**No. DP 19-006**

# SSPJ Discussion Paper Series

## "ARE CAPITAL AND LABOR INPUTS PROPERLY MEASURED IN CHINA?"

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March 2020

Grant-in-Aid for Scientific Research (S) Gran Number 16H06322 Project

**Service Sector Productivity in Japan**
Institute of Economic Research
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http://sspj.ier.hit-u.ac.jp/

# ARE CAPITAL AND LABOR INPUTS PROPERLY MEASURED IN CHINA?

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**Abstract:** We first follow the standard approaches (OECD, 2001) to measure capital and labor services in China during the time period of 1980-2016 using the China Industrial Productivity database, and then investigate the influences of replacing factors services with their stocks, which is often adopted in current studies, on total factor productivity (TFP) growth. We also investigate the resource reallocations and their impacts on TFP growth, and further trace their industry origins. The results show that by taking quality changes into account, the annual growth rates of capital service and labor service are 12.30% and 3.56%, respectively. The economy-wide capital quality declines by 3.68% while labor quality increases by 34.10%. Consequently, the aggregate TFP growth of China is underestimated by 6.58% when only replacing capital service with capital stock, while it is overestimated by 50% when only replacing labor service with labor stock and is overestimated by 43.42% when replacing both capital and labor services with their stocks. There are barriers to factor mobility that cause resources misallocation in China, which could be corrected by following market mechanisms. The net reallocation of capital and labor contributes 60.53% to the aggregate TFP growth. Industries with high (or low) factor input growth and high (or low) factor service price contribute to the improvement of factor allocation while those with high (or low) factor input growth and low (or high) factor service price are responsible for the negative reallocation of factor inputs.

**Keywords:** Inputs services; Inputs quality; Aggregate production possibility frontier; China Industrial Productivity database; Resource reallocation

**JEL Classifications:** C82, O11, O47, O53

# 1. INTRODUCTION

Krugman (1994) concludes that the growth of East Asian economies has been largely driven by extraordinary growth in inputs like capital and labor rather than by gains in efficiency. Since then, the growth model of the Chinese economy has been a focus of many scholars. Numerous studies investigate the total factor productivity (TFP) performance in China from various perspectives. Some studies investigate TFP growth of the overall Chinese economy as a whole (Chow and Li, 2002; Hu and Khan, 1997; Maddison, 2007; Wang and Yao, 2003; World Bank, 1997; Y. Wu, 2003; Zhang and Jiang, 2014). Several studies estimate the TFP growth of Chinese economy from the perspective of certain industries (Hu et al., 2015; Li and Li, 2008; Liu and Li, 2012; Wang et al., 2013; Y. Wu, 2015), while other studies measure the TFP growth of Chinese economy from the perspective of regions (Kuang and Peng, 2012; Li and Liu, 2015; Ma and Hao, 2018; Wang et al., 2010; Yu, 2017). Other studies also explore the regional origins of TFP growth of Chinese industry (Chai and Huang, 2008; Chen et al., 2008; Liu and Zhang, 2010; Pan and Ying, 2013; Wang and Wang, 2017; Wang et al., 2015; Yuan and Xie, 2015).

Given that different datasets are used in these studies, no consensus has been reached. For example, in the reform period, the annual growth rate of TFP is 3.03% according to Chow and Li (2002), 3.9% according to Hu and Khan (1997), 2.41% according to Wang and Yao (2003), and 4.3% according to the World Bank (1997). It turns out that proper measurement of the factor inputs is the critical factor that causes TFP differentials among studies. Generally, the primary factors, capital and labor inputs, have been considered. More and more studies have added more inputs into consideration, such as human capital, land, energy, water, pollution, and environmental factors, which is helpful to estimate actual TFP growth (e.g., Wang and Yao, 2003; Liu and Li, 2012; Chen et al., 2008).

However, the measurement of capital and labor inputs in these studies is inappropriate. Most of them use capital stock as capital input and the number of persons employed as labor input in the TFP calculation, which is conceptually inadequate. As pointed out in the OECD Manual (2001), capital goods that are purchased or rented by a firm are seen as carriers of capital services that constitute the actual input in the production process. Similarly, employees hired for a certain period can be seen as carriers of stocks of human capital and, therefore, as repositories of labor services. Thus, both capital service and labor service, which are the actual inputs involved in production activities, should be measured. Several studies estimate effective labor input by adjusting the number of persons employed based on years of education, which still cannot sufficiently reflect the heterogeneity of the quality of education among different labors.

Furthermore, resource reallocation is another important factor that affects TFP growth. The research on the impacts of resource misallocation on TFP growth goes back to the seminal work of Hsieh and Klenow (2009), who argue that resource misallocation is a critical reason for TFP growth differentials between poor and rich countries. They find that the TFP of the Chinese manufacturing sector would be boosted by 30-50% from 1998 to 2005 by moving to "U.S. efficiency," which means that capital and labor are reallocated to equalize marginal products across plants within each sector to the extent observed in the United States.

Despite various institutional reforms implemented in the past few decades, the excessive investment in physical capital engineered by the government is still an important contributor to Chinese economic growth. Such government intervention instead of market mechanisms causes influential impacts on resource allocation, which in turn have important influences on TFP growth. Therefore, it is necessary to contain resource allocations when estimating the TFP growth in China.

Given that TFP is calculated as a residual, the application of input stocks in TFP calculations by current studies is bound to cause biased measurements of TFP because it ignores the quality changes in factor inputs. Thus, this study first concentrates on the measurement of capital and labor inputs by following the standard approaches, given that both inputs are the most important factors of production. We then evaluate the impacts of current measurements of both inputs on TFP growth. Furthermore, we take resource reallocations into account because it is an integral component of TFP growth, and trace the aggregate reallocation terms at the industry level to look for the industry origins of resource reallocations.

The rest of this study is arranged as follows. Section 2 briefly introduces the procedures adopted in the China Industrial Productivity (CIP) database to construct capital and labor data. Section 3 presents empirical results, and Section 4 concludes this study.

## 2. MEASUREMENT OF CAPITAL AND LABOR SERVICES

The data used in this study are from the CIP Database Project.[1] This section briefly introduces the procedures adopted in the CIP database to construct capital and labor data. For details, please refer to Wu and Ito (2015) for output and price index data, H. Wu (2015a) for capital data, and Wu et al. (2015) for labor data.

### 2.1 Estimation of Capital Services

The perpetual inventory method is adopted to construct capital stock. The investment flow, depreciation rate, initial capital stock, and investment price index are four essential variables in the approach. Most studies use "investment in fixed assets" as investment flow in the approach to estimate capital stock, which is inaccurate for two main reasons. First, the investment in fixed assets might not form the standard fixed assets in the current period, which may ultimately need a long construction period to form fixed asset. Second, part of the investment in fixed assets may never form fixed assets or may even be completely wasted (H. Wu, 2015a). For industrial sectors, H. Wu uses the two-period difference of "original value of fixed assets (OVFA; *guding zichan yuanzhi* in Chinese)"[2] as investment flow, adds back scraped fixed assets in the current period,[3] and makes two adjustments: removing non-productive assets mainly residential structures and adding back productive assets not covered by the official industry investment statistics.[4] Since there are no OVFA data for non-

[1] The CIP project was initiated by Professor Harry X. Wu, who is from the Institute of Economic Research, Hitotsubashi University, under the joint financial support from Hitotsubashi University and the Research Institute of Economy, Trade and Industry in 2010. This project follows the KLEMS principles in data construction and aims to construct consistent sector-level input and output data series that are applicable for analytical studies in a general production function framework, as well as for international comparisons of output and productivity. KLEMS is an acronym of various inputs used in production process: **K**(C)apital, **L**abor, **E**nergy, **M**aterials, and **S**ervices. By definition, gross output of an industry equals total costs of "KLEMS", and gross output of an economy equals the sum of the costs of KLEMS of all industries. The version of CIP3.0 database can be downloaded at the website: https://www.rieti.go.jp/en/database/CIP2015/index.html.

[2] According to the official definition of the 2010 China Statistical Yearbook (page 570), OVFA refers to the total value in monetary terms that an enterprise has spent on fixed assets through construction, purchase, installation, transformation, expansion, or technical upgrading. Generally, it covers cost of purchase, packing, transportation, installation, etc. Thus, OVFA is approximately equivalent to book value of fixed assets.

[3] Since OVFA is an end-of-period value, it does not cover fixed assets scraped in the current period, so this part of fixed assets should be added back.

[4] Since the 1990s, the cut-off point of projects covered by statistics of investment in fixed assets has undergone two adjustments. Since 1997, the cut-off point was raised from an investment of 50 thousand yuan to 500 thousand yuan, except for investment in real estate development, farm household investment, non-farm household investment, and private investment in housing construction in urban, industrial, and mining areas. Since 2011, the cutoff size of projects of investment in fixed assets rose from a total planned investment above 500 thousand yuan to 5 million yuan (2017 China Statistical Yearbook, page 293). Thus, investments in fixed assets that are not covered by official statistics are mainly investment projects that are below the official threshold for investment statistics. Please see Equation (4.3) in H. Wu (2015a) for estimation of investment flow.

industrial sectors, the "newly increased fixed assets (NIFA; *xinzeng guding zichan* in Chinese)" are used as investment flow.[5]

Regarding types of capital assets, H. Wu uses various official statistics to decompose the fixed assets of industrial sectors into four components: equipment, residential structures, non-residential structures, and others; he then removes "residential structures" and redistributes "others" into "equipment" and "non-residential structures" (hereafter, structure) based on their shares. He uses data from the *China Statistical Yearbook of The Tertiary Industry* to divide investment flows into equipment and structure for all service sectors. For agriculture and construction sectors, H. Wu divides investment flows into two types of assets by using investment statistics data of these two sectors. Thus, there are two types of capital assets in CIP database, i.e., equipment and structure.

As for depreciation rate, H. Wu follows the approach of Hulten and Wykoff (1981), that is, $\delta = R/T$, where $\delta$, $R$, and $T$ are the depreciation rate, declining balance rate, and service life of assets, respectively. Various data sources are used to estimate the service life of each type of capital assets, and the results of the declining balance rate are adopted from Hulten and Wykoff to estimate depreciation rates for industrial sectors. The geometric mean of depreciation rates of industrial sectors is used as the depreciation rate for non-industrial sectors. This approach reduces the subjective arbitrariness of choosing depreciation rates, which is often done in current studies.

H. Wu adopts the steady-state method to estimate the initial capital stock, for which it is assumed that the growth rates of capital and output are equal when an economy is in the steady state. This method has been widely adopted in studies, such as Harberger (1978) and King and Levine (1994). In addition, H. Wu uses the industry-specific asset price indices for state-owned enterprises based on an asset survey by the Ministry of Finance with adjustments to estimate the investment price index of industrial sectors. The geometric mean of the investment price index of industrial sectors is used as an investment price index for non-industrial sectors.

The growth rate of capital service of industry $i$ is defined as:

[5] According to the definition, NIFA refers to the value of fixed assets that have completed the construction and purchase process and have been delivered to the production or owner units, including investment in projects that have been completed and put into operation in the current year and the investment in equipment, tools, and appliances that meet the standard of fixed assets and fees that should be apportioned. This is an indicator that demonstrates the results of investment in fixed assets in monetary terms and is important for reflecting the speed of construction and calculating the efficiency of investment (2017 China Statistical Yearbook, page 338). Thus, NIFA is more compatible with the standard concept of fixed asset investment.

$$\Delta lnK_i = \sum_k \frac{P^K_{k,i} Z_{k,i}}{\sum_k P^K_{k,i} Z_{k,i}} \Delta lnZ_{k,i} \quad (1)$$

where $K_i$ represents capital input of industry $i$, $Z_{k,i}$ is its capital stock of type $k$, and $P^K_{k,i}$ is its capital service price of type $k$.[6] $\Delta$ represents the change of a value from period $t-1$ to period $t$.

### 2.2 Estimation of Labor Services

The widely used headcounts of employed persons hides changes in average hours worked. Thus, labor input is most appropriately measured as the total number of hours worked. Furthermore, a worker's contribution to the production process consists of the "raw" labor and services from that worker's human capital. One hour worked by one person does not necessarily constitute the same amount of labor input as one hour worked by another person. There may be differences in skills, education, health, and professional experience that lead to large differences in the contribution of different types of labor. A differentiation of labor input by type of skills is particularly desirable if one wants to capture the effects of a changing quality of labor on the growth of output and productivity (OECD Manual, 2001). Therefore, the CIP data contain detailed characteristics of labor—specifically, two genders, seven age groups, and five education attainments. Thus, each industry includes 70 types of labor in total.[7]

To construct the number of employed persons, hours worked, and hour compensation corresponding to each type of labor, Wu et al. (2015) first look for various forms of marginal matrices (which contain partial dimensions) for benchmark years from various data sources, including the population census, the 1% Population Sample Survey, the Chinese Household Income Project, Rural, Urban, and Migrant in China and so on. They then construct the corresponding full-dimensioned matrices at benchmark years by applying an iterative proportional fitting approach, which is designed to integrate marginal matrices by generating the maximum likelihood estimate of each element of a matrix. Based on constructed full-dimensioned matrices for benchmarks and marginal matrices in time series, they construct a time series of full-dimensioned matrices through linear interpolations and use data from marginal matrices as control totals for non-benchmark years. This is not only useful for estimating the actual labor input involved in production process but also precisely measures the human capital growth in China.

[6] Time subscripts are omitted for convenience wherever possible.
[7] See Table 1 in Wu et al. (2015) for detailed classification.

The growth rate of the labor input of industry $i$ is defined as:

$$\Delta lnL_i = \sum_l \frac{P_{l,i}^L H_{l,i}}{\sum_l P_{l,i}^L H_{l,i}} \Delta lnH_{l,i} \quad (2)$$

where $L_i$ represents labor input of industry $i$, $H_{l,i}$ represents hours worked of type $l$ in industry $i$, and $P_{l,i}^L$ represents labor service price of type $l$ in industry $i$.

## 3. EMPIRICAL RESULTS

Table 1 presents the growth rates of capital service by sectors.[8] The aggregate capital service has achieved high annual growth rate of around 12.30% over the entire period of 1980-2016. To reflect the impacts of external shocks on capital input, the whole time period is divided into five sub-periods. The economic reforms and opening-up policy implemented since 1978 and the southern tour speech in 1992 have stimulated capital input to grow at 10.13% and 12.18% on average during 1980-1991 and 1991-2001, respectively.[9] In 2001, China formally entered the World Trade Organization (WTO), which has further attracted a large amount of foreign direct investment to flow into China.

During the WTO period (2001-2007), most sectors (25 out of 37 sectors) achieved faster growth of capital input, with growth rates exceeding that in the previous sub-period. To remove the negative influences of the Global Financial Crisis in 2008, the central government initiated a 4-trillion-yuan stimulus package, which was accompanied by 18-trillion-yuan projects financed by local governments, to avoid economic recession from the end of 2008. This resulted in a new wave of state-enterprises-led investment (H. Wu, 2015b). As a result, the growth rates of capital input of 26 sectors during 2007-2011 exceeded that in the WTO period. Beginning in 2012, Chinese economic growth has been under tremendous downward pressure. Problems have been gradually emerging, such as increases in factor costs, overcapacity, environmental pollution, and so on. The central government has gradually shifted from stimulating demand to facilitating supply-side reforms, which caused decreases

[8] To save space, we do not present the growth rate of capital stock in each industry, which is available from the author upon request.
[9] After the political turmoil in 1989, the inside of the Chinese central government emerged different opinions on whether to continue reform and opening-up policy. At the beginning of 1992, Xiaoping Deng visited some cities in southern China and made a series of important speeches. The speech reiterated the necessity and importance of deepening economic reform and accelerating development, which stimulated the second wave of China's reform and opening-up. The speech played a key role in promoting China's economic reforms and social progress in the 1990s. This is later known as "southern tour speech".

in the growth rates of capital input of most of sectors and the whole economy in the last sub-period.

As shown in Table 1, the growth rates of capital service exhibit obvious disparity across sectors. For example, the growth rate in capital service of Real Estate is relatively high, at 19.01% annually in 1980-2016, which also maintains a high growth rate in the five sub-periods. On the other hand, the growth rates of capital service in seven sectors, including Coal Mining, Metal Mining, Nonmetal Mining, and so on, are relatively low, at less than 10% on average over the whole period.

Table 1 also shows that the growth rates of capital service of service sectors except for Finance are relatively high at more than 10% on average in all individual sectors during the whole period. The average growth rate of the service industry as a whole is 14.58% over the whole period, which is larger than that of the whole industry (11.70%). Generally, all service sectors have also grown rapidly in terms of capital service in every sub-period. More importantly, every individual service sector has maintained high growth in capital service even in the last sub-period. In 2011-2016, the growth rate of capital service of each service sector was over than 10%, and the average growth rate of the whole service industry was 16.04%, nearly two times that of the whole industry (8.58%).

Along with the spectacular Chinese economic growth over the past nearly four decades, the development of the service industry has also grown rapidly. According to the latest data from the National Bureau of Statistics, the nominal value added of the service industry as a percentage of total economy has increased from 24.6% in 1978 to 51.6% in 2016. In 2001, the share of service industry exceeded that of the whole industry, making it the industry with the largest proportion of the total economy. The rapid increase of both capital and labor inputs (see the following text) in the service industry may imply that it has potential to become the engine of Chinese economic growth in the future.

**Table 1 Growth Rate of Capital Service in Each Industry (%)**

| **Sectors** | **1980-1991** | **1991-2001** | **2001-2007** | **2007-2011** | **2011-2016** | ***1980-2016*** |
|---|---|---|---|---|---|---|
| **Nation** | 10.13 | 12.18 | 13.16 | 16.16 | 13.22 | *12.30* |
| Agriculture | 4.35 | 9.23 | 10.57 | 17.04 | 18.33 | *10.09* |
| Coal Mining | 7.41 | 4.36 | 14.46 | 20.29 | 5.11 | *8.85* |
| Petroleum and Gas | 14.33 | 11.24 | 14.51 | 13.19 | 7.44 | *12.42* |
| Metal Mining | 5.58 | 1.98 | 13.42 | 22.64 | 6.40 | *7.89* |
| Nonmetal Mining | 8.60 | 4.35 | 4.58 | 21.81 | 5.82 | *7.83* |
| Food | 14.97 | 8.67 | 11.98 | 21.62 | 9.74 | *12.73* |
| Tobacco | 24.09 | 15.17 | 3.99 | 10.28 | 6.36 | *14.26* |
| Textile | 15.97 | 3.20 | 11.73 | 10.80 | 4.72 | *9.58* |

| | | | | | | |
|---|---|---|---|---|---|---|
| Wearing Apparel | 18.04 | 10.81 | 12.41 | 12.00 | 15.05 | *14.01* |
| Leather and Fur | 14.01 | 9.19 | 13.34 | 13.67 | 13.05 | *12.39* |
| Timbers and Furniture | 11.76 | 9.03 | 17.35 | 18.72 | 10.86 | *12.58* |
| Paper and Printing | 11.17 | 12.29 | 12.25 | 13.25 | 5.01 | *11.04* |
| Petroleum Processing | 12.68 | 12.81 | 9.40 | 20.25 | 6.00 | *12.08* |
| Chemical Materials | 9.53 | 8.71 | 12.24 | 18.39 | 10.19 | *10.83* |
| Rubber and Plastics | 13.98 | 9.89 | 13.66 | 14.53 | 7.48 | *11.95* |
| Non-metallic Products | 10.98 | 7.49 | 12.49 | 20.30 | 8.64 | *10.97* |
| Metal Pressing | 7.26 | 9.71 | 15.83 | 18.15 | 4.79 | *10.24* |
| Fabricated Metal Products | 10.42 | 8.66 | 13.02 | 20.40 | 12.79 | *11.80* |
| General Equipment | 5.04 | 2.71 | 14.00 | 21.11 | 6.95 | *7.94* |
| Electrical Equipment | 11.73 | 10.71 | 13.56 | 26.91 | 6.68 | *12.74* |
| Electronic Equipment | 12.53 | 15.63 | 20.33 | 13.12 | 11.39 | *14.60* |
| Instruments | 7.52 | 7.35 | 17.14 | 15.93 | 5.88 | *9.78* |
| Transportation Equipment | 5.95 | 10.90 | 15.09 | 20.05 | 10.19 | *11.00* |
| Other Manufacturing | 40.95 | 10.80 | 10.17 | 14.32 | 15.47 | *20.95* |
| Utility | 9.75 | 15.65 | 14.55 | 11.02 | 9.90 | *12.35* |
| Construction | 9.04 | 14.16 | 12.45 | 13.89 | 13.31 | *12.16* |
| Wholesale | 4.42 | 11.49 | 8.67 | 14.25 | 18.48 | *10.14* |
| Hotel and Catering | 11.09 | 16.38 | 14.59 | 21.28 | 17.14 | *15.12* |
| Transportation and Storage | 11.70 | 18.60 | 13.50 | 12.55 | 13.25 | *14.23* |
| Post | 23.80 | 19.94 | 13.18 | 7.22 | 11.68 | *17.43* |
| Finance | 6.33 | 12.24 | 3.38 | 8.64 | 13.95 | *8.80* |
| Real Estate | 16.15 | 24.25 | 19.77 | 17.27 | 15.32 | *19.01* |
| Business Services | 11.72 | 11.40 | 13.61 | 20.96 | 25.79 | *14.92* |
| Public Management | 8.82 | 15.35 | 27.99 | 22.53 | 19.53 | *16.84* |
| Education | 13.09 | 13.03 | 14.75 | 10.31 | 12.21 | *12.92* |
| Healthcare | 14.92 | 13.06 | 17.11 | 17.42 | 17.50 | *15.40* |
| Other Services | 13.00 | 12.88 | 18.41 | 27.27 | 26.82 | *17.37* |

Source: Author’s calculation by using CIP data. See Table A1 for sector description.

To investigate the actual human capital growth in China, we measured the labor service in terms of hours worked, and the results are shown in Table 2.[10] The annual growth rate of labor services in the nation as a whole was 3.56% in 1980-2016 and exhibited fluctuations during each sub-period. The growth patterns of labor services across sectors show that: (1) the annual growth rate of labor service is disparate among sectors; (2) the growth rates of service sectors are usually higher than that of industrial sectors, and the annual growth rates of labor service of the whole service industry and Chinese industry are 6.15% and 3.51% over the whole period, respectively; and (3) the growth rate of labor service of agriculture is declining over time. Combined with the increases of labor service in industrial sectors and service sectors, especially service sectors, this may show that the industry structure of the Chinese economy is gradually transforming from agriculture to industries and services.

**Table 2 Growth Rate of Labor Service in Each Industry (%)**

| **Sectors** | **1980-** | **1991-** | **2001-** | **2007-** | **2011-** | ***1980-*** |
|---|---|---|---|---|---|---|

[10] As in footnote 8, we do not present the growth rate of the employment number in each industry, which is available from the author upon request.

| | 1991 | 2001 | 2007 | 2011 | 2016 | *2016* |
|---|---|---|---|---|---|---|
| **Nation** | 4.16 | 3.40 | 4.07 | 3.42 | 2.08 | *3.56* |
| Agriculture | 1.64 | 0.93 | -2.72 | -4.85 | -5.14 | *-0.95* |
| Coal Mining | 4.84 | -1.20 | 4.47 | -1.49 | -3.87 | *1.19* |
| Petroleum and Gas | 6.51 | -1.29 | 12.11 | 4.69 | -5.41 | *3.42* |
| Metal Mining | 5.40 | 0.29 | 8.45 | -1.77 | -0.20 | *2.91* |
| Nonmetal Mining | 6.48 | 1.01 | 2.28 | -8.02 | -1.92 | *1.48* |
| Food | 5.08 | 2.20 | 5.61 | 3.31 | 1.10 | *3.62* |
| Tobacco | 8.16 | -0.82 | -0.40 | 9.10 | 12.13 | *4.89* |
| Textile | 6.83 | -1.57 | 4.80 | -3.10 | -5.13 | *1.39* |
| Wearing Apparel | 5.93 | 6.43 | 8.54 | -0.31 | -2.10 | *4.70* |
| Leather and Fur | 6.71 | 7.51 | 8.16 | 1.71 | -0.57 | *5.61* |
| Timbers and Furniture | -1.50 | 5.51 | 11.81 | -2.36 | -0.43 | *2.72* |
| Paper and Printing | 6.45 | 1.90 | 4.96 | -0.42 | -0.92 | *3.15* |
| Petroleum Processing | 8.21 | 2.06 | 4.96 | 6.91 | 1.21 | *4.84* |
| Chemical Materials | 5.63 | 1.19 | 4.15 | 5.74 | 2.50 | *3.73* |
| Rubber and Plastics | 6.20 | 4.60 | 8.72 | -1.93 | -2.12 | *4.12* |
| Non-metallic Products | 4.77 | -0.04 | 0.97 | -3.38 | 0.53 | *1.30* |
| Metal Pressing | 4.21 | 1.78 | 3.72 | 5.13 | 0.69 | *3.07* |
| Fabricated Metal Products | 4.58 | 2.41 | 8.35 | 1.33 | 1.22 | *3.78* |
| General Equipment | 2.80 | -3.18 | 7.38 | 1.50 | 0.91 | *1.50* |
| Electrical Equipment | 5.57 | 4.21 | 10.25 | 4.80 | 1.84 | *5.37* |
| Electronic Equipment | 5.21 | 7.16 | 13.76 | 7.42 | 4.29 | *7.29* |
| Instruments | 2.56 | 6.23 | 7.24 | -0.68 | -1.15 | *3.48* |
| Transportation Equipment | 3.10 | 2.13 | 7.55 | 6.16 | 4.66 | *4.13* |
| Other Manufacturing | 4.75 | 1.64 | 2.19 | 0.04 | -0.70 | *2.18* |
| Utility | 6.09 | 5.45 | 4.71 | 1.91 | 0.37 | *4.42* |
| Construction | 9.90 | 7.03 | 2.18 | 5.50 | 3.96 | *6.50* |
| Wholesale | 9.34 | 3.99 | 2.90 | 6.49 | 4.55 | *5.80* |
| Hotel and Catering | 9.06 | 11.07 | 2.90 | 4.13 | 7.19 | *7.78* |
| Transportation and Storage | 5.57 | 2.88 | 2.42 | -1.22 | -3.40 | *2.30* |
| Post | 6.11 | 8.95 | 5.69 | 11.08 | 1.93 | *6.80* |
| Finance | 7.35 | 11.01 | 8.34 | 11.27 | 7.76 | *9.02* |
| Real Estate | 4.91 | 17.66 | 15.94 | 10.96 | 6.94 | *11.24* |
| Business Services | 2.21 | 10.14 | 10.72 | 13.23 | 9.81 | *8.11* |
| Public Management | 9.44 | 6.29 | 7.92 | 9.04 | 5.15 | *7.67* |
| Education | 1.13 | 6.40 | 5.70 | 5.28 | 3.08 | *4.09* |
| Healthcare | 1.70 | 8.06 | 6.02 | 9.19 | 5.95 | *5.61* |
| Other Services | 4.67 | 12.86 | 4.32 | 4.19 | 3.22 | *6.63* |

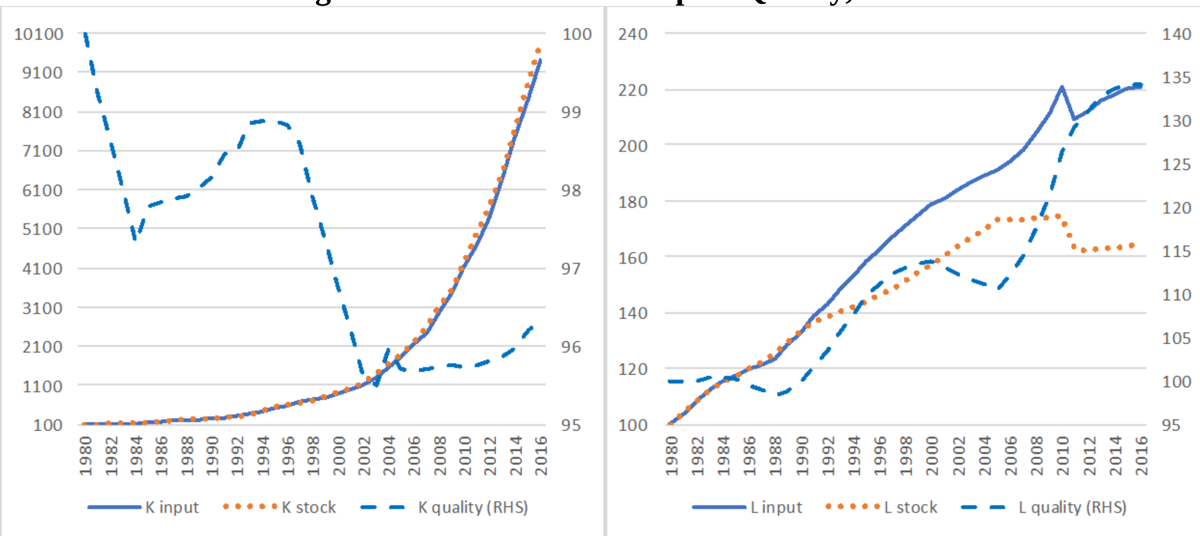
Source: Author's calculation by using CIP data.

We calculated the capital and labor quality of the Chinese economy as a whole, as shown in Figure 1.[11] The left panel in the figure shows that capital quality is generally decreasing over time, given that the growth rate of capital service is slightly lower than that of capital stock. The upward tail of the capital quality line may indicate that the supply-side reforms implemented in recent years may improve capital quality. On the other hand, the right panel shows that labor quality is generally increasing significantly, especially from 2005 onwards. This suggests that replacing input services by input stocks, which is often done in current studies, introduces biases in the measurement of TFP growth because the

[11] Capital (or labor) quality is defined as the ratio of capital (or labor) service to stock. To save space, we do not report the results of capital and labor quality of each sector, which are available from the author upon request.

measurement of input stocks ignores the change of inputs' quality. The impacts of adopting input stocks on TFP results are explored in Table 3.

**Figure 1 Growth Index of Inputs Quality, 1980=100**




Note: The quality indexes are denoted by axes on the right-hand side.
Source: Author's calculation by using CIP data.

To investigate the influences of adopting input stocks on TFP results, we calculate the overall TFP growth of the Chinese economy in various scenarios, and the results are shown in Table 3.[12] The aggregate TFP growth is decomposed into three components: Domar-weighted TFP growth, the reallocation of capital input, and the reallocation of labor input.[13] In Case 1, both capital and labor inputs are measured as service flows by following the standard approaches. The annual growth rate of the overall TFP in this case is 0.76% over 1980-2016 with 0.30% from Domar-weighted TFP growth, -0.16% from capital reallocation, and 0.62% from labor reallocation. The aggregate TFP growth declines constantly from 1980 onwards and even becomes negative in the last two sub-periods due to shocks from the 2008 Global Financial Crisis and economic downturn beginning in 2012.

In Case 2, we replace capital service with capital stock and keep labor service. The annual growth rate of the overall TFP is now 0.71% over 1980-2016 with 0.30% from Domar-weighted TFP growth, -0.21% from capital reallocation, and 0.62% from labor reallocation. There is slight deterioration in capital quality (see the left panel of Figure 1), which declines by 3.68% over the period 1980-2016. As a result, the reallocation of capital further decreases from -0.16% to -0.21%. The impact of little changes in capital quality on

[12] We adopt an aggregate production possibility frontier approach to calculate TFP growth. Please refer to Chapter 8 in Jorgenson et al. (2005) for details.
[13] See Equation (8.34) in Jorgenson et al. (2005).

the Domar-weighted TFP growth is negligible. Thus, the net effect of replacing capital service with capital stock on TFP growth is underestimation of TFP growth by 0.05 percentage points, or by 6.58%, in the whole period.

Similarly, in Case 3, we replace labor service with labor stock and keep capital service. The annual growth rate of the overall TFP is now 1.14% over 1980-2016 with 0.79% from Domar-weighted TFP growth, -0.16% from capital reallocation, and 0.51% from labor reallocation. There is significant improvement of labor quality (see the right panel of Figure 1), which increases by 34.10% over the period 1980-2016. As a result, the reallocation of labor decreases from 0.62% to 0.51% by adopting labor stock in the TFP calculation. Furthermore, due to labor stock ignores the change of labor quality, which underestimates the actual labor input, the growth rate of the Domar-weighted TFP increases from 0.30% to 0.79%. Thus, the net effect of replacing labor service with labor stock on TFP growth is that TFP growth is overestimated by 0.38 percentage points, or by 50%, in the whole period.

In Case 4, we replace both capital and labor services with their stocks. The annual growth rate of the overall TFP is now 1.09% over 1980-2016 with 0.78% from Domar-weighted TFP growth, -0.21% from capital reallocation, and 0.51% from labor reallocation. By ignoring quality changes of both capital and labor inputs, the reallocations of capital and labor inputs decrease from -0.16% to -0.21% and from 0.62% to 0.51%, respectively. The degree of quality improvement of labor input outweighs the quality deterioration of capital input, so the annual growth rate of Domar-weighted TFP increases from 0.30% to 0.78% by adopting both stocks in TFP calculation. Thus, the net effect of replacing both services with their stocks on TFP growth is that TFP growth is overestimated by 0.33 percentage points, or by 43.42%, in the whole period.

**Table 3 Decompositions of National TFP Growth (%)**

| | **1980-1991** | **1991-2001** | **2001-2007** | **2007-2011** | **2011-2016** | ***1980-2016*** |
|---|---|---|---|---|---|---|
| **Case 1: capital service, labor service** | | | | | | |
| Aggregate TFP growth | 2.54 | 1.16 | 0.88 | -1.73 | -2.14 | 0.76 |
| 1.Domar-weighted TFP growth | 1.52 | 1.08 | 0.89 | -2.51 | -2.39 | 0.30 |
| 2.Reallocation of K | 0.46 | -0.27 | -1.10 | -0.11 | -0.22 | -0.16 |
| 3.Reallocation of L | 0.56 | 0.34 | 1.10 | 0.89 | 0.47 | 0.62 |
| **Case 2: capital stock, labor service** | | | | | | |

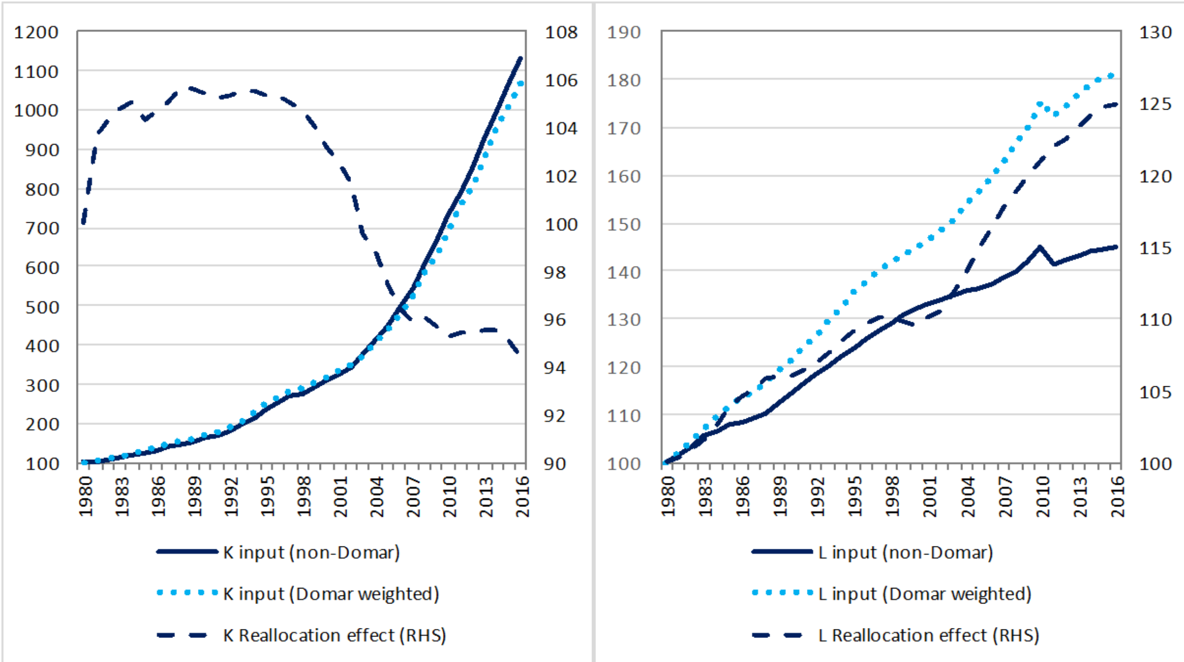
| | | | | | | |
|---|---|---|---|---|---|---|
| Aggregate TFP growth | 2.46 | 1.05 | 0.84 | -1.72 | -2.08 | 0.71 |
| 1.Domar-weighted TFP growth | 1.48 | 1.09 | 0.93 | -2.59 | -2.36 | 0.30 |
| 2.Reallocation of K | 0.42 | -0.38 | -1.20 | -0.02 | -0.19 | -0.21 |
| 3.Reallocation of L | 0.56 | 0.34 | 1.10 | 0.89 | 0.47 | 0.62 |
| **Case 3: capital service, labor stock** | | | | | | |
| Aggregate TFP growth | 2.60 | 1.93 | 1.26 | -1.22 | -1.91 | 1.14 |
| 1.Domar-weighted TFP growth | 1.65 | 1.93 | 1.61 | -1.82 | -2.27 | 0.79 |
| 2.Reallocation of K | 0.46 | -0.27 | -1.10 | -0.11 | -0.22 | -0.16 |
| 3.Reallocation of L | 0.49 | 0.27 | 0.75 | 0.70 | 0.57 | 0.51 |
| **Case 4: capital stock, labor stock** | | | | | | |
| Aggregate TFP growth | 2.52 | 1.83 | 1.21 | -1.22 | -1.85 | 1.09 |
| 1.Domar-weighted TFP growth | 1.61 | 1.94 | 1.66 | -1.89 | -2.24 | 0.78 |
| 2.Reallocation of K | 0.42 | -0.38 | -1.20 | -0.02 | -0.19 | -0.21 |
| 3.Reallocation of L | 0.49 | 0.27 | 0.75 | 0.70 | 0.57 | 0.51 |

Note: In order to make a comparison with results in current studies, labor stock is calculated in terms of natural number of persons employed rather than hours worked while labor service is calculated in terms of hours worked by following the standard approach.
Source: Author's calculation by using CIP data.

Figure 2 shows the annual change trends of reallocations of capital and labor inputs. The left panel shows that the reallocation of capital input increased rapidly in the beginning period of 1980-1984, remained stable until 1994, and declined dramatically from then on. In contrast, the right panel shows that the reallocation of labor input increased remarkably during the whole period. In China, capital input is much more vulnerable to governmental interventions, it is mostly controlled by the government, and a great amount of it tends to flow into state-owned enterprises and state-controlled sectors although the utilization efficiency is relatively low in those sectors, resulting in negative reallocations of capital input during the whole period. In contrast, the labor market is much less controlled than the capital market, and labor forces can move relatively freely across sectors due to the relaxations of regulations on the labor market, especially the gradual relaxation of the household registration system since 1978, which causes labor reallocation to always be positive during the study period.

The significant reallocations of capital and labor have two important implications. First, factor prices are indeed different across sectors, indicating that there are barriers to factor mobility that cause resource misallocation in the Chinese economy. Second, resource misallocation could be corrected via "making the market play the decisive role in allocating factors of production," which would enhance TFP growth (H. Wu, 2015b). However, in the case of China, the net reallocation of capital and labor inputs is 0.46% on average during 1980-2016, which implies that the annual growth rate of the aggregate TFP would decline by 60.53% (from 0.76% to 0.30%) if the resource misallocation could be eliminated.

**Figure 2 Change Trends of Reallocations, 1980=100**




Note: This is based on results of Case 1 in Table 3. The indexes for reallocations are denoted by axes on the right-hand side.
Source: Author's calculation by using CIP data.

To explore the industry origins of reallocations of capital input, we rewrite the second term on the right-hand side of Equation (8.34) in Jorgenson et al. (2005) as:

$$\sum_i \frac{\bar{w}_i}{\bar{v}_i^V} \bar{v}_i^K \Delta lnK_i - \bar{u}^K \Delta lnK$$

$$= \sum_i \left( \frac{\bar{w}_i}{\bar{v}_i^V} \bar{v}_i^K - \bar{w}_i^K \bar{u}^K \right) \Delta lnK_i + \bar{u}^K \left( \sum_i \bar{w}_i^K \Delta lnK_i - \Delta lnK \right) \quad (3)$$

$$= \sum_i \left( \frac{\bar{w}_i}{\bar{v}_i^V} \bar{v}_i^K - \bar{w}_i^K \bar{u}^K \right) (\Delta lnK_i - \Delta lnK) + \bar{u}^K \left( \sum_i \bar{w}_i^K \Delta lnK_i - \Delta lnK \right)$$

where $\Delta lnK$ represents the growth rate of aggregate capital input when capital input in all sectors grows at the same rate. The upper bars denote the two-period average value shares from period $t-1$ to period $t$. $w_i$ is the proportion of industry $i$'s value added in aggregate value added, $v_i^K$ is the share of capital income in industry $i$'s gross output, $v_i^V$ is the ratio of industry $i$'s value added to gross output, and $u^K$ is the share of aggregate capital income in aggregate value added. $w_i^K$ is defined as $w_i^K = \frac{\sum_k P_k^K K_{k,i}}{\sum_i \sum_k P_k^K K_{k,i}}$.

The value of $\frac{\bar{w}_i}{\bar{v}_i^V} \bar{v}_i^K$ is equal to the ratio of capital income in industry $i$ to the aggregate value added. This coefficient shows the percentage increase in aggregate value added for a 1%

increase in capital input in industry $i$. The value of $\bar{w}_i^K \bar{u}^K$ shows the percentage increase in aggregate value added for a 1% increase in capital input in industry $i$ when the average service price of capital across different types of capital in industry $i$ equals the economy-wide average service price of capital, i.e., $\sum_k P_{k,i}^K K_{k,i} = \sum_k P_k^K K_{k,i}$. Thus, the first term on the right-hand side of Equation (3) denotes the inter-industry reallocation of capital input. If the industry-level growth rate of capital input is larger than the economy-wide average growth rate of capital input, i.e., $\Delta lnK_i > \Delta lnK$, in industries where the industry-level capital service price is higher than the economy-wide average capital service price, i.e., $\sum_k P_{k,i}^K K_{k,i} > \sum_k P_k^K K_{k,i}$, and if the industry-level growth rate of capital input is smaller than the economy-wide average growth rate of capital input, i.e., $\Delta lnK_i < \Delta lnK$, in industries where the industry-level capital service price is lower than the economy-wide average capital service price, i.e., $\sum_k P_{k,i}^K K_{k,i} < \sum_k P_k^K K_{k,i}$, there is a positive inter-industry reallocation of capital input (Fukao et al., 2012).

The second term on the right-hand side of Equation (3) can be approximately rewritten in a discrete-time form as:

$$u^K \sum_i \left\{ \frac{\sum_k P_k^K K_{k,i}}{\sum_i \sum_k P_k^K K_{k,i}} \sum_k \left[ \left( \frac{P_{k,i}^K K_{k,i}}{\sum_k P_{k,i}^K K_{k,i}} - \frac{P_k^K K_{k,i}}{\sum_k P_k^K K_{k,i}} \right) \Delta lnK_{k,i} \right] \right\} \quad (4)$$

Thus, we can interpret this term as the reallocation of changes in the capital composition within each industry. Suppose that the price of type $k$ capital relative to the average value of prices for other types of capital in industry $i$ is lower than the macro-level average relative price of type $k$ capital, an increase of capital input of this type in industry $i$ would improve resource allocation and further raise the macro TFP growth rate (Fukao et al., 2012).

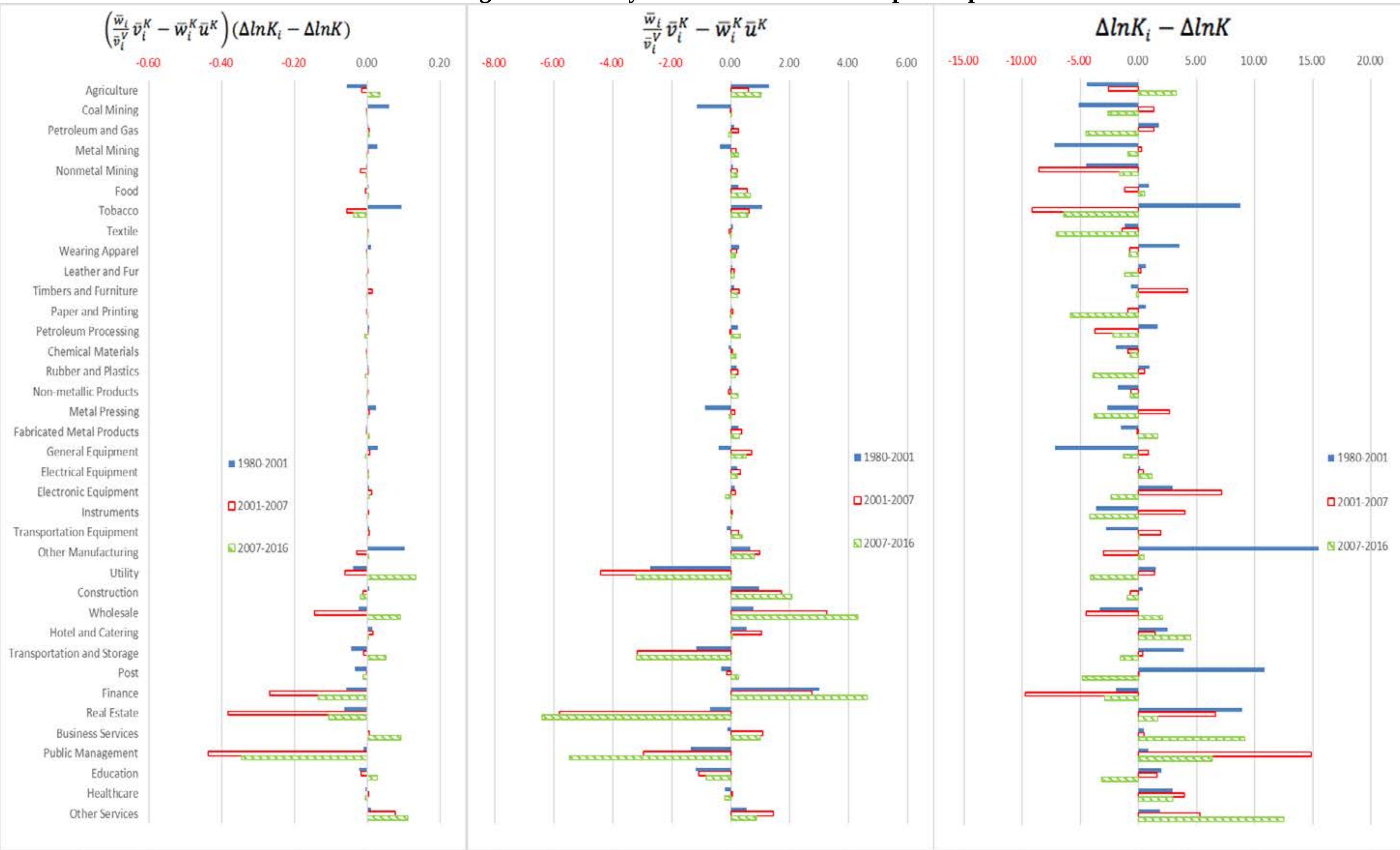
Similarly, the third term on the right-hand side of Equation (8.34) in Jorgenson et al. (2005) can be decomposed into two parts: the inter-industry reallocation of labor input and the reallocation of changes in the labor composition within each industry.

To explore the industry origins of the reallocations of capital and labor inputs, as shown in Equation (3), Figure 3 first shows the industry-level reallocation of capital input, $\left(\frac{\bar{w}_i}{\bar{v}_i^V} \bar{v}_i^K - \bar{w}_i^K \bar{u}^K\right)(\Delta lnK_i - \Delta lnK)$, and the two components of this value, $\left(\frac{\bar{w}_i}{\bar{v}_i^V} \bar{v}_i^K - \bar{w}_i^K \bar{u}^K\right)$ and $(\Delta lnK_i - \Delta lnK)$, for three sub-periods. The growth rates of the capital input of most industries were larger than the national average growth of capital input in 1980-2001 and

2001-2007, while those of many industries decreased in 2007-2016. On the other hand, the service prices of capital input in a majority of industries were higher than the national average capital service price, whereas the capital service prices in Utility, Transportation and Storage, Real Estate, Public Management, and Education were obviously lower than the national average service price. Therefore, industries with high (or low) capital input growth and high (or low) capital service prices, such as Coal Mining, Utility, Business Services, and Other Services, contributed to the improvement of capital allocation. Furthermore, industries with high (or low) capital input growth and low (or high) capital service prices, such as Agriculture, Wholesale, Finance, Real Estate, and Public Management, were responsible for the negative reallocation of capital input. The aggregate capital reallocation also significantly deteriorated in 2001-2007 and partially improved in 2007-2016.

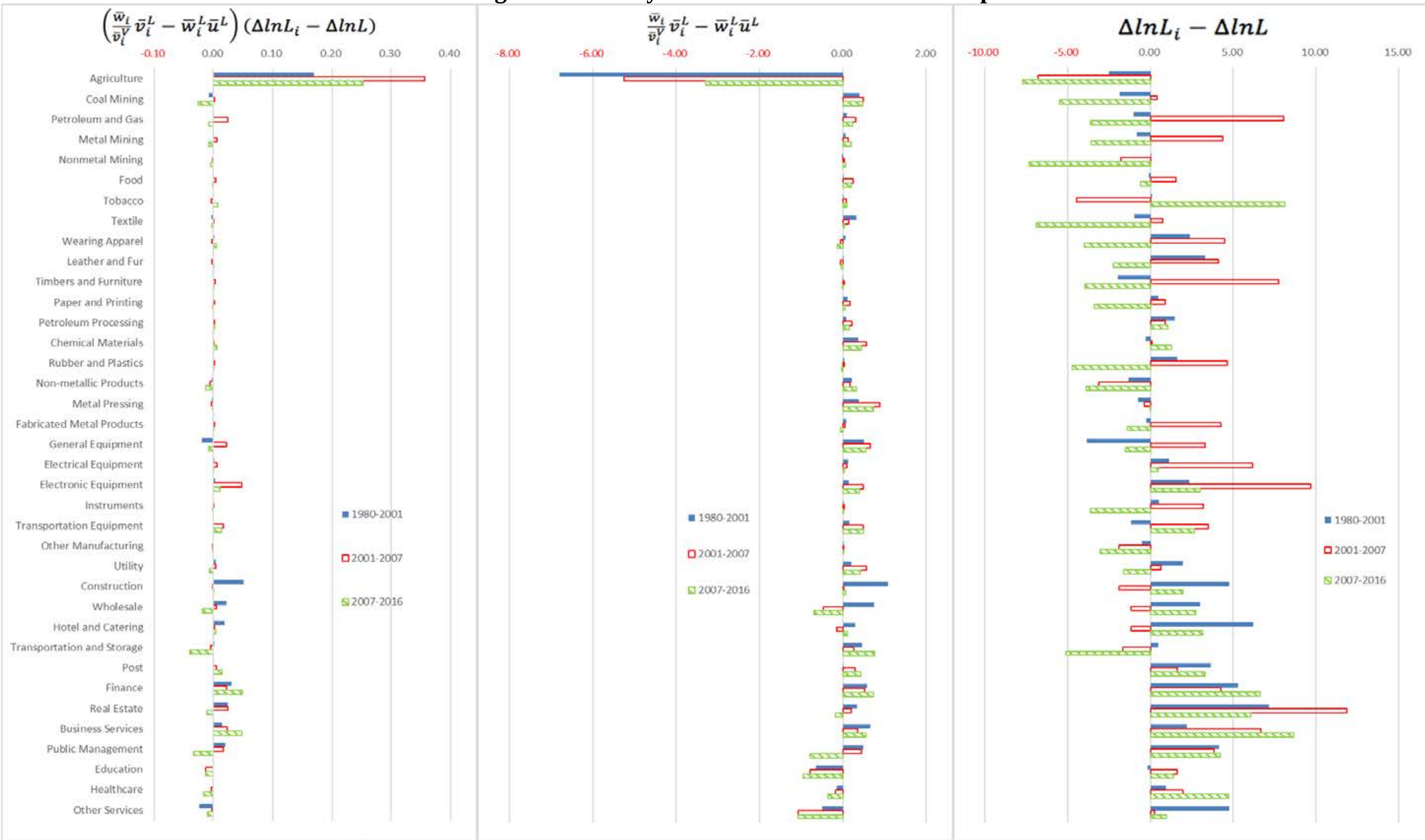
Figure 4 shows the industry-level reallocation of labor input, $\left(\frac{\bar{w}_i}{\bar{v}_i^V}\bar{v}_i^L - \bar{w}_i^L\bar{u}^L\right)(\Delta lnL_i - \Delta lnL)$, and the two components of this value, $\left(\frac{\bar{w}_i}{\bar{v}_i^V}\bar{v}_i^L - \bar{w}_i^L\bar{u}^L\right)$ and $(\Delta lnL_i - \Delta lnL)$, for three sub-periods. In many industries, especially service sectors, the growth rates of labor input were higher than the national average growth of labor input in each sub-period, particularly in 2001-2007. In addition, the service prices of labor input in almost all industries were higher than the national average service price, whereas in Agriculture, Education, Healthcare, and Other Services, they were lower than the national average service price. Therefore, industries with high (or low) labor input growth and high (or low) labor service prices, such as Agriculture, Electronic Equipment, Finance, Real Estate, and Business Services, contributed to the improvement of labor allocation. Furthermore, industries with high (or low) labor input growth and low (or high) labor service prices, such as Coal Mining, Transportation and Storage, Education, Healthcare, and Other Services, were responsible for the negative reallocation of labor input. The aggregate labor reallocation was also improved in 2001-2007 and deteriorated in 2007-2016 compared to it in previous sub-period.

**Figure 3 Industry-level Reallocation of Capital Input**




Source: Author's calculation based on Equation (3).

**Figure 4 Industry-level Reallocation of Labor Input**




Source: Author's calculation.

## 4. CONCLUSIONS

The fact that most current studies adopt capital stock and persons employed as capital input and labor input, respectively, in TFP calculation may affect the reliability of TFP results because inputs' stocks may underestimate the actual quality improvements of factor inputs. The study shows that the economy-wide TFP growth of China is significantly overestimated by replacing both capital and labor services with their stocks. This is mainly because capital quality slightly declines whereas labor quality obviously improves over 1980-2016.

The reallocations of capital and labor remarkably affect TFP growth in China. Capital input is much more vulnerable to governmental interventions, and its allocation is mostly controlled by the government, which may cause misallocation compared to resource allocation that follows the market mechanisms. In contrast, labor mobility may tend to follow the market mechanisms due to the relaxations of regulations on labor market. As a result, the capital reallocation is negative whereas labor reallocation is positive in China over the entire period. The net reallocation of capital and labor largely contributes to the aggregate TFP growth. By further investigating the industry origins of reallocations, we find that industries with high (or low) capital input growth and high (or low) capital service prices contribute to the improvement of capital allocation while industries with high (or low) capital input growth and low (or high) capital service prices are responsible for the negative reallocation of capital input. This is also the case for labor reallocation.

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# Appendix

## Table A1 CIP Industry Classification and Codes

| CIP Code | Industry Description | Short Names |
|---|---|---|
| 1 | Agriculture, Forestry, Animal Husbandry and Fishery | Agriculture |
| 2 | Mining and Washing of Coal | Coal Mining |
| 3 | Extraction of Petroleum and Natural Gas | Petroleum and Gas |
| 4 | Mining of Metal Ores | Metal Mining |
| 5 | Mining of Nonmetallic Ores and Other Ores | Nonmetal Mining |
| 6 | Manufacturing of Foods | Food |
| 7 | Manufacturing of Cigarettes and Tobacco | Tobacco |
| 8 | Manufacturing of Textile | Textile |
| 9 | Manufacturing of Textile Wearing Apparel and Ornament | Wearing Apparel |
| 10 | Manufacturing of Leather, Fur, Feather and Their Products, and Footwear | Leather and Fur |
| 11 | Processing of Timbers, Furniture | Timbers and Furniture |
| 12 | Manufacturing of Paper, Printing | Paper and Printing |
| 13 | Processing of Petroleum, Coking | Petroleum Processing |
| 14 | Manufacturing of Chemical Raw Materials and Chemical Products | Chemical Materials |
| 15 | Manufacturing of Rubber and Plastics Products | Rubber and Plastics |
| 16 | Manufacturing of Non-metallic Mineral Products | Non-metallic Products |
| 17 | Manufacturing and Pressing of Metals | Metal Pressing |
| 18 | Manufacturing of Fabricated Metal Products | Fabricated Metal Products |
| 19 | Manufacturing of General and Special Equipment | General Equipment |
| 20 | Manufacturing of Electrical Machinery and Equipment | Electrical Equipment |
| 21 | Manufacturing of Computers, Communication Equipment and Other Electronic Equipment | Electronic Equipment |
| 22 | Manufacturing of Instrumentation, and Culture, Office Machinery | Instruments |
| 23 | Manufacturing of Transportation Equipment | Transportation Equipment |
| 24 | Other Manufacturing | Other Manufacturing |
| 25 | Production and Distribution of Electricity, Heating Power, Gas and Water | Utility |
| 26 | Construction | Construction |
| 27 | Wholesale and Retail Trades | Wholesale |
| 28 | Hotel and Catering Services | Hotel and Catering |
| 29 | Transportation and Storage | Transportation and Storage |
| 30 | Post and Telecommunication | Post |
| 31 | Finance Intermediation | Finance |
| 32 | Real Estate | Real Estate |
| 33 | Leasing, Technical, Science and Business Services | Business Services |
| 34 | Public Management and Social Organizations | Public Management |
| 35 | Education | Education |
| 36 | Health and Social Welfare Services | Healthcare |
| 37 | Other Services | Other Services |

Source: From CIP database with modification.