Hindawi
Scientific Programming
Volume 2022, Article ID 1044800, 10 pages
https://doi.org/10.1155/2022/1044800

Research Article

Big Data Optimization and Applications in Running Efficiency of Higher Education

Mingxia Lu

Institute of Higher Education, Shanghai University, Shanghai 200444, China

Correspondence should be addressed to Mingxia Lu; wendy@shu.edu.cn

Received 21 September 2021; Accepted 19 November 2021; Published 5 January 2022

Academic Editor: Zhu Xiao

The world is undergoing great changes that have not been seen at present; colleges and universities can only adapt to social development with a more active and open attitude. Meanwhile, colleges and universities strive to obtain more social resources during the process of gradually embedding social funds into the operation system of universities. In such a backdrop, we establish an optimization model for university running efficiency under limited funds, where the objective function is quadratic and restraint condition is linear. With the help of optimization theory, we have obtained the optimal solution of this optimization model and put forward corresponding suggestions to improve the running efficiency of higher education.

1. Introduction

Great changes have taken place in the tertiary education system in China in recent years. Under the guidance of the goal of building first-class universities and first-class disciplines, the Chinese government has gradually increased investment in higher education. Therefore, there is a fierce competition among universities in terms of students, funds, and academic research under the dual promotion of market and government; meanwhile, almost all of the universities have paid much attention to the cost-effectiveness [1].

The cost-effectiveness has attracted increasing attention of scholars and managers; therefore, some new research methods came into being, and one of them is called multiorganization theory. An important conclusion of this theory can be expressed in the following way; that is, the total cost of a single organization is not more than the sum of the costs of production in different organizations if a single organization produces two or more products. This conclusion actually shows that there is a scope economy in this mode of production [2–7]. Baumol et al. pioneered a whole set of cost-effectiveness tools to analyze multiproduction organizations [8]. Their pioneering applied research shows a basic idea of multiorganization theory, that is, frictionlessness in the perfectly contestable market would lead to a sort of competitive equilibrium with desirable welfare consequences under some structural conditions. Therefore, from the perspective of cost-saving, it may be less expensive to produce some things together rather than apart. At the moment, there are three most commonly used forms of various cost functions in the study about multiproduction organization; they are quadratic cost function and mixed transcendental logarithmic cost function [9–11].

The cost function model has two obvious advantages; firstly, the explanatory variables include not only factor input variables, but also output variables, so that this model is more direct than the production function in estimating economies of scale and scope. Secondly, it effectively measures the market competition in the industry, because the cost function model can help us directly estimate the marginal cost equation [12–14]. The transcendental logarithmic cost function is a quadratic Taylor approximation of the cost function for any technique. Because the cost function contains square terms and cross terms, it enables the cost function to avoid the prior assumption of invariance of element substitution elasticity and transformation elasticity; meanwhile, it has a better fitting degree for real data with the hypothesis of symmetry and homogeneity. Although the cost function has these advantages, from the commonly used cost function technology, we can see that the cost function model usually ignores the influence of TFP heterogeneity; this is the disadvantage of the cost function model compared with the production function. Therefore, in the actual application, the existing cost function model is mainly used to measure the scale economy of micro-enterprises and natural monopoly as well as its extension.

The condition of technical efficiency can ensure the drawing of the cost curve. But some errors often occur in data estimation during empirically analyzing the cost function. Indeed, due to different observations, it is difficult for this inefficient phenomenon to disappear. It is undoubtedly a useful exploration for stochastic frontier methods to evaluate the parameters of a multiproduction cost function; the drawback is that this method is limited by some conditions; it would be simple and effective only in the cases of a simple specification [15]. Sarafopoulos has studied the equilibrium state of a bounded rational monopolist model [16]; he assumed that the cost function is quadratic, and the entire demand has a general nonlinear form. Under such assumptions, the equilibrium of the model is equivalent to the level of price maximizing profits, which can be found from the classical microeconomic theory. However, the stability of the equilibrium state has to be discussed because of complex dynamics. Sarafopoulos had to spend a lot of extra energy to display bifurcations, complex dynamics, and chaos through computation sensitive dependence and numerically Lyapunov numbers on initial conditions.

Richard put forward an approximate algorithm for the explicit calculation of the Pareto front for multiobjective optimization problems featuring convex quadratic cost functions and linear constraints based on multiparametric programming. The characteristics of the novel algorithm were highlighted by a numerical example as well as a small computational study [17]. Kim uses two temporary distant cross-sectional data to jointly measure the multifactor elasticity of substitution with the productivity growth for multiple industrial sectors [9]; he selected a sort of multi-factor CES unit cost function to regress the relationship between the growth of per-factor cost shares and factor prices.

Recently, many scholars pay their attention to the application of the quadratic cost function [15, 16, 18–25]. For instance, Lin et al. built an enterprise cost function model that includes industrial pollutants and environmental governance costs and uses the data of Chinese manufacturing companies from 1998 to 2008 to measure the green economies of scale for enterprises and cost elasticity of environmental governance [26]. Jiang et al. consider various factors, including domestic flight delays that affect airline operating costs; they put forward an airline trans-log cost function model to measure the losses caused by domestic flight delays of the four major domestic airlines from 2014 to 2018 [27]. Wang, based on the bounded rational expectation and adaptive expectation, constructed the output game model of duopoly market with a quadratic cost function [28]. The quadratic cost function is widely used to adjust the output through the long-term game to achieve optimal profit. The dynamic evolution properties of the duopoly game model with quadratic cost function are studied. The influence of yield adjustment rate fluctuation on model stability is discussed. Both theoretical analysis and numerical simulation show that the degree of substitution between products and the investment adjustment rate of players will have a great influence on the game results. This builds a theoretical basis for the players' production decisions in the market.

Gomez et al. put forward a novel approach to look for the solution of quadratic cost function by using the delayed output feedback controller [19]. They also designed a concrete case study to show the potential of their approach. Gustavo proposed a new technology to be used in multiple application fields more easily. His simple modification results in maintaining effectively the quadratic program structure of the resulting optimization problem. Vladimirov et al. considered a sort of quadratic exponential functional for linear quantum stochastic systems driven by multi-channel bosonic fields [29]. The method they used is to convert the objective function into a quadratic exponential functional form, for such costs will cause great losses. Zhang and Zhang established a quadratic transportation cost inequality for scalar stochastic conservation laws driven by multiplicative noise [30]. By using techniques of differential dynamics, Orihuela et al. considered such a conflicting situation in which the cost functions are quadratic in the local decision variables. They have derived some stability conditions of Nash equilibrium when the decision variables are not constrained [31].

In a few words, much of the research has been done with various methods focused on cost issue, but considerable research effect has also been directed toward optimization model; their objective function contained many different factors such as cost items, teaching, and scientific research as well as factor price. We have sorted them out in Table 1 below.

There is a general problem of rigid expenditure ratio in university expenditure; meanwhile the proportion of variable cost is low and the proportion of fixed cost is high. Therefore, the administrative cost of colleges and universities is high so the historical burden is heavy. Cost control theory over the world has become mature and stereotyped after 1980. The theory includes target cost control and cost of operation. Though there are quite a lot of mature theories on enterprise cost control, its research in the field of education is rare [17, 42, 43]. It is inspired by the new perspective and inspiration provided by the existing literature. We put forward an optimization model for university running efficiency under limited funds, where we take the quadratic cost function as the objective function and take the financial support of colleges and universities for output and input products as the linear restraint condition. By using the Lagrange multiplier function, we have obtained the optimal solution of this optimization model and put forward the optimization measures to optimize the running efficiency of colleges and universities.

The above empirical researches (see Table 1) offer theory support and practice guide to solve a series of problems such

Table 1: Summary for empirical research about quadratic cost function.

Year	Scholars	Cost item	Teaching	Scientific research	Factor price
2004	Sav [32]	Education and general expenditure	Undergraduate class hours; postgraduate hours	Research funding	Research funding
2008	Johnes et al. [33]	Total operating costs	Number of undergraduates; number of graduate students	Research funds and QR funding	None
2008	Chen [34]	Business expenditure	Number of undergraduates; number of graduate students (Master + PhD)	Research expenditure	Student-teacher ratio; proportion of senior titles
2010	Agasisti and Johnes [35]	General expenditure	Undergraduates number; graduate students number	External research and consulting funding	None
2011	Chen and Dong [36]	General expenditure	Undergraduates number; graduate students number	Research funding	None
2013	Li and Chen [37]	Total cost	Undergraduates number; graduate students number; international students number	Research expenditure	Student-teacher ratio
2016	Song and Peng [38]	Educational expenditure	Undergraduates number; graduate students number	Research expenditure	Total number of full-time teachers
2016	Agasisti and Johnes [39]	Total expenditure	Awarded undergraduate degree; number of research degrees awarded	Research funding	None
2019	Fu et al. [40]	Average cost	Undergraduates number; postgraduates number	Research projects funded by NSC*	Faculty-student ratio
2021	Xia et al. [41]	Total cost	Graduate students number	Research funding	None

*NSC—national science council.

as the weak consciousness of thrift in running schools and low efficiency of resource distribution. Some of the research gave us a good inspiration to optimize various kinds of input elements of regular institutions of higher learning, to meet the social demand of higher education, and to obtain the stability that higher education develops healthily and sustainably.

2. Methodology and Model

Baumol et al. have discussed the desiderata for multi-production cost functions and given three popular specific cost forms as the quadratic cost function, CES, and hybrid trans-log functions [9]. We referenced the cost quadratic function, following Oberdieck and Pistikopoulos [15] and Lin et al. [26]. Thus, our function is of the following form:

$$C(p,q) = \alpha_0 + \sum_{k=1}^{n} \alpha_k p_k + \sum_{i=1}^{m} \beta_i q_i + \frac{1}{2}\sum_{k=1}^{n}\sum_{l=1}^{n} \delta_{kl} p_k p_l + \frac{1}{2}\sum_{s=1}^{m}\sum_{t=1}^{m} \gamma_{st} q_s q_t + \sum_{k=1}^{n}\sum_{t=1}^{m} \rho_{kt} p_k q_t, \tag{1}$$

$$\text{s.t.} \quad \sum_{k=1}^{n} a_k p_k + \sum_{t=1}^{m} b_t q_t = c_0, \tag{2}$$

where α_k denotes the amount of total cost change which is caused by the price of the kth product of the input product increasing by one unit; β_i denotes the amount of total cost change which is caused by the price of the ith product of the output product increasing by one unit; δ_{kl} denotes the price relationship coefficient between product k and product l of input products; γ_{st} denotes the price relationship coefficient between product s and product t of output products; ρ_{kt} denotes the price relationship coefficient between input product k and input product t; c_0 stands for the sum of financial support that universities can provide for all input and output production and external resources of universities; a_k stands for the amount of the kth input product; b_j stands for the amount of the jth output product.

By using Lagrange multiplier method, we received the following results.

Proposition 1. *If the quadratic cost function (1) is constrained by linear condition (2), then the optimal solutions about the optimization problems (1) and (2) are*

$$\begin{aligned} p_k &= \frac{D_k}{D_0}, \quad k = 1, 2, \ldots, n, \\ q_i &= \frac{D_{n+i}}{D_0}, \quad i = 1, 2, \ldots, m, \end{aligned} \tag{3}$$

where

$$D_0 = \det\begin{pmatrix} \Delta & P & A \\ P^T & \Gamma & B \\ A^T & B^T & 0 \end{pmatrix},$$

$$\Delta = \begin{pmatrix} \delta_{11} & \delta_{12} & \cdots & \delta_{12} \\ \delta_{21} & \delta_{22} & \cdots & \delta_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \delta_{n1} & \delta_{n2} & \cdots & \delta_{\mathrm{nn}} \end{pmatrix},$$

$$\Gamma = \begin{pmatrix} \gamma_{11} & \gamma_{12} & \cdots & \gamma_{1m} \\ \gamma_{21} & \gamma_{22} & \cdots & \gamma_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ \gamma_{m1} & \gamma_{m2} & \cdots & \gamma_{\mathrm{mm}} \end{pmatrix}, \quad (4)$$

$$P = \begin{pmatrix} \rho_{11} & \rho_{12} & \cdots & \rho_{1m} \\ \rho_{21} & \rho_{22} & \cdots & \rho_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ \rho_{n1} & \rho_{n2} & \cdots & \rho_{\mathrm{nm}} \end{pmatrix},$$

$$A = (a_1, a_2, \ldots, a_n)^T,$$

$$B = (b_1, b_2, \ldots, b_m)^T,$$

$$d = (\alpha_1, \ldots, \alpha_n, \beta_1, \ldots \beta_m, c_0)^T.$$

D_k is such a determinant which replaces the kth column of D_0 with the column vector d ($k = 1, 2, \ldots, n$), and D_{n+i} is a determinant which replaces the $(n+i)$ th column of D_0 with the column vector d ($i = 1, 2, \ldots, m$).

Proof. Construct Lagrange multiplier function as follows: D_k, $k = 1, 2, \ldots, n$

$$H = C(p, q) + \lambda\left(\sum_{k=1}^{n} a_k p_k + \sum_{t=1}^{m} b_t q_t - c_0\right). \quad (5)$$

Then one-order condition can be calculated as follows:

$$\frac{\partial H}{\partial p_k} = \alpha_k + \sum_{l=1}^{n} \delta_{kl} p_l + \sum_{j=1}^{m} \rho_{kj} q_j + \lambda a_k = 0,$$

$$\frac{\partial H}{\partial q_i} = \beta_i + \sum_{s=1}^{n} \rho_{si} p_s + \sum_{j=1}^{m} \gamma_{ji} q_j + \lambda b_i = 0, \quad (6)$$

$$\frac{\partial H}{\partial \lambda} = \sum_{k=1}^{n} a_k p_k + \sum_{t=1}^{m} b_t q_t - c_0 = 0.$$

By using Cramer rule, the optimal solutions for the optimization problems (1) and (2) can be obtained as follows:

$$p_k = \frac{D_k}{D_0}, \quad k = 1, 2, \ldots, n,$$

$$q_i = \frac{D_{n+i}}{D_0}, \quad i = 1, 2, \ldots, m, \quad (7)$$

where D_k is a determinant that replaces kth column of D_0 with the column vector d ($k = 1, 2, \ldots, n$); D_{n+i} is a determinant that replaces the $(n+i)$th column of D_0 with the column vector d ($i = 1, 2, \ldots, m$); that is, $d = (\alpha_1, \ldots, \alpha_n, \beta_1, \ldots, \beta_m, c_0)^T$. □

3. Special Case and Discussion

In spite of the simplicity, Proposition 1 had a great influence on the different types of universities and found numerous applications. In order to explain its application value, let us discuss the following special case:

$$C_1(p, q) = \alpha_0 + \alpha p + \beta q + \frac{1}{2}\delta p^2 + \frac{1}{2}\gamma q^2 + \rho p q, \quad (8)$$

$$\text{s.t.} \quad a p + b q = c_0. \quad (9)$$

By using a similar proof method to Proposition 1, we have the following results.

Proposition 2. *If the quadratic cost function (8) is constrained by linear condition (9), then the optimal solutions about the optimization problems (8) and (9) are*

$$p_0 = \frac{-\alpha b^2 + (\beta a - \rho c_0) b + \gamma c_0 a}{\gamma a^2 + \delta b^2 - 2\rho a b},$$

$$q_0 = \frac{-\beta a^2 + (\alpha b - \rho c_0) a + \delta c_0 b}{\gamma a^2 + \delta b^2 - 2\rho a b}. \quad (10)$$

Proof. Select Lagrange multiplier function as follows:

$$L = \alpha_0 + \alpha p + \beta q + \frac{1}{2}\delta p^2 + \frac{1}{2}\gamma q^2 + \rho p q + \lambda(a p + b q - c_0). \quad (11)$$

Then one-order condition can be calculated as follows:

$$\frac{\partial L}{\partial p} = \alpha + \delta p + \rho q + \lambda a = 0,$$

$$\frac{\partial L}{\partial q} = \beta + \rho p + \gamma q + \lambda b = 0, \quad (12)$$

$$\frac{\partial L}{\partial \lambda} = a p + b q - c_0 = 0.$$

According to the Cramer rule, we can obtain the solution of problems (8) and (9) as shown in (10). □

Proposition 3. *If* $\rho < \min\{(\beta\delta/\alpha), (\alpha\gamma/\beta)\}$, *then optimal problems (8) and (9) have positive solution (10).*

Proof. According to the result of Proposition 2, the condition for problems (8) and (9) which have positive solution can be written as follows:

(i) $\rho^2 < \delta\gamma$
(ii) $\alpha\rho < \beta\delta$

(iii) $\beta\rho < \alpha\gamma$

Obviously, condition (i) guarantees that denominators of p_0 and q_0 are positive, while conditions (ii) and (iii) guarantee that parameter region in R^2, where both numerators of the p_0 and q_0 are positive, is not empty set.

If inequality $\rho < \min\{(\beta\delta/\alpha), (\alpha\gamma/\beta)\}$ is true, then both conditions (ii) and (iii) are true in the same time; meanwhile, it can guarantee condition (i) is true as well.

From Propositions 2 and 3, we found that when the quadratic cost function reaches its minimum, the functional relationship between output price p and output quantity a is in the form of fraction function. The denominator of the fractional function is the quadratic function of a while the numerator is the linear function of a. Therefore, it can be seen from the derivative function of p to a that there is at least one optimal output quantity for a and the output price p can obtain its optimal value. Likewise, in a similar way, the functional relationship between input price q and input quantity b is also in the form of fraction function. The denominator of the fractional function is the quadratic function of b while the numerator is the linear function of b. Therefore, by calculating the derivative of q to b, there is at least one optimal input quantity for b and the input price q can reach its optimal value.

In order to compare the influence of different parameters on the minimum cost, we made a list of several specific expressions of minimum cost in Table 2 below, where (p_0, q_0) is the coordinates of the extreme value point where the cost function reaches the minimum value.

As shown in Table 2, the minimum value of the cost function $c_4(p,q)$ as $\rho \neq 0$ is greater than that of the cost function $c_1(p,q)$ as $\rho = 0$. The minimum value of the cost function $c_2(p,q)$ as $\alpha \neq 0$ is greater than that of the cost function $c_1(p,q)$ as $\alpha = 0$, because the former costs more than the latter; this part of cost is $(0.5a\alpha\gamma/(\gamma a^2 + \delta b^2)) \cdot c_0$. In the same way, the minimum value of the cost function $c_3(p,q)$ as $\beta \neq 0$ is greater than that of cost function $c_1(p,q)$ as $\beta = 0$, because the former consumes more part of the extra cost than the latter; this part of cost is $(0.5b\beta\delta/(\gamma a^2 + \delta b^2)) \cdot c_0$.

Nevertheless, the upper limit of financial c_0 cannot be a constant; by this reason, colleges and universities do their best to exchange energy and resources in the external environment. Some of them can exchange for more resources, because their knowledge and other related resources have higher market value in competitive external activities. In the internal environment, on the one hand, flat organizational structures and internal competitive environments can make colleges and universities stimulate the vitality of departments and teachers under effective management so that the output level can be improved; on the other hand, colleges and universities can increase the proportion of unrestricted income and enhance financial flexibility carefully, so as to be able to provide conditions for independent adjustment and optimization of efficiency.

Although investment in education is very important for any country, people pay different attention to investment in education in different stages of a country's economic development. China is in the critical period of economic transformation and development; as China enters the middle and later stage of industrialization, the contribution rate of education to economic growth is increasing, and the importance of education investment in various factors is increasing. However, China's education investment has not narrowed the income distribution gap, which is another important dimension of economic sustainable development but expanded the initial distribution income gap. As can be seen from Table 3, we have obtained the following statistic results: From the average value of total investment, the absolute value of this average is close to 67 billion yuan, reaching the level of developed countries; the variance value of total investment is about 4111.20 yuan, which means China's total investment is quite stable in long-term education.

As an important component of education resources, the average education expenditure of local ordinary higher education is a significant indicator to show the fairness of education. Hence, many countries, especially developing countries, pay a great attention to promote this index. As can be seen from Table 4, from two aspects of nominal growth and actual growth rate, it is easy to find out a few features of the average education expenditure of China on local ordinary higher education. First, in time series, the average education expenditure of local ordinary higher education in China is lower in central China than in the eastern and western regions although it has maintained a growth momentum for many years. Meanwhile, the growth rate of per capita expenditure is fluctuating greatly every year, while the nominal growth rate is mostly greater than the actual growth rate. Second, the cold spots of the average education expenditure on local ordinary higher education in China are still mainly distributed in the northeast and central regions, while the hot spots are mainly distributed in the eastern region. Third, in terms of space, the shift of the gravity center of the average education expenditure in China's local ordinary higher education shows imbalance, as most of them shift level by level. Over time, the provinces with low per capita expenditure level have increased, and the vast majority of provinces in the central region are in low-level or sub-low-level areas.

According to data Table 4, we have obtained the following statistic results: From the average value of public expenditure per student in budget, the absolute value of the average is close to 5608 yuan; it shows that the long-term average student expenditure on the whole is a slight decrease in the early stage and a rise in the late stage. In terms of average growth rate, the average increasing speed is in the rising channel with a certain degree of volatility. After comparison, it can be found that there are two distinct and opposite periods of evolution; one is a period of slow decline (2000–2005) and another is a period of rapid rise (2008–2012). In this period of continuous decline, the average rate of decline for five consecutive years was 2.3%; the absolute value of per-student expenditure decreased from 2921 yuan to 2238 yuan in 2005. During the period of rapid rise, this rate was above 15% for four consecutive years; the absolute value of per capita expenditure rose rapidly from 2597 yuan in 2008 to 9040 yuan in 2012. Based on statistical

Table 2: The minimum value of cost function in the special cases.

$c_i(p,q)$	p_0	q_0	$\min c_i(p,q)$
$c_1(p,q) = (1/2)\delta p^2 + (1/2)\gamma q^2$	$(\gamma a/(\gamma a^2 + \delta b^2)) \cdot c_0$	$(\delta b/(\gamma a^2 + \delta b^2)) \cdot c_0$	$(0.5\gamma\delta/(\gamma a^2 + \delta b^2)) \cdot c_0^2$
$c_2(p,q) = \alpha p + (1/2)\delta p^2 + (1/2)\gamma q^2$	$(\gamma a c_0 - \alpha b^2)/(\gamma a^2 + \delta b^2)$	$(\delta b c_0 + \alpha a b)/(\gamma a^2 + \delta b^2)$	$(0.5\gamma\delta/(\gamma a^2 + \delta b^2)) \cdot c_0^2 + (0.5 a\alpha\gamma/(\gamma a^2 + \delta b^2)) \cdot c_0$
$c_3(p,q) = \beta q + (1/2)\delta p^2 + (1/2)\gamma q^2$	$(\gamma a c_0 + \beta a b)/(\gamma a^2 + \delta b^2)$	$(\delta b c_0 - \beta a^2)/(\gamma a^2 + \delta b^2)$	$(0.5\gamma\delta/(\gamma a^2 + \delta b^2)) \cdot c_0^2 + (0.5 b\beta\delta/(\gamma a^2 + \delta b^2)) \cdot c_0$
$c_4(p,q) = (1/2)\delta p^2 + (1/2)\gamma q^2 + \rho p q$	$(\gamma a - \rho b)/(\gamma a^2 + \delta b^2 - 2\rho a b)$	$(\delta b - \rho a)/(\gamma a^2 + \delta b^2 - 2\rho a b)$	$(0.5(\gamma\delta - \rho^2)/(\gamma a^2 + \delta b^2 - 2\rho a b)) \cdot c_0^2$

Table 3: Total higher education investment and its growth rate.

Year	Total higher education investment (RMB 100 million)	Growth rate of total investment of higher education (%)
2020	13999	3.99
2019	13464	11.99
2018	12013	8.15
2017	11109	9.72
2016	10125	6.37
2015	9518	9.48
2014	8694	6.30
2013	8179	2.04
2012	8015	14.16
2011	7021	24.72
2010	5629	17.70
2009	4783	10.03
2008	4347	15.54
2007	3762	17.20
2006	3160*	20.78
2005	2658	17.72
2004	2258	20.50
2003	1874	18.35
2002	1583	26.91
2001	1248	26.89
2000	983	—

*The data for 2006 is estimated by linear interpolation.

Table 4: Public education expenditure budget per student and its growth rate.

Year	Public education expenditure budget per student (RMB yuan)	Growth rate of public education expenditure on per student (%)
2020	8815.84	−3.78
2019	9162.17	3.81
2018	8825.89	3.76
2017	8506.02	5.44
2016	8067.26	−2.57
2015	8280.08	8.41
2014	7637.97	−3.31
2013	7899.07	−12.62
2012	9040.02	21.19
2011	7459.51	70.98
2010	4362.73	14.73
2009	3802.49	17.51
2008	3235.89	24.61
2007	2596.77	3.32
2006	2513.33	12.32
2005	2237.57	−2.65
2004	2298.41	−2.29
2003	2352.36	−4.12
2002	2453.47	−6.13
2001	2613.56	−10.53
2000	2921.23	—

analysis of Tables 3 and 4, it can be found that there are great differences between total investment and per-student expenditure on higher education in China. In the past 20 years, due to the stronger leading role of government investment, the total investment in education increased rapidly, while the growth of per-student expenditure is relatively slow. Since 2013, the level of government investment has slowed down slightly; this led to a significant slowdown in the growth rate of total investment and per-student expenditure. Due to the change in the standard of per-student funding in 2011, the new standard is much higher than the original one. Take Sichuan Province as an example: the average expenditure standard of college students in Sichuan Province was 4500 yuan per student in 2010, and this standard was low nationwide. Since the new standard was implemented in 2011, the original standard has been raised to 9000 yuan per person, which means that the average student expenditure doubled. In the same period, each province had a great improvement; therefore, the growth rate of the national average student expenditure was as high as 71% in 2011. At last, the variance value of public education expenditure per student in budget is about 2905.10, which means that

Table 5: Numerical characteristics of THEI and PEESB.

Index	Minimum	Maximum	Average	Variance
THEI	983	13999	6671.95	4111.20
Growth rate of THEI*	2.04%	26.91%	13.77%	0.07
PEESB	2238	9162	5608.02	2905.10
Growth rate of PEESB**	−12.62%	70.98%	8.74%	0.20

*THEI, total higher education investment. **PEESB, public education expenditure per student in budget.

China's public education expenditure per student in budget is relatively stable in long-term education.

Table 5 shows us that the variance value of public education expenditure per student in budget is about 2905.1; it means that China's public education expenditure in budget is relatively stable in long-term education. Meanwhile, the variance value of total higher education investment in China is about 4111.2; it means that Chinese government's total investment in higher education is also moderately stable.

Every winter, the PRC Ministry of Education will issue the *Statistical Announcement on the Implementation of National Education Funds*. In the announcement, the implementation of education funds in that year is explained from the total amount of education funds and its growth; meanwhile, the structure of education, including per-student expenditure of vocational education and higher education, at all levels in different regions in China is also explained. Relevant statistics show us that there are significant differences in the average student expenditure among different regions in China. In other words, on the premise that there is a large gap in the level of economic development between regions, education public services are mainly the function of local government. Their funds mainly come from the local budget, which is also the main cause of the significant difference of the per-student education funds. Therefore, China has a long way to go to achieve the goal of "the overall realization of equalization of basic public services" in 2020. □

4. Conclusions

Striving for saving limited education sources is reasonable and necessary in any society, but the question is how to achieve that goal in real life. In fact, none of them want to waste their resources among all of the universities in the world. For colleges and universities, only by clarifying the influencing factors of the education cost of colleges and universities, can we control the education cost, optimize the allocation of higher education resources, and enhance the competitiveness of colleges and universities. The colleges and universities directly under the Ministry of Education are typical in China's colleges and universities. The government has recently invested a large amount of funds in the education of colleges and universities directly under the Ministry of Education. However, problems such as unreasonable cost structure and low utilization rate of resources have become more and more serious. The issue of educational cost in colleges and universities directly falls under the Ministry of Education. The key to solving these problems is to analyze the influencing factors of the education cost of the universities directly under the Ministry of Education and then control the influencing factors of the cost of the universities directly under the Ministry of Education.

Since colleges and universities occupy a favorable position in the allocation of social resources, they have to take the corresponding responsibility in their teaching activities, especially in the case of scarce resources. For instance, Renmin University of China has started a program called "Fulfill Your Dream," offering more than one hundred places to students from rural areas in 2020. Tsinghua University, another prestigious Chinese university, also launched similar initiatives to boost transparency during the recruitment session. Colleges and universities should pay more attention to reasonable regulation and scientific management. However, many colleges and universities ignore the cost control in education and teaching activities, and high quality resources are wasted unconsciously. How to control and optimize the cost of running a school and how to establish an effective financial management system have gradually become a major content of the development of universities.

It has been a long time for many scholars to study the education cost for colleges and universities. However, with the system of colleges and universities education from diversification of education investment system deepening, the traditional "reimbursement" accounting system has been unable to meet the demand of college accounting information processing; the voice for a perfect accounting system with relatively strong operability is becoming stronger and stronger. It might be a wise decision to introduce a cost accounting of accrual basis, and then emendation of the accounting system in colleges and universities would bring juncture. Thus, in order to enhance the operability and effectiveness of education cost accounting for colleges and universities, cost accounting object, cost accounting project, cost accounting methods, and other aspects of the problem should be solved by cost accounting.

Funds have been one of the rare resources in the market and became more and more important during teaching and scientific research. Therefore, colleges and universities are fighting fiercely for these scarce resources; particularly, unrestricted funds are more and more popular. However, due to the fierce competition, all colleges and universities can hardly share same opportunities and obtain the same share in the market. In fact, there are many differences among different types of colleges and universities in the aspect of holding unrestricted funds. Generally, the efficiency of running a university directly reflects the level of financial autonomy of colleges and universities. One important reason is the differences of resource endowment conditions in colleges and universities. According to the dissipative structure theory discussed previously by Prigogine, colleges and universities must actively exchange energy and resources with the external environment so as to be able to obtain better resource endowment conditions. Universities rely on higher exchange and bargaining power in the market which are more likely to have priority access to more quality resources. If some colleges and universities take advantage of resource endowment conditions, their relative resources such as knowledge will be higher market value in the external environment, and more likely they can obtain much more resources.

In the light of our three propositions above, we put forward several cost-cutting measures. Firstly, the concept of modern enterprise financial management must be introduced into the work of financial accounting and funds budget in colleges and universities, trying to perfect the cost accounting system of running a university. Secondly, to make better use of Enterprise Management System in the development of tertiary education, colleges and universities must carry out college budget and decision-making in an all-round way. At last, in order to optimize the allocation of resources in colleges and universities and to achieve the goal of reducing the cost of running a university, colleges and universities must carry out market-oriented management. In view of this, colleges and the universities should offer more joint educational programs or do more joint projects first while during the process of gradually embedding social funds into the operation system of universities, scope economies between the academy system and university system may appear, and then it will be easier for the integration or the combination between the two huge different systems. In this way, universities with a more active and open attitude can have more fair opportunities to share the same opportunities and obtain their rightful share in the market.

Data Availability

The data used to support the findings of this study are available upon request to the author.

Conflicts of Interest

The author declares that there are no conflicts of interest.

Acknowledgments

This article was funded by the 2022 Shanghai Education Science Research Project.

References

[1] A. D. Athanassopoulos and E. Shale, "Assessing the comparative efficiency of higher education institutions in the UK by the means of data envelopment analysis," *Education Economics*, vol. 5, no. 2, pp. 117–134, 1997.

[2] E. Cohn, S. L. W. Rhine, and M. C. Santos, "Institutions of higher education as multi-product firms: economies of scale and scope," *The Review of Economics and Statistics*, vol. 71, no. 2, pp. 284–290, 1989.

[3] H. Dundar and D. R. Lewis, "Departmental productivity in American universities: economies of scale and scope," *Economics of Education Review*, vol. 14, no. 2, pp. 119–144, 1995.

[4] J. C. Glass, D. G. McKillop, and N. Hyndman, "Efficiency in the provision of university teaching and research: an empirical analysis of UK universities," *Journal of Applied Econometrics*, vol. 10, no. 1, pp. 61–72, 1995.

[5] K. Hashimoto and E. Cohn, "Economies of scale and scope in Japanese private universities," *Education Economics*, vol. 5, no. 2, pp. 107–115, 1997.

[6] G. Johnes, "Multi-product cost functions and the funding of tuition in UK universities," *Applied Economics Letters*, vol. 3, no. 9, pp. 557–561, 1996.

[7] G. Johnes, "Costs and industrial structure in contemporary British higher education," *The Economic Journal*, vol. 107, no. 442, pp. 727–737, 1997.

[8] W. J. Baumol, J. C. Panzar, and R. D. Willig, *Contestable Markets and the Theory of Industry Structure*, Harcourt Brace Jovanovich, SanDiego, CA, 1982.

[9] J. Kim, S. Nakano, and K. Nishimura, "Multifactor CES general equilibrium: models and applications," *Economic Modelling*, vol. 63, pp. 115–127, 2017.

[10] G. Johnes, "The management of universities; scottish economic society/royal bank of scotland annual lecture, 1999," *Scottish Journal of Political Economy*, vol. 46, no. 5, pp. 505–522, 1999.

[11] S. S. Askar, "On complex dynamics of monopoly market," *Economic Modelling*, vol. 31, pp. 586–589, 2013.

[12] D. R. Lewis and H. Dundar, "Economies of scale and scope in Turkish universities," *Education Economics*, vol. 3, no. 2, pp. 133–157, 1995.

[13] R. Nelson and K. T. Hevert, "Effect of class size on economies of scale and marginal costs in higher education," *Applied Economics*, vol. 24, no. 5, pp. 473–482, 1992.

[14] P. J. Lloyd, M. H. Morgan, and R. A. Williams, "Amalgamations of universities:are there economics of scale or scope?" *Applied Economics*, vol. 25, no. 8, pp. 1081–1092, 1993.

[15] R. Oberdieck and E. N. Pistikopoulos, "Multi-objective optimization with convex quadratic cost functions: a multi-parametric programming approach," *Computers & Chemical Engineering*, vol. 85, pp. 36–39, 2016.

[16] G. Sarafopoulos, "Complexity in a monopoly market with a general demand and quadratic cost function," *Procedia Economics and Finance*, vol. 19, pp. 122–128, 2015.

[17] A. Mian, A. V. Ensinas, and F. Marechal, "Multi-objective optimization of SNG production from microalgae through hydrothermal gasification," *Computers & Chemical Engineering*, vol. 76, pp. 170–183, 2015.

[18] E. Martinez-Budria, J. J. Diaz-Hernandez, and S. Jara-Díaz, "Productivity and efficiency with discrete variables and quadratic cost function," *International Journal of Production Economics*, vol. 132, no. 2, pp. 251–257, 2011.

[19] M. A. Gomez, W. Michiels, and S. Mondié, "Design of delay-based output-feedback controllers optimizing a quadratic cost function via the delay Lyapunov matrix," *Automatica*, vol. 107, pp. 146–153, 2019.

[20] G. Rebello, R. Gondhalekar, E. Dassau, and F. J. Doyle III, "Mixed linear-quadratic cost function design for MPC of an artificial pancreas - improved treatment & safety for a broad range of meal sizes ∗ ∗the authors thank the national institutes of health (NIH) for funding: DP3DK094331, DP3DK104057, R01DK085628. G. Rebello acknowledges funding by the Brazilian government through the Brazil scientific mobility program (BSMP)," *IFAC-PapersOnLine*, vol. 50, no. 1, pp. 7724–7730, 2017.

[21] O. Aydin, S. S. Tezcan, I. Eke, and M. C. Taplamacioglu, "Solving the optimal power flow quadratic cost functions using vortex search algorithm," *IFAC-PapersOnLine*, vol. 50, no. 1, pp. 239–244, 2017.

[22] Z. Hao and K. Fujimoto, "Approximate solutions to the Hamilton-Jacobi Equations for generating functions with a quadratic cost function with respect to the input," *IFAC Proceedings Volumes*, vol. 45, no. 19, pp. 194–199, 2012.

[23] G. Sarafopoulos, "Complexity in a duopoly game with homogeneous players, convex, log-linear demand and quadratic cost functions," *Procedia Economics and Finance*, vol. 33, pp. 358–366, 2015.

[24] J. P. Hwang, S. Park, and E. Kim, "A new weighted approach to imbalanced data classification problem via support vector machine with quadratic cost function," *Expert Systems with Applications*, vol. 38, no. 7, pp. 8580–8585, 2011.

[25] Y. Li, Yu Yao, and X. Hu, "Continuous-time inverse quadratic optimal control problem," *Automatica*, vol. 117, Article ID 108977, 2020.

[26] C. Lin, Q. Xiao, and Z. Niu, "Enterprise cost function model considering environmental governance cost and its application," *The Journal of quantitative and technical economics*, vol. 11, pp. 139–156, 2020.

[27] Z. Jiang, J. Huang, Y. Qi, and L. Wang, "Airline delay cost estimation based on Trans-log cost function," *Logistics Sci-Tech*, vol. 12, pp. 35–39, 2020.

[28] W. Wang, "Analysis of duopoly game model with quadratic cost function," *Journal of Dongguan University of Technology*, vol. 3, pp. 1–4, 2020.

[29] I. G. Vladimirov, I. R. Petersen, and M. R. James, "Frequency-domain computation of quadratic-exponential cost functionals for linear quantum stochastic systems," *IFAC-PapersOnLine*, vol. 53, no. 2, pp. 293–298, 2020.

[30] R. Zhang and T. Zhang, "Quadratic transportation cost inequality for scalar stochastic conservation laws," *Journal of Mathematical Analysis and Applications*, vol. 502, Article ID 125230, 2021.

[31] L. Orihuela, P. Millán, and J. F. Carbonell-Márquez, "Distributed negotiation with a class of quadratic cost functions ∗ ∗the authors acknowledge MCyT (grant dpi (grant tec," *IFAC-PapersOnLine*, vol. 50, no. 1, pp. 12285–12290, 2017.

[32] G. T. Sav, "Higher education costs and scale and scope economies," *Applied Economics*, vol. 36, no. 6, pp. 607–614, 2004.

[33] G. Johnes, J. Johnes, and E. Thanassoulis, "An analysis of costs in institutions of higher education in England," *Studies in Higher Education*, vol. 33, no. 5, pp. 527–549, 2008.

[34] G. Chen, "Study on cost-efficiency of universities in China," *Journal of Jiangxi University of Finance and Economics*, vol. 3, pp. 102–108, 2008.

[35] T. Agasisti and G. Johnes, "Heterogeneity and the evaluation of efficiency: the case of Italian universities," *Applied Economics*, vol. 42, no. 11, pp. 1365–1375, 2010.

[36] X. Chen and Z. Dong, "On the economy of scale and scope of mass higher education in China," *Education Research*, vol. 9, pp. 14–21, 2011.

[37] F. Li and X. Chen, "Economies of scope in distance education: the case of Chinese research universities," *International Review of Research in Open and Distance Learning*, vol. 13, no. 3, pp. 117–131, 2012.

[38] G. Song and W. Peng, "How to improve the compulsory education school choice system:based on the perspective of the education demand," *Reform of Economic System*, vol. 34, pp. 183–187, 2016.

[39] T. Agasisti and G. Johnes, "Efficiency, costs, rankings and heterogeneity: the case of US higher education," *Studies in Higher Education*, vol. 40, no. 1, pp. 60–82, 2015.

[40] T.-T. Fu, A.-D. Sung, K. F. See, and K.-W. Chou, "Do optimal scale and efficiency matter in Taiwan's higher education reform? A stochastic cost Frontier approach," *Socio-Economic Planning Sciences*, vol. 67, pp. 111–119, 2019.

[41] F. Xia, J. Quigley, J. H. Abbott, T. Sajobi, K. Hildebrand, and K. Youcef-Toumi, "A modular low-cost atomic force microscope for precision mechatronics education," *Mechatronics*, vol. 76, Article ID 102550, 2021.

[42] E. Antipova, C. Pozo, G. Guillén-Gosálbez, D. Boer, L. F. Cabeza, and L. Jiménez, "On the use of filters to facilitate the post-optimal analysis of the Pareto solutions in multi-objective optimization," *Computers & Chemical Engineering*, vol. 74, pp. 48–58, 2015.

[43] F. Capitanescu, A. Ahmadi, E. Benetto, A. Marvuglia, and L. Tiruta-Barna, "Some efficient approaches for multi-objective constrained optimization of computationally expensive black-box model problems," *Computers & Chemical Engineering*, vol. 82, pp. 228–239, 2015.