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Conference Paper

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22nd Biennial Conference of the International Telecommunications Society (ITS): "Beyond the Boundaries: Challenges for Business, Policy and Society", Seoul, Korea, 24th-27th June, 2018

Provided in Cooperation with:

International Telecommunications Society (ITS)

Suggested Citation: Lin, Xuchen; Lu, Ting-Jie; Chen, Xia (2018) : Technological change and total factor productivity growth: evidence from China's telecommunications industry, 22nd Biennial Conference of the International Telecommunications Society (ITS): "Beyond the Boundaries: Challenges for Business, Policy and Society", Seoul, Korea, 24th-27th June, 2018, International Telecommunications Society (ITS), Calgary

This Version is available at:

<https://hdl.handle.net/10419/190363>

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Technological change and total factor productivity growth: evidence from China's telecommunications industry

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Abstract. The fast-growing telecommunications industry in China has been experiencing dramatic technological change and substantial productivity growth. The actual productivity growth pattern in the sector, however, need to be empirically examined. In this paper, using input and output data at the provincial level, we employ DEA-based Malmquist productivity index to estimate productivity change, technological change, and relative efficiency change in China's telecommunications industry for the period spanning the years from 2011 to 2015. The results show that based on our sample, the productivity improved by 22.9% per annum, which was exclusively due to an average of 25.5% technological progress in the industry production function, while the average efficiency change is slightly negative. Our results also indicate that regions with relatively low levels of telecommunications (and economic) development have a greater chance and ability of enhancing telecommunications productivity growth through technological catch-up. In addition, we find that the industry experienced significantly higher productivity growth and technological progress in the later sample period between 2013 and 2015 than in the early period between 2011 and 2013.

Keywords: Telecommunications, Productivity, Technological change, Data envelopment analysis, Malmquist index.

1. Introduction

The telecommunications industry has been one of the most dynamic and fast growing industries over the past two decades in China. As of 2016, the penetration rate of mobile phone in China reached 96.2 per 100 persons, and the total business revenue of China's telecommunications industry achieved 3594.8 billion RMB in 2016 (MIIT, 2017). A well-developed telecommunications system plays a key role in the economic growth and development of a country (Dutta, 2001, Datta* and Agarwal, 2004). And the development level of an industry can be measure by the productivity of this industry, although productivity is not the only determinant of economic growth, it does provide a measure of economic prosperity of an industry. Productivity analysis can provide valuable information about the effectiveness of economic policies and, thus, provide a useful tool in policy design to improve economic development and industry performance (Lall et al., 2002).

Since the early 1980s, there has been a growing interest in measuring the productivity of the telecommunications industry. In the early period, the focus was on measuring total factor productivity (TFP) growth, which is the growth in output not accounted for by the growth in inputs. The pioneering studies include Nadiri and Schankerman (1981) and Denny, Fuss, and Waverman (1981), they used an adjusted Divisia TFP index to estimate the TFP growth of the telecommunications sector in the United States and Canada, respectively (Nadiri and Schankerman, 1979, Denny et al., 1979). Some subsequent studies applied the conventional growth accounting and econometric approaches to measure TFP change in telecommunications, such kind of studies include Oniki et al. (1994), Yoon (1999), Rushdi (2000), and Lam and Lam (2005) (Oniki et al., 1994, Yoon, 1999, Lam and Lam, 2005). More recently, production frontier approaches such as data envelopment analysis (DEA) and the Malmquist index have become popular in measuring the productivity performance of the telecommunications industry. Madden and Savage (1999) conducted a panel study to examine the telecommunications productivity, innovation and technological catch-up in 74 countries for the period 1991–1995. Using the Malmquist productivity change index, they found that TFP growth was highest for the subsample of industrialized countries (10.2% per annum) and was negative for countries in Africa (3.7% per annum) and the Western Hemisphere (10.2% per annum). They also

found that developing countries could enhance telecommunications productivity through technological catch-up (Madden and Savage, 1999). Giokas and Pentzaropoulos (2000) also applied the DEA approach to investigate the regional productive efficiency of public telecommunications organizations in Greece in 1998, their studies indicated that out of a total of 36 telecommunications centers, 15 of them were found to be efficient (with a maximum score of one) (Giokas and Pentzaropoulos, 2000). Uri (2000, 2001) examines productivity change, technical progress, and efficiency improvement in the U.S. wireline telecommunications industry, and he found that productivity increased by about 5.0 percent per year, and the growth was due primarily to technology innovation rather than improvements in relative efficiency (Uri, 2000, Uri, 2001). Using a representative sample of 16 firms in the mobile wireless industry in the United States, Banker et al. (2010) examined the productivity growth of the U.S. mobile wireless industry over the period 2000 to 2002, and found that the industry experienced a significant growth of 13% in productivity, which was primarily due to an average technological progress of 9.9% in the industry (Banker et al., 2010). Hisali and Yawe (2011) employed the Malmquist TFP index to measure TFP change of the telecommunications industry in Uganda over the period 2001 to 2006, and the results indicated that there was TFP growth in Uganda's telecommunications industry, which was mainly due to technical or technological progress as opposed to technical efficiency (Hisali and Yawe, 2011).

The previous literature primarily focused on the traditional fixed-line telephone market in the United States or the European countries. Despite the significant expansion of China's telecommunications sector over the last few years, there has been a lack of quantitative studies on the productivity performance of China's telecommunications in the 3G/4G era. From a regulatory perspective, it is important to provide insights into the drivers of the productivity growth in China's telecom industry as well as how efficiently this sector have used the various inputs during the expansion process. Based on this, our study contributes to the existing literature in production economics by examining the drivers of productivity change, and by providing new empirical evidence on productivity growth and technological change in a fast growing high-tech sector of China.

The purpose of this paper is to measure the productivity performance of China's telecommunications industry and examine the drivers of productivity in this industry for the period spanning the years from 2011 to 2015 at the provincial level. The Malmquist productivity change index based on DEA approach is used in the productivity measurement. Economic theory postulates that productivity improvements in industries can arise from technological progress generated by an upward shift in the production possibilities set as well as relative efficiency improvement on the part of inefficient firms in the industry because they "catch up" with the efficient firms over time (Nishimizu and Page, 1982). The telecommunications industry is a high-tech industry driven by continuous technological progress (Laffont and Tirole, 2001, Hausman and Taylor, 2016). Based on this argument and the existing empirical studies listed above, we argue that productivity growth in China's telecom industry is mainly due to industry-wide technological progress rather than efficiency improvement on the part of the inefficient firm. Based on this, in this study, we examine the relative contribution of these two effects to understand the drivers of productivity change in China's telecom industry. In addition, we also analyze the trend in productivity improvements in the telecom industry over time. We hope that the results from this productivity analysis can provide some economic and policy implications for subsequent infrastructure development of the telecommunications industry in China.

The rest of the paper is structured as follows. Section 2 provides a discussion of the methodology and the sample data we use for this study. Section 3 contains empirical analysis of the relationship between productivity growth and its components. Section 4 concludes the whole study and discusses the policy implications of this study for China's telecommunications reform.

2. Methodology and data

2.1 Total factor productivity (TFP)

TFP is defined as the ratio of aggregate output to aggregate input, with outputs and inputs generally aggregated according to revenue and cost share weights, respectively. When all inputs in

the production process are accounted for, TFP growth can be thought of as the amount of growth in real output that is not explained by the growth in inputs. This is why Abramovitz (1956) described the TFP residual as a ‘measure of our ignorance’ (Abramovitz, 1956). It is a relative concept with comparisons either being made across time or between different production units. For example, if it is possible to produce more output in period $t + 1$ when using the same amount of inputs that were used in period t , then productivity is said to have improved. In other words, productivity is higher in the second period compared to the first.

2.2 DEA-based Malmquist productivity change index

TFP growth is often calculated using the Törnqvist index (Diewert, 1976):

$$\begin{aligned}\varepsilon_T &= \left(\frac{\Delta TFP}{TFP} \right) = \sum_i r_i \left(\frac{\Delta y_i}{y_i} \right) - \sum_j c_j \left(\frac{\Delta x_j}{x_j} \right) \\ &= \ln \left(\frac{TFP_{t+1}}{TFP_t} \right) = \sum_i \frac{1}{2} (r_{it+1} + r_{it}) \ln \left(\frac{y_{it+1}}{y_{it}} \right) - \sum_j \frac{1}{2} (c_{jt+1} + c_{jt}) \ln \left(\frac{x_{jt+1}}{x_{jt}} \right)\end{aligned}\quad (1)$$

where ε_T is TFP growth calculated by Törnqvist index, Δ represents time differences (proxied by log differences), r_i are output revenue shares, y_i are outputs, c_j are input cost shares, x_j are inputs and \ln is the natural logarithmic operator. Equation (1) shows that TFP growth is the weighted sum of output growth rates less input growth rates, where the weights are the average output revenue shares and average input cost shares.

One of the problems in conducting a productivity analysis of China’s telecommunications industry is a lack of detailed cost data on the industry. As the industry has long been under state control, service prices, labour wages and capital costs are not based on market values and are all regulated by the government. Hence, due to data availability, it is not possible to apply productivity analysis which requires the use of detailed cost data to China’s telecommunications industry. In view of this, when detailed cost or revenue share data are not available, the non-parametric DEA approach, which does not require the use of cost share data, can be used to calculate productivity growth (Charnes et al., 1978, Färe et al., 1994, Farrell, 1957).

Based on this, this paper employs the Malmquist TFP change index — a DEA-based approach. Besides measuring technical efficiency, it is crucial to assess the evolution of TFP and efficiency through time in order to examine whether a change in the production frontier has occurred. The growth of TFP is defined as the change in output due to technological change and technical efficiency change over time. Technological change is represented by a shift in the production frontier between periods t and $t + 1$, whereas efficiency change is represented by the movement of a decision making unit (DMU) closer or further from the present and past frontiers. Technological change and technical efficiency change cannot be measured accurately using trends in annual average efficiency scores because the average scores are based on separate frontiers estimated for each year over the study period.

In 1953, Malmquist proposed a quantity index for use in consumption analysis (Malmquist, 1953). Although it was developed in a consumer context, the Malmquist quantity index has recently enjoyed widespread use in a production context, in which multiple, but cardinally measurable outputs replace scalar-valued but ordinally measurable utility. In production analysis, Malmquist productivity change index is obtained by constructing quantity indexes as ratios of distance functions, which are functional representations of multiple-output-multiple-input technology which require only input and output quantity data (Malmquist, 1953, Färe et al., 1994, Caves et al., 1982).

Malmquist indexes have a number of desirable features. They are easy to compute, as Fare, Grosskopf, and Roos (1995) have demonstrated (Färe et al., 1995). Under certain conditions they can be related to the superlative Törnqvist and Fisher ideal quantity indexes, as Caves, Christensen, and Diewert (1982) as well as Fare and Grosskopf (1992) have shown (Caves et al., 1982, Färe and Grosskopf, 1992). Another attractive feature of the Malmquist productivity index is that it decomposes total factor productivity growth into technical efficiency change and technological change (shifts in the frontier technology). Fare et al. (1994) showed that the technical efficiency change index of the geometric mean of adjacent-period Malmquist productivity indexes, derived

under the assumption of constant returns to scale, can be expressed as the product of an index of pure technical efficiency change, an index of scale efficiency change and an index of technological change (Färe et al., 1994). The value of each of these decompositions is that they provide insight into the sources of productivity change.

Following Shephard (2015), the output distance function is defined for time period t as (Shepherd, 2015):

$$D_o^t(x_t, y_t) = \inf\{\theta : (x_t, y_t / \theta) \in S_t\} \quad (2)$$

where x_t denotes the input vector, y_t denotes the output vector, and S_t denotes the production technology set that models the transformation of inputs, x_t , into outputs, y_t .

To define the Malmquist, it is necessary to define distance functions with respect to two different time periods such as

$$D_o^t(x_{t+1}, y_{t+1}) = \inf\{\theta : (x_{t+1}, y_{t+1} / \theta) \in S_t\} \quad (3)$$

This distance function measures the maximum proportional change in outputs required to make (x_{t+1}, y_{t+1}) feasible in relation to the technology in period t . Analogously, it is possible to define a distance function that measures the maximum proportional change in output in order to make (x_t, y_t) feasible in relation to the technology in period $t + 1$. This is denoted as $D_o^{t+1}(x_t, y_t)$. Thus, to calculate output-oriented Malmquist productivity change index we must calculate the four component distance functions, which will involve four LP problems.

We begin by assuming constant to scale (CRS) technology, that is,

$$\begin{aligned} [D_o^t(x_t, y_t)]^{-1} &= \max_{\phi, \lambda} \phi, \\ \text{st. } -\phi y_{it} + Y_t \lambda &\geq 0, \\ x_{it} - X_t \lambda &\geq 0, \\ \lambda &\geq 0 \end{aligned} \quad (4)$$

The remaining three LP problems are simple variants of this:

$$\begin{aligned} [D_o^{t+1}(x_{t+1}, y_{t+1})]^{-1} &= \max_{\phi, \lambda} \phi, \\ \text{st. } -\phi y_{i,t+1} + Y_{t+1} \lambda &\geq 0, \\ x_{i,t+1} - X_{t+1} \lambda &\geq 0, \\ \lambda &\geq 0 \end{aligned} \quad (5)$$

$$\begin{aligned} [D_o^t(x_{t+1}, y_{t+1})]^{-1} &= \max_{\phi, \lambda} \phi, \\ \text{st. } -\phi y_{i,t+1} + Y_t \lambda &\geq 0, \\ x_{i,t+1} - X_t \lambda &\geq 0, \\ \lambda &\geq 0 \end{aligned} \quad (6)$$

$$\begin{aligned} [D_o^{t+1}(x_t, y_t)]^{-1} &= \max_{\phi, \lambda} \phi, \\ \text{st. } -\phi y_{it} + Y_{t+1} \lambda &\geq 0, \\ x_{it} - X_{t+1} \lambda &\geq 0, \\ \lambda &\geq 0 \end{aligned} \quad (7)$$

In order to avoid selecting an arbitrary reference (benchmark) technology, the output-oriented Malmquist productivity change index between periods t and $t + 1$ is specified as the geometric mean of two Malmquist productivity indexes:

$$M_o(y_{t+1}, x_{t+1}, y_t, x_t) = \left[\frac{D_o^t(x_{t+1}, y_{t+1})}{D_o^t(x_t, y_t)} \times \frac{D_o^{t+1}(x_{t+1}, y_{t+1})}{D_o^{t+1}(x_t, y_t)} \right]^{\frac{1}{2}} \quad (8)$$

where $D_o^t(x_t, y_t)$ is the output distance function at time t , and x_t and y_t represent the input and output quantities of DMUs at time t , respectively. This represents the productivity of the production point (x_{t+1}, y_{t+1}) relative to the production point (x_t, y_t) . A value greater than one will indicate positive TFP growth from period t to period $t + 1$. Following Fare et al. (1995), the Malmquist productivity change index can be rewritten as (Färe et al., 1995):

$$M_o(y_{t+1}, x_{t+1}, y_t, x_t) = \left[\frac{D_o^t(x_{t+1}, y_{t+1})}{D_o^{t+1}(x_{t+1}, y_{t+1})} \times \frac{D_o^t(x_t, y_t)}{D_o^{t+1}(x_t, y_t)} \right]^{\frac{1}{2}} \times \frac{D_o^{t+1}(x_{t+1}, y_{t+1})}{D_o^t(x_t, y_t)} = TechCh \times EffCh \quad (9)$$

where TechCh is technological change, EffCh is efficiency change. Relative to constant returns to scale (CRS), efficiency change (EffCh) can also be decomposed into scale-efficiency change and pure-efficiency change. That is, $\text{EffCh} = \text{SEffCh} \times \text{PEffCh}$. PEffCh refers to efficiency change calculated under variable returns to scale (VRS).

In the empirical application of this approach that follows, the Malmquist productivity index is calculated using nonparametric programming techniques. Assume that there are $k = 1, 2, \dots, K$ DMUs using $n = 1, 2, \dots, N$ inputs at each time period, x_{nkt} . These inputs are used to produce $m = 1, 2, \dots, M$ outputs, y_{mkt} . All inputs and outputs are strictly positive and the number of DMUs remains constant for each time period.

The production frontier in period t is defined to be

$$\begin{aligned} S_t = \{ & (x_t, y_t) : y_{mt} \leq \sum_{k=1}^K z_{kt} y_{mkt} \ (m = 1, 2, \dots, M); \\ & x_{nt} \geq \sum_{k=1}^K z_{kt} x_{nkt} \ (n = 1, 2, \dots, N); \\ & z_{kt} \geq 0 \ (k = 1, 2, \dots, K) \} \end{aligned} \quad (10)$$

which exhibits constant returns to scale and strong disposability of inputs and outputs. The assumption of constant returns to scale may be relaxed to allow non-increasing returns to scale by adding the following constraint:

$$\sum_{k=1}^K z_{kt} \leq 1 \quad (11)$$

where z_{kt} denotes an intensity variable indicating at what intensity a particular activity may be employed in production.

Thus, as opposed to the Törnqvist index, an interesting feature of the Malmquist TFP index is that it allows productivity growth to be decomposed into technological change or technological innovation (shifts in the frontier technology) (TechCh) and changes in technical efficiency (EffCh). By calculating DEA-based Malmquist productivity change index, changes in total factor productivity over time can be attributed to three separate explanations (Giuffrida, 1999). First, the technical efficiency of an individual DMU may change, at a given scale of operation. Second, the efficiency of the DMU may change in response to a change in the scale of operation. Finally, the underlying technology may change, thereby inducing a shift in the production frontier, which will affect the efficiency of all DMUs. The Malmquist index provides estimates of each of these effects by calculating separate distance functions in each period and by varying the assumption about the available technology.

2.3 Data

The dataset used in this study is compiled from Annual Report of China's Communications Industry Statistics, China Statistical Yearbook and National Bureau of Statistics of China. The available data can be used to measure the productivity growth and technological changes of different DMUs in 2011-2015. The sample covers 31 provinces, municipalities and autonomous regions (all are called provinces henceforth) on the mainland of China. The 31 provinces under study are considered as 31 DMUs in the DEA models and they are grouped into three different regions, namely eastern, central and western, based on the official definitions found in the China Statistical Yearbook. Table 1 shows the operating environments of these 31 DMUs in 2015. As is shown in Table 1, per capita income in the eastern region was much higher than that in the other two regions in 2015. And the penetration rates of internet services and telephone services (both in terms of fixed-line and mobile services) were also much higher in the eastern region, which means that the eastern region of China has a relatively higher level of telecommunications (and economic) development.

Table 1 Operating environments of 31 DMUs (2015)

Decision-making unit (DMU)	Gross Regional Product (billion yuan in current prices)	Population (million)	Per capita GRP(yuan in current prices)	Fixed-line penetration rate(per 100 persons)	Mobile penetration rate(per 100 persons)	Internet penetration rate(%)
<i>Eastern region</i>						
Beijing	2301	21.7	106009	36.2	181.7	76.5
Tianjin	1654	15.5	76178	22.2	88.5	63.0
Liaoning	2867	43.8	132054	23.7	97.9	62.2
Shanghai	2512	24.2	115723	33.0	129.7	73.1
Jiangsu	7012	79.8	322968	24.7	100.2	55.5
Zhejiang	4289	55.4	197543	26.6	131.5	65.3
Fujian	2598	38.4	119668	23.2	108.2	69.6
Shandong	6300	98.5	290200	11.4	92.3	48.9
Guangdong	7281	108.5	335387	25.9	133.5	72.4
Hainan	370	9.1	17056	18.8	98.2	51.6
Whole region	37185	495	75157	24.5	116.2	63.8
<i>Central region</i>						
Hebei	2981	74.3	137292	13.2	82.6	50.5
Shanxi	1277	36.6	58805	12.1	88.5	54.2
Jilin	1406	27.5	64777	20.8	91.2	47.7
Heilongjiang	1508	38.1	69478	15.6	87.4	44.5
Anhui	2201	61.4	101362	12.0	68.2	39.4
Jiangxi	1672	45.7	77033	12.5	66.4	38.7
Henan	3700	94.8	170438	10.7	79.5	39.2
Hubei	2955	58.5	136113	14.9	77.4	46.8
Hunan	2890	67.8	133129	11.6	69.2	39.9
Whole region	20590	505	40790	14	79	45
<i>Western region</i>						
Inner Mongolia	1783	25.1	82135	12.9	94.7	50.3
Guangxi	1680	48.0	77398	9.2	75.0	42.8
Chongqing	1572	30.2	72396	18.6	90.8	48.3
Sichuang	3005	82.0	138430	16.5	82.9	40.0
Guizhou	1050	35.3	48377	8.9	83.3	38.4
Yunnan	1362	47.4	62732	8.0	78.9	37.4
Tibet	103	3.2	4728	10.8	82.9	44.6
Shanxi	1277	36.6	58805	12.1	88.5	54.2
Gansu	679	26.0	31277	12.5	81.0	38.8
Qinghai	242	5.9	11133	17.7	87.9	54.5
Ningxia	291	6.7	13412	12.6	95.3	49.3
Xinjiang	932	23.6	42952	21.2	86.0	54.9
Whole region	13976	370	37770	13.4	85.6	46.1
Whole country	71751	1370	52389	17.1	93.5	51.4

Source: China Statistical Yearbook 2016.

Data about the outputs and inputs of the telecommunications sector are required to measure the productivity of the sector. Telecommunications output is measured by the total revenue, and the input variables include capital and labour.

In the telecommunications sector, the appropriate variable to measure output is not obvious. Some previous studies used the number of subscribers, the total number of calls (in minutes), total revenue or turnover to measure output. Kiss (1983) argued that by using total revenue to measure telecommunications output, changes in the quality of services and the increased number of connected parties could be reflected in telecommunications charges (Kiss, 1983). This study follows Kiss's approach by using the total business revenue (in RMB or Yuan) derived from the provision of telecommunications services as a measure of output. Several other previous studies also used revenue as a proxy for the output of telecommunications (Lien and Peng, 2001, Madden and Savage, 1999, Lam and Shiu, 2008, Banker et al., 2010).

Capital and labour are the two major inputs used in providing telecommunications services. For the capital input data, different kinds of equipment and physical assets are needed in the provision of telecommunications services. Based on data availability, four major capital assets are used to measure capital input. They are the length of optical cable lines (in kilometres), the capacity of long-distance telephone exchanges (in circuits), the capacity of local office telephone exchanges (in exchange lines), and the capacity of mobile telephone exchanges (in subscribers). The capital inputs that we select is consistent with some previous studies on the telecom industry (Lam and Shiu, 2008, Madden and Savage, 1999, Majumdar, 1995, Lien and Peng, 2001). For the labour input, it is more difficult to obtain reliable data. The official data about the number of staff in the telecommunications industry at the provincial level is combined with that in the postal industry and transportation industry. Thus, we estimate the number of staff in the telecommunications sector at the provincial level according to the proportion that telecommunications employees accounted for the employees of those industry. The telecommunications industry is a representative knowledge-embedded service industry (Kang, 2006), so the estimated labour input will not affect the accuracy of the outcomes largely.

Table 2 shows the descriptive statistics for the outputs and inputs used for constructing the DEA Malmquist models in China's telecommunications industry.

Table 2 Descriptive statistics of the input and output variables 2011–2015 (n=31)

	Telecom revenue (million)	Labour (person)	Cap 1	Cap 2	Cap 3	Cap 4
2011						
Mean	37825	48776	390945	515413	14009	55366
Median	30775	43488	378032	433175	12154	44740
S.D.	30489	32707	254058	503184	10424	39246
Minimum	2386	1090	50642	34540	1270	2300
Maximum	161716	152384	1162101	2644348	47815	190767
2012						
Mean	41879	49125	477203	508122	14112	59363
Median	34519	43579	441060	411477	11902	49244
S.D.	33254	32550	325007	497595	9840	42026
Minimum	3301	1090	63145	34540	1336	3420
Maximum	176638	152293	1567817	2587636	43606	203926
2013						
Mean	50668	49600	563023	411595	13254	63406
Median	42938	44245	505633	342237	10255	52558
S.D.	40798	32412	372801	301962	9135	43518
Minimum	3965	1308	74047	16620	1337	3930
Maximum	217609	151377	1735687	1446394	40865	211481
2014						
Mean	58511	50493	664920	315595	13069	66137
Median	52066	44681	584039	224364	8907	58580

S.D.	47187	33387	463481	281664	13534	44984
Minimum	4543	1635	88892	14310	536	3930
Maximum	249354	155175	2081008	1337449	74018	214181
2015						
Mean	75311	50079	802043	268276	8530	70371
Median	69949	44354	656959	207480	7204	58941
S.D.	60863	32599	570614	209756	6017	47591
Minimum	5379	1617	115695	12870	115	4480
Maximum	315003	150432	2511543	851520	28447	220258

Note: Cap 1 = the length of optical cable lines (in kilometres); Cap 2 = the capacity of long-distance telephone exchanges (in circuits); Cap 3 = the capacity of local office telephone exchanges (in thousand exchange lines); Cap 4 = the capacity of mobile telephone exchanges (in thousand subscribers).

3. Empirical results

The output-oriented formulation is used to compute the Malmquist productivity change index to measure the change in productivity of China's telecommunications industry over the period 2011 to 2015. Table 3 reports the annual averages for the Malmquist productivity change index and the associated decompositions, including technological change (TechCh), efficiency change (EffCh), pure efficiency change (PEffCh) and scale efficiency change (SEffCh).¹

Table 3 Malmquist productivity change index

DMU	Annual averages (2011-2015)				
	EffCh	TechCh	PEffCh	SEffCh	TFPCh
<i>Eastern region</i>					
Beijing	1.000	1.110	1.000	1.000	1.110
Tianjin	0.919	1.158	0.986	0.932	1.064
Liaoning	0.872	1.175	0.871	1.001	1.025
Shanghai	0.998	1.137	0.999	0.999	1.134
Jiangsu	1.003	1.246	1.000	1.003	1.250
Zhejiang	1.000	1.218	1.000	1.000	1.218
Fujian	1.019	1.289	1.017	1.002	1.314
Shandong	0.935	1.235	0.936	0.999	1.155
Guangdong	1.000	1.209	1.000	1.000	1.209
Hainan	1.016	1.309	1.000	1.016	1.330
<i>Central region</i>					
Hebei	0.921	1.221	0.924	0.996	1.124
Shanxi	0.929	1.272	0.931	0.998	1.182
Jilin	0.946	1.260	0.952	0.994	1.191
Heilongjiang	0.888	1.177	0.899	0.988	1.045
Anhui	1.040	1.360	1.068	0.974	1.415
Jiangxi	0.993	1.234	0.992	1.001	1.225
Henan	0.987	1.289	1.014	0.973	1.272
Hubei	0.996	1.296	1.003	0.993	1.291
Hunan	0.958	1.266	0.957	1.001	1.213
<i>Western region</i>					
Inner Mongolia	0.914	1.349	0.930	0.983	1.232

¹ The DEA-based Malmquist index are estimated by DEAP version 2.1 {Coelli, 1996 #281}.

Guangxi	0.972	1.137	0.969	1.003	1.105
Chongqing	1.017	1.337	1.015	1.002	1.361
Sichuang	0.963	1.371	1.000	0.963	1.320
Guizhou	1.061	1.166	1.060	1.001	1.237
Yunnan	1.009	1.274	1.009	1.001	1.285
Tibet	1.000	1.351	1.000	1.000	1.351
Shanxi	1.016	1.268	1.022	0.994	1.288
Gansu	1.043	1.291	1.060	0.984	1.347
Qinghai	1.043	1.439	1.000	1.043	1.501
Ningxia	1.006	1.259	1.000	1.006	1.266
Xinjiang	0.932	1.275	0.947	0.983	1.188
Eastern region	0.975	1.207	0.980	0.995	1.177
Central region	0.961	1.263	0.970	0.991	1.214
Western region	0.997	1.291	1.000	0.997	1.287
All regions	0.979	1.255	0.985	0.994	1.229

A value greater than one for TFP and its components represents an improvement in performance, whilst a value less than one represents declining performance. As in shown in Table 3, the average productivity growth rate in China's telecom industry was 22.9% from 2011 to 2015. The average technological change is 25.5%, whilst the average efficiency change is negative (2.1%). The results indicate that, during the study period, technological innovation exclusively contributed to productivity improvements in the telecom industry by significantly expanding the production possibilities set. That is to say, productivity growth in China's telecom industry was driven by industry-wide technological progress rather than improvements in efficiency between 2011 and 2015.

Of the 31 provinces in the sample, 11 provinces showed a slight improvement in efficiency throughout the 2011-2015 period, while 16 provinces declined and 4 provinces operated just efficiently. Technological change among provinces showed considerable variability over the period, ranging from a high of 43.9% per annum (Qinghai) to a low of 11.0% per annum (Beijing). Examination of individual province also shows that the highest productivity growth rates occurred in the western and central region, Qinghai (50.1% per annum), Anhui (40.5%) and Chongqing (36.1%). On average, TFP growth is highest for the subsample of western region (28.7% per annum), while the growth rate for the eastern region is the least (17.7% per annum). This results indicate that regions with relatively low levels of telecommunications (and economic) development have a greater chance and ability of enhancing telecommunications productivity growth through technological catch-up.

Table 4 Malmquist TFP index summary of annual averages during 2011 to 2015

Year	EffCh	TechCh	PEffCh	SEffCh	TFPCh
2012	1.006	1.068	1.006	1.000	1.074
2013	0.916	1.293	0.934	0.981	1.185
2014	1.017	1.293	1.007	1.010	1.315
2015	0.982	1.390	0.993	0.988	1.364

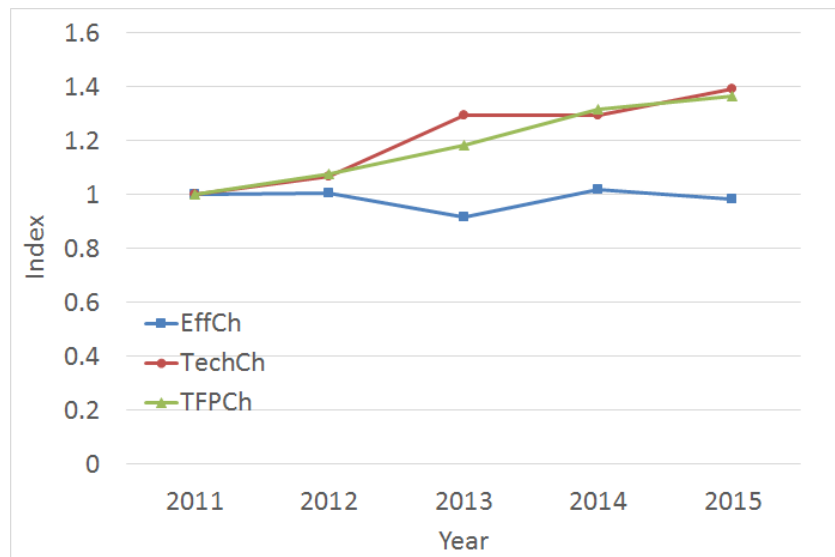


Figure 1 Malmquist TFP index trend versus technological change and efficiency change during 2011 to 2015.

Table 4 reports the Malmquist TFP index summary of annual averages during 2011 to 2015 and Figure 1 show the Malmquist TFP index trend versus technological change and efficiency change during this period. Note that 2012 in Table 4 refers to the change between 2011 and 2012, similarly hereinafter, and in Figure 1, 2011 represents the base year and equals the value of unity. As is shown in Figure 1, Malmquist TFP index (TFPCh) and technological change index (TechCh) roughly followed the same synchronized rising trajectory, while technical efficiency index (EffCh) basically remained stable around one during the period 2011 to 2015. This graph demonstrates more clearly that total factor productivity growth is driven exclusively by technological innovation rather than technical efficiency.

Table 5 Comparison of the indexes between the period of 2011-2013 and the period of 2013-2015

	EffCh	TechCh	PEffCh	SEffCh	TFPCh
2011-2013	0.960	1.175	0.970	0.990	1.128
2013-2015	0.999	1.340	1.000	0.999	1.339

Then, the DEA-based Malmquist productivity index and its decompositions are calculated for the data of the period 2011 to 2013, and 2013 to 2015 separately. The comparison results of productivity change, technological progress and relative efficiency between these two periods are reported in Table 5. We observe that China's telecom industry experienced on average an extra 21.2% improvement in productivity and an extra 16.5% in terms of technological progress per annum during the period 2013 to 2015 than 2011 to 2013, which means that the bulk of the productivity improvement and technological change during our sample period occurred during the latter half. This results are due to the fact that more emerging technologies such as 4G deployed and developed in China in the latter part of our sample period, technological progress directly led to the great improvement in industrial productivity.² In addition, this result means telecom operators have been able to tap into increased demand for their services over time due to network effects (Majumdar, 1995).

4. Conclusions and policy implications

In this paper, the DEA-based Malmquist productivity indexes are calculated to measure productivity change, technological change, and relative efficiency change in China's telecommunications industry for the period spanning the years from 2011 to 2015. The data used in this study involve observations from 31 provinces, municipalities and autonomous regions. Our study provides new empirical evidence on productivity growth and its drivers in the telecom industry during

² The Ministry of Industry and Information Technology (MIIT), China's sector-specific regulatory body in telecommunications, issued 4G TD-LTE licenses to three domestic operators on December 4, 2013.

a period when the industry experienced substantial changes in technology. The empirical results show that China's telecom industry has experienced substantial productivity growth and technological progress during the study period. Based on our sample, the productivity improved by 22.9% per annum, which was exclusively due to an average of 25.5% technological progress in the industry production function, while the average efficiency change is slightly negative. Our results also indicate that regions with relatively low levels of telecommunications (and economic) development have a greater chance and ability of enhancing telecommunications productivity growth through technological catch-up. In addition, we find that the industry experienced significantly higher productivity growth and technological progress in the later sample period between 2013 and 2015 than in the early period between 2011 and 2013.

The importance of technological progress on industry performance shows that telecom regulators need to employ incentive regulation which can promote technological innovations to propel the sustainable development of telecommunications industry. Even if efficient and creative in matching supply and demand, market is usually incapable of organizing the risky, long-term and complex R&D processes which are necessary for creating radical technological innovations (Chesbrough and Teece, 1996). Market is inherently flawed in stimulating technological innovation. More importantly, technological progress in telecommunications not only plays a key role in the productivity growth of the telecommunications industry, but also can strongly promote the development of other industries and help produce huge externalities to the overall productivity (Quinn and Baily, 1994, Correa, 2006, Datta* and Agarwal, 2004). From this standpoint, the government should create an environment that is conducive to technological innovation and adopt regulatory policies that stimulate technological innovations. Telecommunications regulators need to realize that technological innovation is the only essential way to reduce the costs and improve the service quality of telecommunications services, in the condition where technical level is not mature enough, relying solely on structural control to restructure the industry and promote competition, or using price regulation to influence the competitive relationship and profitability of operators cannot help to promote the efficient development of telecommunications industry.

As government regulation is the institutional condition of technological innovation, which is the fundamental driving force for the development of the telecommunications industry, government should play its own important role in promoting technological innovation in the telecommunications industry, eliminating factors that may hinder the pace of technology progress and establishing incentive systems that are conducive to technological innovation in an effort to promote the continuous development of telecommunications technology. As such, the overall productivity of the telecommunications service industry can be improved constantly.

Acknowledgement

This paper was supported by Major Program of the National Social Science Foundation of China under Grant No.15ZDB154 and National Basic Research Program of China (973 Program) under Grant No. 2012CB315805.

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