard deviation of $\{x_j(\mathrm{t_k})\}$.

2. Calculate the real symmetric matrix H_k .

$$H_k = X_k^{\ T} X_k \, ,$$

where

$$X_k=\begin{pmatrix} x_{11}^{'}(\mathrm{t_k}) & \cdots & x_{1m}^{'}(\mathrm{t_k}) \\ \vdots & \cdots & \vdots \\ x_{n1}^{'}(\mathrm{t_k}) & \cdots & x_{nm}^{'}(\mathrm{t_k}) \end{pmatrix} \ , k=1,2,\cdots,T$$

3. Solve the maximum eigenvalue and its corresponding standardized eigenvector λ' of real symmetric matrix H,

$$H = H_1 + H_2 + \cdots + H_k \ (\mathrm{k}=1,2,\cdots,\mathrm{T}) \, .$$

4. Normalize the standard standardized eigenvector λ', and obtain combination weight vector ω_j .

5. Calculate environmental pollution index $P_i(\mathrm{t_k})$.

$$P_i(\mathrm{t_k})=\sum_{j=1}^{n}\omega_j x_{ij}^{'}(\mathrm{t_k}),\ \mathrm{k}=1,2,\cdots,\mathrm{T};\ \mathrm{i}=1,2,\cdots,\mathrm{m}\, .$$