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Input–Output-Based Genuine Value Added and Genuine Productivity in China's Industrial Sectors (1995-2010)

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Abstract The rapid growth of China's economy has brought about huge losses of natural capital in the form of natural resource depletion and damages from carbon emissions. This paper recalculates value added, capital formation, capital stock, and related multifactor productivity in China's industrial sectors by further developing the genuine savings method of the World Bank. The sector-level natural capital loss was calculated using China's official input–output table and their extensions for tracing final consumers. The capital output elasticity in the productivity estimation was adjusted based on these tables. The results show that although the loss of natural capital in China's industrial sectors in terms of value added has slowed, the impacts on their productivity during the past decades is still quite clear.

Keywords Genuine savings method, Total factor productivity, Input–output method, China

1. Introduction to "Green National Accounting"

The current system of national accounts based on nominal GDP is seriously flawed, as it does not deduct the loss of natural assets from the value added created through excessive exploitation of resources and energy. This exaggerates economic benefits by neglecting the costs associated with the rapid depletion of resources and serious environmental degradation, which can result in a reduction in real national welfare. In response, many scholars and abroad have argued for "green" GDP, which considers environmental factors in the system of national accounts. Deducting from GDP the value of depleted natural resources, the costs of ecological degradation and the costs of restoring natural resources and the environment more comprehensively reflects changes in the environmental economy. This effort began with measuring net welfare as part of traditional GDP accounting (Nordhaus and Torbin, 1972; Samuelson and Nordhaus, 1992) as follows:

Net National Products (**NNP**) = GNP - Consumption of Fixed Capital   (1)

The most systematic way to calculate the quantitative costs of resource consumption and pollution release is green national accounting. Since the 1990s, the UN Statistics Division, the UN Environment Programme, the World Bank, and other international institutions have worked together to study the definition of environmental accounting. This work led to the release in 1994 of the System of Integrated Environmental and Economic Accounting (SEEA). With development of the research and practice of integrated economic and environmental accounting, SEEA 2000 was released in June 2001 after discussion and revision, laying out steps to implement a system of integrated economic and environmental accounting. After much revision, SEEA 2003 was released (UN et al., 2003). Through efforts spanning the past 10 years, the SEEA Central Framework (UN et al., 2014) has become the international standard of the UN

Statistical Commission and is now internationally recognized as the statistical framework of environmental and economic accounting.

The SEEA system proposes the concept of environmentally adjusted domestic product (EDP) based on nominal GDP which is the balance of conventional GDP after deducting costs of resource depletion and environmental degradation. Today this is what we call green GDP. Green GDP can be understood as GDP obtained using the System of National Accounts (SNA) after considering external factors and natural resources to more comprehensively reflect the economic welfare of a nation or region. SEEA amends the traditional SNA after considering the economic impact of non-productive natural assets and the environment. In matrix national accounting, the environmental and economic costs of using non-productive resources and releasing pollution should be added into the input, while the benefits of resource restoration and pollution treatment should be added into the output.

Net Domestic Product (**NDP**) = GDP – Resource and Environmental Degradation(2)

The social accounting matrix including resources and the environment by Atkinson and Hamilton and Pearce (1997) focuses on resource depletion and carbon emissions without considering the costs of emitting other pollutants. By combining a theoretical framework for accounting that systematically traces the generation and distribution of value added with green national accounting, we can obtain green national accounting under open conditions. In a social accounting matrix that incorporates resource and environmental factors into net national product (GDP minus productive fixed-asset depreciation that includes foreign savings rate), we can obtain the net resource product (NRP) after deducting resource depletion (nR-ng) from net national product. Similarly, we deduct environmental emission losses (σe- σd) and can obtain net environment product (NEP).

Table1 Social Matrix Including Resources and Environment

<div align="center">DISPOSITION</div>

SUPPLY

	Production	Factors	Institutions	Saving	RoW	Resources	Environment	**Totals**
Production			C	I	X			Total disposition of goods and services
Factors	NDP							Net disposition of goods and services
Institutions		NDP				NRP	NEP	Disposition of welfare
Saving	δK		S_g			n.R	$\sigma.e$	Tot. disposition of saving (investment finance)
Rest of World	M			(X-M)				Total disposition to rest of world
Resources				n.g				Gross Resource Product
Environment			$P_B.B$	$\sigma.d$				Gross Environmental Product
Totals	Total supply of human-made goods and services	Net supply of human-made goods and services	Supply of welfare (MEW)	Total supply of saving	Total supply to rest of world	Total supply of resources	Total supply of environmental benefits	

Source: Atkinson, Hamilton and Pearce et al. (1997)

In 1995, the World Bank began to redefine and re-measure national wealth using genuine national accounting, which is based on their social accounting matrix framework. The formal model of genuine savings is given by Kunte et al. (1998) and Hamilton and Clemens (1998). Compared with systematic green national accounting, the genuine savings accounting and simplified adjusted net savings designed by the World Bank are more practical:

$$G = GNP - C - \delta K - n(R-g) - \sigma(e-d) + m \tag{3}$$

Here, GNP is gross national product, C is consumption, δK is the depreciation rate of produced assets, n is net marginal resource rental rate, g is the amount of growth of resource stocks, R is the amount of depletion of resource stocks, σ is marginal social cost of pollution, e is the amount of growth of the stock of environment benefits, d is the quantity of natural dissipation of the pollution stock, and m is investment in human capital (which is measured with current education expenditures, does not depreciate, and can be considered as a form of disembodied knowledge).

Furthermore, GNP-C is traditional gross savings, which includes foreign savings; GNP-C-δK is traditional net savings; -n(R-g) is resource depletion; -(R-g) is the change in resource stocks (which are assumed to be costless to produce); -σ(e-d) is pollution emission costs; and -(e-d) is the change in pollutant stock.

Natural resources depletion is measured using the rent gained from the exploitation and procurement of natural resources. This rent is the difference between the price of production calculated using the international price and total production costs. These costs include the depreciation of fixed capital and the return on capital. One thing to remember is that while the exploitation of natural resources is necessary for economic growth, if resource rents are too low it can lead to over-exploitation. If the rents gained are not reinvested, but rather used for consumption, it is also "irrational". Pollution loss

here mostly refers to CO_2 pollution. This is calculated using the global marginal loss caused by the emission of one ton of CO_2, which Fankhauser (1995) suggested was 20 US dollars.

It should be noted that in China, this work is still in its infancy, due to the absence of an enabling environment and numerous other difficulties. For example, in resource and environmental accounting, we consider physical quantity accounting for only four natural resources: land, forests, underground mineral resources, and water. Much fundamental work is just beginning, including theoretical research, the design of the integrated framework, formulation of an accounting plan, the establishment of implementation steps, and pilot programs. We are still far from the basic requirements of SEEA. For instance, one key problem in the consideration of resources and the environment in a system of national accounts is how to value these resources and the environment. This requires us to understand more than just the quantitative value of resource consumption and the cost of emitting pollutants. Without a clear understanding of real resource consumption and the amount of pollution in different regions and industries, we are unable to accurately calculate their quantitative value.

Some Chinese scholars (e.g., Lei, 2000, 2011; Liao, 2005, 2012) have attempted to establish green national accounting in China and to build a green input–output table and green society accounting matrix of selected years between 1992 and 2002. Because of limited access to data for the time period, related research efforts all strong assumptions in the physical quantity accounting of resource depletion and pollution release. The green GDP compiled by China's environmental protection agencies in 2004 mainly considered the cost of releasing pollution, not the loss brought about by the consumption of resources, especially non-productive ones. Hu (2001, 2005, 2013) extended the definition given by the World Bank in order to calculate China's green savings rate.

2. Indirect Decomposition at the Sector Level

When we examine natural capital at the sector level in China, the estimation of the rental rate for the natural resources of each sector will become difficult because of the lack of price data. To simplify the accounting, we assume that the total production costs (including the depreciation of fixed capital and return of capital) per unit of the natural resource used is equal across the provinces in a given year. A consequence of this assumption is that the rental rate per unit of the natural resource is also equal across the provinces, since the production price (the international price) is the same. Energy depletion is defined as the product of unit resource rents and the physical quantities of energy extracted. We can therefore calculate the energy depletion of sector i :

$$D_i^E = n_i E_i^E = n E_i^E = \frac{D^E}{E^E} E_i^E = D^E \frac{E_i^E}{E^E} \qquad (n_i = n_j = n) \qquad (4)$$

This shows that the share of the total energy depletion of a sector is actually weighted by its energy extraction share. Here D^E refers to the energy depletion of China as taken from the World Development Indicator Database while E^E refers to the energy extracted (consumption) for China, which can be found in the China Statistical Yearbooks. The energy extracted for each sector E_i^E is taken from the *China Compendium of Statistics 1949-2009* (NBS, 2010) and *China Energy Statistical Yearbook* (NBS and NDRC, various years).

The difficulty in estimating CO_2 Damage is a result of the lack of CO_2 emissions data in any environmental statistics and materials for China. Because CO_2 emissions are of great importance and highly correlated with energy consumption, we must estimate the volume of CO_2 emissions by sector ourselves. We estimate CO_2 emissions using energy

consumption according to the following formula:

$$CO_2 \text{ Emission} = \text{Consumption of Fossil Fuel}^1 \times \text{Carbon Emission Factor} \times \text{Fraction of Carbon Oxidized} + \text{Production of Cement} \times \text{Processing Emission Factor}$$

The Fraction of Carbon Oxidized refers to the physical amount of CO_2 released per unit of pure carbon gasified which is a constant of 3.67 (44/12). The most important coefficient here is the Carbon Emission Factor, which refers to the equivalent carbon emissions in the consumption of fossil fuel. The most commonly used factors are the one from the Energy Research Institute of China's National Development and Reform Committee, which is 0.67, the one from the Carbon Dioxide Information Analysis Center of the US Department of Energy, which is 0.68, and the one from the Institute of Energy Economics of Japan, which is 0.69. We use the first one. In addition, the production of cement will emit more CO_2 than the consumption of fossil fuels because of the calcination of limestone, producing on average 0.365 tons of CO_2 per ton of cement (China Cement Net, 2007).

In this paper, data on energy consumption structure, total energy consumption of 1978-1994 and cement production are from *China Compendium of Statistics 1949-2009* (NBS, 2010), while data on provincial aggregate energy consumption for 1995-2008 are from the China Energy Statistical Yearbook (NBS and NDRC, various years).

The estimation of mineral depletion is slightly more complicated. This is defined as "the product of unit resource rents and the physical quantities of minerals extracted (specifically, bauxite, copper, iron, lead, nickel, phosphate, tin, zinc, gold, and silver).

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[1] More accurate calculations should exclude the carbon stored. Here we use the approximate amount because of limited data.

We exclude two of those minerals, gold and silver, due to a lack of production data. The assumption of one price in total production costs is also used here so we can write the mineral depletion of the province i as follows:

$$D_i^M = n_i E_i^M = n_i^I E_i^I + n_i^P E_i^P = n^I E_i^I + n^P E_i^P = n^M \left(\frac{n^I}{n^M} E_i^I + \frac{n^P}{n^M} E_i^P \right)$$

$$= \frac{D^M}{E^M} \left(\frac{n^I}{n^M} E_i^I + \frac{n^P}{n^M} E_i^P \right) = D^M \frac{w_1 E_i^I + w_2 E_i^P}{w_1 E^I + w_2 E^P} \quad \left(w_1 = \frac{n^I}{n^M}, w_2 = \frac{n^P}{n^M} \right) \quad (5)$$

Here n^M and E^M refer to the rental rate and extraction of minerals and I and P those costs for iron and phosphate. We are restricted to using only the international prices found in *World Bank Commodity Price Data* as weights for the eight mineral resources due to the unavailability of data on their domestic prices. According to the World Bank definition, a country's natural capital is lost in only the domestic production of fossil fuels, ores, and so forth

The decomposition of natural capital lost D therefore occurs on only the block of intermediate inputs and final use in the input–output table. The intermediate "use" of the natural capital lost will be decomposed and re-combined into the real "use" for the first step as follows:

$$D_{out} = A^T D + CD = (A^T + C)D \quad (6)$$

Here D is a $1 \times n$ vector of the natural capital lost in the sector. A^T is the transpose of the direct input coefficient matrix, and C is a diagonal matrix of the ratio of final use in the total of intermediate inputs and final use.

$$C = diag(1 - \sum_i a_{ji}) \quad (7)$$

As these are total input coefficients in the general input–output models, here they must also incorporate the indirect loss of natural capital through the cycling of intermediate goods. Therefore, the final decomposition of the initial natural capital loss is similar to the derivatives of the Leontief inverse and should be written as follows

$$D'_{\text{out}} = CD + CA^TD + CA^TA^TD + \cdots = C(I - A^T)^{-1}D \qquad (8)$$

In the calculation of the data for this paper, the decomposition of the natural capital loss in a sector must first add up the totals for each of the 36 industries[2] by sector according to the classification of the input–output tables and then be divided again after transformation. Therefore, the decomposition is based on the input–output table of the adjacent year of the data (see Table 2).

Table 2 Years Covered in Input–Output Tables

Based input-output table	Number of total sectors	Year covered
1995 extended input-output table	33	1994、1995
1997 input-output table	40	1996、1997、1998
2000 extended input-output table	40	1999、2000
2002 input-output table	42	2001、2002、2003
2005 extended input-output table	33	2004、2005
2007 input-output table	42	2006、2007、2008
2010 extended input-output table	65	2009、2010

Although most energy depletion and all mineral depletion were counted in the consumption of industrial sectors, this decomposition shows that around half of the natural capital loss was finally used by other non-industrial sectors such as construction and transportation. Compared with the unadjusted natural capital lost, the ratio of adjusted loss to gross value added was about 3% to 8% lower, showing a more stable proportion to the total value added of all industrial sectors.

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[2] Mining of Other Ores before 2003, Manufacture of Artwork and Other Manufacturing, and Recycling and Disposal of Waste after 2004 were classified as other due to the lack of a continuous series.
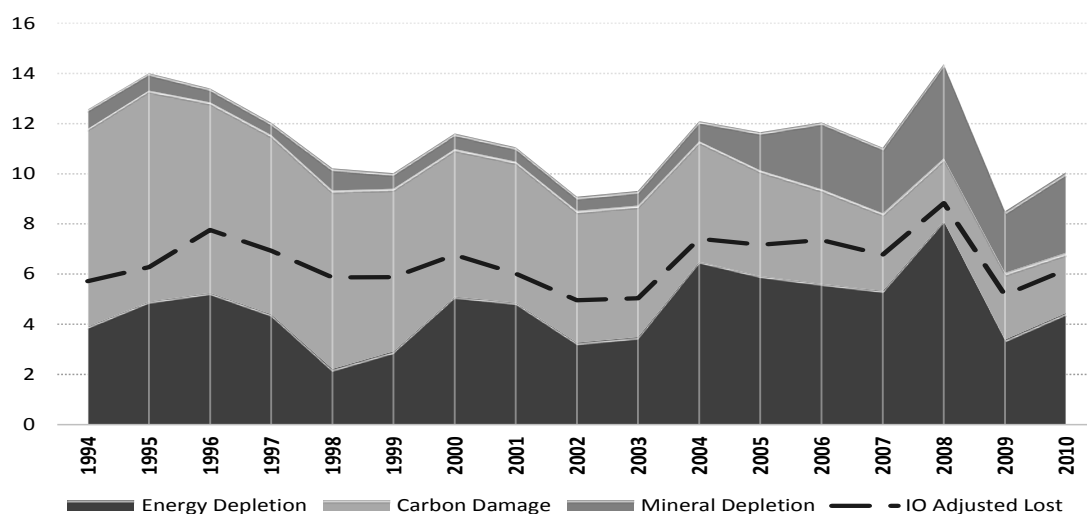
Figure 1 Natural Capital Lost as of Industrial Value Added

3. Genuine Investment and Genuine Capital Stock

(1) Industrial Genuine Value Added

The accounting of the industrial genuine value added uses the same method as the genuine savings rate. With the exception of the Production and Supply of Gas sector, the sector with the lowest share of genuine value added fluctuated between 80% and 85% of traditional value added with a peak of 88.7% in 2004. Before the year 2000, genuine value added in the Production and Supply of Gas sector was always lower than that in the others, especially in 1999 when genuine value was only 71.44% of its value added. This is mainly because of the high energy depletion and comparatively low value added in this sector in the late 1990s.

The sectors with the highest share of genuine value added were usually the Petroleum and Natural Gas and Tobacco sectors. These sectors maintained more than 99% of their traditional GDP. Overall the average share of genuine value added in all sectors rose from 92.7% in 1995 to 96.3% in 2010.
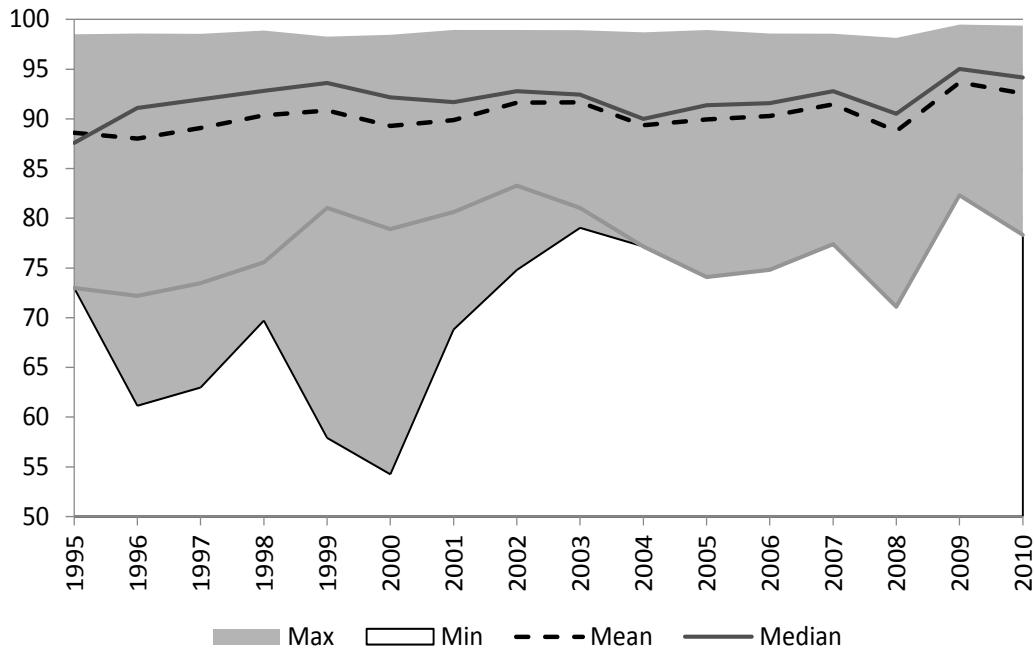
Figure 2 Share of Genuine Value Added as Traditional Value Added

(2) Industrial Genuine Investment

According to formula (1), we can define the genuine investment of sector i:

$$I'_t = I_t - n_i (R_t - g_i) - \sigma_t (e_t - d_t) + m_i \qquad (9)$$

I_{it} is traditional investment, $n_{it} (R_{it} - g_{it}) - \sigma_{it} (e_{it} - d_{it})$ is the natural capital lost, and m_{it} is education expenditure. The data on investment come from various years of the China Statistical Yearbook. From the accounting data of industrial firms, we chart the changes in the original value of fixed assets to form a continuous series of fixed capital formation under the expenditure approach. However, because of the limited availability of data, the deflator for fixed capital formation must use the price index for China's overall fixed asset investment, which is identical across sectors.

The average of the traditional fixed capital formation ratio of the industrial sectors

varied between 16% and 30%. While, the genuine fixed capital formation rate showed greater fluctuation with highs of more than 25% and lows of about 7%. The genuine fixed capital formation rate was lower than the traditional one because the deduction of natural capital lost on capital formation would be more obvious than value added.

However, the impact of natural capital loss on genuine fixed capital formation and genuine value added appear to be different, so the non-input–output adjusted genuine fixed capital formation ratio is higher than the adjusted series. The 2004 peak is a result of adjustments to performance indicators in the National Statistic Bureau's first Economic Survey of China. Because of the lack of suitable benchmark data, we cannot isolate this effect and adjust our own calculations.
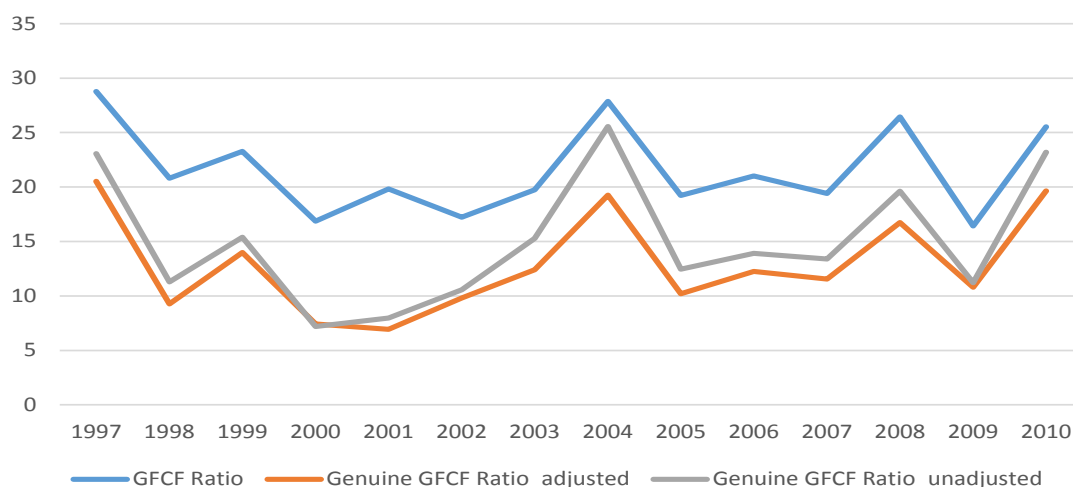

Figure 3 Average Traditional / Genuine Fixed Capital Formation Ratio
Notes: Utility sectors excluded.

(3) Industrial Genuine Capital Stock

In using the perpetual inventory method to measure productivity, the difference in capital formation greatly influences the capital stock. We can define the genuine capital stock as the following:

$$K'_{it} = K'_{it-1}(1-\delta_{it}) + I'_{it} \hspace{6cm} (10)$$

Here, δ_{it} is the depreciation ratio, that is, the ratio of capital depreciation to the original value of fixed assets. In the accounting data of industrial firms, the change in accumulated depreciation (gap between the original value of fixed assets and net value of fixed assets) provides a series of capital depreciation. I'_{it} is the Genuine Fixed Capital Formation.

The capital stock in 1994 for each sector is shown here as their net value of fixed assets as a constant price in the year 2000. genuine capital stock in fact begins in 1995 because of limited data on genuine fixed capital formation. The accumulation of natural resource depletion and environmental damage leads to a decline in genuine capital stock relative to traditional capital stock. The trend reversed after the 2007–2009 global financial crisis, meaning that the growth rate of genuine capital stock has surpassed that of traditional capital stock. Before 2006 the Metal Products sector had the lowest capital stock while the Electrical Machinery and Equipment sector had the next lowest. Both of these sectors suffered because of their heavy use of non-ferrous metals.
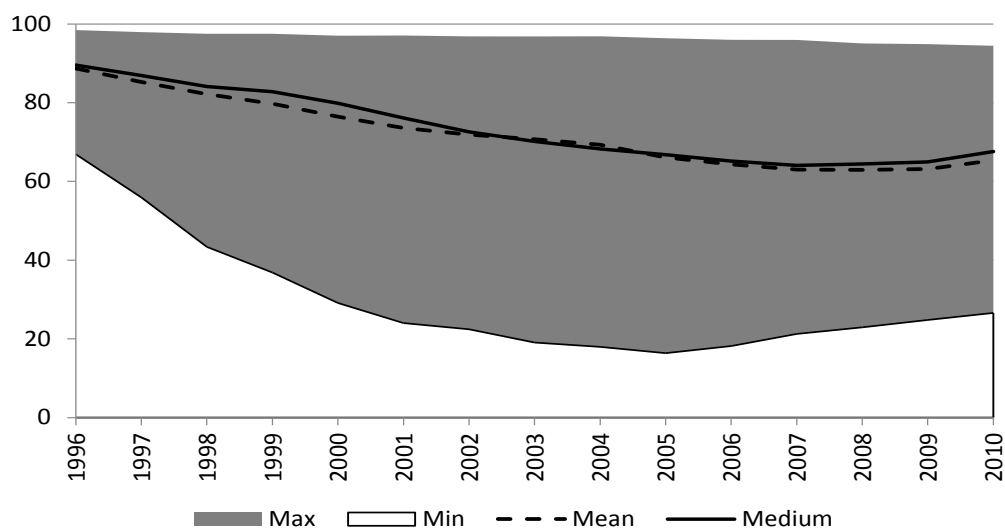

Figure 4 Share of Genuine Capital Stock as a Portion of Traditional Capital Stock

4. Accounting Genuine Productivity

Growth accounting is considered to be the classic method of productivity analysis. Assuming constant returns to scale, we can decompose GDP growth into factor contribution and productivity contribution. The coefficients of capital growth and labor growth, or their elasticity to output, were shown to be their proportion of GDP under the income approach. The new World Input Output Database also provides a complete series of industry-level capital / labor share. The adjustment on the value added will affect the operating surplus portion of capital compensation and therefore change the capital output elasticity:

$$\alpha' = \frac{\alpha - \rho}{1 - \rho} \qquad\qquad (11)$$

α is the original capital output elasticity

ρ is the proportion of natural resource depletion and environmental damage in original value added
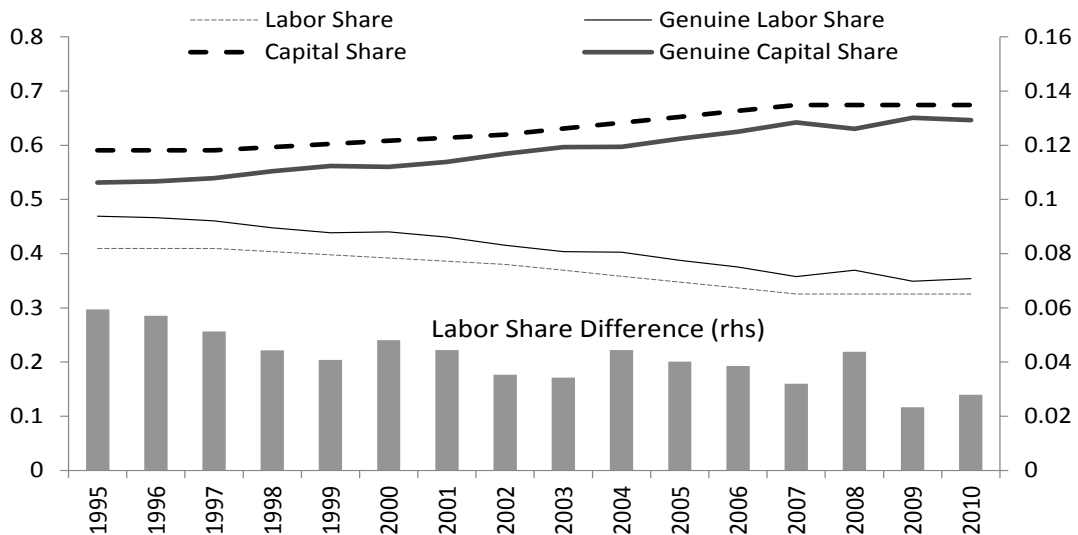

Figure 5 Genuine Labor / Capital Share

With the decline in overall labor share, the gap between traditional and genuine labor share narrowed from 0.06 to 0.02. This indicates a rise in the share of capital and a catching up in the genuine capital share. This gap comes from a loss of capital compensation from resource depletion and environmental damage, while the decrease in natural capital loss was the driving force behind this convergence.

Assuming constant returns to scale where the sum of labor output elasticity and capital output elasticity is equal to 1, the growth rate of genuine total factor productivity can be expressed in the widely used Divisia Productivity Index (Jorgenson and Griliches, 1971; Star and Hall, 1976) recommended by the OECD Productivity Handbook as follows:

$$\dot{A}' = \dot{Y}' - \alpha' \, \dot{K}' - (1 - \alpha') \, \dot{L} \qquad\qquad (12)$$

A' is the genuine total factor productivity

Y' is the genuine value added

K' is the genuine capital stock

α' Is the adjusted labor share

While keeping input factors and output measures in constant price, we see that the contribution of the growth of input factors to the output growth is the key measure in estimating different patterns of productivity. Although the level of genuine value added was lower than the traditional measure, the narrowing gap makes the growth rate of the former higher than the latter on average. The growth rate difference was just 0.4% during the first period between 1995 and 2002. This difference narrowed to 0.3% between 2003 and 2010.

The traditional measure of the growth of capital stock was much higher than the genuine measure because the accumulation effect of natural resource depletion and

environmental damage seriously lowers the growth rate of capital stock in the genuine measure. This effect led to a 3% slowdown of genuine capital stock growth on average. This gap narrowed from 4.8% during the first period of time to 1% during the second period. This indicates that the traditional measure overestimates the contribution of capital stock in the total growth of China's industrial sectors as the natural capital lost was still recorded as part of fixed capital formation. Therefore, under the traditional measure the total growth of capital stock contributed more than 60% of value added but 45% under the genuine measure, similar to the contribution of total factor productivity.

The most important part of growth accounting is total factor productivity. Here the growth rate was 2.5% higher under the genuine measure and its contribution to value added growth is 16% higher even considering that the value added growth was slightly higher. This new pattern fundamentally altered the traditional view that capital stock completely dominated the value added growth in China's industrial sectors. Here we find that total factor productivity played a similar role. There is also a gap in the growth rate of total factor productivity of 3.7% between the two periods, making their contribution to value added growth close to each other, with both lower than one third under the traditional measure. In contrast, the total factor productivity growth rates between the two periods under the genuine measure have a gap of only 1.7%. This emphasizes that its contribution to average industrial value added growth between 1995 and 2002 was much higher at about 64%. This was even 11.5% higher than the average contribution of the growth capital stock. However, this intensive growth model was replaced by a more extensive one during the second period of time. Here total factor productivity growth contributes only around one-third of the genuine value added growth, and there is no obvious difference from the traditional measure.

Table 3 Growth Accounting of Genuine Value Added Growth

	Value added	Labor Growth	Capital Growth	TFP Growth
Traditional Value Added Growth				
1995-2002	9.28	-2.01	13.44	2.69
		(-21.69)	(88.94)	(28.95)
2003-2010	20.89	2.81	14.87	6.37
		(13.44)	(47.04)	(30.47)
1995-2010	14.94	0.37	14.15	4.51
		(2.47)	(60.49)	(30.19)
Genuine Value Added Growth				
1995-2002	9.69	-2.01	8.64	6.20
		(-20.77)	(52.36)	(63.92)
2003-2010	21.10	2.81	13.88	7.88
		(13.31)	(41.52)	(37.34)
1995-2010	15.26	0.37	11.23	7.03
		(2.41)	(45.24)	(46.11)

Notes: Numbers in brackets are contribution as a percentage. They do not add up to 100% as they are averaged over all items. TFP: total factor productivity.

In the detailed industrial sectors in particular we find that all of the total factor productivity growth gaps were positive, which means that they all achieved higher total factor productivity growth under the genuine measure. However, several sectors had lower genuine value added growth compared with the traditional measure. A general pattern is that the higher the value added gap (genuine measure minus traditional measure), the higher the total factor productivity gap. This pattern can be explained when we consider that the higher value growth rate comes mainly from the higher total factor productivity growth under the genuine measure, or that the genuine growth model was a more total factor productivity driven model.

The difference in the Electrical Machinery and Equipment manufacturing sector over the whole period from 1995 to 2010 was on top of the detailed industrial sectors, reaching 6.5% yearly. This was followed by the 5.6% found in the Non-ferrous Metals

Manufacturing and the 4.7% in Metal Products Manufacturing. Among other heavy metal-consuming sectors, the General and Special Purpose Machinery Manufacturing and Ferrous Metals Manufacturing sectors showed the unique characteristics of having high total factor productivity gaps under lower genuine value added growth, meaning that the effects of mineral depletion damaged their output growth but left more room for extra total factor productivity growth under their accumulation in capital stock.
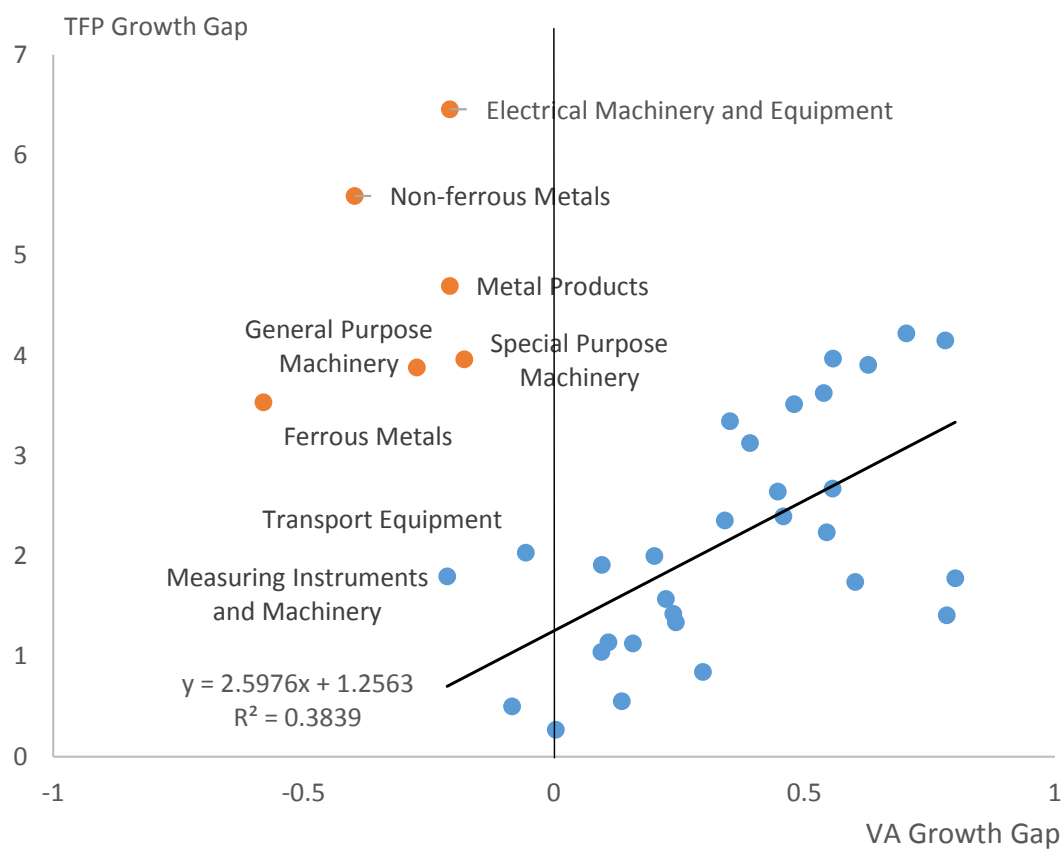

Figure 6 Traditional / Genuine Productivity Difference

5. Conclusion

The natural resource depletion and carbon damage cost nearly one tenth of China's industrial gross value added. The loss to value added fluctuated between 10% in mid

1990s to 8.5% in 2010, while the accumulation effect that drove the loss in capital stock peaked in 2007 at 30% of capital stock on average. They also lead to an average 3% to 6% lower sector-level productivity growth under the traditional measure. However, the genuine measure showed that China's industrial growth model was more productivity driven, especially during the period between 1995 and 2003. However, some heavy metal consumption sectors that showed lower genuine value added growth compared with the traditional measure achieved the highest genuine total factor productivity growth.

The over-consumption of natural resources and the related pollution will greatly discount the value added growth and capital stock of industrial sectors. Greater loss of natural capital will lower the genuine measure of value added compared with the traditional measure and will slow the accumulation of genuine capital stock. More intensive use of natural capital will speed up genuine capital stock growth. We believe that the intensive use of resources, the reduction of carbon, and new technology in resource consumption and emission control all contribute to industrial total factor productivity growth.

One policy implication is that the application of genuine GDP accounting at both the national and industrial levels can help governments to understand the importance of green growth and their environmental and resource constraints. This new measure provides an alternative way to understand the growth model of different industries and can help with the design of industrial policy by integrating the negative effects of environmental pollution and the overconsumption of non-renewable resources into the current national accounting system. This will then provide a new landscape for the structural transformation strategy of the Chinese government.

Furthermore, linking resource depletion and the environmental damage of various

industries through an input–output system provides more comprehensive information about their generation and final consumption so that we can better understand the different levels of responsibility through the production chain. This may help policy makers to understand the systematic influence of a specific industrial policy and to break away from traditional GDP-oriented high-carbon, high-pollution development patterns toward a more comprehensive way of policy making.

One limitation of this study is that we focused on only physical capital loss without explicit consideration of human capital loss. As a possible extension, measuring the effects of environmental damage such as PM2.5 pollution on human health and human capital and then linking these effects to genuine productivity analysis would be a promising area of future research.

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