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Telecommunications, productivity and regional dependence: a comparative analysis between the Brazil, China and main developed regions in the post-reform period

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Abstract

In the last two decades, new technologies and the rapid growth of the telecommunications sector have changed production and trade relations in world economic systems. Regional dependence on the level of productivity, supply and demand of telecommunications has increased worldwide. Our study analyzes the changes in total factor productivity (TFP) of telecommunications and verifies its global and regional importance between 2000 and 2014. We apply the TFP decomposition and extraction technique in an input–output model. The main findings suggest improved efficiency has resulted in TFP gains in developed countries, whose variations were lower than those of Brazilian telecommunications, which exhibit a low capital–labor ratio. Moreover, global and regional dependence is more sensitive to supply than the demand for telecommunications. Although the main effects on the regional output are intraregional, the backward and forward effects denote a heavy regional reliance on USA telecommunications and reciprocity between China and European countries. The increase in telecommunications influenced by national policies in countries with little emphasis on regional composition should generate minor marginal gains in TFP, even with the gain in productive efficiency. These policies are also expected to reduce the dependence on American and Chinese telecommunications.

Keywords: Telecommunications, Productivity, Regional dependency, Input–output model

1 Background

The 1990s were marked by changes in the telecommunications sector, expanding, decentralizing and regionally spreading the offer of this type of service in the world. Trade liberalization measures, privatization policies and technological changes in the sector were the main factors influencing the rapid expansion of telecommunications, which consequently changed the structure of global trade and production (Inklaar and Timmer 2007; Lam and Shiu 2010; Los *et al.* 2015; Silva and Perobelli 2018). New technologies with

satellite development, fiber optics, digital electronic circuits, mobile technology and the Internet have enabled, facilitated and expanded communication and information exchange. These technological advances thus narrowed time horizons and increased the spatial coverage of public and private decision-making, favoring the global fragmentation of productive processes¹ and the commercial and productive integration of world's major economies (Athreye and Cantwell 2007; Krammer 2014). A mutual relationship emerges, that is, while telecommunications services with their new technologies intensify productive fragmentation around the world, they are also shaped by increasing productive globalization and expanding international trade.

In this new world order with a fast rhythm of change, fluctuations in the levels of primary factor productivity and productive efficiency in telecommunications activity began to influence the relative competitive trends of the economic regions in the international trade. Since the 1990s, the spread of mobile telecommunications services has improved the sector's efficiency and productivity, and has also attracted private investment (domestic and foreign investment) to the telecommunications sector (Vijselaar and Albers 2004; Ida and Kuroda 2009). The development of mobile telecommunications has become an important driving force of global economic growth in recent years (Lam and Shiu 2010; Chakraborty and Nandi 2011). In a contemporary period, the 5.0 or 4.0 technologies digital have adapted to the needs of manufacturing industries (a new industrial stage), offering patterns such as smart manufacturing, smart products, smart supply chain and smart working, internet of things, cloud services, big data and analytics (Frank et al. 2019). For these reasons, developed and developing countries have been directing policy instruments that can promote the expansion and modernization of telecommunications in the national territory (Dvornik and Sabolić 2007; Pradhan et al. 2017). The world began to see information taking place in a similar way to energy as an important input in the face of the advances and diffusion of microelectronics and telecommunications technologies (Werthein 2000).

In general, post-reform telecommunications growth in many countries² may have changed the regional composition of the global supply of this type of service, but there are doubts about variations in their sectorial productivity. The results of empirical studies, although they may capture the relationship between telecommunications and economic growth (Gruber 2001; Inklaar and Timmer 2007; Lam and Shiu 2010; Nadiri et al. 2018), and the reforms' effects on sector productivity in many countries (Vijselaar and Albers 2004; Inklaar and Timmer 2007), do not point to the reasons why variations in telecommunications productivity occur within certain world economic systems, especially in terms of productive efficiency and primary factor productivity in recent years. After the reform period, some studies seek to measure fluctuations in the sector's total factor productivity (TFP) for several countries using a partial equilibrium approach (Resende 2008; Kang 2009). However, analysis of these applied research do not take into account the domestic and imported input purchasing relationships in the sector cost structure in

¹ Originating the concept of global value chains (GVCs), a productive system organized in sequential steps (Los et al. 2015).

² Global movement after 1998, a period of major reforms in the sector (new technologies, market openings and privatization).

an interdependent system of world regions, which are asymmetric and changeable over the years with different stages of development.

Moreover, these applied studies do not point to the relative importance of telecommunications in the productions of world's major economies, especially when it is exploited through the direct and indirect channels of international production and trade links established in economic systems. In other words, little is known of the global and regional dependence on the supply and demand of telecommunications activity in an increasingly globalized world integrated with changing patterns of trade and production. It is expected that with the growth of telecommunications and changes in its regional composition of supply in the world, in addition to changes in production structures and international trade, this dependence on the sector has changed and, in some cases, become more or less intensive. This paper fills these two central gaps, i.e., the study conducts a comparative analysis on telecommunications TFP and verifies the relative importance of the sector in the world and in Brazil, China, and main developed economies. To accomplish this task, we use TFP decomposition and hypothetical extraction techniques from interregional input–output matrices, available annually between 2000 and 2014, including the post-reform sector period. The analyses are performed for the eight largest telecommunications-producing economies. Moreover, the analysis does not focus on the companies and market composition of the telecommunications sector, but on a comparative analysis between the main economies of the world, including Brazil.

In addition to this introductory section, this article is organized into five further sections. Section 2 briefly reviews previous research on telecommunications and economy. Section 3 describes the empirical strategy, divided into two steps, sequentially addressing the two techniques of the input–output model. Section 4 discusses the results of TFP decomposition in world telecommunications and the relative importance of the sector considering differentiated production and trade patterns. Finally, Sect. 5 presents the final remarks, highlighting the main conclusive results.

2 Telecommunications and evidence around the world: review of approaches

The literature on the relationship between telecommunications and the economy is broad, and the approach is mainly subdivided into assessments of infrastructure investments, productivity, and economic effects in a particular country or group of world regions. To this end, studies generally use econometric models, data envelopment analysis (DEA) and input–output models, which recognize the direct and indirect channels of production and consumption links established in the economic system. In the econometric approach, some applied research commonly compares telecommunications between countries from the investment perspective—e.g., Aschauer (1989) and Cronin et al. (1993)—or through phone density data—fixed and mobile—and broadband connection—fixed and mobile, e.g., Sridhar and Sridhar (2009). Chakraborty and Nandi (2011) verified the impact of telecommunications infrastructure investments on 93 developing countries in Asia, Europe, Africa and Latin America from 1985 to 2007. The authors' research also indicated the bi-directional relationship between telecommunications growth and economic growth. However, the less developed the economy, the greater the effect. Using sector data for USA and European Union (EU) industries from 1980 to 2000, Dimelis and Papaioannou (2011) evaluated the impact of the growth of the

information and communication technologies (ICT). The authors' results vary depending on the period, the region, as well as the type of industry considered. The ICT effect for the EU was strong in the early 1990s and weakened afterwards, as opposed to the USA where it strengthened in the late 1990s. However, it seems that the productivity effects of ICT are mainly present in the industries which are either ICT producers or heavy. Latif et al. (2018) explored the dynamic relationship between ICT, foreign direct investment (FDI) and economic growth incorporating trade and globalization for the BRICS³ economies in the 2000–2014 period. Findings indicated that ICT, FDI and globalization positively contribute to economic growth. There is a bi-directional causality between GDP and FDI, globalization and economic growth, and trade and economic growth.

Other studies sought to assess the importance of telecommunications on the productivity level of different countries, especially after the growth of mobile telecommunications. Lam and Shiu (2010), for instance, evaluated the telecommunications industry scenario in more than 100 countries in all regions of the world after 1998, a period of major sector reforms. The results indicated the presence of a bi-directional relationship between real GDP growth and telecommunications sector development (measured by the density of fixed and mobile subscribers per 100 inhabitants) in European and high-income countries. They also concluded that in countries where the sector operated in full competition and was privatized, they tended to have higher TFPs. More specifically, Niebel (2018) analyzed the effects of ICT productivity on the economic growth of developing, emerging and developed countries. His regressions do not reveal statistically significant differences in the output elasticity of ICT between these three groups of countries and concluded that developing and emerging countries are not gaining more from investments in ICT than developed economies, calling into question the argument that these countries are 'leapfrogging' through ICT.

With a DEA approach, Tsai et al. (2006) compiled diverse efficiency measures to characterize the productivity efficiency ranked leading global telecom operators and showed that Asia–Pacific telecom operators have better productivity efficiency than those in Europe and America but the differences are not significant. It has been concluded that competition in the global telecom market will continue to be tied to the enhanced productivity efficiency. In this same approach category, Lien and Peng (2001) examined the production efficiency of telecommunications in 24 OECD countries during the 1992–1995 period and concluded that competition in telecommunications tends to be associated with enhanced production efficiency. In turn, Lam and Shiu (2008) analyzed the productivity performance of China's telecommunications sector and concluded that labor redundancy and excess capacity of long-distance optical cable lines are major problems in China's telecommunications sector.

Some applied research has been using input–output models to assess the relative importance of the telecommunications sector through the use of coefficient analyses or structural changes in the sector over a selected period for a set of countries. Rohman (2013), for example, analyzed the importance of ICT sectors for economic performance

³ BRIC is an acronym used to represent four countries that have similar economic development, that is, Brazil, Russia, India, and China.

in European economies, comparing such performance at two time intervals (2000–2005; 1995–2000). Similarly, Rohman and Bohlin (2014) evaluated the role of telecommunications in Indonesia between 1975 and 2008 by comparing structural changes in the telecommunications sector between pre- and post-cellular times. Hong et al. (2016) applied a structural input–output decomposition to analyze ICT activity in South Korea between 1995 and 2009 in terms of structural changes and sector growth factors. Inklaar and Timmer (2007) conducted an exploratory analysis of sectorial measures to compare sectorial productivity across seven high-income economies, highlighting changes in the ICT sector. Their results indicated that productivity levels were relatively similar in European and Anglo-Saxon countries, but there were differences in production structures.

In general, the empirical results from different approaches point to an increasing role of the telecommunications sector in economic growth and in developed and developing countries, albeit in a different way and with varying degrees. Especially the effects in developing countries are still unidirectional so that only expansions in telecommunications have positive effects on average income, but the reciprocal is still doubtful. In addition, there is no consensus in the literature between productivity gains and the expansion of the offer of telecommunications services between world regions. Our paper contributes in this direction by providing a comparative analysis between Brazil, China and the main developed regions. These two developing economies may have taken advantage of countries with lagging technology. Moreover, unlike the study of Inklaar and Timmer (2007), our paper evaluates and compares the variation in the efficiency and productivity of primary factors in telecommunications in interregional economic systems. Unlike Lam and Shiu (2010), our paper is more comprehensive and identifies the factors that promoted TFP variations from the telecommunications production process itself. The results achieved may highlight the structural differences between the world regions, both coming from and transmitted from the domestic and external markets. Thus, our conclusive results may complement the findings of Lam and Shiu (2010) and Chakraborty and Nandi (2011), by pointing out whether the expansion of the telecommunications services supply would be associated with TFP gains and whether the effects would be relatively greater in developing countries.

3 Methodological strategy and database

The analysis of the telecommunications sector's role in the world's major economies proceeds in two successive steps. In the first one, the TFP decomposition technique is applied in the telecommunications sector of the economic regions. Then, the hypothetical extraction technique is used in an interregional input–output approach. This methodological articulation allows for a more detailed analysis of the efficiency of the sector over the years, as well as its relative importance in the world and in the main regions considering its production and trade structures.

3.1 Total factor productivity (TFP)

Total factor productivity (TFP) is defined as the total output growth not attributed to increased inputs. According to the method of Miller and Blair (2009), one can define the output (x_j) as:

$$x_j = \sum_{i=1}^n a_{ij}x_j + v_jx_j = \left(\sum_{i=1}^n a_{ij} + v_j \right) x_j, \tag{1}$$

in which a_{ij} is the technical coefficient of production such that, $a_{ij}x_j$ denotes the use of the input i in the production of sector j ; and v_j represents the coefficient of value added. Differentiating Eq. (1):

$$dx_j = d \left[\left(\sum_{i=1}^n a_{ij} + v_j \right) x_j \right] = \left[\left(\sum_{i=1}^n a_{ij} + v_j \right) dx_j \right] + \left(\sum_{i=1}^n da_{ij} + dv_j \right) x_j. \tag{2}$$

Thus, the growth rate of TFP, τ_j , is now defined by the variation of the sector’s production in the period, i.e.:

$$\tau_j = - \left(\sum_{i=1}^n a_{ij} + v_j \right) dx_j. \tag{3}$$

If the value is negative for τ_j , there is a decline in productivity. Moreover, from Eqs. (2) and (3) it is possible to express them in finite difference form for two sequential periods., $t = 0, 1$, such that $dx_j \cong \Delta x_j = x_j^1 - x_j^0$, $da_{ij} \cong \Delta a_{ij} = a_{ij}^1 - a_{ij}^0$ and $dv_j \cong \Delta v_j = v_j^1 - v_j^0$:

$$x_j^1 - x_j^0 = \Delta x_j = \Delta \left[\left(\sum_{i=1}^n a_{ij} + v_j \right) x_j \right] = \left[\left(\sum_{i=1}^n a_{ij} + v_j \right) \Delta x_j \right] + \left(\sum_{i=1}^n \Delta a_{ij} + \Delta v_j \right) x_j. \tag{4}$$

Therefore, the finite difference form of Eq. (3) becomes:

$$\tau_j = - \left(\sum_{i=1}^n a_{ij} + v_j \right) \Delta x_j, \tag{5}$$

or in matrix terms:

$$\boldsymbol{\tau} = - \left[(\mathbf{i}' \Delta \mathbf{A})' + \Delta \mathbf{v} \right] \left[\left(\sum_{i=1}^n a_{ij} + v_j \right) \Delta x_j \right], \tag{6}$$

in which $\mathbf{A} = [a_{ij}]$ is the technological coefficients matrix, $\mathbf{v} = [v_j]$ is a vector of structural coefficients of value added and \mathbf{i} is a column vector of ones. The relative productivity change rate for an initial product is broken down into two parts: one of efficiency, $(\mathbf{i}' \Delta \mathbf{A})'$, and another of the production factors, $\Delta \mathbf{v}$. Thus, it becomes possible to distinguish the part of the product change attributed to the efficiency gains by the use of intermediate inputs (technological) and the part that can be assigned to the production factors.

3.2 Hypothetical extraction

The hypothetical extraction approach aims to assess the relative importance of a sector or region in the production of the economy (Miller and Blair 2009). In our case, the objective is to verify the effects on output from the telecommunications sector’s extraction of the regions considered. As an interregional input–output model is used, the

sector was extracted in each region one at a time. Such strategy allows not only the effect on the output of the economic system when the sector of a specific region is removed to be obtained, but also the effect on the output of the same region that had the sector extracted and on the output of the other regions separately. This method provides indications about the economy’s relative dependence structure on purchases (demand) and sales (supply) (Miller and Lahr 2001). Our method description was made considering the interregional input–output approach, differing from the procedures presented by Dietzenbacher et al. (1993) and Perobelli et al. (2009) about the regional extraction method. Thus, if we assume an economy with two regions, L and M , and n sectors in each region, the input–output model can be represented as⁴:

$$\mathbf{x} = \mathbf{Z} + \mathbf{f}, \tag{7}$$

in which $\mathbf{x}' = [\mathbf{x}^L \ \mathbf{x}^M]$ is the vector of sectorial output; $\mathbf{f}' = [\mathbf{f}^L \ \mathbf{f}^M]$ corresponds to the final demand matrix;⁵ both matrices partitioned by regions L and M ; and $\mathbf{Z} = \begin{bmatrix} \mathbf{Z}^{LL} & \mathbf{Z}^{LM} \\ \mathbf{Z}^{ML} & \mathbf{Z}^{MM} \end{bmatrix}$ refers to the intermediate consumption matrix so that the sub-matrices \mathbf{Z}^{LM} and \mathbf{Z}^{ML} represent the interregional flows, the sub-matrices \mathbf{Z}^{LL} and \mathbf{Z}^{MM} represent the intraregional flows.

The technological coefficient matrix is defined by $\mathbf{A} = \mathbf{Z}(\hat{\mathbf{x}})^{-1}$, in which $\hat{\mathbf{x}}$ is the diagonalized output vector. Thus, we can rewrite Eq. (7) as:

$$(\mathbf{I} - \mathbf{A})\mathbf{x} = \mathbf{f}, \tag{8}$$

so that \mathbf{I} is the identity matrix. Thus, solving Eq. (8), we have:

$$\mathbf{x} = \mathbf{B}\mathbf{f}, \tag{9}$$

in which $\mathbf{B} = (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse matrix. Assuming that $\Delta\mathbf{f}^M = \mathbf{0}$ and $\Delta\mathbf{f}^L = \mathbf{0}$, we reached, respectively:

$$\mathbf{x}^L = (\mathbf{I} - \mathbf{A}^{LL} - \mathbf{A}^{LM}\mathbf{B}^{MM}\mathbf{A}^{ML})^{-1}\mathbf{f}^L, \tag{10}$$

$$\mathbf{x}^M = (\mathbf{I} - \mathbf{A}^{MM} - \mathbf{A}^{ML}\mathbf{B}^{LL}\mathbf{A}^{LM})^{-1}\mathbf{f}^M, \tag{11}$$

where $\mathbf{B}^{MM} = (\mathbf{I} - \mathbf{A}^{MM})^{-1}$ and $\mathbf{B}^{LL} = (\mathbf{I} - \mathbf{A}^{LL})^{-1}$.

The traditional approach of the extraction method presupposes the suppression of a sector or region from the input–output framework. Alternatively to the system transformation to recognize one less sector or region in the system, it is possible to compute zero values in the intermediate input flows. We adopted this strategy, which has the advantage of maintaining the original size of the system in terms of number of sectors and regions. It facilitates the zero-computation of the telecommunications sector’s intermediate input flow separately for each region.

The extraction of a particular sector j (column) of region L , for instance, means nullify the corresponding value for the whole z_{ij}^{*L} in the system (7) (i.e., they can simply be replaced

⁴ We can also consider that L is a region and M the rest of the economy.

⁵ For more details, see Miller and Blair (2009).

by zeros). With this extraction, we can calculate the new matrix \mathbf{A} , called $\bar{\mathbf{A}}$, and the new matrix \mathbf{B} , defined as $\bar{\mathbf{B}}$. Thus, the matrix form in (9) is redefined as:

$$(\mathbf{I} - \bar{\mathbf{A}})\bar{\mathbf{x}} = \mathbf{f}. \tag{12}$$

By extracting sector j from in each region only, the original matrix \mathbf{A} is altered due to the change in sub-matrices \mathbf{A}^{LL} and \mathbf{A}^{ML} . In these sub-matrices, the column for sector j is null. In (10) and (11), the output vector of region L considers the structure of both sub-matrices and the output vector of region M considers the structure of the second sub-matrix. Therefore, even if extraction occurred in one sector in one region, output from the other region is affected. In this way, the new output vector of the “reduced economy”, $\bar{\mathbf{x}}$, is:

$$\bar{\mathbf{x}} = \bar{\mathbf{B}}\mathbf{f}. \tag{13}$$

In which $\bar{\mathbf{B}} = (\mathbf{I} - \bar{\mathbf{A}})^{-1}$. The output of each region is defined, respectively, by:

$$\bar{\mathbf{x}}^L = \left(\mathbf{I} - \bar{\mathbf{A}}^{LL} - \mathbf{A}^{LM}\mathbf{B}^{MM}\bar{\mathbf{A}}^{ML} \right)^{-1} \mathbf{f}^L, \tag{14}$$

$$\bar{\mathbf{x}}^M = \left(\mathbf{I} - \mathbf{A}^{MM} - \bar{\mathbf{A}}^{ML}\mathbf{B}^{LL}\mathbf{A}^{LM} \right)^{-1} \mathbf{f}^M. \tag{15}$$

Therefore, the difference between \mathbf{x} and $\bar{\mathbf{x}}$ provides the extraction effect of sector j in region L that is, $\bar{\mathbf{x}}^L - \mathbf{x}^L$ would measure j 's importance to the remaining sectors in the L economy, for example. The difference between $\bar{\mathbf{x}}^M - \mathbf{x}^M$ represents the effect on output of the rest of the economy due to the extraction of one of the sectors of the other region of the economy. In general, this analysis refers to the backward effects on the economic system of sector j .

The other analysis that can be done is to exclude sales of a given input to the other sectors of the region itself and of the rest of the economy. In this case, the assessment would be on the effects of a change in the input supply structure i of a region, whose analysis indicates the forward effects (supply). To do so, the allocation matrix is initially defined, $\mathbf{Q} = (\hat{\mathbf{x}})^{-1}\mathbf{Z}$, where the matrix \mathbf{Q} also has interregional and intraregional coefficients, as in matrix \mathbf{A} . Consequently, one has that the output vector is defined as:

$$\mathbf{x}' = \mathbf{x}'\mathbf{Q} + \mathbf{v}', \tag{16}$$

in which \mathbf{v}' is the row vector of primary inputs. Solving the above equation:

$$\mathbf{x}' = \mathbf{v}'\mathbf{G}, \tag{17}$$

such that $\mathbf{G} = (\mathbf{I} - \mathbf{Q})^{-1}$ is the Gosh inverse matrix.

Equations (16) to (17) are analogous to the interregional input–output approach presented above, however they represent the input–output model from the supply perspective, as opposed to the previous one based on demand. With the extraction of sales of sector j in each region, the new economy output vector, $\bar{\mathbf{x}}'$, is:

$$\bar{\mathbf{x}}' = \mathbf{v}'\bar{\mathbf{G}}. \tag{18}$$

The forward effect on output is given by the difference $(\bar{\mathbf{x}} - \mathbf{x})'$, such that $(\bar{\mathbf{x}}^L - \mathbf{x}^L)'$ represents the forward effect on output of the same region in which one of its sectors was extracted and $(\bar{\mathbf{x}}^M - \mathbf{x}^M)'$ corresponds to the forward effect on output of the rest of the economy due to the extraction of one sector from the other region of the economy.

3.3 Database

To apply the TFP hypothetical extraction and decomposition techniques, input–output matrices were used at current prices and at the previous year's prices from the *World Input–Output Database*—WIOD (Dietzenbacher et al. 2013). There are two versions of time series on WIOD. One was launched in 2013 and provides data from 1995 to 2009, but recognizes only the communications sector and therefore does not discriminate against telecommunications from other activities in this sector. However, the tables available in the version released in 2016, which are already in the new reference of the System of National Accounts 2008, cover the period between 2001 and 2014 and explicitly recognize the telecommunications sector and are therefore more appropriate for the scope of our study. According to Arto and Dietzenbacher (2014), WIOD data at constant prices from the previous year are adequate and necessary to measure technology changes year by year. For this reason, the WIOD database was chosen instead of global multi-regional input–output (MRIO), which does not provide tables from the previous year's price, as indicated by Hoekstra et al. (2016).

Dietzenbacher et al. (2013) described the sources of information used and the balance sheet procedures for estimating the annual matrices (so-called SUT–RAS method). The national supply and use tables (SUTs) were derived from statistics published by the National Statistical Institutes. Time series of SUTs have been derived for two price concepts: basic prices and purchasers' prices. Basic prices reflect all costs borne by the producer, whereas purchasers' prices reflect the amounts paid by the purchaser. Supply tables are always in basic prices and often have additional information on margins and net taxes by product. World input–output tables (WIOTs) of the previous year (pyp) was prepared on gross output deflators from the National Accounts of each country, implicitly deflating imports by the exporters' gross output deflators. Then, exchange rates used applied were collected from the International Financial Statistics database of the International Monetary Fund (IMF) to convert national values into of USA dollars (Dietzenbacher et al. 2013). The WIOD Socio Economic Accounts provides capital stocks, but it is measured in in millions of national currency. Therefore, the WIOTs do not provide the inputs on physical units, but the values indicate the physical volume because the study properly used the series of WIOTs in pyp for the TFP decomposition technique. Moreover, this TFP decomposition considers not only the productivity of the labor force, but also the efficiency of the use of capital (Miller and Blair 2009).

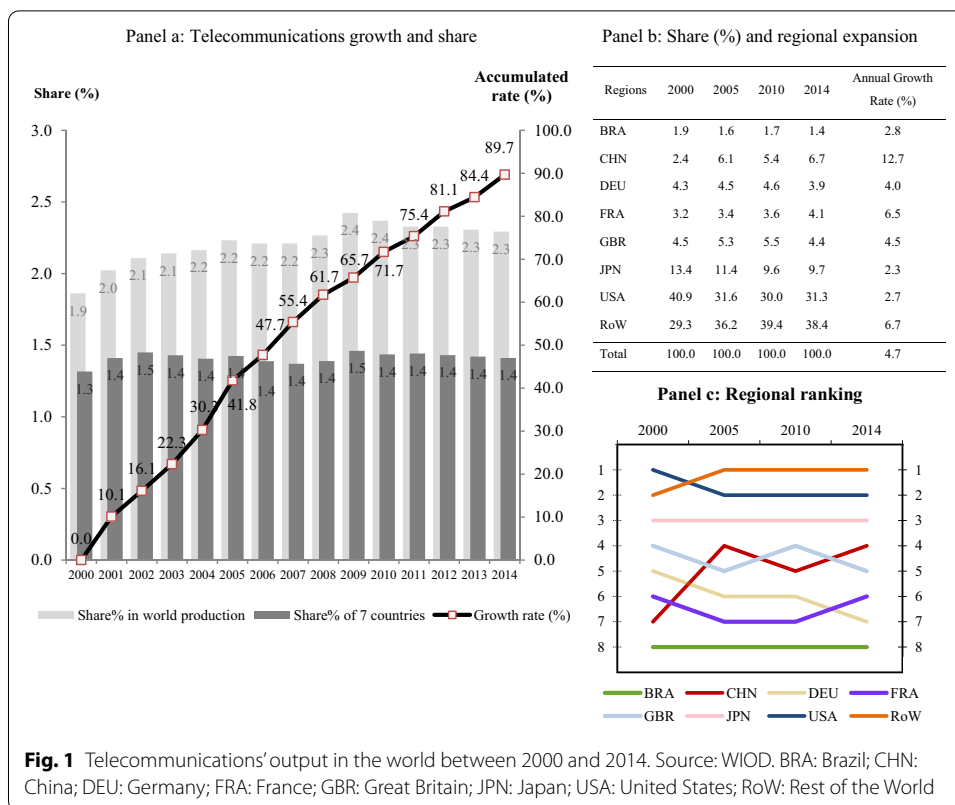
Originally, data from the 2016 WIOD version were available for 43 countries and the rest of the world, and the sectoral structure consists of 56 economic activities. However, for the purpose of our research, they have been scaled to 16 economic activities to facilitate analysis and provide a more general view of the results. In addition, we selected Germany (DEU), Brazil (BRA), China (CHN), France (FRA), Great Britain (GBR), United States (USA), Japan (JPN), and Rest of the World (RoW)—a regional aggregation of the other international regions recognized in the WIOD. The selection criterion took into

account the eight largest telecommunications-producing economies. These countries are also the largest economies in the world, but each has specific sectoral characteristics, distinct interregional interdependencies, as well as territoriality, which differently influence interactions with the telecommunications sector.

The telecommunications sector comprises the provision of mobile and fixed telephony services, multimedia communication, radio broadcasting and subscription channels, solution and equipment providers; companies providing high added value services. The provision of this type of service is divided into three layers. The Physical Layer—covers the manufacture and administration of mechanical, electrical, optical parts, for the management of communication network connections—the Transport Layer—corresponds to the transfer and manipulation services of data between networks in order to ensure that the contracted telecommunication service reaches the end user properly—and the Applications Layer—responsible for providing value-added services specialized in facilitating communication to users on different platforms (Council 2006). Although the first layer is made up of companies whose assembly lines supply the equipment essential for the sector to function, such as manufacturers of chips and electronic boards aimed at telecommunication products (e.g., Intel, Qualcomm and Broadcom) and network equipment (e.g., Siemens, Huawei and Alcatel); and the third facilitates the usability of telecommunications networks, through the availability of web browsing, e-mails and real-time communication (e.g., Microsoft—Skype and Facebook—WhatsApp; among others). Companies that sell on digital platforms, such as eBay, in Chile, Jordan, Peru and South Africa are younger than companies that operate offline in the country. In Morocco, the Anou handicraft platform makes it possible for rural artisans to sell their products globally. Global electronic commerce began to spread in the online environment, as the platforms solved the problems of trust and information by implementing systems for feedback and ranking of purchases, in addition to having mechanisms for the custody of payments and dispute resolution. The facilitation of trade caused by the internet has had an impact both on the goods market and on the services market. Service providers can be local, regional and global.

To assist with the comparative analysis in the following section, Fig. 1 illustrates the representativeness and growth of telecommunications production in the world (panel a), as well as the regional composition of telecommunications services over selected periods (panel b). Between 2000 and 2014, telecommunications output in the world grew by an average of 4.7% per year and almost doubled between 2000 and 2014. This expressive growth is due to the global movement after 1998, a period of major reforms in the sector (new technologies, market openings and privatization),⁶ as well as the spread of mobile telephony in the 2000s, making it one of the most widely used services in the world (Heber and Fischer 1997). By the end of 2016, the industry linked seven billion people—95% of the world's population—to the mobile phone network (World Bank 2016; World Bank Group 2016).

⁶ By the end of 1998, the proportion of privatized telecommunications companies had risen to 42% in 167 countries. As a result, competition in the supply and quality of services has grown, and the state is only responsible for regulating this sector, mediating the interests of investors and users (Li and Xu 2002).



Nevertheless, the growth of telecommunication services has been greater than the expansion of world supply of other productive sectors over the years, thus registering an upward trajectory of sectoral participation in global production. Between 2000 and 2014, the share of the offer of this type of service increased by approximately 0.43%, i.e., from 1.9% to 2.3% in the period (the Appendix Table 5 reports the telecommunications' share in each region). The relative share of the seven most telecommunication-providing countries in the world was almost stable over the same period, which seems to indicate that the largest representation of telecommunications in world production was due to the expansion of these services in other countries of the world (Rest of the World). This statement can be well evaluated when analyzing the regional composition of telecommunications production in the world (Fig. 1b). In this regional composition, China (CHN), France (FRA) and Rest of the World (RoW) gained relative participation. The average annual growth rate of national production in these regions with the supply of telecommunications between 2000 and 2014 registered 3.13% (at constant price). Without telecommunications, this same rate reached 3.10% in the period. The Chinese share, for example, expanded by 4.3% between 2000 and 2014, making it the seventh to fourth largest telecommunications provider in the world (Fig. 1c). On average, Chinese telecommunications grew 12.7% per year. This significant result was due to movements that changed the configurations of the Chinese telecommunications market, beyond the investments made in the 1990s (Yu et al. 2008; Chakraborty and Nandi 2011).

Over the past two decades, China has introduced a number of policies to reform the sector, including the creation of new competitors and organizational restructuring.

However, the country's entry into the World Trade Organization (WTO) in 2001 enabled foreign investment in the operation of telecommunications services, which represented a significant step for the future development and reform of the sector (Lam and Shiu 2008). In 2017, China remained one of the world's leading telecommunications markets, serving around 201 million fixed-line customers and 1.35 billion mobile lines (MII—Ministry of Industry and Information Technology of the People's Republic of China 2017). Then, China has become a significant role within the ICT segment in that it has become a major supplier and a fast growing market in the world (Yu et al. 2008).

Throughout the period, Brazil (BRA) remained in eighth position with annual average growth of 2.8%. The privatization policy and the resulting private investments made between the 1990s and 2000s justify this expansion (Chakraborty and Nandi 2011). In 2004, telecommunications had a total of 111.8 million subscriptions in all their services—telephony (fixed and mobile), Internet (fixed and mobile) and pay TV—a number that grew by 232%, reaching 372 million subscriptions in 2014. There was also a significant expansion in the number of telecommunications service providers. In 2004 there were 293 companies providing fixed broadband services and 39 authorizations to provide telephone services in Brazil. In 2014, these numbers went to 4,879 broadband companies and 198 authorizations (Teleco 2014). The Japanese economy (JPN) and the USA economy (USA), on the other hand, suffered the most losses from regional participation, i.e., a negative variation of 3.7% and 9.7% between 2000 and 2014, respectively. Telecommunications growth in these two developed countries has not followed the industry's global pace, especially those observed in China, France and other countries (RoW).

Thus, there is the confirmation of a movement of regional decentralization of telecommunications' supply in the world. This decentralization is a reflection of the sector's own global restructuring movement encouraged by the advances and diffusion of microelectronics and information technologies (Werthein 2000; Freeman 2001), developing and developing countries have been directing their investment policies towards expansion and modernization (Dimelis and Papaioannou 2011; Pradhan et al. 2017), such as new wireless technologies around the world. Nevertheless, there is still a need to assess whether the regional telecommunication expansions result from or reproduce the productivity gains of primary factors and/or efficiency in the sector over the period. Thus, the next section provides empirical answers to this point by breaking down the TFP of telecommunications in each economy and assessing the relative importance of the sector in the production system itself.

Moreover, the share of employment in the telecommunications sector in relation to total employment in the world represented 0.76% in 2000, while in 2014 this rate dropped to 0.65%. This declining trend also occurred in the sectoral average, that is, telecommunications became a less employing sector, registering 0.44% of the sectoral average in 2000 and 0.27% in 2014 in the six countries (BRA, DEU, FRA, GBR, JPN and USA) (Gouma et al. 2018). The share of total income from telecommunications production factors (value added) in relation to the global total decreased from 1.93% in 2000 to 1.77% in 2014. Associated with the growth in production in the telecommunications sector, these results may indicate an increase in the productivity of production factors, that is, the sector offered more with lower factor requirements, whose analysis will be confirmed by the TFP decomposition.

Table 1 Cumulative variation (%) and contribution related to telecommunications TFP

Region	2000–2005			2000–2010			2000–2014		
	$i'\Delta A$	Δv	TFP	$i'\Delta A$	Δv	TFP	$i'\Delta A$	Δv	TFP
Brazil (BRA)	0.64	0.13	0.77	2.10	-0.25	1.85	-2.94	4.85	1.91
China (CHN)	-29.59	30.00	0.41	6.12	-6.23	-0.11	6.07	-6.23	-0.16
Germany (DEU)	-15.96	16.11	0.15	-12.17	12.43	0.25	-4.72	4.97	0.24
France (FRA)	6.33	-6.34	0.00	3.96	-4.36	-0.41	7.65	-7.47	0.18
Great Britain (GBR)	-3.79	3.72	-0.08	-8.20	4.98	-3.23	-8.14	4.71	-3.44
Japan (JPN)	5.45	-5.43	0.02	18.30	-18.28	0.01	18.44	-18.41	0.03
United States (USA)	8.86	-8.84	0.02	11.14	-11.07	0.07	8.56	-8.35	0.21
Rest of the World (RoW)	1.20	-1.43	-0.22	7.53	-8.32	-0.79	9.66	-10.42	-0.76

Source: research results

4 Results

For an in-depth analysis of the results, we calculate the cumulative percentage change in telecommunications TFP by region between 2000 and 2014. Then, the contribution of each component to the observed TFP result was identified. According to Eq. (6), TFP (τ) is the sum of two components: (i) efficiency variations ($i'\Delta A$), which corresponds to the change in the technical relationship by intermediate inputs; and (ii) change in value added (Δv), which represents gains or losses in the technical relationship by production factors. Thus, efficiency or productivity gains of production factors (value added) indicate lower expenditure for these two components in the telecommunications cost structure per unit of output. Conversely, when telecommunications activity shows losses in these two components, then production costs increased to offer the same product/service unit. Table 1 reports the main results for the telecommunications decomposed between these two aforementioned components.

Despite the great increase in Chinese telecommunications worldwide, with an average annual growth of 12.7% in service supply, total factor productivity (TFP) shrank marginally by 0.16% between 2000 and 2014. By 2005, gains with factor productivity (Δv) more than compensated for the loss of sectorial productive efficiency ($i'\Delta A$), generating TFP growth (0.41%). After this period, Chinese telecommunications began to present efficiency gains, but not enough to overcome the losses in the technical relation of production factors (Δv). In other words, these results indicate that the telecommunications sector began to require less volume of intermediate inputs, but more primary factors per productive unit, whose net result was negative for TFP, even if modest. The increase in Chinese telecommunications supply occurred with a more than proportional growth in the technical requirements of factors in the production process after 2005. This Chinese outlook follows the world trend, that is, in the first five years the telecommunications sector showed, on average, a positive TFP, but this upward trend is reversed in subsequent periods. However, Chinese telecommunications witnessed productivity losses between 2005 and 2014.

Moreover, the deconcentration of telecommunications activity in the Rest of the World, characterized by an annual increase of 6.7% in the provision of this type of services, was associated with an efficient use of intermediate inputs in the production process ($i'\Delta A$). At the same time, there were losses in the productivity of the production

factors (Δv). This resulted in a negative TFP over the period (2000–2014). It is concluded that the participation gains of these two regions (CHN and RoW) in the composition of the world telecommunications production are associated with losses of TFPs between 2000 and 2014, even modest ones. In contrast, with an average annual expansion of 6.5%, French telecommunications were the only ones that simultaneously exhibited marginal gains in global participation and TFP. Throughout the period, productive efficiency ($i' \Delta A$) in the French telecommunications sector was the component responsible for achieving positive TFPs.

When comparing the world regions, the telecommunications sector in Brazil was the one that achieved the largest TFP gains. This result is mainly justified by the productivity of the production factors (Δv), because from 2010 the productive efficiency was negative ($i' \Delta A$). Thus, in Brazil, it is observed that the privatization and investment policy not only expanded the telecommunications supply, but allowed this sector activity to achieve productivity gains (TFP). In this variant, it seems that whose post-privatization scenario required high investments, modernization and efficiency of operations, achieved its goal. Between 2004 and 2014, for example, investments grew by 121%, from R \$14.3 billion to R \$31.7 billion (Teleco 2014). The results observed for Brazil are in accordance with the conclusions of Lam and Shiu (2010) and Chakraborty and Nandi (2011), which together point out that less developed economies where the telecommunications sector is privatized and operating in full competition tend to have greater effects on economic and TFP growth.

As in Brazil, Germany's telecommunications showed productivity gains in all analyzed years. These positive TFP variations exhibited an upward trajectory and were above the national benchmark (TFP_{total}), resulting from productivity gains of primary factors (Δv), as the German telecommunications sector experienced losses in productive efficiency ($i' \Delta A$) between 2000 and 2014. To sum up, the telecommunications activity in Germany showed a lower growth rate (4.0% per year) compared to some of the major producing regions in the world, losing a position in the regional composition. In comparative terms, the positive variation observed for the sector in Germany is only lower than the Brazilian one. However, unlike the German economy, telecommunications in Britain have registered expansions of primary factor productivity (Δv), although insufficient in the face of losses in productive efficiency ($i' \Delta A$).

In the United States and Japan, telecommunications, with annual average growth of 2.3 and 2.7%, respectively, showed technical efficiency regarding the use of intermediate inputs in the production process ($i' \Delta A$), overcoming productivity losses of primary factors (Δv). Consequently, the TFP of this sectoral activity was positive in both economies. This sector in the USA economy, on the other hand, showed growth rates above the national reference after 2005. Despite losing a position in the regional composition of the sector's world production, telecommunications in these two developed countries showed productivity improvements on an upward trajectory.

In summary, the results achieved on the telecommunications sector in the main supplying regions of the world suggest a certain "catch-up effect", similar to that discussed by growth theory (Solow 1957; Romer 1990; Jones 1995; Creti 2001). An economy with less participation in the regional composition of world telecommunication production is easier to grow early in the process compared to a country in a higher position. Countries

in lower positions generally had higher sector productivity. Thus, capital investments or restructuring policies for the telecommunications sector, in addition to substantially increasing the supply of services, have more significant impacts on productivity. Empirical results have already pointed out that privatization and liberalization have improved the sector's productivity and efficiency [see a comprehensive review of Lam and Shiu (2008)]. An example of this is the Brazilian economy, which, situated in a much lower position in this regional composition, presented the largest positive variations of telecommunications TFP. While China was less prominent, the Brazilian economy experienced a positive TFP (2000–2005). In the period when Chinese telecommunications became the fourth largest provider in the world, with the largest amount of capital in the sector, variations in TFP were marginal and negative. As pointed out by Lam and Shiu (2010), during the 1990s, the Chinese economy had a lagged information technology compared to developed countries, but after the reform of the sector, the country took advantage of recent technologies in the development of a national network of fiber optic cables, which avoided a costly re-engineering process of the old analog copper wire network and facilitated the rapid expansion of the telecommunications industry. This advantage of countries with lagging technology in the 1990s seems to have also been taken advantage of by Brazil, but to a lesser extent. The Brazilian result is also consistent with the hypothesis of Lam and Shiu (2010), i.e., countries with lagging telecommunications technologies in the pre-reform period, by implementing the latest technologies, achieved better productivity performance than developed countries. This fact extends to China until 2005.

Telecommunications in developed and prominent countries, such as the United States and Japan, generally have a high amount of capital per worker and, therefore, investment or sectoral policies to expand the provision of such services have a relatively small effect on sector productivity. Productivity growth rates vary across countries at different stages of telecommunications development, but almost all economies have experienced productive efficiency improvements in the sector. These results complement the conclusions of Chakraborty and Nandi (2011) noting that TFP variations are greater in developing economies and lower in the global composition of this type of service offer. However, our results do not yet show whether the effects of the sector on the economies are significant, as already discussed by Chakraborty and Nandi (2011) and Nadiri et al. (2018). To this end, unlike previous empirical literature, we use the hypothetical extraction technique to analyze the dependence of the world and world's major economies on the supply and demand of the telecommunications sector. This relative importance of the sector in production systems is assessed in terms of backward and forward effects on production. The backward effect points to the dependence on intermediate inputs in the telecommunications production process (demand). On the other hand, forward effects of telecommunications activity occurs when other sectors (or regions) need their service as an input (supply). Both the backward and forward effect exploit the direct and indirect channels of production and consumption links established in input–output models. For these reasons, the results of hypothetical extraction differ in relation to the regional proportions of telecommunications production over world production, as partially presented in Fig. 1. Fluctuations in these two effects (backward and forward) indicate changes in the pattern of demand and supply (structural change in countries) in each in

Table 2 Regional share (%) of telecommunications effect on world production

Region	Backward effect			Forward effect		
	2000–2005	2000–2010	2000–2014	2000–2005	2000–2010	2000–2014
Brazil (BRA)	1.85	1.85	1.99	1.50	1.56	1.61
China (CHN)	4.57	7.20	8.37	5.99	8.23	9.45
Germany (DEU)	4.85	5.46	5.25	4.52	4.84	4.74
France (FRA)	3.51	3.61	3.81	3.82	3.90	3.92
Great Britain (GBR)	4.32	4.30	4.33	4.61	4.57	4.54
Japan (JPN)	12.51	11.19	10.19	13.93	12.32	11.49
United States (USA)	36.90	31.78	30.94	33.04	29.43	27.93
Rest of the World (RoW)	31.49	34.60	35.12	32.58	35.15	36.32
Total	100.00	100.00	100.00	100.00	100.00	100.00
Cumulative variation (%)	– 7.5	– 14.8	– 21.9	– 9.1	– 17.6	– 24.8
Billions of US\$	– 4895	– 10,836	– 17,538	– 6004	– 12,854	– 19,666

Source: research results

economic systems. Furthermore, if dependence is increasing, it means that telecommunication sells more to other sectors or buys more from other sectors.

Table 2 presents the relative importance of regional telecommunications sectors in world production between 2000 and 2014. In general, the world production system tends to be more dependent on supply than demand from the telecommunications sector, even if we evaluate all time intervals. Without the supply of telecommunications, world production would fall by 24.8% between 2000 and 2014, accumulating a real loss of US\$19,666 billion. On average, the fall in world production without telecommunications would be 1.70% or \$1311 billion per year. Similarly, the lack of absorption of the telecommunications sector by globally traded inputs would represent a cumulative retraction of 21.9% between 2000 and 2014. Over the period it is observed that the change in world dependence on telecommunications supply and demand would accompany, to some extent, the very modification of the regional composition of the sector. The regions that would gain positions or stand out in the composition of telecommunications production over the years would also be those that would have the most back and forth effects on world output. Both China and the Rest of the World (RoW) would gain prominent positions and the telecommunications offer in these regions would impact 9.45% and 36.32% of world production, respectively (forward effect). These shares would be increasing in each time interval analyzed, including for the backward effect, whose assertion also extends to the Brazilian, German and French economy, albeit marginally.

Although still representative, the effect on the world of USA and Japanese telecommunications would be gradually diminished over the periods, confirming a result from the decentralization movement of this type of service in the world. In addition to the United States and Germany would generate relatively greater backward effects, that is, the world would be more dependent on telecommunications demand than the sector's own supply in these countries (forward effect). For example, the USA industry's dependence on demand would represent 30.94% of the total impact on the world, while the forward effect would reach 27.93% of that total. These effects usually come from intersectoral and interregional channels of each economic system in

Table 3 National production and importance of domestic and international telecommunications

Region	Backward effect								
	2000–2005			2000–2010			2000–2014		
	Total	Intra	Inter	Total	Intra	Inter	Total	Intra	Inter
BRA	– 8.8	91.0	9.0	– 15.4	91.4	8.6	– 20.3	91.8	8.2
CHN	– 7.4	76.1	23.9	– 13.6	71.6	28.4	– 17.8	70.0	30.0
DEU	– 8.1	70.2	29.8	– 15.8	71.1	28.9	– 20.9	70.0	30.0
FRA	– 7.8	77.0	23.0	– 14.6	78.0	22.0	– 20.3	78.5	21.5
GBR	– 7.6	71.9	28.1	– 13.8	71.5	28.5	– 18.5	71.2	28.8
JPN	– 8.8	84.7	15.3	– 15.1	82.0	18.0	– 19.9	81.2	18.8
USA	– 10.5	91.8	8.2	– 17.2	90.6	9.4	– 22.9	90.6	9.4
RoW	– 7.9	81.2	18.8	– 14.4	82.1	17.9	– 19.0	81.7	18.3
Region	Forward effect								
	2000–2005			2000–2010			2000–2014		
	Total	Intra	Inter	Total	Intra	Inter	Total	Intra	Inter
BRA	– 8.8	92.4	7.6	– 15.4	92.6	7.4	– 19.8	92.5	7.5
CHN	– 11.0	89.3	10.7	– 18.2	87.9	12.1	– 22.0	87.6	12.4
DEU	– 9.0	81.9	18.1	– 16.7	82.3	17.7	– 21.6	81.6	18.4
FRA	– 10.3	87.6	12.4	– 18.5	87.2	12.8	– 24.5	86.7	13.3
GBR	– 10.8	82.7	17.3	– 18.6	81.8	18.2	– 24.0	81.7	18.3
JPN	– 10.6	94.5	5.5	– 17.5	93.4	6.6	– 22.8	93.3	6.7
USA	– 11.4	95.7	4.3	– 18.4	95.1	4.9	– 23.5	95.1	4.9
RoW	– 10.0	89.1	10.9	– 17.4	89.4	10.6	– 22.2	89.4	10.6

Source: research results

"Total" shows the cumulative variation (%) of national production; "Intra" and "Inter" correspond to the share (%) of intraregional and interregional effects, respectively

ways that take into account different patterns of trade and production. These asymmetries in the structure of demand and supply would therefore make the production of goods and services more dependent on demand than on the supply of telecommunications located in the United States and Germany (backward effect), whereas in other European countries, Asian economies (i.e., China and Japan) and the world this dependency relationship would be reversed, that is, the forward effect would become prominent. The Brazilian economy is slightly less dependent on the supply of telecommunications services from abroad, as the differences are low, which indicates an almost flat degree of dependence.

The dependence of each region is varied and takes into account not only the domestic provision of this type of service, but also the foreign provision of productive and sales complementarity relations. Thus, once the effects transmitted by the intra and interregional channels are recognized, it is possible to identify the relative importance of the sector located in the national territory and in other countries for a given production system. Table 3 provides the cumulative variation (%) of the total effect on national output, broken down between intra- and interregional.

The results indicate that, for example, Brazil would be a little more dependent on telecommunications demand than on the sector's own supply, especially from 2000 to 2014. While national production would accumulate a negative variation of 19.8% in

the absence in terms of telecommunications supply, the same macroeconomic indicator would fall by approximately 20.3% without the demand for the same activity for intermediate inputs. These variations would represent an average annual retraction of over 1.45% or \$– 20.85 billion over the period. By analyzing the decomposition of the backward and forward effects, it is observed that the dependence of the Brazilian economy was concentrated on domestic telecommunications, representing more than 91% of total impacts (intra). Dependence on the demand for telecommunications from abroad would average 8.2% between 2000 and 2014, and by 2005 this percentage was 9% (inter). The dependence on the supply of telecommunications from abroad would be lower. In general, it is concluded that gradually the Brazilian economy would depend more on domestic telecommunications activity.

Unlike Brazil, other regional economies would depend more on supply than on demand for telecommunications services. The cumulative discrepancy of the forward effect in relation to the backward effect would be relatively greater in Great Britain, France and China. France, Great Britain and the United States would be the regions that would most need telecommunication services as input, i.e., the forward effects would accumulate negative variations of less than 23.5%. This supply-side dependency would come more from domestic production than from abroad. The United States, Japan and Brazil would be the countries that would least need to import telecommunications services in their productive complementarity relations. In both economies, domestic telecommunications activity showed positive TFPs between 2000 and 2014. The German and British productive system would be the most dependent on imports of telecommunications services, and would exhibit an upward trajectory of interregional participation in the total forward effect (over 18.3% over the entire period). Therefore, it is observed that the telecommunications service of these two economies was widely used as an input in the other production systems.

On the other hand, in the composition of the backward effect, it is noted that the Chinese and British economies depend much more on demand than on the supply of telecommunications from abroad, with interregional dependence being above 28% of the total effect between 2000 and 2014. This result shows that national production in both economies is more sensitive to exports of goods and services to the foreign telecommunications production process. Except for France and the Rest of the World, when comparing time intervals, it appears that this dependence on demand from the telecommunications sector located abroad would be increasing. Again, Brazil and the United States would show less dependence on external telecommunications demand, that is, the effect of national production would be mostly coming from domestic telecommunications demand (above 91%). Alongside Germany, these economies would also have the most backward effect (a variation of less than—20.3%).

Thus, the major world economies would depend more on supply than on telecommunications demand, except for the Brazilian economy. Most economies would have an interregional dependence above the world average. Brazil, the United States and Japan would reveal a degree of intraregional dependence above the world average, both in terms of backward and forward effect. Even with this varying degree of interregional effects, we can identify the main regional channels that would give rise to these impacts, which are recognized in international trade interactions. Table 4 reports the distribution

Table 4 Regional origin of interregional effects between 2000 and 2014 (%)

Region	Backward effect								
	BRA	CHN	DEU	FRA	GBR	JPN	USA	RoW	Total
BRA	0.0	9.7	3.4	3.7	4.0	3.4	19.3	56.4	100.0
CHN	0.8	0.0	6.5	3.4	6.1	3.2	17.3	62.7	100.0
DEU	0.8	5.2	0.0	8.4	9.7	1.3	11.0	63.7	100.0
FRA	0.7	4.2	8.8	0.0	11.1	1.2	11.6	62.4	100.0
GBR	0.5	2.4	7.2	7.3	0.0	2.1	14.1	66.3	100.0
JPN	0.5	15.4	6.2	2.2	4.8	0.0	16.7	54.3	100.0
USA	0.9	4.3	7.7	3.3	5.3	3.1	0.0	75.3	100.0
RoW	2.7	19.3	13.3	9.1	12.8	7.4	35.4	0.0	100.0
Average	1.4	10.3	8.6	5.8	8.4	4.0	19.9	41.5	100.0
Region	Forward effect								
	BRA	CHN	DEU	FRA	GBR	JPN	USA	RoW	Total
BRA	0.0	5.6	5.6	3.3	2.8	3.6	13.2	65.9	100.0
CHN	1.7	0.0	4.4	2.4	2.2	10.2	8.4	70.8	100.0
DEU	0.4	3.4	0.0	5.2	6.4	2.3	21.7	60.6	100.0
FRA	0.7	3.3	9.9	0.0	10.9	2.0	12.4	60.9	100.0
GBR	0.5	2.5	10.4	10.7	0.0	2.4	7.5	66.0	100.0
JPN	0.9	10.9	3.1	1.8	3.9	0.0	15.4	64.0	100.0
USA	1.4	6.8	5.2	3.3	5.2	6.1	0.0	72.0	100.0
RoW	2.0	13.8	14.5	9.7	14.7	10.7	34.7	0.0	100.0
Average	1.4	8.2	8.9	6.3	8.5	7.1	20.0	39.6	100.0

Source: research results

The elements of the main diagonal of the matrices denote intraregional relationships and are therefore null

of backward and forward interregional effects between 2000 and 2014. Interregional dependence on the backward effect originates mainly from imports of telecommunications inputs located in the United States and the Rest of the World. That is, the interregional backward effect of a country denotes the degree of dependence on the demand for inputs of the telecommunications sector located in regions abroad. As the calculation of this backward effect is based on the Leontief matrix, it captures the effects transmitted directly and indirectly in the economic interactions of the WIOT annual matrices. The economy of Great Britain reacts to the demand for inputs of Chinese telecommunications services, even if with a less expressive degree (2.4%). That is, the demand of Chinese telecommunications directly and indirectly affects the production of Great Britain. First, because Great Britain itself exports inputs for Chinese telecommunications. Or because Britain itself sells goods to other economies that are affected by Chinese telecommunications demand.

Apart from these two world regions in the analysis, it is clear that European countries (i.e., France and Great Britain) would tend to have a high volume of interregional dependencies on European and Chinese telecommunications demands. The greater European representativeness would be due to the reduction of artificial, tariff and non-tariff barriers in trade between members of the European Union. So, there is certain reciprocity of these effects for the Chinese economy, which in addition to being dependent on telecommunications demands of countries such as France and Great Britain, would

also be dependent on the Japanese. It is noteworthy that even with the fall of artificial barriers between countries like China and Japan due to the costs of international trade, the production of the Japanese economy would react more to the demand for inputs from the Chinese sector (15.4%) than China to the Japanese telecommunications demand (3.2%). Moreover, disregarding the Rest of the World, developing economies such as Brazil and China would show greater reliance on the USA telecommunications production process, even though Brazil has had little interregional effect (Table 3). Despite being low, the interregional need for USA telecommunications demand would originate more from French and British economy (16.3% total) than from China and Japan (7.4% total).

The dependency pattern observed by the demand side resembles the telecommunications supply side (forward effect). Nevertheless, China's national output would depend less on USA telecommunications supply (8.4%) than on demand (17.3%). Reciprocity also seems to occur between Japan and China, so it would reveal a close participation in the interregional composition of the forward effect between both economies, and this more symmetrical relationship would not exist in the backward effects. With a share of more significant interregional effects (Table 3), Great Britain would need more telecommunications supply from other European countries (i.e., France and Germany) to meet national production (Table 4). On the other hand, Germany would be more dependent on the supply of telecommunications services in the United States.

5 Final remarks

This paper has contributed to the debate on the variations in TFP and the role of telecommunications in the main producing economies of this type of service, assessing their relative importance in terms of demand and supply in a period after the global movement of sector restructuring. To do so, the technique of TFP decomposition and hypothetical extraction from interregional input–output matrices was applied between 2000 and 2014. The TFP's decomposition analysis provides an “inside-the-industry” perspective, that is, we evaluate changes in the technical relations of production in the telecommunications sector in each of the major producing regions. In this first analysis, the results indicate that the strong expansion of Chinese telecommunications in the period, with gains of participation in the regional composition in supplying this type of services, was associated with losses of TFP in the sector in recent periods, even showing positive variations in productive efficiency. Brazil, stagnant in terms of position in this regional composition, with a low growth rate of service supply, showed TFP gains over the period. Developed and prominent countries in this regional composition exhibited positive TFPs, although with smaller variations than those of the Brazilian economy. Only telecommunications in Britain revealed TFP losses. A certain catch-up effect seems to emerge in Brazilian results, that is, the positive effect of TFP related has shown an upward trajectory because telecommunications in this country have a relatively low amount of capital per worker. Like China, Brazil seems to have taken advantage of countries with lagging technology in the 1990s, as suggested by Lam and Shiu (2010).

The hypothetical extraction analysis showed that the world would be more dependent on the telecommunications supply and demand of the US, Japanese, Chinese and Rest of the World economy, reflecting, to some extent, the very trajectory of change in

the regional composition of the world production of this service, marked by a regional decentralization movement following sector reforms in the 1990s. The USA output would be the least affected by foreign telecommunications supply and demand, but such a region would be the most dependent on domestic supply. This greater independence of the foreign telecommunications market would also be observed for Brazil, whose economy would be more dependent on the demand for domestic activity. Other economic regions would be more dependent on domestic telecommunications supply, although telecommunications imported from other international regions would not be negligible. The backward and forward effects arising exclusively from interregional relations would denote the world's economies' heavy reliance on telecommunications from the United States and the Rest of the World. The exception would be in Great Britain.

Therefore, the political implications of these results are straightforward. Countries that have been directing their investment and privatization policies in the expansion and modernization of national telecommunications, as well as making trade agreements to reduce artificial, tariff and non-tariff barriers, allow the supply of telecommunications services to be increased, but without guarantees of increases in productivity in the sector, as other economic conditions influence TFP, as shown by Chakraborty and Nandi (2011). The continued expansion of the amount of capital per worker in telecommunications in world regions, which have little prominence in the regional composition of their production, should lead to diminishing marginal TFP gains, even when primary factor productivity losses outweigh efficiency. Still, the global movement of telecommunications investment policies in certain countries may dampen the reliance on this service from the United States and China and even positively influence other economies through interregional interactions of economic systems. However, the downward trend in trade barriers between certain regions, without these appropriate investment policies or incentives for technological advances in the sector, must deepen the dependence on foreign telecommunications for productive systems that are increasingly fragmented and integrated globally.

The results of the TFP decomposition and hypothetical extraction techniques are derived or conditioned from WIOTs in pyp, which provide the complete picture of supply and demand operations in certain markets for an overall year. It is a net result of all direct and indirect changes on these operations for an economy. In the input–output model, the final demand users are exogenous and, therefore, there are no supply-side reactions for them, such as gross fixed capital formation. Eventual increases in investments in telecommunications in the same year were recorded in the vector of gross fixed capital formation, but their indirect effects were internalized in operations in the intermediate consumption sectors. It is expected that current telecommunications investments in the implementation phase (demand effect) can become operational in the future so that the productive capacity of the sector grows (supply effect). TFP gains would be observed with growth in supply in the operating phase of investments made in the past if it is accompanied by a reduction in the technical requirements of primary factors. On the other hand, this expansion in the supply of telecommunications services in a given economy, resulting from the operational phase of the investments, could alter the intra and interregional forward effect, causing changes in the production pattern of the other sectors of the economy itself and in

the pattern of trade. With the rest of the world's economies. This limitation is inherent to the input–output model, which can be reduced by simulations of investment policies in a multi-country computable general equilibrium model (CGE) of the world economy (GTAP-Dyn), whose theoretical structure models the supply-side reactions of certain users of final demand and the accumulation of physical capital occurs through the perpetual method of allocating investments in economies.

Appendix

See Table 5.

Table 5 Telecommunications' share in each region

Regiões	2000	2005	2010	2014
Brazil (BRA)	1.87	2.05	2.17	1.74
China (CHN)	0.9	1.7	1.0	0.9
Germany (DEU)	1.5	2.0	2.3	2.1
France (FRA)	1.5	2.1	2.6	3.2
Great Britain (GBR)	1.9	2.8	3.2	2.6
Japan (JPN)	1.8	2.0	2.2	2.4
United States (USA)	2.6	2.5	2.9	3.1
Rest of the World (RoW)	1.5	2.2	2.5	2.4
Total	1.9	2.2	2.4	2.3

Source: research results

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s40008-022-00263-x>.

Additional file 1. Additional figures and tables.

Authors' contributions

All authors read and approved the final manuscript.

Funding

This study was funded by Conselho Nacional de Desenvolvimento Científico e Tecnológico, Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, Fundação de Amparo à Pesquisa do Estado de Minas Gerais.

Availability of data and materials

The datasets generated and/or analyzed during the current study are available in the World Input–Output Database (WIOD) repository, <http://www.wiod.org/>.

Declarations

Competing interests

The manuscript has no financial competing interests and has academic interest.

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Received: 31 March 2020 Revised: 25 February 2022 Accepted: 26 February 2022

Published online: 31 March 2022

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