Innovation Efficiency of High Tech Industry in Yangtze River Economic Belt

—A Perspective of Heterogeneity

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Abstract: Using the meta-frontier theory and the two-stage DEA model, taking the pharmaceutical manufacturing industry as an example, the measurement and analysis of high-tech industry technology research efficiency, achievement transformation efficiency and regional technology gaps in 2010-2014 are carried out, and the reasons for inefficiency are decomposed. The result shows that: the two-stage innovation efficiency is low and are obviously different in different provinces and groups. The average value of technology research efficiency is from “upstream to midstream to downstream”, and the achievements transformation efficiency is decreasing in “downstream- midstream -upstream”. The gap between groups is larger in technology research stage and there is an expanding trend. In general, internal management of enterprises is the main factor leading to the inefficiency of two-stage innovation.

1. Introduction

China's economy has shifted from high-speed development to high-quality development. The Yangtze River Economic Belt relies on the golden waterway and spans the three major regions of the East, Central and West. Its population size, economic aggregate and innovative resources all occupy an important position in the country [1]. In 2018, Chairman Xi pointed out that the Yangtze River Economic Belt should be the main force for high-quality economic development. High-tech industries are technology-intensive and strategic-leading industries that best reflect regional technological innovation capabilities and economic development levels. The level of its innovation efficiency will directly affect regional high-quality development. China's high-tech industry has a large regional development gap, and there are obvious boundaries between regions [2]. Different geographical advantages, Resource reserve and market environment in different regions make high-tech enterprises have different innovation production technologies. If ignoring the heterogeneity and assuming that they have the same production front, it is impossible to accurately judge the loss of innovation efficiency. With the continuous increase of innovation investment, how to objectively evaluate and then specifically improve the innovation efficiency of high-tech industries in various regions has become an urgent problem to be solved. Taking full account of regional heterogeneity, this paper takes the pharmaceutical manufacturing industry as an example to analyze the innovation efficiency and regional gap of high-tech industries in various regions of the Yangtze River Economic Belt, and to decompose the sources of inefficiency. It is of great significance to shorten regional gaps, promote inter-regional coordinated development and finally realize the high-quality development of the Yangtze River Economic Belt.

2. Literature review

The measurement methods of high-tech industry innovation efficiency mainly include stochastic frontier approach (SFA) and data envelopment analysis (DEA). Compared with the SFA method, DEA is more objective and widely used in efficiency measures for multiple outputs. Gui [3] investigated the innovation efficiency of China's high-tech industry and explored its influencing factors. And found that large-scale capital investment failed to improve innovation efficiency. Shao

et al. [4] applied the BCC-DEA model and panel data of 29 provinces and cities in China to study the innovation efficiency characteristics and influencing factors of pharmaceutical manufacturing industry. The results showed that the innovation efficiency is not positively correlated with regional economic strength. Wu et al. [5] applied the DEA-Malmquist and the Tobit model and investigated the technological innovation efficiency of the Yangtze River Economic Belt. The results found significantly differences in the innovation efficiency of the upper, middle and lower reaches. With the deepening of the understanding of the process of technological innovation, some scholars have specified efficiency analysis into sub-processes, opening the black box of traditional efficiency evaluation. Kao et al. [6] proposed a network DEA model considering the relevance of sub-processes. On the basis of this, Guan et al. [7] divided the high-tech industry innovation process into two interrelated sub-processes of R&D and achievements commercialization and investigated the efficiency of high-tech industry innovation of China's provinces. Feng et al. [8] further constructed a resource-constrained two-stage DEA model to analyze the R&D innovation efficiency of 17 sub-sectors in China's high-tech industry. The results showed that the efficiency of the sub- processes are low in the two sub-segments.

In above studies, DMUs are assumed to be homogeneous. In order to evaluate and compare the efficiency of DMUs of technical heterogeneity groups, Battese et al. [9] proposed a research framework of meta-frontier and used SFA model for efficiency measurement. O'Donnell et al. [10] combined the meta-frontier with DEA and proposed a model for calculating group and common technical efficiency. Since meta-frontier method has obvious advantages in dealing with multi-group efficiency evaluation, it has been widely used in environmental efficiency and bank efficiency research [11-13]. In recent years, more literatures use meta-frontier theory to conduct research on innovation efficiency. Liu et al. [14] divided 37 industrial sectors into two groups according to technology intensity, and found that technological innovation efficiency varied greatly between different groups and industries within the same group. Xiao et al. [15] proposed a parallel network DEA model and measured the innovation efficiency of China's high-tech industry in 2007-2015. The research showed that there is a large loss in the ineffectiveness of technological innovation in the Chinese medicine manufacturing industry. However, none of the above studies have analyzed in depth which part of the innovation activity is lost.

This paper introduces the meta-frontier theory, and at the same time divides the innovation activities into two stages: technology research and achievement transformation. It analyzes its innovation efficiency, regional gap and decomposes the specific loss source of efficiency in the Yangtze River Economic Belt pharmaceutical manufacturing industry.

3. Method

3.1 Two-stage association network DEA

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Based on the regional technical heterogeneity, this study divides the high-tech industry in the Yangtze River Economic Belt into three groups: upstream, midstream and downstream. The upstream groups include Chongqing, Sichuan, Guizhou, and Yunnan provinces (cities). The following are collectively referred to as provinces. The middle group includes three provinces: Jiangxi, Hubei, and Hunan. The downstream groups include Shanghai, Jiangsu, Zhejiang, and Anhui. Firstly, the group-frontier is constructed, and the high-tech industries in each province are taken as a DMU. The inputs x and outputs y of the DMU in each group can be classified into technical collections $T^g = \{(x, y): x \geq 0, y \geq 0;\ \text{x can produce y in g group}\},\ g = 1, 2, 3,$ The upper bound of production set of the group g, $P^g(x) = \{y: (x, y) \in T^g\}$ is the group-frontier. and the production

of the groups may be set. cutting edge. Next, build the meta-frontier. considering all evaluation units, the meta technology set is $\mathrm{T} = T^1 \cup T^2 \cup T^3$, and its upper boundary is the meta-frontier of the high-tech industry in the Yangtze River Economic Belt.

Technological innovation is a continuous, multi-stage system engineering. The traditional DEA model only focuses on the initial input and final output. The two-stage DEA decomposes the complex production process, and increases the efficiency relationship between input and output to the whole production process by adding intermediate variables to examine the overall efficiency of each sub-stages. Lewis et al. [19] constructed a two-stage network DEA, but regarded the two stages as independent units. Kao et al. [6] proposed the associated network DEA model by solving the efficiency in the same stage by the same weight of the same kind of elements. This study uses the meta-frontier theory and the two-stage network DEA model to construct the group and meta-frontier. This study uses $x_{i,j}, y_{\mathrm{r},j}$ to represent the innovation input indicator of technology research and the output indicator of achievement transformation; $z_{p,j}$represents the output of the first stage, and the input of second stage; j is the DMUs, $j = 1, \cdots, n$. Under the meta-frontier, the comprehensive innovation efficiency and the efficiency of technology research stage of DMU k are the optimal solutions of the following models.

$$\left[\mathrm{D}\left(x_{i,k}, y_{r,k}\right)\right]^{-1} = E_k = max \sum_{r=1}^{s} u_r y_{r,k} \tag{1}$$

$$s.t. \quad \sum_{i=1}^{m} v_i x_{i,k} = 1$$

$$\sum_{r=1}^{s} u_r y_{r,j} - \sum_{i=1}^{m} v_i x_{i,j} \leq 0$$

$$\sum_{p=1}^{q} w_p z_{p,j} - \sum_{i=1}^{m} v_i x_{i,j} \leq 0$$

$$u_r, v_i, w_p \geq \varepsilon, r = 1, \cdots, s, i = 1, \cdots m, p = 1, \cdots, q$$

$$\left(x_{i,j}, y_{r,j}\right), \left(x_{i,j}, z_{q,j}\right), \left(z_{q,j}, y_{r,j}\right) \in T$$

$$\left[\mathrm{D}\left(x_{i,k}, z_{p,k}\right)\right]^{-1} = E_k^1 = max \sum_{p=1}^{q} w_p z_{p,k} \tag{2}$$

$$s.t. \quad \sum_{i=1}^{m} v_i x_{i,k} = 1$$

$$\sum_{r=1}^{s} u_r y_{r,k} - E_k \sum_{i=1}^{m} v_i x_{i,k} = 0$$

$$\sum_{r=1}^{s} u_r y_{r,j} - \sum_{i=1}^{m} v_i x_{i,j} \leq 0$$

$$\sum_{p=1}^{q} w_p z_{p,j} - \sum_{i=1}^{m} v_i x_{i,j} \leq 0$$

$$\sum_{r=1}^{s} u_r y_{r,j} - \sum_{p=1}^{q} w_p z_{p,j} \leq 0$$

$$u_r, v_i, w_p \geq \varepsilon, r = 1, \cdots, s, i = 1, \cdots m, p = 1, \cdots, q$$

$$\left(x_{i,j}, y_{r,j}\right), \left(x_{i,j}, z_{q,j}\right), \left(z_{q,j}, y_{r,j}\right) \in T$$

Where $D(\cdot)$ is the distance function of the DMU $k$under the meta-frontier; E_k, E_k^1 are the comprehensive innovation efficiency and efficiency of the technology research stage; $x_{i,k}$ is the ith

innovation input of the the technology research stage of k; $z_{p,k}$ is the pth output of the technology research stage and the pth input value of the achievement transformation stage; $y_{r,k}$ is the rth output value of the second stage of k. u_r, v_i, w_p is the weight of the rth, ith, pth input or output indicator; and ε>0 is the non-Archimedean infinitesimal quantity.

For DMU k, $E_k$and two-stage innovation efficiency E_k^1, E_k^2 can be expressed as:

$$E_k = \sum_{r=1}^{s} u_r^* y_{r,k} / \sum_{i=1}^{m} v_i x_{i,k} \le 1$$
$$E_k^1 = \sum_{p=1}^{q} w_p^* z_{p,k} / \sum_{i=1}^{m} v_i x_{i,k} \le 1 \quad (3)$$
$$E_k^2 = \sum_{r=1}^{s} u_r^* y_{r,k} / \sum_{p=1}^{q} w_p z_{p,k} \le 1$$

The efficiency of the achievement transformation can be obtained by:

$$E_k^2 = E_k / E_k^1 \quad (4)$$

From (1), (2), (4), the two-stage efficiency under the meta-frontier can be obtained. In the same way, by transforming the technology set, the two-stage efficiency of the high-tech industries in each province under the group-frontier of the downstream group, the middle group and the upstream group can be respectively obtained.

3.2 Technology drop rate and inefficient decomposition

According to the ratio of the efficiency at the meta-frontier and the group-frontier, the TGR can be obtained. The TGR of the DMU technology research stage and the achievement transformation stage of the DMU in the g group are RGR^g and AGR^g. The higher the ratio value is, the closer the group's innovative production technology is to the meta- frontier optimal level.

$$0 \le RGR^g = \frac{E^{1m}}{E^{1g}} \le 1 \quad (5)$$

$$0 \le AGR^g = \frac{E^{2m}}{E^{2g}} \le 1 \quad (6)$$

The technology gap theory divides the reasons for efficiency loss into technology gap inefficiency (TGI) and management inefficiency of group-specific frontiers (GMI) [17]. Taking the technology research stage as an example, the inefficient decomposition formula is:

$$TEI = 1 - MRE = TGI + GMI \quad (7)$$

$$TGI = GRE(1 - RGR^g) = GRE - MRE \quad (8)$$

$$GMI = 1 - GRE \quad (9)$$

4. Data and indicator selection

This paper takes the high-tech industries of 11 provinces in the Yangtze River Economic Belt as the DMUs, and divides them into three technical heterogeneity groups according to the upper, middle and lower reaches. The research time span is 5 years (2010-2014). Since the R&D investment to economic output has a certain time lag, according to the usual practice, the lag period is set for 2 years. The input index of the technology research stage selects the data from 2010 to 2014, the output of the technology research stage selects the data from 2011 to 2015, and the output of the results transformation stage selects the data from 2012 to 2016. The data is derived from China High-tech Industry Statistical Yearbook and China Statistical Yearbook.

This paper divides the stage of technological innovation into two stages: technology research and achievement transformation. The investment in technology research stage is generally measured from the perspective of human input and capital investment [18] [19]. The number of R&D

personnel (X1) is selected for human resources investment; the R&D internal expenses (X2) is chosen for the capital expenditure. Considering the re-innovation model of technology introduction, digestion and absorption is still an important way for Chinese high-tech industry technology innovation. This paper uses non-R&D investment (X3) as a supplementary indicator of input factors at this stage. The value is the sum of technology introduction costs, digestion and absorption costs, technical renovation costs and purchase of domestic technology fees. Due to the accumulation and time lag effect of R&D funds, its early investment will not only significantly affect the current knowledge output, but also affect the later knowledge output. Therefore, the capital investment adopts the stock index. Referring to the practice of Wu [20], the R&D inventory is calculated as:

$$K_t = E_t + (1 - D)K_{t-1} \tag{10}$$

K_t is the capital stock of the tth period; D is the depreciation rate, which is 15%. The actual R&D expenditures use the R&D price index to reduce nominal R&D expenditures. The construction method of R&D price index refers to Li [51]. Use 2000 as the base period, the base stock = 2000 R&D expenditure internal expenditure/10%. The non-R&D investment measurement method is similar to the internal expenditure of R&D expenditure.

The innovative output of the technology research stage is the input of the transformation stage of the results. This paper selects the number of patent applications (Z1) and the number of valid invention patents (Z2) to measure the R&D output. Invention patents can reflect the original creativity of enterprises and independent intellectual property rights technology, and are one of the internationally recognized scientific and technological indicators [22]. The number of valid invention patents reflects the maintenance and new authorization of invention patents, representing the level of development of the company's technical level [23]. Therefore, the above two indicators can better reflect the original innovation and comprehensive scientific and technological strength of the high-tech industry. The ultimate goal of the achievement transformation stage is to produce new products and achieve economic benefits. The new product revenue reflects the actual economic benefits and sustainable development capabilities of high-tech innovations, often as an important output indicator [24]. Therefore, the new product sales revenue (Y1) was selected to measure the results of the transformation stage of the results. With 2000 as the constant price, the industrial product price index was used for deflation.

Table 1. Input-output indicators for of pharmaceutical manufacturing industry

Stage	Type	Variable	Description and measurement
technology research	input	R&D personnel	R&D personnel full-time equivalent (X1)
		R&D investment	R&D expenditure internal expenditure (X2)
		Non-R&D investment	The sum of technology introduction costs, digestion and absorption costs, technical renovation costs, and purchase of domestic technology fees (X3)
	output	Patent application	Number of patent applications (Z1)
		Patent invention	Number of valid invention patents (Z2)
achievement transformation	output	New product	New product sales revenue (Y1)

5. Empirical analysis

5.1 Analysis of the two-stage innovation efficiency under meta-frontier

The traditional efficiency study ignores the technological gap between regions. In this study, the Yangtze River Economic Belt is divided into three heterogeneous groups: downstream, midstream, and upstream. The frontiers of each group are constructed to construct the meta-frontier According to the previous model and method, Matlab2017 software is used to measure the two-stage innovation efficiency value of the pharmaceutical manufacturing industry in various regions of the Yangtze River Economic Belt. Table 2 shows the results under the meta-frontier. In the technology research

stage, the overall innovation efficiency of the Yangtze River Economic Belt is 0.516, which is at a medium level. The efficiency from high to low are upstream (0.689), midstream (0.442) and upstream (0.399). The absolute value of R&D investment in the upstream area is the lowest, but the input and various factors are fully utilized in the industrial operation. The efficiency value during the inspection period is maintained at 0.610~0.751, which is always better than the middle and lower reaches; the absolute value of input and output in the middle reaches is moderate, and the efficiency value at an average annual rate of 5%, the downward trend is strong; the downstream region has a strong economic foundation, and long-term focus on the accumulation of innovative resources. The absolute value of input and output is the largest, and the average value of innovation efficiency is always the lowest. From the perspective of the provinces, the innovation efficiency of Sichuan, Guizhou, Yunnan, and Anhui is at the leading level; the innovation efficiency of Jiangsu, Zhejiang, Shanghai, and Hubei is low, and the average value is less than 0.4, which is related to the large investment in innovation and unreasonable resource allocation.

From the perspective of the results transformation stage, the average efficiency of each province during the inspection period was 0.587, which was higher than the technology research stage, but there was a large room for improvement. The average conversion efficiency of the results is the largest in the downstream area, followed by the middle reaches, and the lowest efficiency in the upper reaches. The downstream region dropped to 0.616 year by year with a growth rate of 5.8%, and rose to a maximum of 0.759 in 2013. The efficiency value of the middle reaches showed fluctuations from 0.599 to 0.746; the efficiency of the upstream region was below 0.5 for a long time. The calculation results show that the higher the patent investment, the stronger the efficiency of economic results transformation. Most provincial companies focus on patent filings and outputs, and are not sufficiently concerned about the economic output of patents. From the perspective of specific provinces, Hubei Province has the highest efficiency of fruit conversion; the absolute amount of patent investment in Sichuan is large, and there are problems such as repeated patents and insufficient output of results, and the results have the lowest conversion efficiency. Shanghai, Jiangsu, and Zhejiang have relatively rich innovation resources and higher efficiency than the regional average; Guizhou and Yunnan provinces and Jiangxi have invested in at least three provinces, but the efficiency value is only 80% and 46% of Jiangxi, and it is necessary to strengthen patent results to market. The economic transformation capacity of demand.

Table 2. Two-stage innovation efficiency under the meta-frontier

Province	MRE				MAE			
	2010	2012	2014	Mean	2010	2012	2014	Mean
Shanghai	0.327	0.315	0.310	0.338	0.947	0.746	1.000	0.828
Jiangsu	0.261	0.271	0.268	0.278	0.804	0.786	0.928	0.796
Zhejiang	0.255	0.292	0.314	0.291	0.775	0.684	0.613	0.688
Anhui	0.663	0.796	0.560	0.689	0.434	0.340	0.497	0.407
Jiangxi	0.495	0.372	0.409	0.416	0.436	0.570	0.585	0.534
Hubei	0.351	0.448	0.304	0.397	1.000	0.795	0.945	0.849
Hunan	0.579	0.491	0.436	0.515	0.465	0.620	0.707	0.572
Chongqing	0.407	0.618	0.414	0.456	0.597	0.387	0.901	0.655
Sichuan	0.702	0.629	0.963	0.848	0.514	0.418	0.130	0.307
Guizhou	0.662	0.742	0.613	0.737	0.435	0.426	0.566	0.430
Yunnan	0.669	0.805	0.615	0.717	0.449	0.417	0.342	0.394
Downstream	0.376	0.418	0.363	0.399	0.740	0.639	0.759	0.680
Midstream	0.475	0.437	0.383	0.442	0.634	0.662	0.746	0.652
Upstream	0.610	0.698	0.651	0.689	0.499	0.412	0.485	0.447
Total	0.488	0.525	0.473	0.516	0.623	0.562	0.656	0.587

5.2 Analysis of the difference in innovation efficiency between the two frontiers

In Figures 2 and 3, it can be seen that the efficiency of the provinces under the meta-frontier are not higher than the group-frontier in the two stages of technology research and achievement transformation. The efficiency value under the Yangtze River Economic Belt as a whole, the average

efficiency of the technology research stage and the achievement transformation stage under the meta-frontier are 0.516 and 0.587, respectively, which is significantly smaller than the efficiency value of the group-frontier (0.705, 0.644). The reason is that the meta-frontier is based on the overall potential optimal technology level of the Yangtze River Economic Belt, and the group-frontier is based on the potential optimal technology level under each group's existing conditions. The input and output data sets of each province are distance groups. The distance of the leading edge is less than the distance of the common leading edge, so the efficiency under the leading edge of the group is greater than the common leading edge efficiency value. Taking the technology research stage of Hubei Province in the middle reaches as an example, the innovation efficiency under the meta-frontier is 0.397, which indicates that if the potential R&D technology level of the Yangtze River Economic Belt is reached, and the innovation resource input is reduced by 60.3%, the current level of scientific and technological output can be achieved. The room for improvement is large. Based on the potential optimal level of the middle group, the innovation efficiency value is 0.842, and the innovation efficiency improvement space is only 15.8%. The difference between the two is 44.5%. There is a phenomenon of underestimating the potential for improvement. The result also reflects the between the two frontiers. The technical gap.

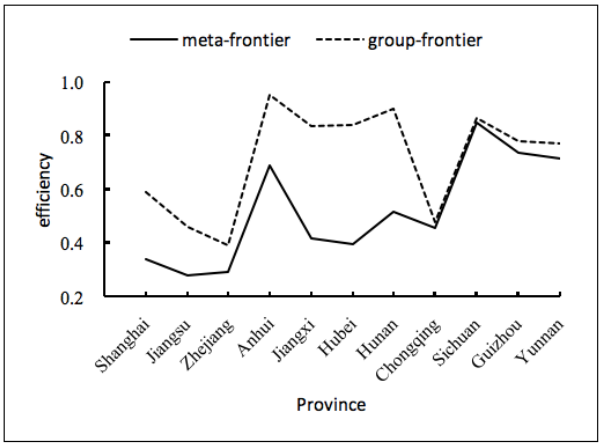

Figure 1. Mean value of technology research efficiency

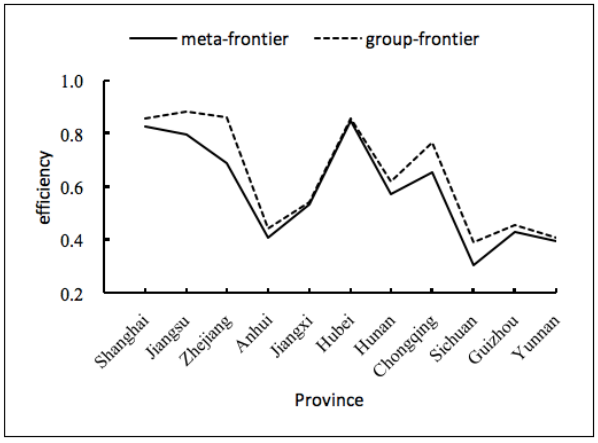

Figure 2. Mean value of achievement transformation efficiency

The TGR reflects the gap between the meta-frontier and the group-frontier efficiency value. The greater the TGR, the smaller the technical distance between the two frontiers. The three group TGR were analyzed and the results are shown in Table 3. First of all, the TGR of the two groups in both two stages are less than 1, indicating that there are different degrees of gap with the optimal technical level in the group, whether it is downstream, midstream or upstream. In the technology research stage, the average RGR of the downstream, midstream and upstream regions is 0.664, 0.514 and 0.952, indicating that the upstream region has achieved 95.2% of the national best technology, which is closer to the effective frontier of R&D innovation activities, and basically represents the most

regional overall. Excellent level. There is a gap between the technological research and development capabilities of the middle and upstream regions and the frontier levels of the Yangtze River Economic Belt. The RGR value has decreased from 2011 to 2011, indicating that the gap is gradually expanding, and it is necessary to pay attention to the reasons for the long-term existence of the gap. In the stage of achievement transformation, the AGR value of the middle reaches is 0.966, which has the highest economic conversion capacity and is more advantageous in the utilization efficiency of innovative resources. Innovative technologies in the upstream and downstream regions have a small gap in regional optimal levels, and gradually narrowed to 92.7% during the inspection period.

Table 3. RGR and AGR of pharmaceutical manufacturing industry

	RGR			AGR		
Year	Downstream	Midstream	Upstream	Downstream	Midstream	Upstream
2010	0.592	0.536	0.973	0.877	0.963	0.843
2011	0.746	0.543	0.974	0.862	0.960	0.848
2012	0.680	0.522	0.946	0.893	0.948	0.903
2013	0.680	0.489	0.949	0.899	0.972	0.927
2014	0.622	0.480	0.920	0.943	0.985	0.953
Mean	0.664	0.514	0.952	0.895	0.966	0.895

5.3 Inefficient decomposition

This study decomposes innovation inefficiency into technology gap inefficiency (TGI) and management inefficiency of group-specific frontiers (GMI). As shown in Figure 3, the mean values of technology research and results conversion inefficiency are 0.484 and 0.413, respectively. In the technology research stage, the regional technology gap inefficiency value is 0.198, accounting for 41.02%, and the management inefficiency value is 0.285, accounting for 58.98%. In the upstream and downstream areas, the innovation environment is superior in the technology research stage, the inefficiency mainly comes from GMI; the inefficiency in the middle reaches is 75% from TGI. In the stage of achievement transformation, the proportion of GMI is about 86.17%. The proportion of GMI in the upper, middle and lower reaches is 89%, 94%, and 74%, respectively. Internal management is the main reason for the inefficiency of economic transformation.

For specific provinces, in the technology research stage, Chongqing, Sichuan, Zhejiang, Guizhou, Yunnan GMI accounted for more than 80%, which shows that these areas basically represent the country's best technology research level, from the internal management efficiency of the enterprise Upgrade. Shanghai and Zhejiang GMI and TGI occupy a considerable proportion, and it is necessary to pay attention to the improvement of production technology level and internal management level. The proportion of TGI in Anhui, Jiangxi, Hubei and Hunan is more than 70%, and it is urgent to strengthen the R&D technical level. In the transformation stage of results, Shanghai, Anhui, Jiangxi, Hubei, Hunan, and TGI have less than 20% contribution to inefficiency, indicating that these provinces have mature development environment in the transformation of scientific and technological achievements, and need to strengthen the industrialization and commercialization efficiency of internal internal results. . The proportion of TGI in Sichuan, Yunnan, and Guizhou is as high as 88%, 96%, and 97%, due to the low efficiency value under meta-frontier, resulting in higher inefficiency value (denominator), and TGI value (molecular) compared with the same group of provinces. Closer, resulting in a lower TGI. Jiangsu, Zhejiang, and Chongqing have a considerable proportion of TGI and GMI. They need to strengthen the management of their own enterprises while paying attention to the construction of regional technological innovation environment.

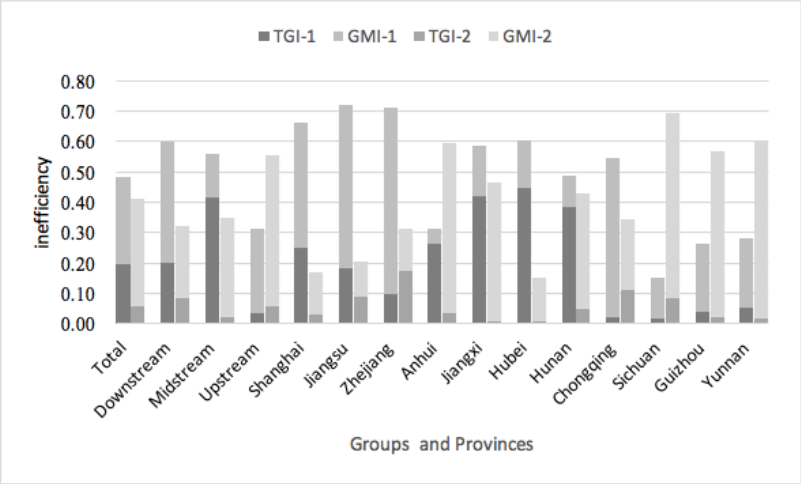

Figure 3. Two-stage innovation inefficiency decomposition of each group and province

6. Conclusion

(1) The efficiency of the two stages of innovation is low, and it also has a large potential for improvement. Under the meta-frontier, the average technology R&D efficiency of the pharmaceutical manufacturing industry in the Yangtze River Economic Belt in 2010-2014 was 0.516, and the average value of the transformation stage was 0.587, which was at a medium level.

(2) There is a clear gap in innovation levels between groups, and different stages present different characteristics. In the technology research stage, the technological innovation capability presents a pattern of “upstream-middle-stream-downstream” decline. Technology research is the core of high-tech innovation activities. The upstream region is closest to the overall optimal technology level of the region; the gap between the middle and downstream regions and the potential optimal technology is large, and there is an expanding trend.

(3) Internal management issues are the key reason for the loss of efficiency in the two-stage innovation. In the technology research stage, the innovation environment in the upstream and downstream areas is superior, and the inefficiency in the middle reaches is mainly lost in TGI; in the stage of achievement transformation, the GMI loss ratio in the upper, middle and lower reaches is significant, and the technical environment needs to be improved.

Based on the above conclusions, this paper proposes the following efficiency improvement strategies:

(1) Improve the innovation and cooperation mechanism and promote the development of regional integration. The innovation efficiency of the Yangtze River Economic Belt is obviously different, and there is a technological gap between the groups. The government should strengthen the innovation and cooperation of resources across regional enterprises, break the barriers to innovation, and give full play to the technological and management advantages of high-efficiency enterprises. Utilize the spillover effect of collaborative innovation to narrow the gap between innovations in the region and achieve high-quality development of the Yangtze River Economic Belt.

(2) Improve the technology and product market mechanisms and promote the effective transformation of regional innovation results. The pharmaceutical manufacturing industry in various regions of the Yangtze River Economic Belt has lost innovation efficiency in both stages. In the future, R&D and market demand should be closely combined. At the same time, a scientific and technological achievement trading platform should be established, industrialization and market-oriented service institutions should be promoted, and the whole industry should be guided to the high end of the value chain.

(3) Implement differentiated innovation policies to strengthen the development of urban agglomerations along the Yangtze River. Urban agglomerations are the new engine of regional economic growth. Central provinces with higher levels of innovation and development can enhance the driving effect on peripheral regions through technology transfer and capital output. At the same

time, the provinces are able to locate the location and give full play to the location advantages to enhance the innovation efficiency of the overall group. High-tech enterprises should not only focus on improving the introduction, digestion, absorption and application of technology, but also pay attention to the adjustment of internal management systems and structures.

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