Relative Advantage Production Position and Applications

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Abstract

This paper defines a new indicator named relative advantage production position to clarify the position differences in global value chain between economies, and puts forward an approximation algorithm to calculate it on the basis of Input-Output model and Layer Lemma. In empirical parts, this paper calculates the RAPPs for each sector based on China's non-competitive Input-Output Table of year 2007 and 2012, and 2012 US non-competitive Input-Output Table. The results verify the positive correlation between a sector's RAPP and its upstreamness. Meanwhile, this paper uses the 2007 and 2014 WIOD world Input-Output Table to measure each sector's RAPP in different economies. The statistic results confirm that the non-uniqueness of RAPP is rooted in the characteristic of the certain sectors. Furthermore, the comparison of RAPPs in economy dimension reveals the heterogeneity across economies. The comparison in time dimension suggests positional changes in global value chain.

Key words: upstreamness, production position, Input-Output table, global value chain

1 Introduction

As the globalization goes deepening, production has been fragmented into a series of processes based in different economies; the vertical specialization has been a distinctive feature of the world economy (Hogan Chen et al, 2005; Dean, 2009); and "Global Value Chain" has been a popular topic in recent decades (Antràs and Chor, 2013). Furthermore, the role of each economy in global value chain, or in other words, the heterogeneity between economies in global value chain becomes an increasingly focused question. Addressing this question, as Antras (2012) says, requires first and foremost a sector measure of relative production line position.

There are two popular indicators for measuring the position in global value chain. One is the GVC_Position by Koopman(2010), and the other is Antras's measurement of sector upstreamness. The $GVC\_Position_{ir}$, constructed by the gross exports E_{ir} , a portion of domestic value-added exports IV_{ir} which is intermediate inputs that are transformed into final goods and exported to a third economy for consumption, and the foreign value added embodied in gross exports FV_{ir} , measures how upstream the sector r of economy i is in global value chain. The greater the $GVC\_Position_{ir}$, the more upstream position in global value chain the sector r of economy i is located in.

The GVC_Position embodies the rank of upstreamness in global value chain among sectors. However, it has little to do with the certain distances in global value chain. On the contrary, Antras's measurement of sector upstreamness, which is calculated on the basis of Input-Output Analysis, is an average distance in global value chain from final use weighted by the proportion of a sector's output at each distance in total output of this sector.

Antras's measurement is a fruitful tool (Erik Dietzenbacher et al, 2013). Many researchers quote it to do some empirical research about global value chain (Timmer et al, 2014; Cattaneo and Gereffi, 2013). But, as is interpreted above, Antras's measurement is a weighted average, and the property of technical coefficients decides that the outputs at each distance decline significantly as the distance increases. Thus, the Antras's measurement of sector upstreamness leads to less notable results between sectors, especially the same sectors across different economies. It weakens the distinctions of labor-division and specialization across different economies in global value chain.

This paper defines the input flows matrixes and allocation coefficients matrixes at each distance on the basis of Layer Lemma, and puts forward an approximation algorithm to calculate the relative advantage production position(Hereinafter referred to as RAPP), which can reveal more notable heterogeneity across different economies. A sector's RAPP is a certain distance in global value chain. At this distance, the sector's output, relative to the total outputs of all sectors at the same distance, has an advantage over that of the sector at the distance nearby.

The next section briefly introduces the standard Leontief input-output model and Layer Lemma, and presents the proof, property and interpretation of Layer Lemma. Section 3 presents the definition of RAPP, provides some interpretations of RAPP, and puts forward an approximation algorithm to calculate it. Section 4 verifies the positive correlation between the sector upstreamness and sector RAPP, and uses the 2007 and 2014 WIOD world Input-Output Table to measure the sector RAPPs in different economies, and makes comparisons both in country/region dimension and time dimension. The summary and conclusions are presented in Section 5.

2 Leontief Model and Layer Lemma

Considering the following simplified Input-Output table

Table 1：Simplified Input-Output Table

Z	f	x
v'		
x'		

Here, Z is the matrix of intermediate flows, and its typical element Zij denotes the value of deliveries from sector I to sector J. f denotes the sectoral final demands and v denotes the value added in each sector. The value of each sector's output, which equals the input, is given by the vector x. The summation vector $e=(1,1,\ldots,1)'$, and then for each sector, the following accounting equation is obtained (Leontief, 1986).

$$Ze + f = x \quad (1)$$

Measuring the direct input coefficients $A = Z\hat{x}^{-1} = (a_{ij})$, the typical element aij denotes the value of input from sector i for each dollar output of sector j. The traditional Leontief model assumes the input coefficients is fixed, then the following equation is obtained

$$Ax + f = x \quad (2)$$

$$x = (I - A)^{-1} f = \tilde{B}f \quad (3)$$

$$Ze = Ax = A(I - A)^{-1} f = ((I - A)^{-1} - I) f = Bf \quad (4)$$

Here, $\tilde{B} = (\tilde{b}_{ij}) = (I - A)^{-1} = I + A + A^2 + \cdots$ is known as the Leontief inverse or the total requirements matrix[8], $\tilde{b}_{ij}$ denotes the complete output of industry i demanded by the manufacture of per unit output in industry j ; $B = (b_{ij}) = (I - A)^{-1} - I) = \tilde{B} - I = A + A^2 + \cdots$ is complete input matrix, and b_{ij} denotes the complete input (both direct and indirect input) from industry i to the manufacture of per unit output in industry j(Miller and Blair, 2009).

Layer Lemma: on the basis of Leontief model and its assumption, given $z_{n-1} = A^{n-1} f$ and $Z_n = A\hat{z}_{n-1} =$, then $Z = Z_1 + Z_2 + Z_3 + \cdots$

Proof：

Under Leontief model， $x = (I - A)^{-1} f$ ，

$$\mathrm{Z} = \mathrm{A}\hat{x} = A\,\widehat{(I - A)^{-1} f} = A\,\widehat{(I + A + \cdots) f} = A(\hat{f} + \hat{z}_1 + \cdots) = Z_1 + Z_2 + \cdots \quad (5)$$

PROPERTY 1：On the basis of the framework of Input- Output Analysis, given that the technical coefficients are fixed, then Layer Lemma is the necessary and sufficient conditions for Leontief model.

Proof：

Necessary condition：it is immediate from the proof of Layer Lemma。

Sufficient condition：from the Layer Lemma， $A\hat{x} = Z = Z_1 + Z_2 + \cdots = A(\hat{f} + \hat{z}_1 + \cdots)$, sum the rows ， then $x - f = Ze = A(\hat{f} + \hat{z}_1 + \cdots)e = A(f + z_1 + \cdots) = A(I + A + \cdots) f$

$=((I-A)^{-1}-I)f$, $x=(I-A)^{-1}f$.

The interpretation of Layer Lemma: the intermediate flows matrix Z is the sum of direct input flows matrix and indirect input flows matrix at each production step or each distance in global value chain.

Proof：

On the basis of Leontief model, $z_{n-1}=A^{n-1}f$ denotes the input from each sector at production step n-1(where the final demands production is called production step 1) or distance n-1 in global value chain(where the final demands production is called distance 1). In order to input such intermediate at step n-1, we need to manufacture it at step n. So the input flows matrix at step n equals $Z_n=A\hat{z}_{n-1}$, when n=1, Z_1 denotes the direct input flows matrix; when n>1, Z_n denotes the indirect input flows matrix at each production step. By introducing Layer Lemma, it is proved that $Z=Z_1+Z_2+Z_3+\cdots$, which denotes that the intermediate flows matrix Z is the sum of direct input flows matrix and all indirect input flows matrix at each production step or each distance in global value chain.

The proof, property and interpretation of Layer Lemma presented above are proved under the Input-Output table in value. As for the physical Input-Output table and non-competitive Input-Output table, the proofs are similar by using physical A and physical f to replace A and f, or by using domestic technical coefficients A^D to replace A.

3 Relative Advantage Production Position

By Layer Lemma, the intermediate flows matrix Z can be divided into all input flows matrix Z_n at each production step or each distance in global value chain. Furthermore, by comparing the input flows matrixes, we can find out in which step or distance a certain sector has a relative advantage, and we can learn more about the characteristics of the certain sectors.

A sector’s RAPP is a certain distance in global value chain. At this distance mentioned above, the sector’s output, relative to the total outputs of all sectors at the same distance, has an advantage over that of the sector at the distance nearby. In other words, at a sector’s RAPP, the proportion of this sector's output in total outputs of all sectors at such distance would be greater than such proportion at the distance nearby.

As shown in Figure 1 and Figure 2, the proportion of Indonesia "Manufacture of Chemicals and Chemical" sector's output in total outputs of all sectors increases first and then decreases as the distance in global value chain increases. The only extreme value appears at the distance 3. Therefore, we call the RAPP of Indonesia "Manufacture of Chemicals and Chemical" sector is 3. The proportion of China "Manufacture of Electrical Equipment" sector's output in total outputs of all sectors increases first and then decreases and then increases again. Distance 2 and distance 8 both satisfy the definition of RAPP. So we call the RAPP of China "Manufacture of Electrical Equipment" sector is 2 and 8.

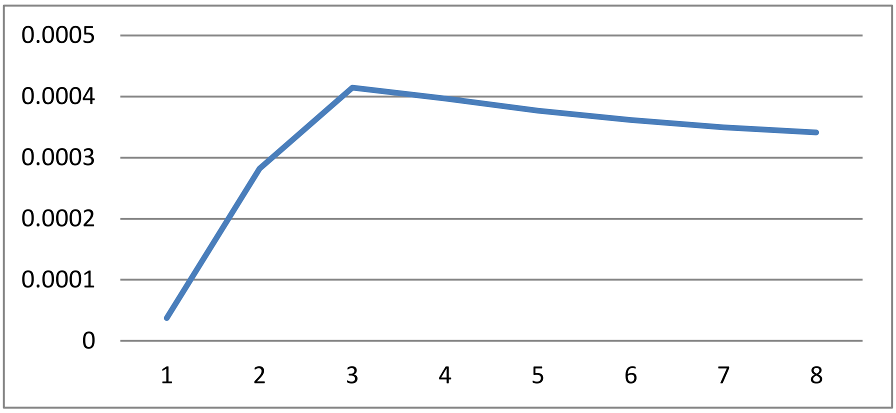

Figure 1： The proportion of Indonesia "Manufacture of Chemicals and Chemical" sector's output in total outputs of all sectors at each distance

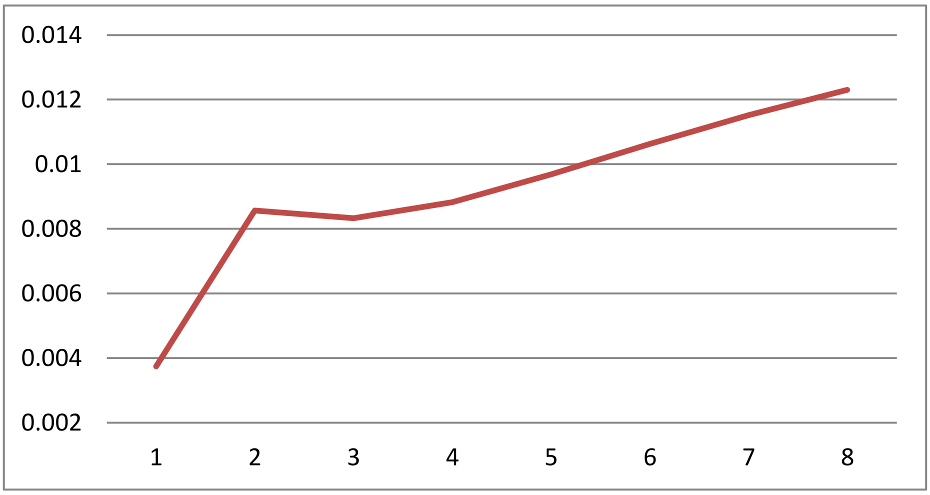

Figure 2： The proportion of China "Manufacture of Electrical Equipment" sector's output in total outputs of all sectors at each distance

There is a positive correlation between the sector RAPP and its upstreamness. If a certain sector has a greater RAPP, the proportion of this sector's output in total outputs of all sectors increases as the distance in global value chain increases. Meanwhile, in the global value chain, except the final demand, the outputs at a distance are the inputs at next distance. Therefore, if a certain sector has a greater RAPP, the proportion of the input from this sector in total input from all sectors increases as the distance in global value chain increases, and this sector is located in an upper position in global value chain.

A sector's RAPP is decided by its characteristics, and, of course, the heterogeneity of different sectors leads to different RAPPs. But in the case of the same sectors in different economies, if their products are totally homogeneous, their RAPP will be equal. Accordingly, the differences of the RAPP between the same sectors across different economies arise from the heterogeneity of such sectors in global value chain, which is due to the different products or different application of products between those sectors. For example, in WIOD world input-output table, clothes, cloths and cotton yarn all belong to the sector "Manufacture of Textiles, Wearing Apparel and Leather Products". Assuming the major product of "Manufacture of Textiles, Wearing Apparel and Leather Products" sector in economy A is clothes while the major product of this sector in economy B is cotton yarn, since cotton yarn is used to produce clothes, without considering the situation that a plenty of cotton yarn are manufactured as final demand worldwide, the RAPPs and the upstreamness of such sectors in economy A and B are definitely different. Meanwhile, assume that the major product of the sector in economy C is also cotton yarn, and that the cotton yarns from economy C are mostly used for cloth manufacture while the cotton yarns from economy B are mostly used for clothes manufacture. Obviously, the RAPPs and the upstreamness of the sector in economy B and C are also definitely different.

The Antras's measurement of sector's upstreamness also tells the differences of the upstreamness and specialization in global value chain between the same sectors across different economies. However, the Antras's measurement is an average distance in global value chain weighted by the proportion of a sector's output at each distance in total output of such a sector, and the property of technical coefficients decides that the outputs at each distance decline significantly as distance increases. Thus, the Antras's measurement of sector upstreamness leads to less notable results between sectors, especially the same sectors across different economies.

According to the results calculated from 2014 WIOD world input-output table, after individual outliers are ruled out, the range of the measurements among the same sectors across different economies is around 2, which weakens the distinctions of labor-division and specialization across different economies in global value chain. On the contrary, the RAPP is a certain distance in global value chain, if the heterogeneity between the same sectors across different economies is significant, the gap between such sectors' RAPP is at least 1, which can reveal more notable heterogeneity across different economies.

According to the definition of RAPP given above, we can calculate all sectors' outputs at each distance and then measure their RAPPs. But as for the sectors with low outputs and the sectors with fine classifications, the proportion of such sector's output in total outputs of all sectors would be very small and the data seems stable, which makes it difficult to find their RAPPs. Therefore, this paper defines allocation coefficients on the basis of Layer Lemma, and puts forward an approximation algorithm by comparing the allocation coefficients at adjacent distances.

By Layer Lemma given above, we can obtain all input flows matrixes Z_n at each production step or each distance in global value chain. By the similar method of calculating output coefficients, we can calculate the allocation coefficients at each distance as the following:

$$D_n = (\hat{z}_n^{-1}) Z_n \tag{6}$$

$D_n = (d_{ij}^n)$, d_{ij}^n denotes the proportion of the input from sector i to sector j in the total output of sector i at distance n, and is called the allocation coefficient from sector i to sector j at distance n. At each distance, consider the self-allocation coefficient of sector I as d_{ii}^n. If $d_{ii}^n > d_{ii}^{n-1}$ and $d_{ii}^n > d_{ii}^{n+1}$, then we say the extreme value of self-allocation coefficient of sector i appears at distance n. Based on the following theorem, the distance, at which the extreme value of self-allocation coefficient appears, is the RAPP of the sector.

Theorem 1： when the extreme value of self-allocation coefficient of sector i appears at distance n, then at distance n, the output of sector i, relative to the total outputs of all sectors at the same distance, to some degree, is greater than distance n-1 and n+1.

Proof: the Theorem 1 is proved in Appendix.

RAPP is a certain distance in global value chain where the extreme value of self-allocation coefficient appears. For the following reasons, we have to set an upper bound of distance, and leave the distance greater than the upper bound out of account.

1、 The eigenvalues of direct input coefficients matrix A are all less than 1, so $\lim_{n\to+\infty} A^n = 0$, $\lim_{n\to+\infty} z_n = A^n f = 0$. With distance increasing, the row sum of input flows matrix Z_n at each distance converge to 0 rapidly. Thus, as distance increases, the allocation coefficients would be more sensitive due to the decline of denominator, which weaken the comparability of self-allocation coefficient.

2、 If no upper bound exists, the excessively far distance would go beyond the distance we need to consider in global value chain and lead to a worthless results rather than RAPP.

3、 For some upstream sectors, for example the natural resource sectors, if no upper bound exists, their self-allocation coefficient increases constantly as distance increases. So their RAPP cannot be calculated.

4 The Application of RAPP in WIOD World Input-Output Table

4.1 The Non-Uniqueness of RAPP

World Input-Output Database contains annual time-series worldwide multi-regional input-output tables covering the period from 1995 to 2014, and each table gives the value of transactions among 56 sectors in 43 economies plus the 'Rest of the World'(Timmer et al, 2015; Timmer et al, 2016). According to the rule of thumb, making the upper-bound equal 7, we calculate the RAPP of each sector in WIOD world input-output table for years 2007 and 2014 by using the algorithm given above.

The RAPP of a certain sector might not be unique. In other words, a certain sector may have more than 1 RAPP. The non-uniqueness appears most frequently in such sectors as supply of water, electricity and gas, and appears least frequently in manufacturing and mining. According to the results measured from the 2014 WIOD world input-output table, with exception of the waste collection sectors and the sectors that have no outputs, there are 126 Agricultural sectors, of which 34 have more than 1 RAPP, accounting for 26.98% of the total; 44 mining sectors, of which 7 have more than 1 RAPP, accounting for 15.91%; 816 manufacturing sectors, of which 79 have more than 1 RAPP, accounting for 9.7%; 85 sectors about supply of water, electricity and gas, of which 37 have more than 1 RAPP, accounting for 43.53%; 44 Construction sectors, of which 10 have more than 1 RAPP, accounting for 22.73%; and 1128 sectors of tertiary industry, of which 289 have more than 1 RAPP, accounting for 25.62%. The statistics results from the 2007 WIOD world input-output table are similar to those of 2014.

The non-uniqueness of RAPP is rooted in the characteristic of the certain sectors. Reviewing the definition of RAPP, RAPP denotes the distance in global value chain where the proportion of a certain sector's output in total outputs of all sectors at the same distance would be greater than that at the distance nearby. Since the outputs at a distance are the inputs at next distance in global value chain, the products of that sector are more important raw material for sectors at next distance from RAPP than that at the distance nearby. Thus, if the products of a certain sector are an essential input at multiple distances (here we regard the final demand also as a kind of input), the sector's RAPP may present its non-uniqueness.

Look backwards the statistics given above. The products of manufacturing and mining mainly serve a single purpose. The products of mining are mainly input at the upstream positions in global value chain. As for the products of manufacturing, some of them are mainly produced as final demands, and some of them are mostly the direct input or in direct input for the final demands. Hence, the non-uniqueness of RAPP appears least frequently in manufacturing and mining. Conversely, the products of sectors about supply of water, electricity and gas are not only the indispensable commodities as final demands, but also the essential inputs in production activity of other sectors. So the non-uniqueness appears most frequently in these sectors. The productive service sectors share the similar characteristic. Let us take the transport service sectors for example. There are 132 transport service sectors in 2014 WIOD world input-output table (except the sectors without outputs), of which 45 have more than 1 RAPP, accounting for34.10% of the total. Among them, 21 of 44 water transport service sectors have more than 1 RAPP, accounting for47.73% of the total. The statistic results from the 2007 WIOD world input-output table are similar to that of 2014.

4.2 The Positive Correlation between Sector RAPP and Sector Upstreamness

In order to verify the positive correlation between the sector's RAPP and its upstreamness, we calculate RAPPs for each sector based on China's non- competitive Input-Output Table for years 2007 and 2012, and 2012 US non-competitive Input-Output Table. China's Input-Output Tables are published by the National Bureau of Statistics of the People's Republic of China every five years. The 2012 US non-competitive Input-Output Table is made on the basis of the supply and use table published by the Bureau of Economic Analysis (BEA) on their website. The following tables lists the sectors (in 2007 China's non- competitive Input-Output Table) whose unique RAPP is the maximum (due to the upper bound) or minimum distance in global value chain. The results calculated from another two Input-Output Table are presented in Appendix.

Table 2: the China's sectors with least and most RAPPs in 2007

sectors whose unique RAPP are the maximum distance in global value chain
Coal mining, washing and processing
Crude petroleum and natural gas products
Refined oil and fuel products
Other versatile devices
Electricity, steam and hot water production and supply
Water production and supply
sectors whose unique RAPP are the minimum distance in global value chain
Convenience food
Dairy products
Other foods
Knitted and crocheted fabrics
Textile garments
Professional equipment for chemical, wood, nonmetal production
Other professional equipment
Railroad transport equipment
Power transmission and distribution and operating device manufacturing
Household electric & non-electric appliances
Communication device
Radio, television, radar and auxiliary equipment
Electronic computer
Radio, television and communication equipment and apparatus
Instrument and apparatus
Cultural and office equipment
Other manufacturing products
construction
Software services
Wholesale and retail trade
Real estate

tourism
Water conservancy management
Residential services
Education
Hygienic
Social security
Social welfare
Public management and social administration
Public Facility Management
Sports

On the one hand, the sectors whose unique RAPP is the maximum distance in global value chain tend to be involved in the processing of raw materials or energies. On the other hand, the outputs of sectors with minimum RAPP go mostly to the end-users.

The results also reveal direct upstream relationship between sectors, especially between the sectors with single-purposed products. For example, the RAPP of Agriculture is 5. Since pesticides and fertilizers are directly inputs in the production process of agriculture product, the RAPP of "manufacture of pesticide" and "manufacture of fertilizer" are 6. For another example, the RAPP of "Non-ferrous Metal Mining" is 5. "Non-ferrous Metal Smelting" is the direct downstream sector, so the RAPP of "Non-ferrous metal smelting" is 4. In the same way, the RAPP of "Non-ferrous Metal Pressing" is 3.

There are some other sectors have a RAPP at the maximum distance in global value chain, e.g. "Manufacture of Boiler and Prime Mover" and "Manufacture of Motor", because their products are essential inputs for the outputs of upstream sectors. There are also some other sectors with a minimum RAPP, e.g. "supply of gas", because their products also play an important part in final demands.

4.3 The Change of RAPP and the Comparison between Economies

This paper takes China as the benchmark, and picks up 9 representative economies to find out the changes of RAPP of each sector in a certain economies at the period from 2007 to 2014 and the differences of RAPP between the same sectors across different economies at the same period. The 9 representative economies are: Japan, Korea, Indonesia, India, German, the United States, Brazil and Mexico. The calculation results of RAPP of each sector in these economies are presented in Appendix.

4.3.1 Comparison in Economy Dimension

The RAPPs of the same sectors across different economies may vary. On the one hand, for the sectors with high-leveled vertical specialization, it reveals the different division of labor in global value chain across economies. On the other hand, for the sectors with low-leveled vertical specialization, i.e. the sectors whose products are mainly for domestic use, it discloses the heterogeneity of industrial structure across economies.

In order to concentrate on heterogeneity in global value chain across economies, we have to pick out the sectors with high-leveled vertical specialization at first place. Since the high-leveled vertical specialization represents high-leveled labor-division and more international intermediate trade. This paper, on the basis of the intermediate flows matrix of WIOD world Input-Output Table, calculates the proportion of each sector’s output involved in international intermediate product trade in the total intermediate output of the corresponding sector. This paper calculates the mean of the proportion among economies, and then picks up the sectors ranked at the top one-third, which are mainly involved in manufacturing and transport service. The RAPPs of these sectors in the representative economies in 2014 are listed as the following.

Table 3: The RAPPs of the chosen sectors in the representative economies in 2014

	2014	CHN	IDN	IND	JPN	KOR	USA	DEU	BRA	MEX
labor-intensive sectors	Manufacture of textiles, wearing apparel and leather	3	1	1	4	5	3	2	1	1
	Manufacture of wood and of products of wood and cork, except furniture;	2	2	2	2	2	3	3	3	3
	Manufacture of paper and paper products	6	4	4	5	6	4	5	4	4
	Manufacture of furniture; other manufacturing	1/4	1	2	2	4	2	1	1/4	2
	Water transport	7	3	1/5	7	1/7	2/4	6	6	1
	Air transport	2	1	2	1/3	2	3	1	2	1/3
capital-intensive sectors	Mining and quarrying	7	3	5	3/7	7	3/5	7	6	5
	Manufacture of coke and refined petroleum products	7	2	4	2/7	7	2/4	1/6	6	3
	Manufacture of chemicals and chemical products	7	3	5	7	7	1/5	5	1/4	4
	Manufacture of basic pharmaceutical products	2	2	1/5	2	2	5	2	2	2
	Manufacture of rubber and plastic products	7	2	4	4	3	3	3	3	2

	Manufacture of other non-metallic mineral products	2	2/5	2	2	2	2	3	2	2
	Manufacture of basic metals	4	2	3	7	5	5	6	3	5
	Manufacture of fabricated metal products, except machinery and equipment	2	2	2	2	2	3	3	2	3
technology-intensive sectors	Manufacture of computer, electronic and optical products	7	1	4	4	5	2	2	1	1
	Manufacture of electrical equipment	2/7	2	2	1	2	2	3	2	2
	Manufacture of machinery and equipment n.e.c.	1/7	1/4	1	1	2	1/4	1	1	2/4
	Manufacture of motor vehicles, trailers and semi-trailers	1	1	1	4	2	1	1	1	2
	Manufacture of other transport equipment	1	2	1	2	1	2	1	1	2
	Scientific research and development	2/7	0	0	0	1/3	3	1	2	2

Here, the chosen sectors are classified into 3 groups by the characteristic of each sector. The 3 groups are "labor-intensive sectors", "capital-intensive sectors" and "technology-intensive sectors". To deserve to be mentioned, we can also find the positive correlation discussed in 4.2. The capital-intensive sectors are usually involved in the processing of raw materials, while labor-intensive sectors and technology-intensive sectors are more involved in the production for final demand. So the RAPPs of capital-intensive sectors are greater than the other two groups in general.

To get back to the point, the differences of RAPPs of the same sectors across different economies, as illustrated as above, reveals the different divisions of labor in global value chain across economies. For example, China, Indonesia, India, Brazil and Mexico are all developing countries that focus on labor-intensive manufacturing sectors. But the RAPPs of those labor-intensive manufacturing sectors indicate that China, compared with the other 4 countries, is more upstream in the global value chain. It corresponds with the facts in Input-Output Table. By calculating the proportions of each labor-intensive manufacturing sector's intermediate output in the total output of the corresponding sector, we can find that the proportions of China are greater than those of the other 4 countries in the same sector. It suggests that the outputs of those labor-intensive manufacturing sectors in China are more used as intermediate input than the other 4 countries, and that China is more upstream in the global value chain.

For another example, Mexico and the USA are important trade partners. According to the statistics from WTO, the goods exporting from Mexico to the USA account for 78.64% of the total exports of Mexico, of which Machinery, electrical equipment and motor vehicles ranked at the top. Mexico is at one distance more in general than the USA in the RAPPs of "Manufacture of electrical equipment", "Manufacture of machinery and equipment n.e.c." and" Manufacture of motor vehicles, trailers and semi-trailers". It coincides with the above-mentioned situations, and reveals the direct upstream relationship between the two countries.

4.3.2 Comparison in Time Dimension

Considering the changes of RAPP of each sector in the 9 representative economies at the period from 2007 to 2014, with exception of the waste collection sectors and the sectors that have no outputs, there are 144 of 433 sectors whose RAPPs have changed at the period from 2007 to 2014. Hereinto, 83 sectors have lower RAPPs, and 61 sectors have greater RAPPs.

As is illustrated at 4.3.1, on the one hand, for the sectors with high-leveled vertical specialization, it reveals the positional changes of the corresponding sectors in global value chain. On the other hand, for the sectors with low-leveled vertical specialization, it discloses the changes of industrial structure of the economy which the sector belongs to.

Here we still focus on the sectors picked out above, and observe changes of RAPPs of those sectors in 9 representative economies at the period from 2007 to 2014. Then we can find out the following results: the sectors that belong to China and Mexico have greater RAPPs in general; conversely, the sectors that belong to Brazil and Indonesia have lower RAPPs in general; the RAPPs of the sectors that belong to India, Japan and Korea almost stay stable; the American manufacturing sectors have lower RAPPs at that period, while the sectors about transport service and scientific research have greater RAPPs; the RAPPs of the manufacturing sectors in German stay stable at that period in general, while the sectors about transport service and scientific research have lower RAPPs.

The results presented above almost tally with the changes of WIOD world Input-Output Tables from year 2007 to 2014. On the basis of 2007 and 2014 WIOD world Input-Output Table, we calculate the proportions of each sector's intermediate output in the total output of that sector. Comparing the proportion between the same sectors in different years, we can get conclusions that coincide with the above-mentioned results. For example, the outputs of China's chosen sectors are more used as intermediate input in 2014 than 2007. It reveals that China has played an increasingly important role at the upstream. So the China's sectors have greater RAPPs in general at that period. For another example, the outputs of Brazil's chosen sectors are less used as intermediate input in 2014 than 2007. It suggests Brazil is more focusing on the production at downstream, so Brazil's sectors have lower RAPPs in general at that period.

5 Conclusion

This paper defines a new indicator named relative advantage production position to clarify the position differences in global value chain between economies, and puts forward an approximation algorithm to calculate it on the basis of Input-Output model and Layer Lemma. In empirical parts, this paper measures the RAPPs based on several national Input-Output Tables and world Input-Output Tables, and draw conclusion as follows:

1. The RAPP of a certain sector might not be unique. The non-uniqueness appears most frequently in such sectors as supply of water, electricity and gas, and appears least frequently in manufacturing and mining. The non-uniqueness of the RAPP is rooted in the characteristic of the certain sectors.

2. There is a positive correlation between the sector's RAPP and its upstreamness. Furthermore, the RAPP can also reveal the direct upstream relationship between sectors, especially between the sectors with single-purposed products.

3. The RAPPs of the same sectors across different economies may vary. For the sectors with high-leveled vertical specialization, it reveals the different division of labor in global value chain across economies.

4. For the sectors with high-leveled vertical specialization, the change of the RAPP reveals the positional changes of the corresponding sectors in global value chain.

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Appendix

Theorem 1： when the extreme value of sector i's self-allocation coefficient appears at distance n, then the output of sector i at distance n, relative to the total outputs of all sectors at the same distance, to some degree, is greater than distance n-1 and n+1.

Proof: we will prove this Theorem in the case of two sectors Input-Output Table and three sectors Input-Output Table. The proof of the case with more than three sectors is similar with that of three sectors Input-Output Table. Since the sectors in Input-Output Table can be arranged in arbitrary order, we can just focus on sector 1 as a representative to prove the Theorem. Besides, we need to introduce Lemma 2 to help the proof. The following is the proof of Lemma 2.

Lemma 2: assuming a, b, c, d are all greater than 0, if $\frac{c+d}{a+b} > \frac{c}{a}$, then $\frac{d}{b} > \frac{c}{a}$; on the other hand, if $\frac{c+d}{a+b} < \frac{c}{a}$, then $\frac{d}{b} < \frac{c}{a}$.

Proof：

if $\frac{c+d}{a+b} > \frac{c}{a}$, since a and b are greater than 0, then $a(c+d) > c(a+b)$, $ac+ad > ac+bc, ad > bc$, $\frac{d}{b} > \frac{c}{a}$.

if $\frac{c+d}{a+b} < \frac{c}{a}$, it can be proved in the same way that $\frac{d}{b} < \frac{c}{a}$.

The case of two sectors Input-Output Table：

Assuming the input flows matrix at distance n-1 is $Z_{n-1} = \begin{pmatrix} a & b \\ c & d \end{pmatrix}$, then the input flows matrix at distance n should be $Z_n = \begin{pmatrix} a_{11}(a+b) & a_{12}(c+d) \\ a_{21}(a+b) & a_{22}(c+d) \end{pmatrix}$ on the basis of Layer Lemma.

Furthermore, the allocation coefficients matrix at distance n-1 and n are respectively

$$D_{n-1} = \begin{pmatrix} \frac{a}{a+b} & \frac{b}{a+b} \\ \frac{c}{c+d} & \frac{d}{c+d} \end{pmatrix} \qquad (7)$$

$$D_n = \begin{pmatrix} \dfrac{a_{11}(a+b)}{a_{11}(a+b)+a_{12}(c+d)} & \dfrac{a_{12}(c+d)}{a_{11}(a+b)+a_{12}(c+d)} \\ \dfrac{a_{21}(a+b)}{a_{21}(a+b)+a_{22}(c+d)} & \dfrac{a_{22}(c+d)}{a_{21}(a+b)+a_{22}(c+d)} \end{pmatrix} \quad (8)$$

If the extreme value of sector 1's self-allocation coefficient appears at distance n, then $d_{11}^{n} > d_{11}^{n-1}$,and $d_{11}^{n} > d_{11}^{n+1}$. According to （7），（8）and the condition that $d_{11}^{n} > d_{11}^{n-1}$, we can get

$$\frac{a_{11}(a+b)}{a_{11}(a+b)+a_{12}(c+d)} = \frac{a_{11}a+a_{11}b}{a_{11}(a+b)+a_{12}(c+d)} > \frac{a}{a+b} \quad (9)$$

By Lemma 2[1], when inequation (9) is satisfied， then

$$\frac{a_{11}b}{a_{12}(c+d)} > \frac{a}{(a+b)} \quad (10)$$

$$\frac{z_1^n}{z_{else}^n} = \frac{z_1^n}{z_2^n} = \frac{a+b}{c+d} > \frac{a/a_{11}}{b/a_{12}} = \frac{z_1^{n-1}}{z_2^{n-1}} = \frac{z_1^{n-1}}{z_{else}^{n-1}} \quad (11)$$

Here, z_1^n denotes the outputs of sector 1 at distance n. On the other hand, we can deduce that $\frac{z_1^n}{z_2^n} > \frac{z_1^{n+1}}{z_2^{n+1}}$ from the condition that $d_{11}^{n} > d_{11}^{n-1}$, in the same way as above. In the case of two sectors Input-Output Table, sector 2 is the only other sector, and therefore, if the extreme value of sector 1's self-allocation coefficient appears at distance n, then the output of sector 1, relative to the total outputs of all sectors at the same distance, is greater than distance n-1 and n+1.

The case of three sectors Input-Output Table：

Assuming the input flows matrix at distance n-1 is $Z_{n-1} = \begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \end{pmatrix}$, then the input flows

[1]To ensure the Prerequisite of Lemma 2, the Input- Output table should be world Input- Output Table or non-competitive Input-Output Table. And the direct input coefficients which equal 0 should be replaced by the positive that is very close to 0.

matrix at distance n should be $Z_n=\begin{pmatrix} a_{11}(a+b+c) & a_{12}(d+e+f) & a_{13}(g+h+i) \\ a_{21}(a+b+c) & a_{22}(d+e+f) & a_{23}(g+h+i) \\ a_{31}(a+b+c) & a_{32}(d+e+f) & a_{33}(g+h+i) \end{pmatrix}$ on the basis of Layer Lemma. Furthermore, the allocation coefficients matrix at distance n-1 and n are respectively

$$D_{n-1}=\begin{pmatrix} \frac{a}{a+b+c} & \frac{b}{a+b+c} & \frac{c}{a+b+c} \\ \frac{d}{d+e+f} & \frac{e}{d+e+f} & \frac{f}{d+e+f} \\ \frac{g}{g+h+i} & \frac{h}{g+h+i} & \frac{i}{g+h+i} \end{pmatrix} \qquad (2)$$

$$D_n=\begin{pmatrix} \frac{a_{11}(a+b+c)}{a_{11}(a+b+c)+a_{12}(d+e+f)+a_{13}(g+h+i)} & d_{12}^n & d_{13}^n \\ \frac{a_{21}(a+b+c)}{a_{21}(a+b+c)+a_{22}(d+e+f)+a_{23}(g+h+i)} & d_{22}^n & d_{23}^n \\ \frac{a_{31}(a+b+c)}{a_{31}(a+b+c)+a_{32}(d+e+f)+a_{33}(g+h+i)} & d_{32}^n & d_{33}^n \end{pmatrix} \qquad (3)$$

Similarly， if the extreme value of sector 1‘s self-allocation coefficient appears at distance n, then $d_{11}^n > d_{11}^{n-1}$, and $d_{11}^n > d_{11}^{n+1}$. According to （12）,（13）and the condition that $d_{11}^n > d_{11}^{n-1}$, we can get

$$\frac{a_{11}(a+b+c)}{a_{11}(a+b+c)+a_{12}(d+e+f)+a_{13}(g+h+i)} > \frac{a}{a+b+c} \qquad (4)$$

By Lemma 2, when inequation (9) is satisfied，then

$$\frac{a_{11}(b+c)}{a_{12}(d+e+f)+a_{13}(g+h+i)} > \frac{a}{a+b+c} \qquad (5)$$

$$\frac{a+b+c}{a_{12}(d+e+f)+a_{13}(g+h+i)} > \frac{a/a_{11}}{(b+c)} \qquad (6)$$

$$\frac{z_1^n}{z_{else}^n} = \frac{a+b+c}{(d+e+f)+(g+h+i)} > \frac{a/a_{11}}{(b+c)/l} = \frac{z_1^{n-1}}{(z_{else}^{n-1})^*} \qquad (7)$$

Hereinto,

$$l = \frac{a_{12}(d+e+f)+a_{13}(g+h+i)}{(d+e+f)+(g+h+i)} \quad (8)$$

Actually, $(z_{else}^{n-1})^* = {(b+c)}/{l}$ is not the exact output of other sectors at distance n-1. But when we merge all sectors except sector 1 into an integrated sector on the basis of each sector's output at distance n, the direct inputs coefficient of this integrated sector from sector 1 equals l. Meanwhile, $(b+c)$ equals the input from sector 1 to the integrated sector at distance n-1. Thus, we can regard ${(b+c)}/{l}$ as the generalized outputs of the integration sector, which are also the generalized outputs of other sectors (sector 1 excepted) at distance n-1.

In the same time, we can deduce that $\frac{z_1^{n+1}}{z_{else}^{n+1}} < \frac{z_1^n}{(z_{else}^n)^*}$ under the condition that $d_{11}^n > d_{11}^{n-1}$, in the same way as above. Consequently, in the case of three sectors Input-Output Table, if the extreme value of sector 1's self-allocation coefficient appears at distance n, then the output of sector 1, relative to the total outputs of all sectors at the same distance, is greater than distance n-1 and n+1, to some degree.

Table 4: the China's sectors with least and most RAPPs in 2012

sectors whose unique RAPP are the maximum distance in global value chain
Special chemical products
Crude petroleum and natural gas products
Pesticides
Coal mining, washing and processing
Services of mining and others
Refined oil and fuel products
Repairing services of metal products, machinery and equipment
Manmade chemical products
Electricity, steam and hot water production and supply
sectors whose unique RAPP are the minimum distance in global value chain
Materials handing equipment
Cultural and office equipment
Hygienic
Slaughtering and meat processed products
Communication device
Railroad transport equipment
Vegetables, fruits, nuts and other foods
Radio, television and communication equipment and apparatus
Social security

Software and information technology services
Dairy products
Other foods
Professional equipment for agriculture, forestry, animal husbandry and fishery
Residential services
Metal processing machinery
Education
Household electric & non-electric appliances
Furniture
Electronic computer
Professional equipment for chemical, wood, nonmetal production
Radio, television, radar and auxiliary equipment
Radio, television, film and video recordings
Public Facility Management
Public management and social administration
Textile articles
Textile garments
Real estate
Convenience food
Professional equipment for mining, metallurgy, architecture

Table 5: the American sectors with least and most RAPPs in 2012

sectors whose unique RAPP are the maximum distance in global value chain
Mining, except oil and gas
Wood products
Primary metals
Paper products
Chemical products
Rail transportation
Other transportation and support activities
Insurance carriers and related activities
Rental and leasing services and lessors of intangible assets
Legal services
Scrap, used and secondhand goods

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Support activities for mining
Construction
Motor vehicles, bodies and trailers, and parts
Apparel and leather and allied products
Motor vehicle and parts dealers
Food and beverage stores
General merchandise stores
Publishing industries, except internet (includes software)
Funds, trusts, and other financial vehicles

Amusements, gambling, and recreation industries
Food services and drinking places
Noncomparable imports and rest-of-the-world adjustment [1]
Housing
Federal general government (defense)
Federal general government (nondefense)
State and local general government

Table 6: The RAPPs of the sectors in the representative economies in 2014

2014	CHN	IDN	IND	JPN	KOR	USA	DEU	BRA	MEX
Crop and animal production, hunting and related service activities	3	3	2	3	3	3	3	2	2
Forestry and logging	7	3	1/3	4	1/3	5	1/5	1/4	1/4
Fishing and aquaculture	2	2	1	3	2	5	2	1/4	1/4
Mining and quarrying	7	3	5	3/7	7	3/5	7	6	5
Manufacture of food products, beverages and tobacco products	1	2	1	2	2	2	2	1	1
Manufacture of textiles, wearing apparel and leather products	3	1	1	4	5	3	2	1	1
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	2	2	2	2	2	3	3	3	3
Manufacture of paper and paper products	6	4	4	5	6	4	5	4	4
Printing and reproduction of recorded media	2/4/7	2	1/4	2/5	3	2	3	4	2
Manufacture of coke and refined petroleum products	7	2	4	2/7	7	2/4	1/6	6	3
Manufacture of chemicals and chemical products	7	3	5	7	7	1/5	5	1/4	4
Manufacture of basic pharmaceutical products and pharmaceutical preparations	2	2	1/5	2	2	5	2	2	2
Manufacture of rubber and plastic products	7	2	4	4	3	3	3	3	2
Manufacture of other non-metallic mineral products	2	2/5	2	2	2	2	3	2	2
Manufacture of basic metals	4	2	3	7	5	5	6	3	5
Manufacture of fabricated metal products, except machinery and equipment	2	2	2	2	2	3	3	2	3
Manufacture of computer, electronic and optical products	7	1	4	4	5	2	2	1	1
Manufacture of electrical equipment	2/7	2	2	1	2	2	3	2	2

Manufacture of machinery and equipment n.e.c.	1/7	1/4	1	1	2	1/4	1	1	0
Manufacture of motor vehicles, trailers and semi-trailers	1	1	1	4	2	1	1	1	2
Manufacture of other transport equipment	1	2	1	2	1	2	1	1	2
Manufacture of furniture; other manufacturing	1/4	1	2	2	4	2	1	1/4	2
Repair and installation of machinery and equipment	0	0	0	0	0	1	5	0	2
Electricity, gas, steam and air conditioning supply	7	6	4	2	7	2	2/5	5	2
Water collection, treatment and supply	2/7	1/3	1	2	2/7	2	1/5	2	0
Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	1/7	0	0	2	7	2/5	6	0	2/5
Construction	1/7	1/4	1	1	1	1	1	1	1
Wholesale and retail trade and repair of motor vehicles and motorcycles	0	2	2	3	3	1	2	1	1
Wholesale trade, except of motor vehicles and motorcycles	2/7	2	2	2	3	2	2	2	1
Retail trade, except of motor vehicles and motorcycles	2/7	2	2	1	3	1	1	2	1
Land transport and transport via pipelines	2/7	2	1/3	2	1/7	4	6	3	1
Water transport	7	3	1/5	7	1/7	2/4	6	6	1
Air transport	2	1	2	1/3	2	3	1	2	1/3
Warehousing and support activities for transportation	4/7	2	3	2	7	3	6	3	2
Postal and courier activities	2/7	3	0	2	3	4	2	0	2
Accommodation and food service activities	2/7	1	1/4	1	1	1	1	1	2
Publishing activities	0	2	0	4	2	2	2	2	2
Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities	0	4	0	1/5	2	3	1/4	5	1
Telecommunications	2/7	1/3	4	3	3	2	1/4	1/3	2
Computer programming, consultancy and related activities; information service activities	1/7	3	1	2	1	2	4	3	3
Financial service activities, except insurance and pension funding	2/7	3	3	3	2	3	3	2	2
Insurance, reinsurance and pension funding, except compulsory social security	1/7	4	3	1	1	2	1/3/5	0	1

Activities auxiliary to financial services and insurance activities	0	0	0	0	3	2	2/4	0	2
Real estate activities	1/3/7	1/3	1	1	1	2	1	1	0
Legal and accounting activities; activities of head offices; management consultancy activities	3/7	2/4	2	0	3	3	4	4	2
Architectural and engineering activities; technical testing and analysis	0	0	2	0	2	2	4	2	2
Scientific research and development	2/7	0	0	0	1/3	3	1	2	2
Advertising and market research	0	0	0	3	3	2	3	0	0
Other professional, scientific and technical activities; veterinary activities	2/7	0	0	2	2	3	3	0	2
Administrative and support service activities	1/7	3	1/4	2	6	3	4	2	2
Public administration and defence; compulsory social security	1/4	1/4	0	1/3	1	1	1	1	0
Education	1/7	1	1/5	1/3	1/6	1	1	1/3	1
Human health and social work activities	1/7	1	0	1	1	1	1	1	0
Other service activities	2/7	1	1	1/5	1	1	1	1/5	1
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	0	0	0	2	0	1	0	0	0
Activities of extraterritorial organizations and bodies	0	0	0	0	0	0	0	0	0

Table 7: The RAPPs of the sectors in the representative economies in 2007

2007	CHN	IDN	IND	JPN	KOR	USA	DEU	BRA	MEX
Crop and animal production, hunting and related service activities	3	3	2	3	3	3	3	2	2
Forestry and logging	6	3	3	1/4	1/3	5	1/5	1/5	1/4
Fishing and aquaculture	3	2	1	3	2	5	2	1/5	1/4
Mining and quarrying	7	6	5	3/7	7	3/5	7	7	4
Manufacture of food products, beverages and tobacco products	1/3	2	1	2	2	2	2	1	1
Manufacture of textiles, wearing apparel and leather products	2	1	1	4	3	3	2	1	1
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	3	2	2	2	2	3	3	3	3

Manufacture of paper and paper products	5	5	5	6	6	5	6	4	4
Printing and reproduction of recorded media	2	2	1/4	2/5	3	2	5	3	3
Manufacture of coke and refined petroleum products	7	2/4	4	2/7	7	2/4	1/6	7	3
Manufacture of chemicals and chemical products	7	4	5	7	7	5	5	1/5	5
Manufacture of basic pharmaceutical products and pharmaceutical preparations	2	2	1/5	2	2	5	2	2	2
Manufacture of rubber and plastic products	5	2	4	4	3	2	3	3	2
Manufacture of other non-metallic mineral products	2	2	2	2	2	2	3	2	2
Manufacture of basic metals	4/7	3	3	7	6	5	6	4	4
Manufacture of fabricated metal products, except machinery and equipment	3	2	2	2	2	3	3	2	2
Manufacture of computer, electronic and optical products	1	1	1/4	4	5	3	1	1	1
Manufacture of electrical equipment	2/7	2	2	1	2	2	2	2	2
Manufacture of machinery and equipment n.e.c.	1/7	1/4	1	1	2	1/4	1	1/7	2/4
Manufacture of motor vehicles, trailers and semi-trailers	1/7	1	1	1/4	2	2	1	1	1
Manufacture of other transport equipment	1	1	1	2	2	2	2	1	2
Manufacture of furniture; other manufacturing	1/5	1	1	2	2	2	1	1/5	2
Repair and installation of machinery and equipment	0	0	0	0	0	1	1/6	0	2
Electricity, gas, steam and air conditioning supply	7	5	5	2/7	2/7	2	6	5	2
Water collection, treatment and supply	7	1/4	2	2	2/7	2	2/6	2/4	0
Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	2/7	0	0	2	2/7	2/6	1/7	0	2/5
Construction	1/7	1/4	1	1	1	1	1/6	1	1
Wholesale and retail trade and repair of motor vehicles and motorcycles	0	1	3	3	2	1	1	1	1
Wholesale trade, except of motor vehicles and motorcycles	2	2	3	2	2	2/4	2	2	1
Retail trade, except of motor vehicles and motorcycles	2	2	3	1	2	1	1	2	1
Land transport and transport via pipelines	2/7	3	3	2	1/3 /6	2/4	6	4	1
Water transport	7	1/4	0	7	1/7	1/4	1/7	7	1

Air transport	2	1	2	1/3	2	1/3	1/4	2/5	1/3
Warehousing and support activities for transportation	2	3	2	2	5	3	6	3/5	2
Postal and courier activities	2	3	0	2	3	4	2	0	2
Accommodation and food service activities	2/7	1	1/4	1	1	1	1	2	1
Publishing activities	0	2	0	1/4	2	1	2/5	2	2
Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities	0	3	0	1/5	4	2	1/4	1/5	1
Telecommunications	2/7	1/4	4	3	3	2	1/5	2	2
Computer programming, consultancy and related activities; information service activities	1/7	3	2	2	2	2	5	2	3
Financial service activities, except insurance and pension funding	3/7	4	3	3	2	3	3	2	2
Insurance, reinsurance and pension funding, except compulsory social security	1/3 /7	1/4	3	1/3	1	2	1/6	0	1
Activities auxiliary to financial services and insurance activities	0	0	0	0	2	4	2/4 /7	0	2
Real estate activities	1/3 /7	1	1	1	1	2	1	1	0
Legal and accounting activities; activities of head offices; management consultancy activities	3	1/4	2	0	3	2	5	4	2
Architectural and engineering activities; technical testing and analysis	0	0	0	0	2	2	5	2	2
Scientific research and development	3/7	0	0	0	1/3	2	2	2	2
Advertising and market research	0	0	0	3	2	2	2	0	0
Other professional, scientific and technical activities; veterinary activities	2/7	0	0	2	2	2	4	0	2
Administrative and support service activities	1/3	1/4	1/5	2	3	2	4	2	2
Public administration and defence; compulsory social security	1/7	1/4	0	1/3	1/4	1	1/6	1	0
Education	1/7	1	1/3	1/3	1	1	1	1/3	1
Human health and social work activities	1/7	1	0	1	1	1	1	1	0
Other service activities	1/7	1	1/3	1/5	1	1	1	1/5	1
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	0	0	0	2	0	1	0	0	0
Activities of extraterritorial organizations and bodies	0	0	0	0	0	0	0	0	0