Mismeasurement in TFP Growth of Chinese Total Economy due to Hicks' Aggregation and Tariff Effect

ChenYu

06.10.2014

Abstract

After the economic reform in 1978, Chinese international trade has been increasing largely. The ratio of Chinese international trade to Chinese nominal GDP increased from 9.7% in 1978 to 47% in 2012, which signifies the importance of trade in Chinese economy. When it comes to trade, tariff cannot be ignored, for we all know that tariff affects productivity through import prices. The main aim of this paper is to unveil a mismeasurement in TFP due to the inappropriate means of measurement. Mostly, the scholars inclined to use either GDP or revenue method to measure TFP. However, both of these two methods overlooked either tariff or Hicks' aggregation effect. Therefore, this thesis suggests the method of gross output to measure TFP, instead of these two frequently used methods. By comparing these three means of measuring TFP, this paper finds out that TFP has been overestimated in the use of GDP and revenue measurement. In addition, this paper compares TFP growths measured by tariff-included with tariff-excluded cost function, and the result finds out that the real TFP growth is overestimated by the latter measurement.

1 Introduction[1]

After the economic reform iniciated by Deng Xiaoping in 1978 in China, the economic system has progressively become open to private business and foreign market. Chinese trade with foreign countries has been soared up. The trade value increased from 35.5 billion RMB in 1978 to 24416 billion RMB in 2012[2]. According to IMF, China has become the biggest country for trade and export, and the second largest country for import in the whole world. The ratio of Chinese international trade to Chinese nominal GDP increased from 9.7% in 1978 to 47% in 2012, which indicates the significance of trade in Chinese economy. Figure 1 in the appendix demonstrates the details of Chinese international trade in these 35 years. When it comes to trade, tariff cannot be ignored, for we all know that tariff affects productivity through import prices.

In order to improve economic development through international trade, Chinese government reduced many limits of export and import. The decline trend of import tariff rates in most of the import sectors manifested a more loose trade policies. Chinese tariff system changed in the year 1985, 1992, and 2002 respectively, with small changes in the first two times, but with enormous decline of the tariff rates in 2002, because China entered WTO at the end of 2001. An overview of tariff variation can be found in table A1 in the appendix[3].

Productivity is one of the best measures of a country's average standard of living. The productivity of a production unit is defined as the output produced by the unit divides the input used over the same time period. If the input measure is comprehensive, then the productivity concept is called total factor

[1] The author Chen Yu would like to thank especially Prof. Mamuneas TP, who has been supervising him meticulously for the data colletion, model specification, and econometric softwares of the whole thesis.

[2] According to China's Statistical Bureau.

[3] Nov. 10th, 2001 the fourth ministerial conference of the WTO verified and qualified the application of China's accession to WTO. According to the agreement with the WTO, China has to decrease import tariffs in various products for the benefits of all WTO member countries.

productivity (TFP) or multifactor productivity[4]. Living standard can be improved by the raising of national productivity, because the more the workers produce, the more income they receive, and the more they can purchase goods and services, enjoy leisure, improve housing and education, and contribute to social and environmental programs.

Many researchers have discussed how variations of terms of trade, which is the ratio of export price over import price, affect economic indicatiors, especially productivity measurement.The relationship between the change of terms of trade and national welfare was a hot topic. Scholars, such as Lloyd and Schweinberger (1983), Greenlees and Zieschang (1984) and Hamada and Iwata (1984), explain terms of trade adjustment issue either by using the effects on a single consumer or by thinking of a community utility function. Both of the approaches have difficulties in aggregation over consumers.

The work of Diewert WE and Morrison CJ (1986) first takes into account the measurement of the impact of the variation of terms of trade from the producer's side. Instead of researching the relationship between the variation of terms of trade and welfare, the objective function is changed into real output in their work. They find out that TFP increases with the ratio of export over import price. Some followers adopt the thoughts or models from Diewert WE and Morrison CJ's paper (1986) and develop new models. Gregorio JD and Wolf HC (1994) examine the effects of the movement of terms of trade and productivity differentials accoss sectors on the behavior of the real exchange rate. Their study discloses that the improvement of terms of trade leads to a faster productivity growth in the tradable sector than that of non-tradable sector. Kehoe TJ and Ruhl KJ (2007) point out that the effect of terms of trade on real GDP and productivity is ambiguous.

Some empirical works are also written in response to Diewert WE and Morrison CJ's work (1986). Easterly, Kremer, Pritchett, and Summers (1993) use a large panel of countries to discuss the reasons of long-run growth and aggregated volatility. They summarize that terms of trade plays a significant role in

[4] This definition comes from Diewert WE (2012).

explaining output growth. Easterly, Islam, and Stiglitz (2001) investigate the case of developing countries and find out that terms of trade volatility are more correlated with output volatility than money growth, fiscal balance, and capital flows. Additionally, they conclude that shocks of terms of trade may have the same impact as negative technology shocks.

Diewert WE and Morrison CJ's work (1986) has been applied to analyze and to compare that how the changes of terms of trade affect producitivity growth in different countries. Morrison CJ and Diewert WE (1991) compare the data between Japan and the US from 1968 to 1982, and their study shows that the Japanese terms of trade adjustment values tend to be slightly lower than that of the US, however its productivity is far greater than that of the US. Kohli U (2004) points out that when the terms of trade increases, the conventional measurement of real GDP underestimates the growth in real value-added. He uses data from New Zealand over 15 years and provides an underestimation of average 0.4% per year in real GDP. Kohli U (2006) uses data from Hongkong between 1961 and 2003 and demonstrates that the average real growth in Hongkong has been underestimated by 0.4% each year. Feenstra RC, Reinsdorf MB, and Slaughter MJ (2008) argue that part of the growth in productivity in the US since 1995 can be explained by gains in the terms of trade and tariff reductions, especially for the information-technology industries[5].

For the TFP studies on China, the following papers are worthwhile to mention. Jefferson (1990), Dollar (1992), Jefferson and Xu (1994), and Xu and Wang (1999) examine differences of productivity accroding to types of ownership in China. Lin (1992), Jefferson, Rawski and Zheng (1992), (1996), and Wu (2000) concentrate on examining differences of sectoral TFP growth. Demurger (2001), Bao et al. (2002), and Demurger et al. (2002) investigate TFP differences among Chinese regions. Chen (2001) adopts method of the Malmquist indexes of TFP growth, and decompose the TFP growth into efficiency change and technologi-

[5] **See also Mann (2003) and Houseman (2007), they have almost the same conclusions as Robert C. Feenstra, Marshall B. Reinsdorf, and Matthew J. Slaughter (2008)**

cal change effects. He finds positive average TFP growth. Wu (1999) examines the productivity growth in China's reforming economy using stochastic frontier approach. He shows positive productivity growth rate between 1978 and 1998. Hsieh and Klenow (2007) point out that resource misallocation can be a reason for lower TFP in manufacturing. All of the researchers use the data which are based on the level of either nation, sector, or region.

After the economic reform, the TFP in China has experienced a high speed of growth. Perkins DH and Rawski TG (2008) apply official GDP estimate and gain an average of 3.8% Chinese TFP growth rate between 1978 and 2005. The Chinese Statistical Bureau uses the same method, and acquires an average 5.6% TFP growth rate between 2001 and 2010. However, GDP calculated by government does not consider tariff cost, for it is included in the government revenue. In this way, TFP growths evaluated by Perkins DH and Rawski TG (2008) and the Chinese Statistical Bureau are inaccurate, because tariff is ignored. Instead of official GDP, Feenstra RC, Reinsdorf MB, and Slaughter MJ (2008) use revenue estimate to measure TFP, which subtracts tariff revenue from GDP. Diewert WE (1993) points out that substitution of value-added for gross output leads to mismeasurement, which is called Hicks' aggregation effect. Thus, revenue method, avoiding the intervention of tariff, still cannot measure TFP correctly owing to the existence of Hicks' aggregation effect.

As we've analyzed above, there exist limits in both measurements, that is, GDP and revenue. Therefore, this thesis turns to another measurement which is much more correct, because it avoids the influence of tariff effect and Hicks' aggregation effect. This paper posits that TFP growth has been overestimated owning to the absence of tariff and Hicks' aggregation effect. This paper adopts the method of gross output to find out the real TFP, and then compares it to the TFP growth measured by GDP and revenue. In so doing, this paper discloses an overestimation of TFP growth measured by GDP as well as revenue. The overestimation of TFP growth by GDP is 0.38% per annum, and 110.9% in 27 years. This paper also builds TFP growth measured by tariff-included and tariff-excluded cost. TFP growth of tariff-excluded cost overestimates its real value. Technical change effects of GDP and of gross output are generally higher than that of cost. The reasons lie in the means of constructing technical change, and unmeasured returns to scale effect of GDP and gross output.

This paper is organized into five further sections. TFP growth rate will be decomposed into technical change effect and terms of trade effect in section 2 by GDP, revenue, and gross output methods. The differences of TFP growth among these three methods can be explained by tariff effect and Hicks' aggregation effect. In section 3, TFP growth is decomposed into technical change effect and returns to scale effect by cost method. In order to compare the results between section 2 and section 3, cost term is separated as total cost measured with tariff and that without it. The reason for the difference of TFP growth measured by cost is solely lack of tariff term. Section 4 displays data descriptions. Section 5 compares the results from section 2 and 3 and from other relevant research. Finally, section 6 concludes the paper.

2 Evaluation by GDP, Revenue, and Gross Output Functions

2.1 Model Specification

In this section, TFP growth is decomposed into technical change effect and terms of trade effect by GDP, revenue, and gross output methods. Based on the models of Diewert WE and Morrison CJ (1986) and Feenstra RC, Reinsdorf MB, and Slaughter MJ (2008), which treat imports as intermediate inputs into the economy's profit function,[6]TFP growth can be defined as the shift in the economy's

[6] **Though such an uniform treatment for all imports might appear to ignore the significant representation of finished goods, these two papers argue that imports can all be treated as intermediate inputs in the value-added production function because even imports of finished products generally require domestically produced distribution services to reach final consumers. We could apply this result directly into this thesis, because imported finished consumer goods are treated in just the same way as imported intermdiates in the import price indexes, and**

profit function while holding prices and factor endowments fixed. Let there be N final goods of the economy, with quantities $y^t \geq 0$, t denotes the technology which changes over time. Additionally, let there be M exported and imported goods. The output is both consumed in domestic market and exported to the foreign market. Let q^t be output consumed in domestic market, x^t be export, thus $y^t = q^t + x^t$. The weighted average price for the final output y^t is $p^t > 0$. For simplicity we ignore taxes and subsidies on exports. In order to produce output y^t, primary and intermediate inputs are used. Primary factors are constituted by labor input, capital input, energy and material, which can be taken from domestic market. Intermediate inputs are energy and material, which we may obtain from foreign market. $X = (x_L^t, x_K^t, x_M^t, x_{IM}^t)$, denote amount of labor, capital, energy and material purchased in domestic market, and energy and material imported from foreign market respectively. $W = (w_L^t, w_K^t, w_M^t, w_{IM}^t)$ demonstrate prices of labor, capital, energy and material purchased in domestic market, and energy and material imported from foreign market respectively. The tariff-included import prices of intermediate inputs is $w_{IM}^t\left(1+\tau^t\right)$, where τ^t denotes the tariff rate of import. $P^t = (p^t, p^t, p_m^t)$ is the price vector for domestic, export and import prices, and $Y^t = (q^t, x^t, m^t)$ is the quantities of these goods. Let $VX^t = p^t x^t$ be the value of export and $VM_{DF}^t = p_m^t m^t = w_{IM}^t m^t$ the value of duty-free import. $VY^t = p^t y^t$ denotes value of gross output. The value of import counted with tariff is $VM_D^t = w_{IM}^t\left(1+\tau^t\right) m^t = p_m^t\left(1+\tau^t\right) m^t$.

The economy chooses the optimal input and output combinations to maximize the profit. Thus, the revenue function for the whole economy is written as follows:

$$R^t\left(P^t, \tau^t, X^t, t\right) = \max_{y^t \geq 0}\left\{p^t q^t + p^t x^t - p_m^t\left(1+\tau^t\right) m^t | y^t \in S^t\left(X^t\right)\right\} \tag{1}$$

where $S^t\left(X^t\right)$ is a convex technology set that depends on a country's endowment of primary factors X^t. $S^t\left(X^t\right)$ is assumed to be strictly convex, so the

any bias in these indexes have the same impact on the measurement of real GDP growth.

maximization problem is well-behaved. Tariff is included by the measurement of revenue. However, tariff contributes to government's income, for this reason, Chinese Statistical Bureau and Perkins DH and Rawski TG (2008) apply GDP measurement that takes out tariff to express the profit. Thus,

$$GDP^t\left(P^t, \tau^t, X^t, t\right) = p^t q^t + p^t x^t - p^t m^t \tag{2}$$

The difference between GDP and revenue is the tariff revenue:

$$GDP^t = R^t + p_m^t m^t \tau^t \tag{3}$$

To see the effect of tariff changes on the measure of GDP, equation (3) is used to describe the optimality of free trade in a small open economy. According to Feenstra RC, Reinsdorf MB, and Slaughter MJ (2008), if the price index P^t and the primary input index X^t are fixed, GDP is maximized when tariff equalizes zero. In a small open economy, if technology, price index and primary input index are constant between periods, thus $S^{t-1} = S^t$,$P^{t-1} = P^t$, $X^{t-1} = X^t$. The decline of tariff from $\tau_i^{t-1} > 0$ to $\tau_i^t = 0$ will increase the TFP measured without tariff, while the TFP measured with tariff stays unchanged. If technology and primary input stay constant between periods, therefore $S^{t-1} = S^t$, $X^{t-1} = X^t$. If $\tau_i^{t-1} \neq 0$ or $\tau_i^t \neq 0$, then tariff-excluded TFP changes regardless the fact that tariff-included TFP does not change.

The researches of Diewert WE and Morrison CJ (1986) and Feenstra RC, Reinsdorf MB, and Slaughter MJ (2013) use value-added estimates, either with tariff or without tariff. They only regard labor input and capital input as primary inputs, and ignored material and energy inputs, which are produced and demanded by domestic market, from primary inputs. This treatment will lead to mismeasurement of TFP growth because of Hicks' aggregation effect. Their production function is shown here:

$$y^t = f\left(x_K^t, x_L^t, t\right) \tag{4}$$

where x_K and x_L denote primary inputs, capital and labor. So, GDP defined by Feenstra RC, Reinsdorf MB, and Slaughter MJ (2013) can be demonstrated as:

$$\begin{aligned} GDP^t &= p^t q^t + p^t x^t - p^t m^t \\ &= w_K^t x_K^t + w_L^t x_L^t \end{aligned} \tag{5}$$

Our intention is to include these material and energy inputs into primary inputs, and adopt gross output measurement so as to present an accurately estimated TFP growth rate. The production function adopted by Diewert WE (1993) is written as follows:

$$y^t = f\left(x_K^t, x_L^t, x_M^t, t\right) \tag{6}$$

where x_M denotes primary inputs of domestic produced and consumed energy and material. In this way, corrected GDP in this essay can be defined as:

$$GDP_c^t = w_K^t x_K^t + w_L^t x_L^t + w_M^t x_M^t \tag{7}$$

Thus, the gross output VY is expressed as follows:

$$VY^t = w_K^t x_K^t + w_L^t x_L^t + w_M^t x_M^t + p^t m^t \tag{8}$$

2.2 TFP growth rate measured by GDP function

2.2.1 Methodology

According to the studies of the following scholars: Caves DW, Christensen LR and Diewert WE (1982), Diewert WE and Morrion CJ (1986), Kohli UR (1990, 2004, 2005, 2006), Diewert WE (2008), and Feenstra FC, Reinsdorf MB, and Slaughter MJ (2008), TFP growth, assuming that prices and factor endowments stay constant, is defined as the shift in the profit function.

A lot of researchers use nominal GDP as estimate of profit, so the productivity index ignoring terms of trade effect can be written as follows:

$$T^{t-1} = \frac{GDP^{t}\left(P^{t-1}, \tau^{t-1}, X^{t-1}, t-1\right)}{GDP^{t-1}\left(P^{t-1}, \tau^{t-1}, X^{t-1}, t-1\right)} \text{ or } T^{t} = \frac{GDP^{t}\left(P^{t}, \tau^{t}, X^{t}, t\right)}{GDP^{t-1}\left(P^{t}, \tau^{t}, X^{t}, t\right)} \quad (9)$$

Both of TFP index cannot be measured because the numerator of T^{t-1} and the denominator of T^{t} cannot be observed. Therefore, this paper turns to measure the geometric mean of the two terms:

$$TFP1 = \left(T^{t-1}T^{t}\right)^{1/2} \quad (10)$$

The tariff-excluded TFP growth ignoring terms of trade effect is defined as follows:

$$TFPT1 = \left(\frac{GDP^{t}}{GDP^{t-1}}\right) / \left[P_1\left(P^{t-1}, P^{t}, Y^{t-1}, Y^{t}\right) Q_1\left(X^{t-1}, X^{t}, W^{t-1}, W^{t}\right)\right] \quad (11)$$

where the price index can be defined as:

$$\begin{aligned} & \ln P_1\left(P^{t-1}, P^{t}, Y^{t-1}, Y^{t}\right) & (12) \\ = \; & 0.5\left(\frac{p^{t-1}q^{t-1}}{GDP^{t-1}} + \frac{p^{t}q^{t}}{GDP^{t}}\right)\left(\ln p^{t} - \ln p^{t-1}\right) \end{aligned}$$

The primary input quantity index can be expressed as:

$$\ln Q_1\left(X^{t-1}, X^{t}, W^{t-1}, W^{t}\right) = \sum_{i=L,K} 0.5\left(\frac{x_i^{t-1}w_i^{t-1}}{GDP^{t-1}} + \frac{x_i^{t}w_i^{t}}{GDP^{t}}\right)\left(\ln x_i^{t} - \ln x_i^{t-1}\right) \quad (13)$$

The tariff-excluded TFP growth ignoring terms of trade effect can be understood as technical change effect, which can be written as:

$$
\begin{aligned}
t1 &= \left(\ln GDP^{t} - \ln GDP^{t-1}\right) \\
&\quad -0.5\left(\frac{p^{t-1}q^{t-1}}{GDP^{t-1}} + \frac{p^{t}q^{t}}{GDP^{t}}\right)\left(\ln p^{t} - \ln p^{t-1}\right) \\
&\quad -\sum_{i=L,K} 0.5\left(\frac{x_i^{t-1}w_i^{t-1}}{GDP^{t-1}} + \frac{x_i^{t}w_i^{t}}{GDP^{t}}\right)\left(\ln x_i^{t} - \ln x_i^{t-1}\right)
\end{aligned} \tag{14}
$$

The logarithm of tariff-excluded TFP growth that involves terms of trade is calculated as follows:

$$
\begin{aligned}
\ln TFP1 &= \left(\ln GDP^{t} - \ln GDP^{t-1}\right) \\
&\quad -0.5\left(\frac{p^{t-1}q^{t-1}}{GDP^{t-1}} + \frac{p^{t}q^{t}}{GDP^{t}}\right)\left(\ln p^{t} - \ln p^{t-1}\right) \\
&\quad -\sum_{i=L,K} 0.5\left(\frac{x_i^{t-1}w_i^{t-1}}{GDP^{t-1}} + \frac{x_i^{t}w_i^{t}}{GDP^{t}}\right)\left(\ln x_i^{t} - \ln x_i^{t-1}\right) \\
&\quad +0.5\left(\frac{p^{t-1}x^{t-1}}{GDP^{t-1}} + \frac{p^{t}x^{t}}{GDP^{t}}\right)\left(\ln p^{t} - \ln p^{t-1}\right) \\
&\quad -0.5\left(\frac{p_m^{t-1}m^{t-1}}{GDP^{t-1}} + \frac{p_m^{t}m^{t}}{GDP^{t}}\right)\left(\ln p_m^{t} - \ln p_m^{t-1}\right)
\end{aligned} \tag{15}
$$

On the right hand side of equation (15), the first three terms equalizes technical change effect t, the last two terms constructs logarithm of terms of trade, which is defined as ratio of export price divides import price.

Terms of trade effect can be here clearly represented as:

$$
\begin{aligned}
\ln TOT1 &= 0.5\left(\frac{p^{t-1}x^{t-1}}{GDP^{t-1}} + \frac{p^{t}x^{t}}{GDP^{t}}\right)\left(\ln p^{t} - \ln p^{t-1}\right) \\
&\quad -0.5\left(\frac{p_m^{t-1}m^{t-1}}{GDP^{t-1}} + \frac{p_m^{t}m^{t}}{GDP^{t}}\right)\left(\ln p_m^{t} - \ln p_m^{t-1}\right)
\end{aligned} \tag{16}
$$

After rearranging equation (15), we see that the logarithm of tariff-excluded TFP growth can be further decomposed into technical change effect and terms of trade effect:

$$
\ln TFP1 = t1 + \ln TOT1 \tag{17}
$$

2.2.2 Result

Table 1: TFP growth decomposition of GDP

Period	$lnTFP1$	$t1$	$lnTOT1$
1986-2012	0.056016	0.052940	0.0030756
1986-1990	-0.020421	-0.033224	0.012803
1991-1995	0.090261	0.073469	0.016792
1996-2000	0.034641	0.034548	0.000092601
2001-2005	0.053836	0.061116	-0.0072808
2006-2012	0.092058	0.094810	-0.0027523

Table 1 manifests the results of TFP growth rate decomposition of GDP estimate from 1986 to 2012. Apart from showing the results between 1986 and 2012, this table also cus the results into five periods. As we could see from this table, TFP growth increased from -0.020421 in the period of 1986-1990 to 0.092058 in the period of 2006-2012, with an average value of 0.056016. t is an element that expresses technical change effect; t>0 shows technical progress while t<0 exhibits technical regress. In table 1, t1 of period 1986-2012 is 0.052940, which means technical progress for China's economy, with an exception from 1986 to 1990. The reason for this exception is because that China had reformed its economic system from the old unproductive state-owned economy to a new productive mix-owned economy, and the period 1986-1990 was a transit period for the economy because economy needs time to be more productive. The average growth rate of terms of trade is 0.0030756 in period 1986-2012, and this tells us that the ratio of export price over import price kept increasing. The increasing rate fell from 0.012803 in period 1986-1990 to -0.0027523 in period 2006-2012, which implies a restructuring process of the Chinese international trade. TFP growth rate can be decomposed into techincal change effect and terms of trade effect, technical effect is the most important factor for positive productivity growth[7].

[7] See figure 5 in appendix.

2.2.3 Methodology

In order to compare the difference between the tariff-included TFP growth and the TFP growth reported by Chinese Statistical Bureau, this paper bases on the work of Feenstra FC, Reinsdorf MB, and Slaughter MJ (2008) and creates TFP2 to represent the productivity measured with tariff. TFP2 is measured as that the revenue deflating by the tariff-included price index, divides the growth of primary input $Q_2\left(X^{t-1}, X^t, W^{t-1}, W^t\right)$.

Jorgenson and Griliches (1972) discover that while measuring productivity growth, tariffs and similar taxes on intermediate inputs should be counted into input prices. By applying revenue function, tariff is required to be included. The productivity index ignoring terms of trade effect can be written as follows:

$$T^{t-1} = \frac{R^t\left(P^{t-1}, \tau^{t-1}, X^{t-1}, t-1\right)}{R^{t-1}\left(P^{t-1}, \tau^{t-1}, X^{t-1}, t-1\right)} \text{ or } T^t = \frac{R^t\left(P^t, \tau^t, X^t, t\right)}{R^{t-1}\left(P^t, \tau^t, X^t, t\right)} \tag{18}$$

Feenstra FC, Reinsdorf MB, and Slaughter MJ (2008) show that the tariff-inclusive TFP growth ignoring terms of trade effect is:

$$TFPT2 = \left(T^{t-1}T^t\right)^{1/2} = \left(\frac{R^t}{R^{t-1}}\right) / \left[P_2\left(P^{t-1}, P^t, Y^{t-1}, Y^t\right) Q_2\left(X^{t-1}, X^t, W^{t-1}, W^t\right)\right] \tag{19}$$

where the price index is defined as:

$$\begin{aligned} & \ln P_2\left(P^{t-1}, P^t, Y^{t-1}, Y^t\right) \\ = \; & 0.5\left(\frac{p^{t-1}q^{t-1}}{R^{t-1}} + \frac{p^t q^t}{R^t}\right)\left(\ln p^t - \ln p^{t-1}\right) \end{aligned} \tag{20}$$

The quantity index is defined as:

$$\ln Q_2\left(X^{t-1}, X^t, W^{t-1}, W^t\right) = \sum_{i=L,K} 0.5\left(\frac{x_i^{t-1}w_i^{t-1}}{R^{t-1}} + \frac{x_i^t w_i^t}{R^t}\right)\left(\ln x_i^t - \ln x_i^{t-1}\right) \tag{21}$$

The tariff-included TFP growth ignoring terms of trade effect can be explained as technical change effect, thus:

$$\begin{aligned} t2 \quad = \quad & \left(\ln R^{t} - \ln R^{t-1}\right) \\ & -0.5\left(\frac{p^{t-1}q^{t-1}}{R^{t-1}} + \frac{p^{t}q^{t}}{R^{t}}\right)\left(\ln p^{t} - \ln p^{t-1}\right) \\ & -\sum_{i=L,K} 0.5\left(\frac{x_i^{t-1}w_i^{t-1}}{R^{t-1}} + \frac{x_i^{t}w_i^{t}}{R^{t}}\right)\left(\ln x_i^{t} - \ln x_i^{t-1}\right) \end{aligned} \tag{22}$$

According to Diewert WE and Morrion CJ (1986), TFP growth that contains terms of trade effect can be understood as combination of technical change and terms of trade. In this way, TFP growth can be expressed by:

$$\begin{aligned} \ln TFP2 \quad = \quad & \left(\ln R^{t} - \ln R^{t-1}\right) \\ & -0.5\left(\frac{p^{t-1}q^{t-1}}{R^{t-1}} + \frac{p^{t}q^{t}}{R^{t}}\right)\left(\ln p^{t} - \ln p^{t-1}\right) \\ & -\sum_{i=L,K} 0.5\left(\frac{x_i^{t-1}w_i^{t-1}}{R^{t-1}} + \frac{x_i^{t}w_i^{t}}{R^{t}}\right)\left(\ln x_i^{t} - \ln x_i^{t-1}\right) \\ & +0.5\left(\frac{p^{t-1}x^{t-1}}{R^{t-1}} + \frac{p^{t}x^{t}}{R^{t}}\right)\left(\ln p^{t} - \ln p^{t-1}\right) \\ & -0.5\left(\frac{p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)}{R^{t-1}} + \frac{p_m^{t}m^{t}\left(1+\tau^{t}\right)}{R^{t}}\right) \\ & *\left(\ln\left[p_m^{t}\left(1+\tau^{t}\right)\right] - \ln\left[p_m^{t-1}\left(1+\tau^{t-1}\right)\right]\right) \end{aligned} \tag{23}$$

where logarithm of terms of trade effect is:

$$\begin{aligned} \ln TOT2 \quad = \quad & 0.5\left(\frac{p^{t-1}x^{t-1}}{R^{t-1}} + \frac{p^{t}x^{t}}{R^{t}}\right)\left(\ln p^{t} - \ln p^{t-1}\right) \\ & -0.5\left(\frac{p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)}{R^{t-1}} + \frac{p_m^{t}m^{t}\left(1+\tau^{t}\right)}{R^{t}}\right) \\ & *\left(\ln\left[p_m^{t}\left(1+\tau^{t}\right)\right] - \ln\left[p_m^{t-1}\left(1+\tau^{t-1}\right)\right]\right) \end{aligned} \tag{24}$$

After rearranging equation (23), we see that the logarithm of tariff-included TFP growth can be further decomposed into technical change effect and terms of trade effect[8]:

$$\ln TFP2 = t2 + \ln TOT2 \tag{25}$$

2.2.4 Result

Table 2: TFP growth decomposition of revenue

Period	$lnTFP2$	$t2$	$lnTOT2$
1986-2012	0.057084	0.052635	0.0044492
1986-1990	-0.022168	-0.035123	0.012954
1991-1995	0.092852	0.073356	0.019496
1996-2000	0.039360	0.035052	0.0043077
2001-2005	0.055406	0.060893	-0.0054868
2006-2012	0.090682	0.094643	-0.0039605

Table 2 expresses results of TFP growth rate decomposition of revenue estimate that includes tariff effect which is ignored by GDP estimate. According to this table, TFP growth increased from -0.022168 in the period 1986-1990 to 0.090682 in the period 2006-2012, with an average value of 0.057084. In table 2, t2 of period 1986-2012 is 0.052635, which shows technical progress except the period 1986-1990. The average growth rate of terms of trade is 0.0044492, which manifests a increasing trend of terms of trade. Technical change effect is the main driver of positive growth of TFP in China[9].

2.2.5 Methodology

Constructing TFP growth by revenue solves the problem of missing tariff term in GDP estimate. However, according to Khang (1971) and Diewert WE (1993), the substitution of real value-added for gross output is not justified except that prices for outputs and intermediate inputs vary in strict proportion, which generally cannot exist in the real world. So, to construct TFP in use of revenue

[8] Diewert WE and Morrison CJ (1986) give derivation of this result.
[9] See figure 6 in appendix.

and GDP instead of value of gross output creates one effect, called Hicks' aggregation effect. Hicks' aggregation effect originates from Hicks' aggregation theorem, which was proved by Hicks (1946), Wold (1953), and Gorman (1953), and was developed in context with production theory by Diewert (1993). Hicks' theorem states that substitution of value-added for gross output leads to mismeasurement. In this paper, we call mismeasurement, which is caused by not using gross output, Hicks' aggregation effect.

To search how Hicks' effect affects TFP measurement, a new productivity growth index measured by gross output is established:

The tariff-included TFP growth ignoring terms of trade effect is:

$$TFPT3 = \left(T^{t-1}T^{t}\right)^{1/2} = \left(\frac{VY^{t}}{VY^{t-1}}\right) / \left[P_3\left(P^{t-1}, P^{t}, Y^{t-1}, Y^{t}\right) Q_3\left(X^{t-1}, X^{t}, W^{t-1}, W^{t}\right)\right] \tag{26}$$

where the price index is defined as:

$$\begin{aligned} & \ln P_3\left(P^{t-1}, P^{t}, Y^{t-1}, Y^{t}\right) \\ = \; & 0.5\left(\frac{p^{t-1}q^{t-1}}{VY^{t-1}} + \frac{p^{t}q^{t}}{VY^{t}}\right)\left(\ln p^{t} - \ln p^{t-1}\right) \end{aligned} \tag{27}$$

The quantity index is defined as:

$$\ln Q_3\left(X^{t-1}, X^{t}, W^{t-1}, W^{t}\right) = \sum_{i=L,K,M,IM} 0.5\left(\frac{x_i^{t-1}w_i^{t-1}}{VY^{t-1}} + \frac{x_i^{t}w_i^{t}}{VY^{t}}\right)\left(\ln x_i^{t} - \ln x_i^{t-1}\right) \tag{28}$$

TFP growth ignoring terms of trade can be interpreted as technical change effect, thus:

$$\begin{aligned} t3 \; = \; & \left(\ln VY^{t} - \ln VY^{t-1}\right) \\ & -0.5\left(\frac{p^{t-1}q^{t-1}}{VY^{t-1}} + \frac{p^{t}q^{t}}{VY^{t}}\right)\left(\ln p^{t} - \ln p^{t-1}\right) \\ & - \sum_{i=L,K,M,IM} 0.5\left(\frac{x_i^{t-1}w_i^{t-1}}{VY^{t-1}} + \frac{x_i^{t}w_i^{t}}{VY^{t}}\right)\left(\ln x_i^{t} - \ln x_i^{t-1}\right) \end{aligned} \tag{29}$$

According to Diewert WE and Morrion CJ (1986), TFP growth that includes terms of trade can be understood as a sum of technical change and terms of trade. In this way, TFP growth can be expressed by:

$$
\begin{aligned}
\ln TFP3 \quad = \quad & \left(\ln VY^{t} - \ln VY^{t-1}\right) \\
& -0.5\left(\frac{p^{t-1}q^{t-1}}{VY^{t-1}} + \frac{p^{t}q^{t}}{VY^{t}}\right)\left(\ln p^{t} - \ln p^{t-1}\right) \\
& - \sum_{i=L,K,M,IM} 0.5\left(\frac{x_i^{t-1}w_i^{t-1}}{VY^{t-1}} + \frac{x_i^{t}w_i^{t}}{VY^{t}}\right)\left(\ln x_i^{t} - \ln x_i^{t-1}\right) \\
& +0.5\left(\frac{p^{t-1}x^{t-1}}{VY^{t-1}} + \frac{p^{t}x^{t}}{VY^{t}}\right)\left(\ln p^{t} - \ln p^{t-1}\right) \\
& -0.5\left(\frac{p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)}{VY^{t-1}} + \frac{p_m^{t}m^{t}\left(1+\tau^{t}\right)}{VY^{t}}\right) \\
& * \left(\ln\left[p_m^{t}m^{t}\left(1+\tau^{t}\right)\right] - \ln\left[p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)\right]\right)
\end{aligned} \tag{30}
$$

where logarithm of terms of trade effect is:

$$
\begin{aligned}
\ln TOT3 \quad = \quad & 0.5\left(\frac{p^{t-1}x^{t-1}}{VY^{t-1}} + \frac{p^{t}x^{t}}{VY^{t}}\right)\left(\ln p^{t} - \ln p^{t-1}\right) \\
& -0.5\left(\frac{p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)}{VY^{t-1}} + \frac{p_m^{t}m^{t}\left(1+\tau^{t}\right)}{VY^{t}}\right) \\
& * \left(\ln\left[p_m^{t}m^{t}\left(1+\tau^{t}\right)\right] - \ln\left[p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)\right]\right)
\end{aligned} \tag{31}
$$

After rearranging equation (30), we see that the logarithm of tariff-included TFP growth can be further decomposed into technical change effect and terms of trade effect[10]:

$$\ln TFP3 = t3 + \ln TOT3 \tag{32}$$

2.2.6 Result

Table 3: TFP growth decomposition of gross output

[10] Diewert WE and Morrison CJ (1986) give derivation of this result.

Period	$lnTFP3$	$t3$	$lnTOT3$
1986-2012	0.052175	0.048243	0.0039321
1986-1990	-0.016285	-0.027453	0.011169
1991-1995	0.082547	0.066221	0.016325
1996-2000	0.033098	0.029434	0.0036639
2001-2005	0.052656	0.056830	-0.0041732
2006-2012	0.082883	0.085957	-0.0030743

Distinguished from GDP and revenue estimates, TFP growth, in this part, is constructed by gross output function. Table 3 shows the results of TFP decompostion in use of value of gross output. TFP growth increased from -0.016285 in the period 1986-1990 to 0.082883 in the period 2006-2012, with an average value of 0.052175. In table 3, technical progress can be concluded, for t3 of period 1986-2012 equalizes 0.048243. The average growth rate of terms of trade is 0.0039321, which reveals a small increasing trend of terms of trade. Technical change effect is the reason for the growth of TFP in China[11].

2.3 The Difference

This section tries to find differences between TFP growth rates measured in the previous subsections.

2.3.1 The Difference between GDP and revenue methods

Based on equation (3) that, GDP can be rewritten as follows:

$$\begin{aligned} GDP^t &= R^t + p_m^t m^t \tau^t \\ &= R^t \frac{(R^t + p_m^t m^t \tau^t)}{R^t} \\ &= \alpha^t R^t \end{aligned} \tag{33}$$

where

[11] See figure 7 in appendix.

$$\alpha^t = \frac{(R^t + p_m^t m^t \tau^t)}{R^t} \tag{34}$$

The difference between TFP growth measured without tariff rate and that with it is computed as follows:

$$
\begin{aligned}
& \ln TFP1 - \ln TFP2 \qquad (35) \\
= & \left(\ln\alpha^t - \ln\alpha^{t-1}\right) \\
& +0.5\left[\left(\frac{p^{t-1}q^{t-1}}{R^{t-1}} + \frac{p^t q^t}{R^t}\right) - \left(\frac{p^{t-1}q^{t-1}}{R^{t-1}}\frac{1}{\alpha^{t-1}} + \frac{p^t q^t}{R^t}\frac{1}{\alpha^t}\right)\right] \\
& *\left(\ln p^t - \ln p^{t-1}\right) \\
& +0.5\left[\left(\frac{p^{t-1}x^{t-1}}{R^{t-1}}\frac{1}{\alpha^{t-1}} + \frac{p^t x^t}{R^t}\frac{1}{\alpha^t}\right) - \left(\frac{p^{t-1}x^{t-1}}{R^{t-1}} + \frac{p^t x^t}{R^t}\right)\right] \\
& *\left(\ln p^t - \ln p^{t-1}\right) \\
& +0.5\left[\begin{array}{c} \left(\frac{p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)}{R^{t-1}} + \frac{p_m^t m^t\left(1+\tau^t\right)}{R^t}\right) \\ -\left(\frac{p_m^{t-1}m^{t-1}}{R^{t-1}}\frac{1}{\alpha^{t-1}} + \frac{p_m^t m^t}{R^t}\frac{1}{\alpha^t}\right) \end{array}\right]\left(\ln p_m^t - \ln p_m^{t-1}\right) \\
& +0.5\left(\frac{p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)}{R^{t-1}} + \frac{p_m^t m^t\left(1+\tau^t\right)}{R^t}\right) \\
& *\left[\ln\left(1+\tau^t\right) - \ln\left(1+\tau^{t-1}\right)\right] \\
& +\sum_{i=L,K} 0.5\left[\begin{array}{c} \left(\frac{w_i^{t-1}x_i^{t-1}}{R^{t-1}} + \frac{w_i^t x_i^t}{R^t}\right) \\ -\left(\frac{w_i^{t-1}x_i^{t-1}}{R^{t-1}}\frac{1}{\alpha^{t-1}} + \frac{w_i^t x_i^t}{R^t}\frac{1}{\alpha^t}\right) \end{array}\right]\left(\ln x_i^t - \ln x_i^{t-1}\right)
\end{aligned}
$$

Different from the work of Feenstra FC, Reinsdorf MB, and Slaughter MJ (2008) in which they decompose TFP growth into technical change effect and terms of trade effect, and find the difference between TFP growth measured with and without tariff, but their paper stopped there without giving a clear reason. This paper extends to a further decomposition of the difference between TFP measured by GDP and by revenue into Hicks' aggregation effect and tariff effect.

The difference between technical change effect measured by GDP and that measured by revenue can be shown here:

$$
\begin{aligned}
& t1 - t2 \qquad (36) \\
= \; & \left(\ln \alpha^t - \ln \alpha^{t-1}\right) \\
& +0.5 \left[\begin{array}{c} \left(\frac{p^{t-1}q^{t-1}}{R^{t-1}} + \frac{p^t q^t}{R^t}\right) \\ -\left(\frac{p^{t-1}q^{t-1}}{R^{t-1}}\frac{1}{\alpha^{t-1}} + \frac{p^t q^t}{R^t}\frac{1}{\alpha^t}\right) \end{array} \right] \left(\ln p^t - \ln p^{t-1}\right) \\
& +\sum_{i=L,K} 0.5 \left[\begin{array}{c} \left(\frac{x_i^{t-1}w_i^{t-1}}{R^{t-1}} + \frac{x_i^t w_i^t}{R^t}\right) \\ -\left(\frac{x_i^{t-1}w_i^{t-1}}{R^{t-1}}\frac{1}{\alpha^{t-1}} + \frac{x_i^t w_i^t}{R^t}\frac{1}{\alpha^t}\right) \end{array} \right] \left(\ln x_i^t - \ln x_i^{t-1}\right)
\end{aligned}
$$

The difference of technical change can be understood as Hicks' aggregation effect.

We can get the difference between terms of trade effect measured by GDP and that measured by revenue in use of following expression:

$$
\begin{aligned}
& \ln TOT1 - \ln TOT2 \qquad (37) \\
= \; & 0.5 \left[\begin{array}{c} \left(\frac{p^{t-1}x^{t-1}}{R^{t-1}}\frac{1}{\alpha^{t-1}} + \frac{p^t x^t}{R^t}\frac{1}{\alpha^t}\right) \\ -\left(\frac{p^{t-1}x^{t-1}}{R^{t-1}} + \frac{p^t x^t}{R^t}\right) \end{array} \right] \left(\ln p^t - \ln p^{t-1}\right) \\
& -0.5 \left[\begin{array}{c} \left(\frac{p_m^{t-1}m^{t-1}}{R^{t-1}}\frac{1}{\alpha^{t-1}} + \frac{p_m^t m^t}{R^t}\frac{1}{\alpha^t}\right) \\ -\left(\frac{p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)}{R^{t-1}} + \frac{p_m^t m^t\left(1+\tau^t\right)}{R^t}\right) \end{array} \right] \\
& * \left(\ln p^t - \ln p^{t-1}\right) \\
& +0.5 \left(\frac{p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)}{R^{t-1}} + \frac{p_m^t m^t\left(1+\tau^t\right)}{R^t}\right) \\
& * \left[\ln\left(1+\tau^t\right) - \ln\left(1+\tau^{t-1}\right)\right]
\end{aligned}
$$

The first two terms of the right hand side of equation (37) can be explained as Hicks' aggregation effect, while the last term of the right hand side shows the tariff change effect. So, the difference of tariff-excluded and tariff-included TFP growth should not be understood solely as tariff effect, but a combination of tariff effect and Hicks' aggregation effect.

2.3.2 Result

Table 4: Difference between GDP and revenue methods

Period	$\ln TFP1 - \ln TFP2$	$t1 - t2$	$\ln TOT1 - \ln TOT2$
1986-2012	-0.0010688	0.00030475	-0.0013736
1986-1990	0.0017473	0.0018986	-0.00015126
1991-1995	-0.0025909	0.00011317	-0.0027040
1996-2000	-0.0047193	-0.00050423	-0.0042151
2001-2005	-0.0015707	0.00022323	-0.0017939
2006-2012	0.0013751	0.00016691	0.0012082

Period	Hicks for t	Hicks for TOT	Hicks total	Tariff
1986-2012	0.00030475	0.0012036	0,00150835	-0.0025772
1986-1990	0.0018986	-0.00015126	0,00174734	0.00000
1991-1995	0.00011317	0.0022536	0,00236677	-0.0049576
1996-2000	-0.00050423	0.00080737	0,00030314	-0.0050225
2001-2005	0.00022323	0.0015475	0,00177073	-0.0033415
2006-2012	0.00016691	0.0012652	0,00143211	-0.000057006

The above table presents the results of TFP decompositions based on GDP and revenue functions. Both GDP measured TFP and revenue measured TFP can be decomposed into technical change effect and terms of trade effect. However, TFP growths estimated by these two methods are unequal because of the existence of Hicks' aggregation effect and tariff effect. On one hand, technical change effect in GDP differs from that in revenue, and this difference proves the existence of Hicks' effect; on the other hand, there is a difference between terms of trade effect in GDP and that in revenue, which is the equivalence of Hicks' aggregation effect and tariff effect. The difference between lnTFP1 and lnTFP2 as well as that of terms of trade effect reveal a declining trend between 1986 and 2012, the difference between t1 and t2 shows a tiny increase trend. Difference of productivity growth decreased from 0.0017473 in period 1986-1990 to 0.0013751 in period 2006-2012, with an average rate -0.0010688. Difference of technical change fell from 0.0018986 to 0.00016691, with an average value of 0.00030475, and difference of terms of trade rose from -0.00015126 to 0.0012082, with an average value of -0.0013736, within the same time period. The fundamental cause of the differences in TFP growth is the distinct terms of trade effects. The difference between TFP1 and TFP2 is further decomposed into Hicks' aggregation effect and tariff effect here in this section. The difference of technical change is fully because of Hicks' aggregation effect, while the difference of terms of trade depends on both Hicks' aggregation effect and tariff effect. The absolute value of total tariff effect is average 0.0025772 during the 27 years period, which is almost one time more than the positive Hicks' aggregation effect, 0,00150835 and contributes to the negative variation of TFP growth. The negative tariff effect indicates that higher tariff growth rates lead to higher growth rates of terms of trade, thus leads to a lower mismeasurement of TFP growth[12].

2.3.3 The Difference between revenue and gross output methods

Value of gross output can be expressed as the following:

$$\begin{aligned} VY^t &= R^t + w_M^t x_M^t + p_m^t m^t \left(1+\tau^t\right) \\ &= R^t \frac{\left(R^t + w_M^t x_M^t + p_m^t m^t \left(1+\tau^t\right)\right)}{R^t} \\ &= \gamma^t R^t \end{aligned} \tag{38}$$

where

$$\gamma^t = \frac{\left(R^t + w_M^t x_M^t + p_m^t m^t \left(1+\tau^t\right)\right)}{R^t} \tag{39}$$

The difference between TFP growth measured by gross output and that by revenue is computed as follows:

[12] See figure 4 and figure 11 in the appendix.

$$
\begin{aligned}
& \ln TFP3 - \ln TFP2 \qquad (40) \\
= \; & \left(\ln \gamma^{t} - \ln \gamma^{t-1}\right) \\
& +0.5\left[\left(\frac{p^{t-1}q^{t-1}}{R^{t-1}} + \frac{p^{t}q^{t}}{R^{t}}\right) - \left(\frac{p^{t-1}q^{t-1}}{R^{t-1}}\frac{1}{\gamma^{t-1}} + \frac{p^{t}q^{t}}{R^{t}}\frac{1}{\gamma^{t}}\right)\right] \\
& * \left(\ln p^{t} - \ln p^{t-1}\right) \\
& +0.5\left[\left(\frac{p^{t-1}x^{t-1}}{R^{t-1}}\frac{1}{\gamma^{t-1}} + \frac{p^{t}x^{t}}{R^{t}}\frac{1}{\gamma^{t}}\right) - \left(\frac{p^{t-1}x^{t-1}}{R^{t-1}} + \frac{p^{t}x^{t}}{R^{t}}\right)\right] \\
& * \left(\ln p^{t} - \ln p^{t-1}\right) \\
& +0.5\left[\begin{array}{c} \left(\frac{p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)}{R^{t-1}} + \frac{p_m^{t}m^{t}\left(1+\tau^{t}\right)}{R^{t}}\right) \\ -\left(\frac{p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)}{R^{t-1}}\frac{1}{\gamma^{t-1}} + \frac{p_m^{t}m^{t}\left(1+\tau^{t}\right)}{R^{t}}\frac{1}{\gamma^{t}}\right) \end{array}\right] \\
& * \left(\ln\left[p_m^{t}\left(1+\tau^{t}\right)\right] - \ln\left[p_m^{t-1}\left(1+\tau^{t-1}\right)\right]\right) \\
& +\sum_{i=L,K} 0.5\left[\begin{array}{c} \left(\frac{w_i^{t-1}x_i^{t-1}}{R^{t-1}} + \frac{w_i^{t}x_i^{t}}{R^{t}}\right) \\ -\left(\frac{w_i^{t-1}x_i^{t-1}}{R^{t-1}}\frac{1}{\gamma^{t-1}} + \frac{w_i^{t}x_i^{t}}{R^{t}}\frac{1}{\gamma^{t}}\right) \end{array}\right]\left(\ln x_i^{t} - \ln x_i^{t-1}\right) \\
& -\sum_{j=M,IM} 0.5\left[\left(\frac{w_j^{t-1}x_j^{t-1}}{R^{t-1}}\frac{1}{\gamma^{t-1}} + \frac{w_j^{t}x_j^{t}}{R^{t}}\frac{1}{\gamma^{t}}\right)\right]\left(\ln x_j^{t} - \ln x_j^{t-1}\right)
\end{aligned}
$$

The difference between TFP3 and TFP2 can be decomposed into the difference between technical change effect of TFP3 and that of TFP2, and the difference between of terms of trade effect of TFP3 and that of TFP2.

The difference between technical change effect measured by gross output and that measured by revenue can be shown here:

$$
\begin{aligned}
& t3 - t2 \qquad (41)\\
= \; & \left(\ln\gamma^t - \ln\gamma^{t-1}\right)\\
& +0.5\left[\begin{array}{c}\left(\frac{p^{t-1}q^{t-1}}{R^{t-1}}+\frac{p^tq^t}{R^t}\right)\\ -\left(\frac{p^{t-1}q^{t-1}}{R^{t-1}}\frac{1}{\gamma^{t-1}}+\frac{p^tq^t}{R^t}\frac{1}{\gamma^t}\right)\end{array}\right]\left(\ln p^t - \ln p^{t-1}\right)\\
& +\sum_{i=L,K}0.5\left[\begin{array}{c}\left(\frac{w_i^{t-1}x_i^{t-1}}{R^{t-1}}+\frac{w_i^tx_i^t}{R^t}\right)\\ -\left(\frac{w_i^{t-1}x_i^{t-1}}{R^{t-1}}\frac{1}{\gamma^{t-1}}+\frac{w_i^tx_i^t}{R^t}\frac{1}{\gamma^t}\right)\end{array}\right]\left(\ln x_i^t - \ln x_i^{t-1}\right)\\
& -\sum_{j=M,IM}0.5\left[\left(\frac{w_j^{t-1}x_j^{t-1}}{R^{t-1}}\frac{1}{\gamma^{t-1}}+\frac{w_j^tx_j^t}{R^t}\frac{1}{\gamma^t}\right)\right]\left(\ln x_j^t - \ln x_j^{t-1}\right)
\end{aligned}
$$

The difference of technical change can be understood as Hicks' aggregation effect.

We can get the difference between terms of trade effect measured by gross output and that measured by revenue in use of following expression:

$$
\begin{aligned}
& \ln TOT3 - \ln TOT2 \qquad (42)\\
= \; & 0.5\left[\begin{array}{c}\left(\frac{p^{t-1}x^{t-1}}{R^{t-1}}\frac{1}{\gamma^{t-1}}+\frac{p^tx^t}{R^t}\frac{1}{\gamma^t}\right)\\ -\left(\frac{p^{t-1}x^{t-1}}{R^{t-1}}+\frac{p^tx^t}{R^t}\right)\end{array}\right]\left(\ln p^t - \ln p^{t-1}\right)\\
& -0.5\left[\begin{array}{c}\left(\frac{p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)}{R^{t-1}}\frac{1}{\gamma^{t-1}}+\frac{p_m^tm^t\left(1+\tau^t\right)}{R^t}\frac{1}{\gamma^t}\right)\\ -\left(\frac{p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)}{R^{t-1}}+\frac{p_m^tm^t\left(1+\tau^t\right)}{R^t}\right)\end{array}\right]\\
& *\left(\ln\left[p_m^t\left(1+\tau^t\right)\right] - \ln\left[p_m^{t-1}\left(1+\tau^{t-1}\right)\right]\right)
\end{aligned}
$$

The difference of terms of trade can also be interpreted as Hicks' aggregation effect.

2.3.4 Result

Table 5: Difference between revenue and gross output methods

Period	$\ln TFP2 - \ln TFP3$	$t2 - t3$	$\ln TOT2 - \ln TOT3$
1986-2012	0.0049095	0.0043924	0.00051703
1986-1990	-0.0058837	-0.0076692	0.0017854
1991-1995	0.010305	0.0071341	0.0031708
1996-2000	0.0062623	0.0056185	0.00064378
2001-2005	0.0027499	0.0040635	-0.0013136
2006-2012	0.0077994	0.0086856	-0.00088625

Period	Hicks for t	Hicks for TOT	Hicks total	Tariff
1986-2012	0.0043924	0.00051703	0.00490943	0
1986-1990	-0.0076692	0.0017854	-0.0058838	0
1991-1995	0.0071341	0.0031708	0.0103049	0
1996-2000	0.0056185	0.00064378	0.00626228	0
2001-2005	0.0040635	-0.0013136	0.0027499	0
2006-2012	0.0086856	-0.00088625	0.00779935	0

This part compares the results of TFP decompositions that based on revenue and gross output functions. TFP growth measured by revenue and gross output can be decomposed into technical change effect and terms of trade effect. Both technical change effect and terms of trade effect of revenue differ from those of gross output because of the Hicks' aggregation effect, since both TFP2 and TFP3 contain tariff term. The difference between TFP2 and TFP3 increased from -0.0058837 in period 1986-1990 to 0.0077994 in period 2006-2012, with an average rate of 0.0049095, difference between technical changes rose from -0.0076692 to 0.0086856, with an average value of 0.0043924, and difference between terms of trade effects shrinked from 0.0017854 to -0.00088625, with an average value of 0.00051703, in the same time space. The most important reason for the difference in TFP growth lies in different technical effects. As we could read from the table, there is no tariff effect. Thus, the difference between technical change of TFP2 and that of TFP3 and the difference between terms of trade of TFP2 and that of TFP3 should be the result of Hicks' aggregation effect[13]. The mismeasurement of TFP growth can be decomposed into Hicks' aggregation effect and tariff effect, and these two effects amount to 0.49095% per year. Suppose that the TFP level is 100 in 1986, the mismeasurement of 0.49095% implies that TFP level becomes 114 in 2012.

2.3.5 The Difference between GDP and gross output methods

The difference between TFP growth measured by gross output and that by GDP can be computed as follows:

$$
\begin{aligned}
& \ln TFP3 - \ln TFP1 \qquad (43) \\
= \; & \left(\ln \gamma^t - \ln \gamma^{t-1}\right) - \left(\ln \alpha^t - \ln \alpha^{t-1}\right) \\
& +0.5 \left[\begin{array}{c} \left(\frac{p^{t-1}q^{t-1}}{R^{t-1}} \frac{1}{\alpha^{t-1}} + \frac{p^t q^t}{R^t} \frac{1}{\alpha^t}\right) \\ -\left(\frac{p^{t-1}q^{t-1}}{R^{t-1}} \frac{1}{\gamma^{t-1}} + \frac{p^t q^t}{R^t} \frac{1}{\gamma^t}\right) \end{array} \right] \\
& * \left(\ln p^t - \ln p^{t-1}\right) \\
& +0.5 \left[\begin{array}{c} \left(\frac{p^{t-1}x^{t-1}}{R^{t-1}} \frac{1}{\gamma^{t-1}} + \frac{p^t x^t}{R^t} \frac{1}{\gamma^t}\right) \\ -\left(\frac{p^{t-1}x^{t-1}}{R^{t-1}} \frac{1}{\alpha^{t-1}} + \frac{p^t x^t}{R^t} \frac{1}{\alpha^t}\right) \end{array} \right] \\
& * \left(\ln p^t - \ln p^{t-1}\right) \\
& +0.5 \left[\begin{array}{c} \left(\frac{p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)}{R^{t-1}} \frac{1}{\alpha^{t-1}} + \frac{p_m^t m^t \left(1+\tau^t\right)}{R^t} \frac{1}{\alpha^t}\right) \\ -\left(\frac{p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)}{R^{t-1}} \frac{1}{\gamma^{t-1}} + \frac{p_m^t m^t \left(1+\tau^t\right)}{R^t} \frac{1}{\gamma^t}\right) \end{array} \right] \\
& * \left(\ln p_m^t - \ln p_m^{t-1}\right) \\
& -0.5 \left(\frac{p_m^{t-1}m^{t-1}\left(1+\tau^{t-1}\right)}{R^{t-1}} \frac{1}{\gamma^{t-1}} + \frac{p_m^t m^t \left(1+\tau^t\right)}{R^t} \frac{1}{\gamma^t}\right) \\
& * \left(\ln\left(1+\tau^t\right) - \ln\left(1+\tau^{t-1}\right)\right) \\
& +\sum_{i=L,K} 0.5 \left[\begin{array}{c} \left(\frac{w_i^{t-1}x_i^{t-1}}{R^{t-1}} \frac{1}{\alpha^{t-1}} + \frac{w_i^t x_i^t}{R^t} \frac{1}{\alpha^t}\right) \\ -\left(\frac{w_i^{t-1}x_i^{t-1}}{R^{t-1}} \frac{1}{\gamma^{t-1}} + \frac{w_i^t x_i^t}{R^t} \frac{1}{\gamma^t}\right) \end{array} \right] \left(\ln x_i^t - \ln x_i^{t-1}\right) \\
& -\sum_{i=M,IM} 0.5 \left[\left(\frac{w_i^{t-1}x_i^{t-1}}{R^{t-1}} \frac{1}{\gamma^{t-1}} + \frac{w_i^t x_i^t}{R^t} \frac{1}{\gamma^t}\right)\right] \left(\ln x_i^t - \ln x_i^{t-1}\right)
\end{aligned}
$$

[13] See figure 4 and figure 12 in the appendix.

The difference of these two TFP growths attributes to Hicks' aggregation effect and tariff effect. The difference between technical change effect measured by gross output and that measured by GDP can be shown here:

$$
\begin{aligned}
& t3 - t1 \qquad (44) \\
= \; & \left(\ln \gamma^t - \ln \gamma^{t-1}\right) - \left(\ln \alpha^t - \ln \alpha^{t-1}\right) \\
& +0.5 \left[\begin{array}{c} \left(\frac{p^{t-1}q^{t-1}}{R^{t-1}} \frac{1}{\alpha^{t-1}} + \frac{p^t q^t}{R^t} \frac{1}{\alpha^t}\right) \\ -\left(\frac{p^{t-1}q^{t-1}}{R^{t-1}} \frac{1}{\gamma^{t-1}} + \frac{p^t q^t}{R^t} \frac{1}{\gamma^t}\right) \end{array} \right] \left(\ln p^t - \ln p^{t-1}\right) \\
& +\sum_{i=L,K} 0.5 \left[\begin{array}{c} \left(\frac{x_i^{t-1} w_i^{t-1}}{R^{t-1}} \frac{1}{\alpha^{t-1}} + \frac{x_i^t w_i^t}{R^t} \frac{1}{\alpha^t}\right) \\ -\left(\frac{x_i^{t-1} w_i^{t-1}}{R^{t-1}} \frac{1}{\gamma^{t-1}} + \frac{x_i^t w_i^t}{R^t} \frac{1}{\gamma^t}\right) \end{array} \right] \left(\ln x_i^t - \ln x_i^{t-1}\right) \\
& -\sum_{i=M,IM} 0.5 \left[\left(\frac{x_i^{t-1} w_i^{t-1}}{R^{t-1}} \frac{1}{\gamma^{t-1}} + \frac{x_i^t w_i^t}{R^t} \frac{1}{\gamma^t}\right)\right] \left(\ln x_i^t - \ln x_i^{t-1}\right)
\end{aligned}
$$

The difference of technical change can be understood as Hicks' aggregation effect.

We can get the difference between terms of trade effect measured by gross output and that measured by GDP in use of following expression:

$$
\begin{aligned}
& \ln TOT3 - \ln TOT1 \qquad (45) \\
= \; & 0.5 \left[\begin{array}{c} \left(\frac{p^{t-1}x^{t-1}}{R^{t-1}} \frac{1}{\gamma^{t-1}} + \frac{p^t x^t}{R^t} \frac{1}{\gamma^t}\right) \\ -\left(\frac{p^{t-1}x^{t-1}}{R^{t-1}} \frac{1}{\alpha^{t-1}} + \frac{p^t x^t}{R^t} \frac{1}{\alpha^t}\right) \end{array} \right] \left(\ln p^t - \ln p^{t-1}\right) \\
& -0.5 \left[\begin{array}{c} \left(\frac{p_m^{t-1} m^{t-1}\left(1+\tau^{t-1}\right)}{R^{t-1}} \frac{1}{\gamma^{t-1}} + \frac{p_m^t m^t \left(1+\tau^t\right)}{R^t} \frac{1}{\gamma^t}\right) \\ -\left(\frac{p_m^{t-1} m^{t-1}}{R^{t-1}} \frac{1}{\alpha^{t-1}} + \frac{p_m^t m^t}{R^t} \frac{1}{\alpha^t}\right) \end{array} \right] \\
& * \left(\ln p_m^t - \ln p_m^{t-1}\right) \\
& -0.5 \left(\frac{p_m^{t-1} m^{t-1}\left(1+\tau^{t-1}\right)}{R^{t-1}} \frac{1}{\gamma^{t-1}} + \frac{p_m^t m^t \left(1+\tau^t\right)}{R^t} \frac{1}{\gamma^t}\right) \\
& * \left(\ln\left(1+\tau^t\right) - \ln\left(1+\tau^{t-1}\right)\right)
\end{aligned}
$$

The difference of terms of trade can be understood as a combination of Hicks' aggregation effect and tariff effect.

2.3.6 Result

Table 6: Difference between GDP and gross output methods

Period	$\ln TFP1 - \ln TFP3$	$t1 - t3$	$\ln TOT1 - \ln TOT3$
1986-2012	0.0038406	0.0046972	-0.00085655
1986-1990	-0.0041364	-0.0057706	0.0016341
1991-1995	0.0077140	0.0072473	0.00046674
1996-2000	0.0015430	0.0051143	-0.0035713
2001-2005	0.0011792	0.0042868	-0.0031075
2006-2012	0.0091745	0.0088525	0.00032196

Period	Hicks for t	Hicks for TOT	Hicks total	Tariff
1986-2012	0.0046972	0.0012885	0.0059857	-0.0021451
1986-1990	-0.0057706	0.0016341	-0.0041365	0.00000
1991-1995	0.0072473	0.0046565	0.0119038	-0.0041897
1996-2000	0.0051143	0.00071934	0.00583364	-0.0042907
2001-2005	0.0042868	-0.00049872	0.00378808	-0.0026088
2006-2012	0.0088525	0.00036855	0.00922105	-0.000046588

After comparing the decomposition of TFP estimated by GDP with that estimated by revenue and comparing the decomposition of TFP estimated by revenue with that estimated by gross output, this part focuses on the decomposition of TFP estimated by GDP and that by gross output. As we've known from the previous sections, TFP growth measured by GDP and gross output can be both decomposed into technical change effect and terms of trade effect. The difference between lnTFP1 and lnTFP3 rose from -0.0041364 in 1986 to 0.0091745 in 2012, the average value is 0.0038406. The difference of technical effect increased from -0.0057706 to 0.0088525, with an average value of 0.0046972. The difference between terms of trade effects demonstrates an decreasing trend, from 0.0016341 to 0.00032196, its averaged difference is -0.00085655 during the 27 years. Distinct technical effects are the main driver of TFP growth mismeasurement. The difference of technical change is fully because of Hicks' aggregation effect, while the difference of terms of trade comes from Hicks' aggregation effect and tariff effect. The total Hicks' aggregation effect is in an average of 0.0059857 in the whole period, which is more than two times higher than the absolute value of tariff effect, 0.0021451, and plays the most important role to the positive change of TFP growth. According to the analysis in this section, the TFP growth rate of the whole Chinese economy is mismeasured by the Chinese Statistical Bureau and by many researchers, for the reason that value-added production instead of gross output is used to construct productivity growth index. The mismeasurement of TFP growth can be decomposed into Hicks' aggregation effect and tariff effect, and these two effects amount to 0.38406% per year. Suppose that the TFP level is 100 in 1986, the mismeasurement of 0.38406% implies that TFP level becomes 110.9 in 2012[14].

3 Evaluation by Cost Function

3.1 Model Specification

Instead of value-added cost, this section uses total cost measured with tariff and that measured without tariff to compute TFP growth, so in this case there is no Hicks' effect, but only tariff effect.

Chinese economy faces a tariff-included cost minimization problem, which is as follows:

$$C_1\left(W^t, \tau^t, y^t, t\right) = \min_X \left\{ \sum_{m=L,K,M,IM} w_m^t x_m^t \left(1+\tau_m^t\right) \right\} \tag{46}$$

The tariff term τ_m^t is apparently zero for labor input, capital input, domestic produced energy input, and domestic produced material input, however, it becomes positive when energy and material inputs are imported from foreign countries.

According to Diewert WE (2012), this paper assumes that the logarithm of the industry's period t cost function is the following non-constant returns to

[14] See figure 4 and figure 13 in the appendix.

scale translog joint cost function:[15]

$$\begin{aligned}\ln C_1\left(W^t,\tau^t,y^t,t\right) &= -\tau t+\alpha_0+\sum_l \alpha_l \ln\left[w_l^t\left(1+\tau_l^t\right)\right]+\beta\ln y^t \\ &+0.5\sum_l\sum_{k\neq l}\delta_{kl}\ln\left[w_l^t\left(1+\tau_l^t\right)\right]\left[w_k^t\left(1+\tau_k^t\right)\right] \\ &+\sum_l \varphi\ln\left[w_l^t\left(1+\tau_l^t\right)\right]\ln y^t\end{aligned} \tag{47}$$

where the parameters on the right hand side satisfy the following conditions:

$$\sum_l \alpha_j = 1 \tag{48}$$

$$\sum \delta_{kl} = 1 \text{ for } l = L, K, M, IM \tag{49}$$

$$\delta_{kl} = \delta_{lk} \tag{50}$$

$$\sum_l \varphi = 0 \tag{51}$$

According to Shephard's Lemma, which is proved by Shephard R (1953), the cost minimizing vector of input demands in period t should equalize the first partial derivatives of the cost function with respect to the corresponding input prices:

$$x_m^t = \partial C_1\left(W_m^t,\tau^t,y^t,t\right)/\partial\left[w_m^t\left(1+\tau_m^t\right)\right] \tag{52}$$

According to Morrison CJ (1999), TFP growth using cost function is expressed as:

[15] **The basic translog functional form was introduced by Christensen, Jorgenson and Lau (1971). This particular functional form was introduced by Diewert (1974; 139) as a joint revenue function, but the parameter k on the right hand side was set to 1 and the technical progress term $-\tau t$ was missing. The translog joint cost function was first introduced by Burgess (1974).**

$$-TFPGC1 = \left(\ln C_1^t - \ln C_1^{t-1}\right) - \left(\ln y^t - \ln y^{t-1}\right) \quad (53)$$
$$-0.5 \sum_m \left[\frac{w_m^{t-1}\left(1+\tau_m^{t-1}\right) x_m^{t-1}}{C_1^{t-1}} + \frac{w_m^t\left(1+\tau_m^t\right) x_m^t}{C_1^t}\right]$$
$$* \left\{\ln\left[w_m^t\left(1+\tau_m^t\right)\right] - \ln\left[w_m^{t-1}\left(1+\tau_m^{t-1}\right)\right]\right\}$$

TFP measured by cost is further decomposed, so as to compare the technical change effects and the scale effects between tariff-excluded and tariff-included productivity.

Based on Diewert WE (1976) and Diewert WE (2012), the difference of logarithm of tariff-included cost can be written as:

$$\ln C_1\left[W_j^t\left(1+\tau_j^t\right), y^t, t\right] - \ln C_1\left[W_j^{t-1}\left(1+\tau_j^{t-1}\right), y^{t-1}, t-1\right] \quad (54)$$
$$= 0.5\left(\partial \ln C_1^{t-1}/\partial t + \partial \ln C_1^t/\partial t\right)\left[(t)-(t-1)\right]$$
$$+0.5\left(\partial \ln C_1^{t-1}/\partial \ln y + \partial \ln C_1^t/\partial \ln y\right)\left(\ln y^t - \ln y^{t-1}\right)$$
$$+0.5\sum_m \left\{\partial \ln C_1^{t-1}/\partial \ln\left[w_m\left(1+\tau_m\right)\right] + \partial \ln C_1^t/\partial \ln\left[w_m\left(1+\tau_m\right)\right]\right\}$$
$$* \left\{\ln\left[w_m^t\left(1+\tau_m^t\right)\right] - \ln\left[w_m^{t-1}\left(1+\tau_m^{t-1}\right)\right]\right\}$$

where

$$0.5\left(\partial \ln C_1^t/\partial \ln y + \partial \ln C_1^{t-1}/\partial \ln y\right) = k1 \text{ and } \partial \ln C_1^t/\partial \ln\left[w_m\left(1+\tau_m\right)\right] = s_{m1}^t \quad (55)$$

in which $k1 = 0.5\left(\frac{p^t y^t}{C_1^t} + \frac{p^{t-1} y^{t-1}}{C_1^{t-1}}\right)$, and $s_{m1}^t = w_m^t x_m^t\left(1+\tau_m^t\right) / \sum_m w_m^t x_m^t\left(1+\tau_m^t\right)$. s_{m1}^t is the share of each factor input of the total cost.

Rearranging equations (53) to (55), TFP growth can be further decomposed into technical change effect and returns to scale effect:

$$-TFPGC1 \quad (56)$$
$$= 0.5\left(\partial \ln C_1^{t-1}/\partial t + \partial \ln C_1^t/\partial t\right)\left[(t)-(t-1)\right]$$
$$+\left(k1-1\right)\left(\ln y^t - \ln y^{t-1}\right)$$
$$= tc1 + RS1$$

Technical change effect of the tariff-included cost measure can be derived by subtracting scale effect from TFP growth rate:

$$tc1 = -TFPGC1 - RS1 \tag{57}$$

3.2 Result

Table 7: TFP growth decomposition of cost measured with tariff

Period	-TFPGC1	tc1	k1	RS1
1986-2012	0.039571	0.039571	1	0
1986-1990	-0.039165	-0.039165	1	0
1991-1995	0.047399	0.047399	1	0
1996-2000	0.026517	0.026517	1	0
2001-2005	0.053769	0.053769	1	0
2006-2012	0.078153	0.078153	1	0

Table 7 shows the results of technical change effect and returns to scale effect, which are decomposed from TFP measured by cost. According to this table, TFP growth increased from -0.039165 to 0.078153 during the 27 years, with an average value of 0.039571. The variation of TFP growth resembles that of technical change effect, for returns to scale effect for each period group is 0. k is able to show returns to scale effect: If k<1, then we have increasing returns to scale; if k>1, then we have decreasing returns to scale; if k=1, then we have constant returns to scale. In this table, k1=1, and RS1=0, which indicates a constant returns to scale[16].

In order to find the tariff effect, this section creates one tariff-excluded cost function:

$$C_2\left(W^t, y^t, t\right) = \min_X \left\{ \sum_{m=L,K,M,IM} w_m^t x_m^t \right\} \tag{58}$$

Let us assume that the logarithm of the industry's period t cost function is the following non-constant returns to scale translog joint cost function:

[16] See figure 9 in the appendix.

$$\begin{aligned} \ln C_2\left(W^t, y^t, t\right) &= -\tau t + \alpha_0 + \sum_l \alpha_l \ln w_l^t + \beta \ln y^t \\ &+0.5 \sum_l \sum_{k \neq l} \delta_{kl} \ln w_l^t w_k^t \\ &+\sum_l \varphi \ln w_l^t \ln y^t \end{aligned} \tag{59}$$

The parameters on the right hand side satisfy the same conditions as that of tariff-included cost function.

According to Shephard's Lemma, the cost minimizing vector of input demands in period t should equalize the first partial derivatives of the cost function with respect to the corresponding input prices:

$$x_m^t = \partial C_2\left(W_m^t, y^t, t\right) / \partial w_m^t \tag{60}$$

TFP growth is defined as:

$$\begin{aligned} -TFPGC2 &= \left(\ln C_2^t - \ln C_2^{t-1}\right) - \left(\ln y^t - \ln y^{t-1}\right) \\ &-0.5 \sum_m \left(\frac{w_m^{t-1} x_m^{t-1}}{C_2^{t-1}} + \frac{w_m^t x_m^t}{C_2^t}\right)\left(\ln w_m^t - \ln w_m^{t-1}\right) \end{aligned} \tag{61}$$

In order to compare the technical change effects and the scale effects between tariff-excluded and tariff-included productivity, TFP measured by cost is further decomposed.

Based on Diewert WE (1976) and Diewert WE (2012), the difference of logarithm of tariff-excluded cost can be written as:

$$\begin{aligned} &\ln C_2\left(W_k^t, y^t, t\right) - \ln C_2\left(W_k^{t-1}, y^{t-1}, t-1\right) \\ =\ &0.5\left(\partial \ln C_2^{t-1}/\partial t + \partial \ln C_2^t/\partial t\right)[(t)-(t-1)] \\ &+0.5\left(\partial \ln C_2^{t-1}/\partial \ln y + \partial \ln C_2^t/\partial \ln y\right)\left(\ln y^t - \ln y^{t-1}\right) \\ &+0.5 \sum_m \left(\partial \ln C_2^{t-1}/\partial \ln w_m + \partial \ln C_2^t/\partial \ln w_m\right)\left(\ln w_m^t - \ln w_m^{t-1}\right) \end{aligned} \tag{62}$$

where

$$0.5\left(\partial \ln C_2^t/\partial \ln y + \partial \ln C_2^{t-1}/\partial \ln y\right) = k2 \text{ and } \partial \ln C_2^t/\partial \ln w_m = s_{m2}^t \quad (63)$$

in which $k2 = 0.5(\frac{p^t y^t}{C_2^t} + \frac{p^{t-1}y^{t-1}}{C_2^{t-1}})$, and $s_{m2}^t = w_m^t x_m^t / \sum_m w_m^t x_m^t$. s_{m2}^t is the share of each factor input of the total cost.

Rearranging equations (61) to (63), TFP growth can be further decomposed into technical change effect and returns to scale effect:

$$\begin{aligned} & -TFPGC2 \quad (64) \\ = \; & 0.5\left(\partial \ln C_1^{t-1}/\partial t + \partial \ln C_1^t/\partial t\right)[(t)-(t-1)] \\ & + (k2-1)\left(\ln y^t - \ln y^{t-1}\right) \\ = \; & tc2 + RS2 \end{aligned}$$

Technical change effect of the tariff-excluded cost measure can be obtained by using TFP growth to subtract returns to scale effect:

$$tc2 = -TFPGC2 - RS2 \quad (65)$$

3.3 Result

Table 8: TFP growth decomposition of cost measured without tariff

Period	-TFPGC2	tc2	k2	RS2
1986-2012	0.042634	0.045546	1.03058	-0.0029118
1986-1990	-0.036609	-0.034850	1.04579	-0.0017585
1991-1995	0.056716	0.062435	1.04649	-0.0057192
1996-2000	0.027680	0.029599	1.02450	-0.0019190
2001-2005	0.056539	0.059787	1.02531	-0.0032481
2006-2012	0.078607	0.080642	1.01864	-0.0020345

Table 8 demonstrates the decomposition of TFP growth computed by cost that measured without tariff, which is in accordance with the decomposition of TFP evaluated by GDP function. We find that TFP growth rose from -0.036609 to 0.078607 between 1986 and 2012, with an average value of 0.042634. The technical change effect also showed a rising trend from -0.034850 to 0.080642, with an average value of 0.045546. The scale effect also indicates an decreasing trend for the same period, which has an average value of -0.0029118. k2=1.03058 during the 27 years, which means decreasing returns to scale for the whole economy. Technical change effect is more than 15 times greater than scale effect, and it, in a large scale, affects TFP growth[17].

3.4 The Difference

This part will analyze the difference between tariff-excluded and tariff-included TFP measured by cost.

We know from construction of cost functions that tariff-included cost equalizes tariff-excluded cost plus tariff revenue:

$$\begin{aligned} C_1^t &= C_2^t + w_{IM}^t x_{IM}^t \tau^t \\ &= C_2^t \frac{(C_2^t + w_{IM}^t x_{IM}^t \tau^t)}{C_2^t} \\ &= \beta^t C_2^t \end{aligned} \tag{66}$$

The difference between TFP growth measured without and with tariff rate can be computed as follows:

[17] See figure 10 in the appendix.

$$
\begin{aligned}
& TFPGC2 - TFPGC1 \qquad (67)\\
= \; & \left(\ln \beta^{t} - \ln \beta^{t-1}\right) \\
& + \sum_m 0.5 \left[\begin{array}{c} \left(\frac{w_m^{t-1} x_m^{t-1}}{C_2^{t-1}} + \frac{w_m^t x_m^t}{C_2^t}\right) \\ - \left(\frac{w_m^{t-1}\left(1+\tau_m^{t-1}\right) x_m^{t-1}}{C_2^{t-1}} \frac{1}{\beta^{t-1}} + \frac{w_m^t \left(1+\tau_m^t\right) x_m^t}{C_2^t} \frac{1}{\beta^t}\right) \end{array} \right] \\
& * \left(\ln w_m^t - \ln w_m^{t-1}\right) \\
& - \sum_m 0.5 \left(\begin{array}{c} \frac{w_m^{t-1} x_m^{t-1}\left(1+\tau_m^{t-1}\right)}{C_2^{t-1}} \frac{1}{\beta^{t-1}} \\ + \frac{w_m^t x_m^t \left(1+\tau_m^t\right)}{C_2^t} \frac{1}{\beta^t} \end{array} \right) \\
& * \left[\ln\left(1+\tau_j^t\right) - \ln\left(1+\tau_j^{t-1}\right)\right]
\end{aligned}
$$

This difference is what we call the tariff effect.

The difference between tariff-excluded and tariff-included returns to scale effect is as follows:

$$
\begin{aligned}
& RS2 - RS1 \qquad (68)\\
= \; & \left[(k2-1) - (k1-1)\right] \left(\ln y^t - \ln y^{t-1}\right) \\
= \; & 0.5 \left[\left(\frac{p^t y^t}{C_2^t} + \frac{p^{t-1} y^{t-1}}{C_2^{t-1}}\right) - \left(\frac{p^t y^t}{C_1^t} + \frac{p^{t-1} y^{t-1}}{C_1^{t-1}}\right) \right] \\
& * \left(\ln y^t - \ln y^{t-1}\right) \\
= \; & 0.5 \left[\left(\frac{p^t y^t}{C_2^t} + \frac{p^{t-1} y^{t-1}}{C_2^{t-1}}\right) - \left(\frac{p^t y^t}{C_2^t} \frac{1}{\beta^t} + \frac{p^{t-1} y^{t-1}}{C_2^{t-1}} \frac{1}{\beta^{t-1}}\right) \right] \\
& * \left(\ln y^t - \ln y^{t-1}\right)
\end{aligned}
$$

The difference between two returns to scale effects is due to a lack of tariff term.

3.5 Result

Table 9: Difference between cost methods with and without tariff

Period	-TFPGC2+TFPGC1	tc2-tc1	RS2-RS1	Tariff
1986-2012	0.0030635	0.0059754	-0.0029118	0.0030635
1986-1990	0.0025567	0.0043152	-0.0017585	0.0025567
1991-1995	0.0093164	0.015036	-0.0057192	0.0093164
1996-2000	0.0011629	0.0030819	-0.0019190	0.0011629
2001-2005	0.0027701	0.0060182	-0.0032481	0.0027701
2006-2010	0.00045403	0.0024885	-0.0020345	0.00045403

This table presents the decomposition results of TFP measured by cost functions with and without tariff. The difference between these two TFP growths is 0.0030635 per annum. The positive value reveals that TFP growth is overestimated by cost function constructed without tariff. The reason for this difference is solely because of tariff. During the 27 years, the scale effect measured without tariff is lower than that with tariff, while the technical effect of tariff-excluded cost is higher than that of tariff-included cost, the combined effect is positive. Setting the TFP level in 1986 as 100, let it grow 0.30635% per year, TFP level will arrive to 108.6. It means that TFP growth overestimation using cost method exits[18].

4 Construction and Description of the Data

This paper uses pooled time-series data of the whole Chinese economy between 1986 and 2012 to compute TFP growth and its decomposition.

Data on quantities and prices of output, labor, physical capital, energy and material for the whole economy from 1986 to 2012 are collected from 27 years of the Bureau of China Statistical Yearbook, China Labor Statistical Yearbook, China Energy Statistical Yearbook, China Urban Life and Price Yearbook, China Industry, Transportation, Energy statistical Yearbook between 1949 and 1999. All price indexes have been normalized to be equal to one at year 2000 value. The output quantity index is measured as the value of gross output di-

[18] See figure 8 and figure 14 in the appendix.

vides by the output price index. The factor input quantity index is obtained by the cost of each factor dividing its input price index. The physical capital input is the sum of structure and equipment capital, which is measured by Qiao Fan (2012) in use of the following equation:

$$K^t = I^t + (1 - \delta) K^{t-1} \tag{69}$$

where I^t denotes the new investment, $0 \leq \delta \leq 1$ demonstrates the depreciation rate of capital. All the data that this paper adopts to construct capital input and price can be obtained from China Statistical Yearbook.

Annual data on the import prices and export prices of the whole economy can be gained from the 27 years of China Statistical Yearbook of International Trade. Annual data on tariff rate is from the 27 years of Customs Import and Export Tariff of the People's Republic of China. The tariff index is calculated as the annual rate divides the base year 2000 rate[19].

5 Comparison of the results

This section sets to solve the following problems. First, what are the differences between the decomposition of TFP in GDP method and that in tariff-excluded method? Second, what are the differences between the decomposition of TFP measured by gross output and that by tariff-included cost? Third, how does this paper contribute to the present researches.

As for the first question, first of all, TFP growth is mismeasured by both GDP and tariff-excluded cost estimates, as we've discussed in this paper. Moreover, their lack of tariff term should be responsible for this mismeasurement. One additional reason for TFP mismeasurement by GDP estimate is Hicks' aggregation effect. Furthermore, TFP growth measured by tariff-excluded cost is 0.042634 (see table 8), which is lower than that by GDP, 0.056016. Technical change effect in GDP is 0.052940 (see table 1), which is higher than that in cost,

[19] China's economy data descriptive statistics (1986-2012) can be found in table A1, figure 2 and figure 3 in the appendix.

0.045546[20]. There are two reasons for this result. One is that technical change in cost is evaluated by subtracting quantity input index of primary and intermediate inputs, while the technical change in GDP is computed by only subtracting labor and capital input index. The other is that TFP growth evaluated by GDP cannot decompose into returns to scale effect, thus, the scale effect is involved in the technical effect. Technical change effects in GDP and in tariff-excluded cost are the main drivers for the positive TFP growth. The difference between tariff effect in GDP and that in gross output is -0.0021451 (see table 6), while the difference between tariff effect in tariff-excluded and that tariff-included cost is 0.0030635 (see table 9). Clearly, the latter difference is much higher than that of the former one. In short, tariff effect plays a less important role than Hicks' aggregation effect in TFP growth measured by GDP, whereas tariff effect is the only reason why TFP growth is overestimated by tariff-excluded cost.

Regarding the second question, TFP growth rate is correctly computed by both value of gross output and tariff-included cost methods, however, they depart from each other in the elements of TFP growth decomposition. TFP growth evaluated by gross output is 0.052175 (see table 3), whose value is higher than that evaluated by tariff-included cost, 0.039571 (see table 7)[21]. Technical change decomposed from TFP by gross output method is 0.048243 (see table 3), which is higher than that by cost, 0.039571 (see table 7), because the construction of technical change of cost is different than that of gross output. Gross output also measures terms of trade effect, however, terms of trade effect cannot be found in cost estimate. Technical change effects in both gross output and tariff-included cost are the most important reason for positive TFP growth.

For the last question, this paper revisits most of the papers and researches concerning TFP mismeasurement, and finds out the fundamental causes of the mismeasurement: tariff effect and Hicks' aggregation effect. Chinese Statistical Bureau and American Statistical Bureau use GDP estimate to evaluate TFP growth rate, which ignores tariff effect, thus leads to mismeasurement. Based

[20] See figure 15 in the appendix.
[21] See figure 16 in the appendix.

on Diewert WE and Morrion CJ (1986), many economists tried to decompose TFP growth into technical effect and terms of trade effect, and found out that real GDP and TFP growth are mismeasured when terms of trade varies. Using data from 26 countries, Kohli U (2003) finds that when terms of trade improves, the conventional measure of real GDP underestimates the growth of real value-added. Kohli U (2006), adopting data from Hong Kong between 1961 and 2003, states that real GDP underestimates the growth rate of real domestic value-added, real GDI, and welfare when the terms of trade increases. Feenstra RC, Reinsdorf MB, and Slaughter MJ (2008) employ revenue function, instead of GDP function, to decompose TFP growth, and argue that part of the growth in productivity in the US since 1995 can be explained by gains in terms of trade and tariff reductions, especially for the information-technology industries. There are many studies on TFP growth in China. A prestigious one would be Perkins DH and Rawski TG (2008), they apply official GDP estimate and gain an average of 3.8% Chinese TFP growth rate between 1978 and 2005. The result of TFP growth of their paper and that of Chinese Statistical Bureau are incorrect as we've analyzed in this thesis. Neither is revenue method employed by Feenstra RC, Reinsdorf MB, and Slaughter MJ (2008) accurate to compute TFP growth, because Hicks' aggregation effect also causes a mismeasurement. As for this paper, we, adopting pooled time-series data of the whole economy of China from 1986 to 2012, construct TFP growth through gross output method so as to get a correct productivity measurement. In addition, GDP, revenue, tariff-excluded and tariff-included cost estimates are all carefully examined in order to compare the distinct results of TFP growth and its decomposition. We decompose not only TFP growth into technical change and terms of trade effect as most of the researchers do, but also the difference of TFP growth measured among three methods: GDP, revenue, and gross output, into Hicks' aggregation effect and tariff effect. Our results indicate that both GDP and revenue estimates overestimate TFP growth mainly because of Hicks' aggregation effect. A tiny part of the reason should be tariff effect. Another advantage of this thesis is its construction of tariff-excluded and tariff-included cost function to compute

TFP growth. In so doing, we could compare with the other three methods: GDP, revenue, and gross output. According to our observations, TFP growth measured by tariff-excluded cost is higher than that by tariff-included cost, in which the only reason is tariff.

6 Conclusion

In conclusion, there is a mismeasurement in the evaluation of TFP growth in most researches. Devoting in the study of this mismeasurement, this paper probes into the following approaches to measure TFP: GDP, revenue, tariff-excluded cost, tariff-included cost, and gross output function. Among them, the first three methods are incorrect; while the last two are correct but they diverge from each other in results because of different means of construction. Each of the first three methods has its own shortcomings. For GDP, it excludes tariff and its substitution of gross output would lead to a mismeasurement. The overestimation of TFP growth by GDP is 0.38% per annum, and 110.9% in the 27 years. When it comes to revenue method, though takes into account tariff, its output cannot correctly evaluate gross output. Lastly, tariff-excluded cost discards tariff effect, which is obviously wrong in the evaluation of TFP. What's more, we seek to decompose the difference of these TFP growths evaluated by these five methods, which no scholars have experimented before. Through a close comparison among the decomposition of those differences, we advance that either Hicks' aggregation effect or tariff effect should be responsible for the differences of TFP growths. Furthermore, Hicks' aggregation effect overpowers tariff effect.

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7 Appendix

7.1 Table

Variable	Mean	Std. Dev.
Output	1.63083D+07	1.34263D+07
Labor	6550539.22222	967115.88649
Capital	3895988.50231	2992416.06249
Energy and material domestic	64984.41392	24028.19165
Import	2566199.32118	2311302.65492
Labor price	1.40891	1.34126
Capital price	0.90696	0.32367
Energy and material domestic price	0.96425	0.42464
Import price without tariff	0.90401	0.29734
Tariff	0.27526	0.19155

Table A1: China's economy data descriptive statistics (1986-2012)

Variable	Min	Max
Output	3660669.75	4.74316D+07
Labor	4600864	7890521
Capital	797907.1875	1.09570D+07
Energy and material domestic	24230.40039	105164.91406
Import	159393.60938	6838492.5
Labor price	0.14813	4.77693
Capital price	0.38539	1.52453
Energy and material domestic price	0.2457	1.7347
Import price without tariff	0.57595	1.55339
Tariff	0.098	0.58

Table A1: China's economy data descriptive statistics (1986-2012), continued

7.2 Figures

Figure 1: Share of international trade in GDP, 1978-2012

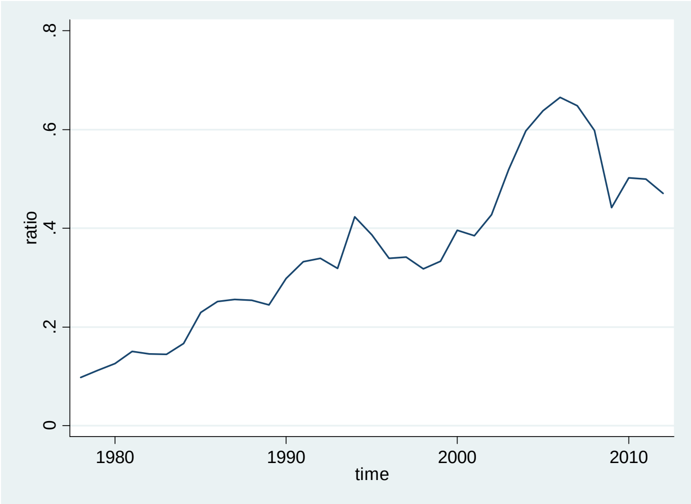

Figure 2: Input/output ratios, 1986-2012

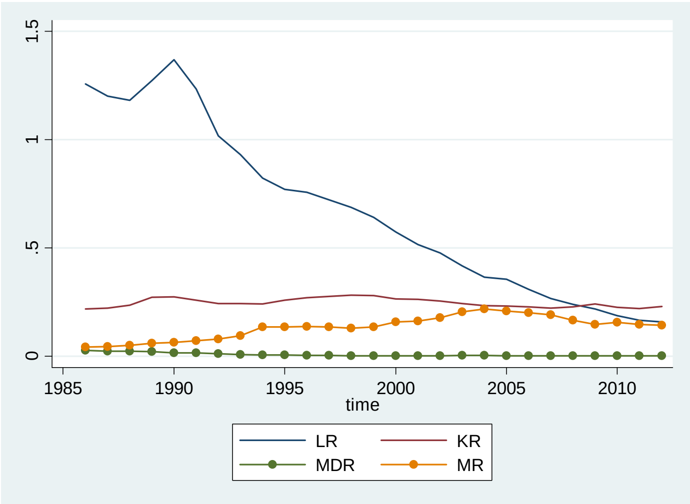

Figure 3: Acquisition/hiring prices, 1986-2012

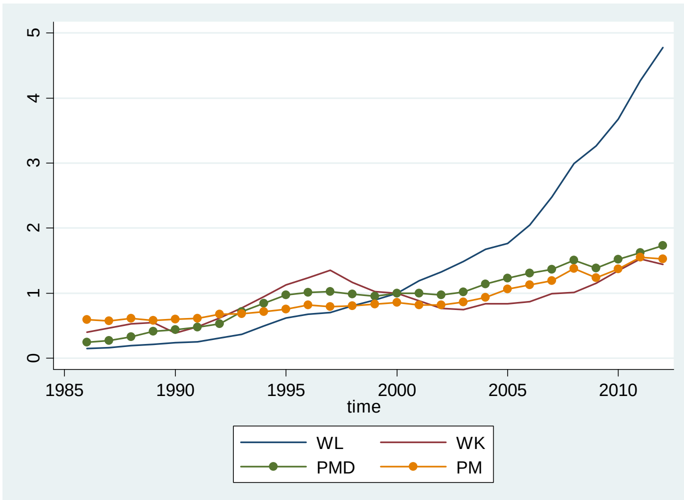

Figure 4: TFP growths measured with GDP, revenue, and gross output, 1986-2012

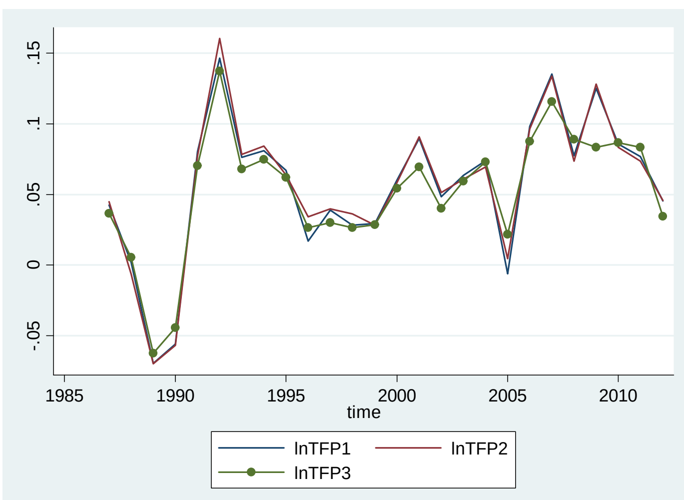

Figure 5: TFP growth measured with GDP and its decomposition, 1986-2012

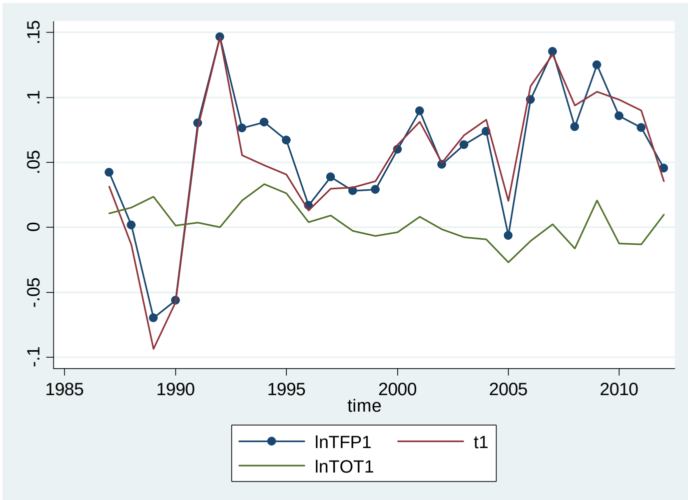

Figure 6: TFP growth measured with revenue and its decomposition, 1986-2012

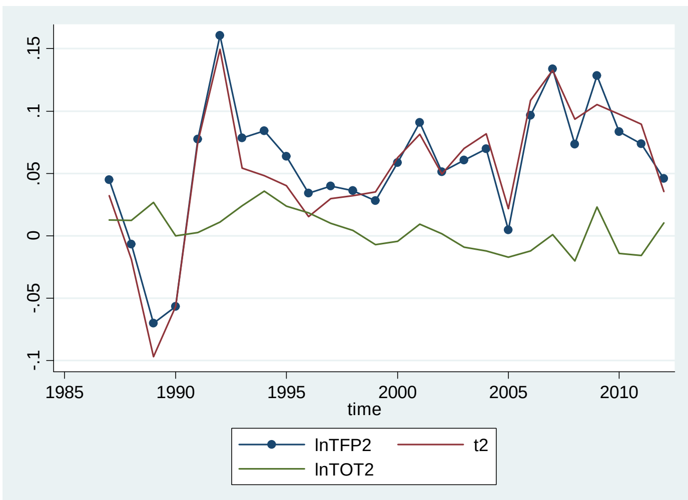

Figure 7: TFP growth measured with gross output and its decomposition, 1986-2012

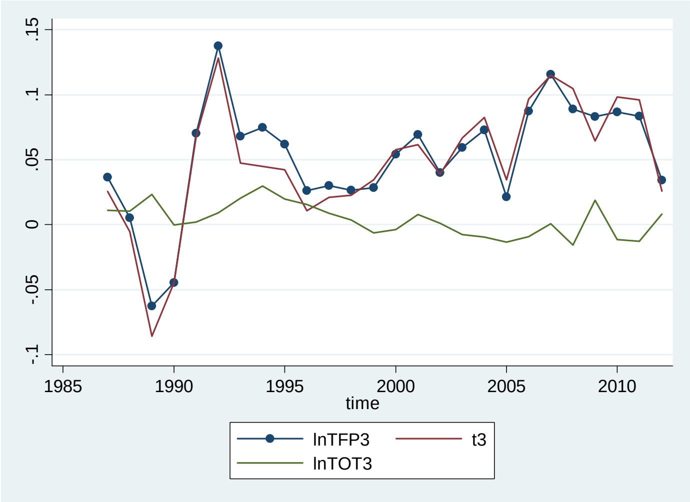

Figure 8: TFP growth measured with cost with tariff and without tariff, 1986-2012

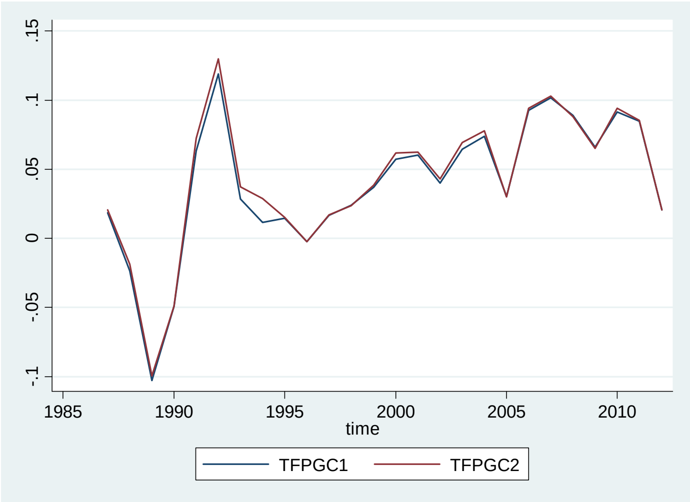

Figure 9: TFP growth measured with tariff-included cost and its decomposition, 1986-2012

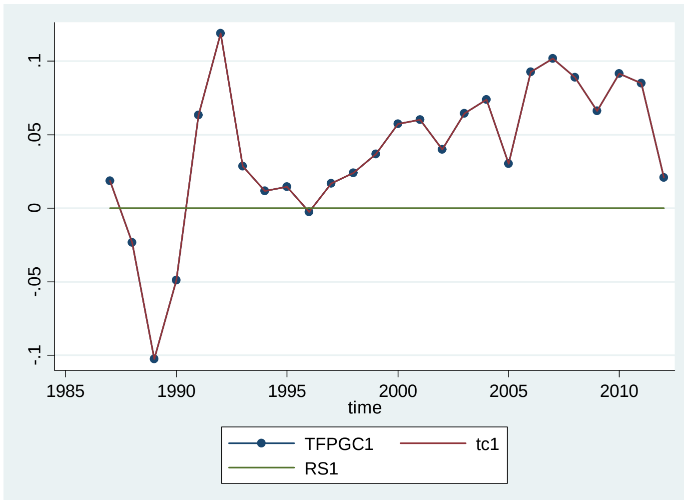

Figure 10: TFP growth measured with tariff-excluded cost and its decomposition, 1986-2012

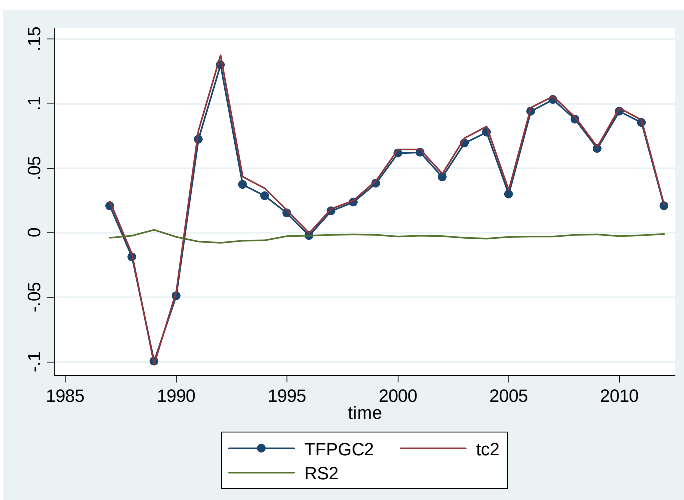

Figure 11: TFP growth difference of GDP and revenue, and its decomposition, 1986-2012

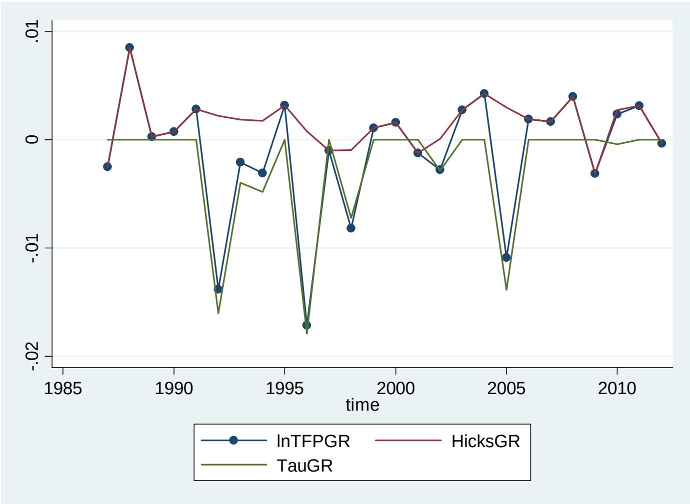

Figure 12: TFP growth difference of revenue and gross output, and its decomposition, 1986-2012

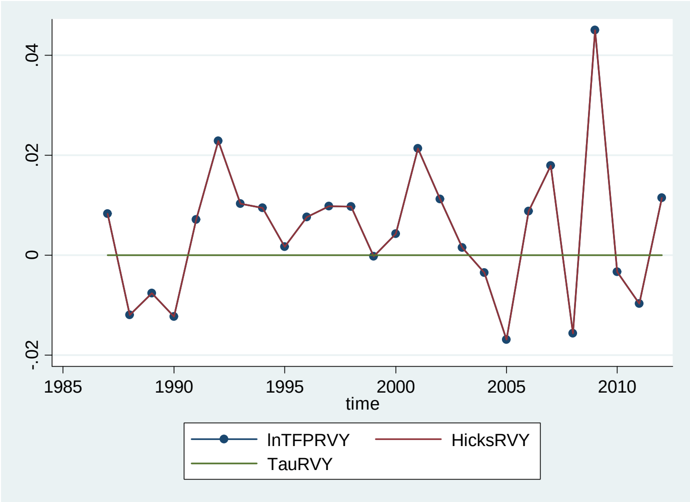

Figure 13: TFP growth difference of GDP and gross output, and its decomposition, 1986-2012

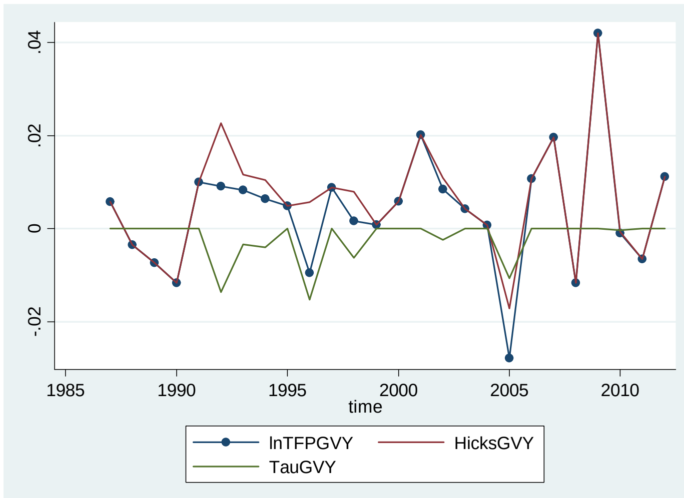

Figure 14: TFP growth difference of tariff-excluded and tariff-included cost, and its decomposition, 1986-2012

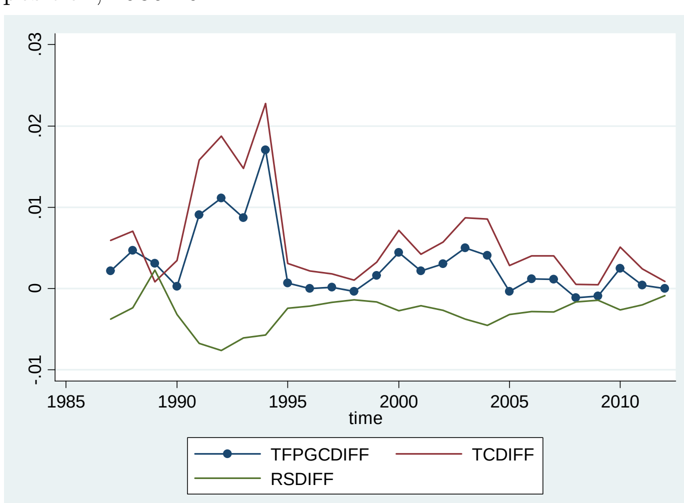

Figure 15: Comparison between TFP growth of GDP and tariff-excluded cost, 1986-2012

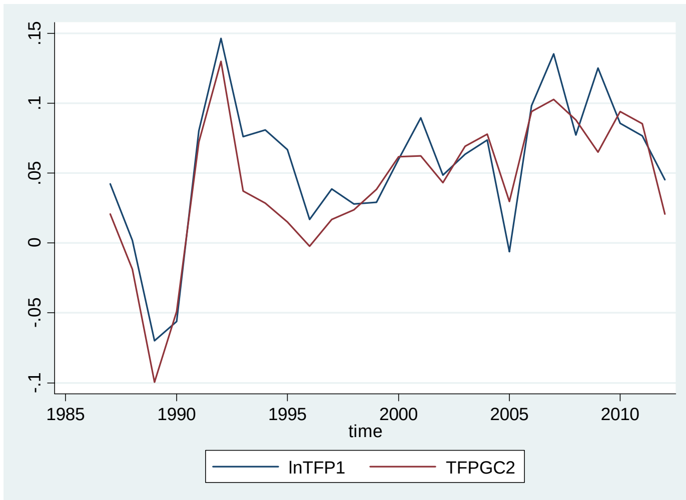

Figure 16: Comparison between TFP growth of gross output and tariff-included cost, 1986-2012