The R&D Efficiency Evaluation of the University Teachers Based on A Two-Stage DEA Model

Xuehao Sun1, Zhengkui Lin1, Lei Zhang1, Yu Lian1 and Lei Ding1
1School of Computer Science and Technology, Dalian Maritime University
dalianjx@163.com

Abstract. This paper measures university teacher’s R&D efficiency based on a two-stage DEA model. Firstly, this paper analyzes traditional DEA model and proposes a two-stage DEA model to overcome the disadvantage of traditional DEA, and then builds a new input-output index system to evaluate teacher’s R&D efficiency. The new model is applied to analyze the R&D efficiency of 75 teachers of a university in 2014. The result show that professors, female teachers and engineering teachers have larger efficiency.

1. Introduction

At present, many scholars, at home or abroad, have made some progress in related researches of the performance of university R&D input-output. Kim[1]applied DEA model to evaluate 38 university R&D, and utilized all kinds of input-output variables to ensure technology and scale efficiency. And then, in a concrete case, he discussed how to use a way of organizational change to improve the performance of inefficiency university R&D. On the basis of bibliometrics methods, Abramo et al.[2] applied DEA method to evaluate university R&D efficiency of cross-discipline in Italy. In this method, the input values are researcher’s levels and research funds, the output values are quantity, quality and contribution levels of scientific publications. During 2000-2009 year, Feng, Chen and Tian[3] applied DEA method to evaluate the integral development of university R&D efficiency in our country. Then, they used Malmquist exponent to analyze dynamic change of university R&D efficiency. The result suggested university input-output as a whole is efficient in our country. And there is a trend that R&D efficiency in eastern region is the highest and that in central region is higher than that in western region. There are two times from 1999 to 2002 and from 2003 to 2006, respectively. Tian and Miao[4] applied DEA method to evaluate R&D efficiency in universities of our country, aimed to make references for R&D administrators making resources allocation policies and how to improve R&D efficiency of universities.

By the existing literature, we found DEA model is one of the widest application methods. But, at present, multi-stage DEA model is not yet applied to evaluate the university R&D efficiency. Based on above studies, this paper constructs two-stage DEA model and two-stage index system of university R&D efficiency, and utilizes empirical data of a university to analyze university R&D efficiency. Hence, we get the corresponding results.

2. A two-stage associated DEA model

Based on the traditional model, the two-stage associated DEA model is improved, the improved content is as follows:
Suppose there are n DMUs, each of DMUs may fall into two successive sub-processes, i.e., sub-process 1 and sub-process 2. As you can see in Figure 1, \( x_{ij} \) and \( y_{ij} \) represent the i-th input of DMU \( j \) and the r-th output, respectively. Intermediate product \( z_{pj} \) represent the p-th output of sub-process 1 and the p-th input of sub-process 2, respectively. Where \( i = 1,2,\ldots,m \), \( r = 1,2,\ldots,s \) and \( p = 1,2,\ldots,q \).

![Figure 1. Productive Process of DMU](image)

In a method of the efficiency of measured two-stage productive process, the interconnected relation between sub-processes is not considered, namely, all kinds of sub-processes regard as separate productive processes[5]. Suppose \( \theta_k \) represents the overall efficiency of DMU. \( \theta_k^1 \) represents the efficiency of sub-process 1 and \( \theta_k^2 \) represents the efficiency of sub-process 2. Applied CCR-DEA model of constant returns to scale, the overall efficiency \( \theta_k \) of DMU \( k \) can be calculated in this paper as follows:

\[
\theta_k = \max \left\{ \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}} \right\}
\]

subject to

\[
\frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}} \leq 1, \quad j = 1, \ldots, n \]
\[
u_i, v_i \geq \varepsilon, \quad r = 1, \ldots, s; \quad i = 1, \ldots, m
\]

Where \( \varepsilon \) represents non-Archimedean infinitesimal. \( \theta_k = 1 \) represents that DMU \( k \) is relative efficiency, while \( \theta_k < 1 \) represents that DMU \( k \) is inefficiency. On the same theory, we can construct two CCR-DEA model as follows:

\[
\theta_k^1 = \max \left\{ \frac{\sum_{p=1}^{q} \pi_p x_{pk}}{\sum_{i=1}^{m} v_i x_{ik}} \right\}
\]

subject to

\[
\frac{\sum_{p=1}^{q} \pi_p x_{pj}}{\sum_{i=1}^{m} v_i x_{ik}} \leq 1, \quad j = 1, \ldots, n \]
\[
\pi_p v_i \geq \varepsilon, \quad r = 1, \ldots, s; \quad i = 1, \ldots, m
\]

\[
\theta_k^2 = \max \left\{ \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{p=1}^{q} \pi_p x_{pk}} \right\}
\]

subject to

\[
\frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{p=1}^{q} \pi_p x_{pj}} \leq 1, \quad j = 1, \ldots, n \]
\[
u_r, \pi_p \geq \varepsilon, \quad r = 1, \ldots, s; \quad p = 1, \ldots, q
\]

Where \( \theta_k^1 \) represents the efficiency of sub-process 1, and \( \theta_k^2 \) represents the efficiency of sub-process 2 in measured DMU \( k \).

In a measured method of the efficiency of the formulas 5.2 and 5.3, the interconnected relation between sub-processes is not considered, and this method do not accord to facts. The outputs of sub-process 1 is the inputs of sub-process 2, and the production of sub-process 1 has important influence for the efficiency of sub-process 2. By using separate DEA model, we can easy to calculate the results that may be hard to understand.

The intermediate product has kind of a dual role in productive process. A weighed mean \( \sum_{p=1}^{q} \pi_p z_{pj} \) of intermediate product \( z_{pj} \) should be consistent in the formula (2) and the formula (3).
If $u^*_r$, $v^*_i$ and $\pi^*_p$ are optimal multipliers of DMU $k$, then

$$
\begin{align}
\theta_k &= \sum_{r=1}^n u^*_ry_{rk} / \sum_{i=1}^m v^*_ix_{ik} \leq 1 \\
\theta_k^1 &= \sum_{p=1}^q \pi^*_pz_{pk} / \sum_{i=1}^m v^*_ix_{ik} \leq 1 \quad \forall_i \\
\theta_k^2 &= \sum_{r=1}^n u^*_ry_{rk} / \sum_{p=1}^q \pi^*_pz_{pk} \leq 1
\end{align}
$$

(4)

From the computational process of the formula (4), we can find that as follows:

$$
\theta_k = \frac{\sum_{r=1}^n u^*_ry_{rk}}{\sum_{i=1}^m v^*_ix_{ik}} = \frac{\sum_{p=1}^q \pi^*_pz_{pk} \times \sum_{r=1}^n u^*_ry_{rk}}{\sum_{p=1}^q \pi^*_pz_{pk}} = \theta_k^1 \times \theta_k^2
$$

(5)

For the formula (5) hold, a key is that we can get optimal multipliers $u^*_r$, $v^*_i$ and $\pi^*_p$. Then

$$
\theta_k = \max \sum_{r=1}^n u^*_ry_{rk} / \sum_{i=1}^m v^*_ix_{ik}
$$

s.t.

$$
\begin{align}
\sum_{r=1}^n u^*_ry_{rk} &\leq 1, j = 1, \ldots, n \\
\sum_{j=1}^m v^*_ix_{ik} &\leq 1, j = 1, \ldots, n \\
\sum_{p=1}^q \pi^*_pz_{pk} &\leq 1, j = 1, \ldots, n
\end{align}
$$

(6)

The formula (6) is a fraction programming model. By using ChamesCooper transform, we can translate the formula (6) into linear programming as follows:

$$
\theta_k = \max \sum_{r=1}^n u^*_ry_{rk} / \sum_{i=1}^m v^*_ix_{ik}
$$

s.t.

$$
\begin{align}
\sum_{r=1}^n u^*_ry_{rk} &\leq 1, j = 1, \ldots, n \\
\sum_{j=1}^m v^*_ix_{ik} &\leq 1, j = 1, \ldots, n \\
\sum_{p=1}^q \pi^*_pz_{pk} &\leq 1, j = 1, \ldots, n
\end{align}
$$

(7)

The formula (6) and the formula (7) integrate the constraint condition of the formulas (1)-(3). The associated relation of between sub-process 1 and sub-process 2 is considered. By dual transform, we have get a dual model of the formula (7) in this paper as follows:

$$
\min \theta_k
$$

s.t.

$$
\begin{align}
\sum_{i=1}^n a_ix_{ik} &+ \sum_{j=1}^n b^*_jx_{ij} \leq \theta_kx_{rk}, i = 1, \ldots, m \\
\sum_{i=1}^n a^*_ix_{ik} &+ \sum_{j=1}^n b_jy_{ij} \leq y_{rk}, r = 1, \ldots, s \\
\sum_{j=1}^n b^*_jx_{ij} &- \sum_{j=1}^n \gamma_jx_{ij} \leq \theta_k, j = 1, \ldots, n
\end{align}
$$

(8)

On the basis of the formula (7) or the formula (8), we can calculate the overall efficiency of DMU $k$. In the same theory, we also can construct the associated DEA model that measures $\theta_k^1$ and $\theta_k^2$. Where $\theta_k^1$ represents the efficiency of sub-process 1 and $\theta_k^2$ represents the efficiency of sub-process 2. For under the same standard to compare $\theta_k^1$ with $\theta_k^2$, we also construct the associated DEA model that measures the efficiency of sub-processes. Under keeping the constant overall efficiency of evaluated DMU, we get the efficiency of sub-processes in evaluation DMU $k$. A formula (9) represents the associated DEA model that measures the efficiency of sub-process 2.
\[ \theta_k^2 = \max \sum_{s=1}^s u_r y_{rk} \]
\[ \sum_{p=1}^q \pi_p x_{pk} = 1 \]
\[ \sum_{s=1}^s u_r y_{sj} - \theta_k \sum_{i=1}^m v_i x_{ij} = 0 \]
\[ \sum_{s=1}^s u_r y_{sj} - \sum_{i=1}^m v_i x_{ij} \leq 0, j = 1, \ldots, n \]
\[ \sum_{p=1}^q \pi_p x_{pj} - \sum_{i=1}^m v_i x_{ij} \leq 0, j = 1, \ldots, n \]
\[ \sum_{s=1}^s u_r y_{sj} - \sum_{p=1}^q \pi_p x_{pj} \leq 0, i = 1, \ldots, m; j = 1, \ldots, n \]
\[ u_r, v_i, \pi_p \geq \varepsilon \]
\[ r = 1, \ldots, s; i = 1, \ldots, m; p = 1, \ldots, q \]  

Applied above model, we can calculate the efficiency of sub-process 2. And then, by the formula \( \theta_k^2 = \theta_k / \theta_k^2 \), we can get the efficiency of sub-process 1.

3. The construction of DEA model input-output index system

An input-output analysis of DMU is a foundation to construct evaluation index system. Based on multianalysis of the input-output relation of between universities and teachers, an evaluation index system of the teacher’s R&D input-output is constructed. This method considers problem domain and requirements of evaluation index system.

3.1 The structure of teacher’s R&D process

Teacher’s R&D activities include R&D project, government sponsored research, academic paper and so on. By the wages and crossing research project expenditure, teacher’s R&D is supported. And teachers have win over the more government sponsored research expenditure. The final achievements of teacher’s R&D work are academic paper. This also also an important aspect that consider the efficiency of teacher’s R&D input-output. Therefore, as show in figure 2, teacher’s R&D work may fall into two sub-processes, i.e., R&D project and corresponding academic paper.

![Figure 2. Process of Teacher Research Work](image)

3.2 The construction and illustration of model input-output index system

Considering teacher’s R&D characteristic as well as the availability of data, we select several indexes in this paper as follows:

1. The salary \( x_1 \) includes wages and end of year performance pay.
2. The working age \( x_2 \) is teacher’s work seniority. The longer working age is, the longer teacher work on their professional skills. In general, teachers have better R&D resource.
3. The crossing research project fund \( x_3 \) is teacher’s project fund from firm.

(2) The output variables of production system and that of stage 2.

The score of paper \( y_1 \) is the total score of papers in a whole year. \( y_1 \) represents teacher’s achievements in papers. In this paper, papers can fall into four grades. Every grade has different score. The score of the highest grade paper is 120, and the lowest is 30.
(3) Intermediate variables of production system

Government sponsored research fund $z_i$ is that teachers get fund from national and provincial departments. Government sponsored research is both the output of sub-process 1, and the input of sub-process 2. In this paper, project grades can fall into four grades. On the basis of different scores of four grades, we can calculate amount among different projects.

4. Empirical analysis

4.1 Data acquisition

The empirical data of this paper was drawn from the same university teacher’s management system. Where the data includes 75 teacher’s wages, crossing research project fund, government sponsored research fund, score of paper, personal information and so on in 2014. Statistical description of average input-output indexes shown in table 1.

| Variables | average | Standard deviation | minimum | maximum |
|-----------|---------|-------------------|---------|---------|
| $x_1$     | 201196  | 59088             | 101164  | 419544  |
| $x_2$     | 16.5    | 8.7               | 2       | 37      |
| $x_3$     | 896610  | 2033059           | 6250    | 14185700|
| $z_1$     | 661324  | 1412749           | 1000    | 10500000|
| $y_1$     | 183     | 165               | 4       | 691     |

4.2 The result analysis

In this paper, we apply two-stage associated DEA model to calculate the overall efficiency of teacher sample data and the efficiency $\theta_k$, $\theta^1_k$ and $\theta^2_k$ of sub-processes. We get the results shown in table 2. Computational process mainly applies the formula (5.7) and the formula (5.9) to measure every teacher’s R&D and the efficiency of paper, then we apply $\theta_k^1 = \theta_k^1 / \theta_k^2$ to calculate the efficiency of R&D projects.

| DMU | $\theta_k^1$ | $\theta_k^2$ | $\theta_k$ | DMU | $\theta_k^1$ | $\theta_k^2$ | $\theta_k$ |
|-----|--------------|--------------|------------|-----|--------------|--------------|------------|
| 1   | 0.17500      | 0.00600      | 0.00105    | 39  | 0.12100      | 0.00300      | 0.0003     |
| 2   | 1.00000      | 0.00100      | 0.00100    | 40  | 0.07800      | 0.00900      | 0.0007     |
| 3   | 0.20600      | 0.00100      | 0.00210    | 41  | 0.02800      | 0.02500      | 0.0007     |
| 4   | 0.27800      | 0.00100      | 0.00028    | 42  | 0.41700      | 0.00100      | 0.0004     |

From the result of table 2, we can find that individual teacher has difference in both R&D projects and academic papers. It may relate to university teacher’s feature attributes and concentration. Faced the increasingly R&D competition, what measures should apply the administrative department of university R&D take to analyze efficiency. For a manifestation of a sample of teachers in different production stages, the efficiency average of two-stage associated DEA is a boundary line by which 75 teachers are divided into four classes (as show in figure 3). On the basis of this foundation, we can
analyze different type of teachers to take proper measures.

![Research and Academic Efficiency Matrix](image)

**Figure 3. Research and Academic Efficiency Matrix**

In addition to this, this paper uses teacher’s feature attributes to cross-analysis from another point of view. There are many feature attributes such as professional title, department category, sex and so on.

As shown in Table 3, we get the analysis results.

| attributes          | $\theta_1^k$Average | $\theta_2^k$Average | $\theta_k$Average |
|---------------------|---------------------|---------------------|-------------------|
| Total               | 0.239               | 0.0265              | 0.00067           |
| Professional title  |                     |                     |                   |
| Professor           | 0.267               | 0.029               | 0.00068           |
| Associate professor | 0.18                | 0.021               | 0.00065           |
| Lecturer            | 0.035               | 0.013               | 0.000455          |
| Sex                 |                     |                     |                   |
| Male                | 0.22                | 0.0132              | 0.000627          |
| Female              | 0.307               | 0.0756              | 0.00081           |
| The large classification of subjects |                   |                     |                   |
| Administration      | 0.16                | 0.0173              | 0.000613          |
| Marine              | 0.267               | 0.0056              | 0.000516          |
| Marine engineering  |                     |                     |                   |
| Marine              | 0.267               | 0.0056              | 0.000516          |
| Engineering         |                     |                     |                   |
| Engineering course  | 0.278               | 0.0179              | 0.000822          |
| Science             | 0.212               | 0.004               | 0.000848          |

By above analysis results and the result in Table 3, we can get the tentative conclusions that are about the relation of between input-output efficiency of university teacher’s R&D and teacher’s feature attributes.

From aspect of professional title, professors are higher than other teacher’s profession title in two-stage and input-output efficiency of overall R&D. On the one hand, it might be because professors have a certain social status. Professors can obtain sufficient resources, and have abundant academic knowledge and higher R&D level. On the other hand, professors generally are doctoral supervisor or master tutor, and team leader. Many excellent young teachers, doctors and masters share achievements with professors in R&D. So professors have higher efficiency of R&D.

From aspect of sex, female teachers are higher than male teachers in two-stage and input-output efficiency of overall R&D. This is a interesting phenomenon that it might be because female teachers are more carefully than male teachers in projects and papers. It also might be because female teachers have heavier work pressure than male teachers. On the basis of above reason, female teachers have put
her heart and soul into R&D and project application.

From category of college, the teachers in engineering course and marine engineering are higher than the average efficiency of all the teachers in the first stage R&D input-output efficiency; The teachers in culture are much higher than the average efficiency of all teachers in the second stage R&D input-output efficiency; The teachers in engineering course and science are higher than the average of all the teacher in overall R&D input-output efficiency. Compared with social science, natural science has a relatively large proportion in natural and enterprise’s projects. Natural science can directly generate the productive forces, so it gets serious attention by many people.

5. Conclusions
From subjective and objective points of view, this paper applies two-stage associated DEA model to construct the relation between university R&D resource inputs and university teacher’s R&D outputs, it is convenient to evaluate university teacher’s R&D. This paper applies teacher’s feature attributes to cross-analyze teacher’s R&D input-output efficiency an teacher’s feature attributes. We can obtain some advise that assist university R&D administration to a certain degree.

Reference
[1] Kim S. A Comparison Study on University Research Efficiency Using DEA Analysis: focused on A University Case[J]. 2013, 15(1):249-258.
[2] Abramo G, D’Angelo C A, Pugini F. The measurement of Italian universities’ research productivity by a non parametric-bibliometric methodology[J]. Scientometrics, 2008, 76(2):225-244.
[3] Feng Guangjun, Chen Wei, Tian Jinfang. Analysis of Scientific Research Efficiency in Universities in China Based on DEA-Malmquist Method——Experiential Research from 30 Provincial Panel Data[J]. Modern Finance and Economics-Journal of Tianjin University of Finance and Economics, 2012(9):61-73.
[4] Tian Dongping, Miao Yufeng. Evaluation of Scientific Research Efficiency in Universities in China Based on DEA[J]. Journal of Design Art, 2005, 24(4):6-8.
[5] Wu Desheng. Research on several theories and methods of data envelopment analysis[D]. University of Science and Technology of China, 2006.