

Review of Quantitative Methods Used in Chinese Educational Research, 1978–2018

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Abstract

Purpose: This article reviews the development of quantitative methods in educational research in China since 1978.

Design/Approach/Methods: For this summary and literature review, we used data from the China National Knowledge Infrastructure (CNKI), relevant books, and research output from the Graduate School of Education, Peking University.

Findings: We divided the development of quantitative methods in Chinese educational research into four stages: the Startup Stage (1978–1988), the Gradual Application Stage (1989–1998), the Growth Spurt Stage (1999–2008), and the Integrated and Diverse Development Stage (2009–2018). Overall, the development of quantitative methods in Chinese educational research shows sustained innovation in numerous aspects, including research methods, data sources, utilization of advancements in computing technology and statistical software, and research topics. However, despite the relatively advanced state of quantitative methods, education measurement and evaluation require further attention. The questionnaire and experimental research data currently available indicate the need to improve the mining and utilization of big data. Moreover, while Chinese educational researchers have demonstrated their proficiency in using quantitative research methods, improvements remain to be made with respect to collaboration and sharing.

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Originality/Value: This article is the first to analyze systemically the development of quantitative methods in Chinese educational research. It provides an original summary of the development and characteristics of quantitative methods in educational research in China.

Keywords

Course of development, educational research, literature review, quantitative methods

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China has experienced rapid economic development since the implementation of the reform and opening-up policy in 1978. During the same period, the country's education system has also made remarkable progress—laying a solid foundation for China's transition from being merely a populous country to being one with strong human resources. Faced with the various new problems and challenges that have emerged from the process of educational development, Chinese education researchers have conducted extensive, in-depth research in the growing field of education.

According to the famous Chinese proverb, “good tools are a prerequisite for the successful execution of any job”; similarly, solid educational research is inseparable from sound research methodology. Scholars have devoted increasing attention to the standardization of research processes and methods, as well as the in-depth investigation and analysis of current social realities. In order to solve practical education problems, Chinese scholars have incorporated empirical research tools into their educational research. Indeed, the proportion of papers and postgraduate dissertations utilizing empirical research is only increasing.

Empirical research is a general term for various methods that establish and test theoretical propositions based on the observation of empirical facts under the condition of value neutrality. There are many types and levels of empirical research—such as experimental research, surveys, qualitative research, interviews, the archaeological approach, textual analysis, case studies, observation records, experience screening, and computer simulations. Although broad in scope, *empirical research* generally refers to methods based on actual situations. Empirical research typically seeks solutions for real-world problems with a view toward practical application.

Among the various empirical research methods, quantitative research is considered one of the most important research paradigms. Quantitative research has become increasingly popular among educational researchers as a result of its growing significance. This is particularly true in the current era of globalization, the Internet, and big data, as the scope and methodologies of educational research are continuously expanding and increasing. Educational research increasingly relies on data to describe phenomena, models to explain changes, theories to analyze reasons, and empirical evidence as a reference when proposing policy suggestions and recommendations.

Quantitative research focuses on “what is?” (facts) rather than “what should be?” (ideals). Its goal is to identify the axioms of various phenomena, explain human behavior from a group (rather than an individual) perspective, and uncover the relationship between variables. Data are the basis of quantitative research. Indeed, quantitative research rests on the principle that no research method is valid without reliable data, making the quality of the data critical. There are numerous sources of data for quantitative research in the field of education, the most common of which include questionnaires, experiments, and public historical data.

Since its reform and opening-up, China has gradually become integrated into the global economy. At the same time, Chinese scholars have become part of the international academic community, and certain areas of domestic research (particularly in the field of economics) are already interconnected with the research conducted in other countries. The basic analytical framework and research methods of modern economics have been widely accepted and applied in economic education and research in China (Tian, 2005). However, the connection between Chinese and international educational research remains underdeveloped, largely as a result of the significant methodological differences between the research conducted in China and the West. Before China’s reform and opening-up, educational research conducted in the country tended to focus on summarizing the experiences of educational practice. Many educational practitioners and personnel from departments in charge of education became experts and policy-makers in the field. Since China’s reform and opening-up, advanced educational theories and research findings from other countries have increasingly been introduced to China, while a growing number of Chinese educational scholars have begun using quantitative methods in their research.

This study reviews the application of quantitative research methods in Chinese educational studies since the country’s reform and opening-up. This study utilizes the published research of education scholars in China since 1978 to uncover the development and characteristics of quantitative educational research in China. The articles included in this study were predominantly extracted from the China National Knowledge Infrastructure (CNKI) project. This study also draws upon essential academic-level books, as well as representative papers and research by education scholars. In doing so, this study divides the development of quantitative research in education into four periods: the Startup Stage (1978–1988), the Gradual Application Stage (1989–1998), the Growth Spurt Stage (1999–2008), and the Integration and Diversification Stage (2009–2018).

The concept of a National Knowledge Infrastructure (NKI) project was first proposed by the World Bank in 1998. CNKI’s online databases were launched in June 1999 by Tsinghua University and the Tsinghua Tongfang Company. CNKI is the world’s largest digital library in terms of volume of journals and provision of full-text data. CNKI is widely utilized as an information platform by the academic community in China. However, CNKI’s collection of full-text publications is incomplete: the earlier a paper’s publication date, the less likely it is to be available on the

database. Nonetheless, this study focuses on tracking the evolution of the methods used in quantitative educational research over the past 40 years, rather than simply analyzing the number of quantitative educational research papers published in each period.

The Startup Stage, 1978–1988

Prior to the reform and opening-up of China, domestic researchers possessed a limited knowledge of empirical research and lacked awareness of its methods. Although the number of empirical studies on education that applied quantitative research methods remained limited in the first decade following the opening of China, certain Chinese scholars began recognizing the importance of educational statistics and econometrics and started publishing papers that introduced principles and theories related to quantitative research methods.

Review of quantitative studies on education in China

In the early days of China's reform and opening-up, the social sciences generally did not utilize or incorporate quantitative research methods. In the field of educational research, a number of scholars slowly began using statistical methods to study educational issues. Education statistics predominantly consist of statistical descriptions and inferences. The statistical description method is used to analyze samples and data sets, and apply corresponding statistical indicators to extrapolate the patterns and characteristics of different types of variables. For continuous variables in educational research, certain statistical indicators are adopted to measure the variables from the perspectives of central tendency, variability, and distribution. Measures of central tendency include the mean, median, mode, and mid-quartile range; measures of variability include variance, standard deviation, range, the ratio of the extremes, coefficient of variation, Gini coefficient, Theil index, and McLoone Index; while measures of distribution include kurtosis and skewness.

In this study, an advanced search function with the keywords “*jiaoyuxue lei qikan*” (educational journals) was used to extract journal articles from CNKI. Between 1978 and 1988, 52 papers used the mean as a statistical indicator, 9 papers used the median, while 4 papers used the coefficient of variation. These measures were mainly used to analyze student performances and psychological measurements. These studies marked the first application of statistical methods in Chinese educational research and gained particular popularity in the field of educational psychology.

Statistical inference methods are used to identify the overall patterns and characteristics of a certain set of data. The introduction of statistical inference methods in educational research was especially significant for the study of educational management and educational psychology. Statistical inference methods can provide more universal and scientific information for the investigation of education situations, summation of educational experiences, evaluation of the effectiveness of education, as well as the exploration of axioms in education. The most commonly

used statistical inference methods are parameter estimation and hypothesis testing. During the startup period, certain Chinese scholars began introducing statistical inference methods such as comparison of means tests, analysis of variance (ANOVA), and correlation analysis.

Among the examined papers we extracted, correlation analysis began to be introduced into educational research area. Four papers were published in this stage, indicating that Chinese researchers began focusing on the relationship between two variables in performing certain evaluations and tests. The majority of these studies investigated the correlations between college students' test results, learning performance, and the job they obtained following graduation. For example, some studies analyzed the correlation between the performance of college students at school and in their job following graduation in order to evaluate the overall quality of higher education.

ANOVA analyzes the contribution to the total variation of the different means at various levels and the differences caused by random factors in order to determine the significance of the factors that affect experimental results. Among the papers collected by this study, 10 applied ANOVA to analyze the impact of teaching methods on student performance.

Based on their research proposals, certain studies from this period applied more specific and targeted statistical methods such as factor analysis, cluster analysis, and discriminant analysis. Factor analysis reduces all of the variables into a few potential factors while minimizing information loss. The obtained factors significantly summarize the information about the material. The method reduces the number of variables that are to be considered in the model and reveals the intrinsic relationship between them. Factor analysis is also known as dimensionality reduction and is often used in processing the variables in educational survey data. Ning (1987) introduced the algorithms and procedures for factor analysis. Three later papers used factor analysis to analyze student achievements and teaching quality. Another paper conducted a preliminary evaluation of the quality of a university's curriculum by utilizing factor analysis to explore the common factors of various courses that contributed to the development of student abilities.

Similar to factor analysis, cluster analysis is a statistical technique that divides research subjects into groups based on certain shared similarities. Also called classification analysis or numerical taxonomy, cluster analysis can be used to group both observations and variables. Following the publication of five papers that introduced cluster analysis methodology and its potential application in educational research, Chinese scholars began using the approach in empirical studies. For instance, cluster analysis was used to analyze student performance by grouping students into knowledge structure categories.

Two papers from this period combined cluster analysis and discriminant analysis methods. Discriminant analysis is a multivariate statistical method that assigns a given research subject to a predetermined group based on the similarity of the subject's attributes to those of the group. For example, certain researchers employed cluster analysis to classify students' knowledge structures

Table 1. Summary of the application of quantitative research methods, 1978–1988.

Category	Methods	Published	
		papers	Primary research topics
Statistical description	Central tendency Variability	52	Student performance and psychological measurement.
Statistical inference	Variance analysis	10	The impact of various teaching methods on student performance.
	Correlation analysis	4	The correlations between college students' test results, learning performance, and post-graduation employment.
	Factor analysis	4	Student performance and the quality of education.
	Cluster analysis	10	Analyzing students' test results and clustering them into knowledge structures.
	Discriminant analysis	2	Classifying students' knowledge structures and then applying discriminant analysis to assign the students excluded from the cluster analysis to the corresponding knowledge-structure groups.

before applying discriminant analysis to assign the students excluded from the cluster analysis to their corresponding knowledge-structure groups.

Although Chinese scholars began using quantitative methods during this period, experience studies and speculative research continued to dominate in the field of educational research, while descriptive statistics prevailed in data analysis. Studies that utilized quantitative research methods were limited. Table 1 provides a summary of the specific measures and methods applied during the startup stage.

Analysis of representative papers

The earliest published Chinese educational research that used econometric regression methods and yielded significant findings concluded that “expenditure on education should account for 4% of China’s gross domestic product (GDP)” (Li & Chen, 1988, p. 134). In the early 1980s, Yongquan Wang, the director of Peking University’s Higher Education Institute, contacted Yining Li and suggested conducting research on education economics. Wang and Li organized a research team to study the reasonable proportion of educational expenditure from national income and the economic benefits of investment in education, with Li serving as the leader of the project (Li & Chen, 1988). The project was awarded a grant from the Key Projects of the National Social Science Fund in the Sixth Five-Year Plan period (1980–1985). More than 20 research units participated in the project, including the National Institute of Education Sciences (NIES), Beijing Normal University, and

Xi'an Jiaotong University, while Peking University served as the leading organization. Liangkun Chen (Peking University), Shanmai Wang (Beijing Normal University), and Mingyi Meng (NIES) presided over and individually undertook numerous subprojects.

The conclusion that public expenditure on education should account for approximately 4% of national income was reached by a subproject entitled "International Comparison of Reasonable Proportions of Education Funds from National Income," which was managed by Chen (Chen et al., 1986). The project's main findings were published as a monograph, *Education Economics Research* by Shanghai People's Publishing House in 1988. Li was the editor-in-chief, while Chen, Meng, and Wang served as deputy editors. Prior to publication, Li submitted the project's main conclusions to the central government. Thereafter, the "4% of GDP" suggestion was included in the "Final Proof Version of Domestic News" published by the Xinhua News Agency (1986, No. 616) and circulated among various decision-making departments of the government.

Using GDP per capita as an indicator of national economic development, the research team attempted to uncover international averages of the proportion of education investment compatible with different levels of economic development in order to eliminate the incomparability resulting from the variations in economic development. The researchers extracted the data on public education expenditure and GDP per capita of 38 countries that had populations over ten million. They then employed an econometric regression method to estimate the average public education expenditure in countries with different levels of economic development. The results showed that, when the GDP per capita of a country reached 1,000 USD, the average public education expenditure was 4.24% of national income. In the study's policy recommendation section, the research team proposed that an appropriate ratio of education expenditure to national income in China by the year 2000 would be 4%.

During the startup period, a group of university educators and researchers—most notably, researchers from Peking University, Fudan University, and Beijing Normal University—began introducing western economic theories and methods into Chinese educational research. The purpose was to adopt new perspectives and new empirical methods to investigate education-related issues in China. *Education Economics Research* collected a number of important empirical studies from the early and mid-1980s. These studies made use of time series and national data to investigate China's education economy by constructing mathematical and econometric regression models (Ding, 2010).

In terms of research methods, there was a tendency during this period to favor simple statistical descriptions and econometric regression. This was partly shaped by a lack of available resources: together with insufficient research data, computers were fairly uncommon and had limited memory, statistical software packages had relatively simple functions and were difficult to use, while professors capable of understanding and using quantitative research methods were scarce.

Nevertheless, in the late 1980s, students that studied abroad following China's reform and opening-up returned and began teaching in schools and universities. These teachers and professors helped introduce the advanced educational research methods used in other countries. For example, Professor Min Weifang received his PhD in the economics of education from Stanford University in 1987 and returned to China and began teaching at Peking University in 1988.

The Gradual Application Stage, 1989–1998

Review of quantitative studies on education in China

In the second decade following the reform and opening-up of China, the number of studies that utilized quantitative research methods—such as ANOVA, correlation analysis, factor analysis, cluster analysis, and discriminant analysis—increased noticeably, marking the gradual development and application phase of the statistical inference methods introduced during the startup period. Researchers turned their focus to more specific research topics and began adopting other statistical methods, as well as interdisciplinary methods. Quantitative research methods received additional attention during this period and were widely applied in the context of Chinese educational research.

Of the papers collected for this study, 26 used ANOVA to analyze the characteristics of students' development, test scores, personality traits, professional choices, motivations, classifications of teachers, and so on. Certain studies used ANOVA to explore the psychological identity of students who applied different learning methods and compared their performance in learning social norms.

Using correlation analysis, 60 papers presented research on educational technology, teaching quality, student achievement, student personality traits, mental health, and family background. Several studies combined correlation analysis with ANOVA. For example, a number of studies used correlation analysis to investigate the links between the needs of members of the one-child generation and their learning performance, while others explored the correlation between intelligence and morality.

Sixty-six papers employed factor analysis and mainly focused on topics relating to student competence structures, curriculum design, and psychological factors in learning. Factor analysis is generally used to construct and analyze measurement scales. Certain scholars also introduced ideas—such as self-concept, self-worth, and personality trait theory—from other disciplines in the social sciences, including sociology and psychology. For example, one study applied factor analysis to questionnaire developed by the researcher in order to extract the dimensions of college students' self-concepts (Zheng & Huang, 1998).

Forty-three papers utilized cluster analysis to analyze higher education, education reform, curriculum design, career selection, education evaluation, teaching evaluation, and teacher

assessment. Other research methods—such as normality tests, correlation coefficients, and fuzzy statistics—were used alongside cluster analysis. For instance, one study applied cluster analysis to classify the samples and indicators according to the unified indicator system of scientific and technological activities in colleges and universities (Xiao, 1999).

Eight papers employed discriminant analysis, investigating student achievements, teaching quality, and career selection. One paper applied discriminant analysis to study the exercise load of physical education in primary and secondary schools (Chen & Gao, 1990). Another examined the relationship among the grades, academic achievement, and learning strategies of middle school students, and utilized discriminant analysis to identify the dimensions of improved learning strategies (Xin & Li, 1998).

During this second period (1989–1998), econometric regression methods received greater attention and were more widely applied. Indeed, more than 60 related papers were collected from this period. The methods were predominantly used to examine questions related to the academic achievements of students (regression analysis of college entrance examination scores and academic performance in universities), the economic benefits of higher education (regression analysis of educational expenditure and industrial output), as well as student mental health (influence of parenting methods on adolescent mental health). In 1993, a study (Cao, 1993) used logistic regression to investigate the factors affecting vision loss, with regression analysis applied when the dependent variables were categorical variables among Chinese educational researchers. Thereafter, the logistic model was widely applied in analyses of the causes of poor academic performance and behavioral problems.

Moreover, two papers published during this period adopted the artificial neural network method in qualitative educational research (Chen, 1996; Wang, 1994). A paper published in 1994 used artificial neural networks (multilayer perceptron and an improved backpropagation [BP] algorithm) to evaluate student performance, signifying a meaningful attempt to apply artificial neural networks to higher education management (Wang, 1994). In 1996, another paper adopted the neural network method to construct a comprehensive ability assessment model for university researchers (Chen, 1996).

Wang (1995) used a simultaneous equation model to examine the relationship between population and education. Although the simultaneous equation model reveals the relationships between different economic variables in complex systems, it was not widely applied during this period. The structural equation model only emerged in Chinese educational research in 1995, with one paper mentioning such model and its potential application in the field of education (Zhang & Meng, 1995). No papers published during this period, however, applied the method in empirical research.

Table 2. Summary of the application of quantitative research methods, 1989–1998.

Category	Methods	Primary research topics	Development	Evaluation
Statistical analysis	Correlation analysis, factor analysis, cluster analysis, discriminant analysis, and ANOVA.	Teaching quality and evaluation; student achievement, personality traits, mental health, and ability structure; curriculum design; profession choices; education evaluation.	The research topics became more specific and other statistical and interdisciplinary methods were adopted.	Correlation, factor, and cluster analyses were the most commonly used methods.
Econometric regression and similar research methods	Regression analysis, simultaneous equation models, logit models, DEA, and neural network analysis.	Admission decisions, research on scientific research systems in higher education, and the evaluation of development levels in science and education.	The use of these methodologies was still in an incipient stage. With the exception of regression analysis, each research method had only one or two related papers.	Regression analysis was the most commonly used method.

Note. ANOVA = analysis of variance.

One empirical study used data envelopment analysis (DEA), an efficiency evaluation method for systems with multiple inputs and outputs. Published in 1997, the paper used DEA to explore the development of science and education in China's provinces, autonomous regions, and municipalities, quantitatively demonstrating the overall scientific and technological capacity of each region and the gaps among them (Wang & Liu, 1997).

Between 1989 and 1998, correlation analysis, factor analysis, and cluster analysis were the most commonly used quantitative methods in Chinese educational research, though discriminant analysis methods were also applied. These methods were mainly used to study issues related to teaching and student development in higher education. Furthermore, more complex research methods—such as multiple linear regression models, simultaneous equation models, DEA, and neural network analyses—were also applied in the field of educational research. Table 2 summarizes the research methods and the topics for which they were used, as well as the development, evaluation, and application of corresponding methods. Table 3 presents the development of established and emerging research methods during this period.

Table 3. Comparison between the number of papers using quantitative methods published in the first (1978–1988) and second (1989–1998) decades.

	Correlation analysis	Factor analysis	Cluster analysis	Discriminant analysis	Variance analysis	Regression analysis	Logit analysis	Structural equation models	Simultaneous equation models	Neural network	DEA
The first decade	4	4	10	2	10	0	0	0	0	0	0
The second decade	60	66	43	8	26	60	1	3	1	3	1

Note. DEA = data envelopment analysis.

Analysis of representative papers

During the Eighth Five-Year Plan period (1991–1995), Min and Ding, Peking University scholars, conducted an empirical study on the efficiency of management in higher education institutions. Their classic quantitative study had an important impact on the direction of higher education in China. Their policy suggestions emphasized the importance of the government focusing on “intensive” development that brings out the full potential of higher education (Min & Ding, 1993). This concept later became an important part of China’s national education development strategy (Ding, 1995).

Higher education in China developed rapidly following the implementation of economic reform and opening up. During the 1980s, China’s higher education mainly followed an “extensive” development path. The number of higher education institutions increased from 598 in 1978 to 1,075 in 1988. A large number of these institutions, however, were relatively small. While the average number of students per institution was less than 2,000, many colleges and universities only had between 200 and 300 students—far less than universities in the United States and the former Soviet Union, which averaged 3,000–4,000 students. From the perspective of economies of scale, this “extensive” form of development led to a dispersed distribution of higher education institutions, small student population size, and an inefficient utilization of resources.

Consequently, Min and Ding conducted an empirical study on the economies of scale of higher education institutions in China. The two professors adopted hyperbolic, quadratic and modified hyperbolic functions to analyze survey data from 156 universities in Shaanxi, Guizhou, Hubei, Yunnan, and Shanxi. Their empirical results showed that the scale of higher education institutions in China is an important factor influencing the cost per student, and that the appropriate number of students per college/university was approximately 4,000. They thus proposed that,

The expansion of higher education in China should adopt an “intensive” development strategy. Specifically, the government should focus on exploring the potential, improving efficiency, and expanding the size of existing institutions, in order to promote further growth of the higher education system (Ding, 1995, p. 3).

During this period, Chinese education researchers increased their use of statistical analysis and econometric regression methods. Research institutions began attaching greater importance to the construction of survey data and databases while the Internet became an important channel for obtaining data. Researchers utilized computers at a higher rate, owing to their increased affordability and the availability of more user-friendly statistical software packages (aided by the introduction of Windows 95). Finally, in terms of faculty resources, this period saw an increase in the number and proportion of teachers holding doctoral degrees in their respective fields.

The Growth Spurt Stage, 1999–2008

Review of quantitative studies on education in China

Since the beginning of the 21st century, the number of published papers utilizing quantitative methods has increased drastically. The number of papers that applied ANOVA, correlation analysis, and factor analysis grew rapidly, and there was a massive upsurge in the number of empirical studies. The number of papers that employed multiple linear regression models, logit models, simultaneous equation models, DEA, and neural network methods gradually increased.

ANOVA was used in 123 papers. Furthermore, Chinese researchers extended ANOVA to the analysis of covariance (ANCOVA) and combined the methods with regression analysis and survey analysis. The majority of these papers focused on academic performance, teaching quality and effectiveness, professional values, and college students' mental health. Certain studies employed ANCOVA to evaluate teaching efficiency and the differences in the employment skills of college graduates.

The number of papers using correlation analysis increased significantly starting around 2004—marking a growth spurt in the third decade after the reform and opening-up (1999–2008), with 280 papers published during this period. Although research remained focused on student achievement, mental health, and personality, the research subjects expanded from college students to junior and senior high school students.

Factor analysis was used by 549 papers, often in conjunction with cluster analysis. Research subjects expanded from college students to teachers and middle school students. Scholars employed factor analysis to explore the constraints of numerous practical issues and propose appropriate countermeasures. Examples of the use of factor analysis during this period include the analysis of internal and external constraints on the development of vocational and technical schools in rural areas, economic constraints on the development of higher education for women, and the benefits of higher education in general. In addition, researchers applied these methods in an increasingly rigorous manner, and a growing number of studies paid attention to the reliability and validity of the questionnaires.

Of the papers collected for this study, 80 used econometric regression analysis in the empirical study of education-related topics. The majority utilized linear regression analysis and the research subjects included college teachers, graduate education, the scale of higher education, and student achievement. Twelve papers applied logit models in their analyses. The research subjects of these studies included college students, graduates, and farming households, and primarily focused on influential factors in admission rates, individual willingness to invest in education, health-risk behaviors, employment, and financed entrepreneurship. Some studies adopted the nested logit model to analyze education-related choices.

Forty-two studies applied structural equation models to investigate topics such as the employment status, mental health, and subjective well-being of college students. Neural network analysis was used in 25 papers, the majority of which applied the BP neural network algorithm to analyze the risk and early warning system of college loans, teaching quality and evaluation indicators, the measurement and evaluation of student competencies, as well as the prediction of college entrance examination scores. Seventeen papers employed DEA to assess the allocation efficiency of school resources and performance evaluation of higher education institutions. Several studies also combined these approaches with other methods such as factor analysis.

In 2001, China joined the World Trade Organization, and the openness of the country's economy, society, and education increased significantly. Consequently, the connection between education in China and other countries became increasingly close. New quantitative research methods—such as cointegration analysis, stochastic frontier analysis, causality tests, and instrumental variables—were increasingly adopted by Chinese educational researchers.

The traditional econometric research method assumes that the corresponding system is dynamically stable. However, economic time series are usually nonstationary. Therefore, using the horizontal values of the variables to study the equilibrium relationship directly can lead to false conclusions. Certain studies during this period began using cointegration analysis to enhance the econometric analysis on time series data. However, only three papers applied cointegration analysis to analyze the relationship between education and economic growth during this period.

During this period, Chinese researchers began using instrumental variables in quantitative studies of education. These variables were primarily used to minimize selection bias when measuring the rate of return on investment in education. In 2008, five empirical studies used instrumental variables to analyze issues such as school efficiency, the rate of return on personal education, the effect of higher education on wages, and the relationship between education and regional economic differences.

Chinese education researchers first used spatial correlation analysis in 2006. When spatial correlation is found in the least-squares regression model, a spatial regression model is applied to estimate the spatial correlation between variables. Published between 2006 and 2009, three papers investigated the spatial relationship between educational expenditure and tuition, including an examination of the influence of proximate regions on the allocation of financial resources in basic education from a spatial perspective.

Similar to logit models, a probit model is a type of discrete choice model. Probit models are predominantly used in the regression of data that respect a normal distribution. Chinese educational research that applied probit models first emerged in 2007. For instance, one study (Liu et al., 2007) used a probit model to analyze the relationship between education and the elimination of

rural poverty, while another used it to analyze the influential factors in school dropouts among rural adolescents in China (Du, 2008).

Between 1999 and 2008, six papers applied multiple linear regression to empirically investigate the factors influencing student performance, school efficiency, and the educational performance of migrant children. Another paper published in 2007 utilized empirical methods and econometric analysis to investigate the efficiency of the management of higher education institutions, which imported stochastic frontier analysis (Li & You, 2006).

Table 4 summarizes the development of quantitative research method application between 1999 and 2008.

Analysis of representative papers

The rate of return on education is a key research topic in education economics, as it reflects the personal and socioeconomic benefits of investment in education. During the third decade after China's reform and opening-up, domestic scholars conducted extensive research in this area, using the Mincer earnings function to empirically analyze the rate of return on education for urban residents in China (Chen et al., 2003; Ding, 1998; Ma & Ding, 2005; Yue, 2004).

Ordinary least squares (OLS) was the most traditional method used to calculate the rate of return on education. OLS provides the estimated value of the dependent variable based on a predetermined set of independent variables. The implicit assumption of this regression method is that the effects of the independent variables on the dependent variables are the same at different distribution points. In this case, the assumption is that the rate of return on education is the same among individuals with comparable levels of education and work experience. Thus, when applying OLS, the regression coefficient is assumed to be constant throughout the conditional distribution of income. However, such an approach limits the examination of important features of the income distribution data.

Quantile regression is a more general estimation method, the purpose of which is to observe the various effects of independent variables on different quantiles in the distribution. In terms of income distribution, this method focuses on the difference in the rate of return on education at various income points in the overall income distribution. Using data collected by the Urban Social-Economic Survey, conducted by the National Bureau of Statistics, Yue and Liu (2006) applied quantile regression to empirically investigate the relationship between income and education among different income groups in urban areas of China. The results showed that the rate of return on education of low-income groups was significantly higher than that of high-income groups. The policy implication of this finding is that, in controlling public education resources, the government should guarantee the right of students from low-income groups to receive education and provide

Table 4. Summary of the application of quantitative research, 1999–2008.

Category	Method	Primary research topics	Published papers	Comments
Existing research methods	Variance analysis	College students' mental health, academic performance, teaching quality and effectiveness.	123	The research method was extended from ANOVA to ANCOVA. Other methods, such as regression analysis and survey analysis, were used alongside ANCOVA.
	Correlation analysis	Student achievement, mental health, and personality.	280	Research topics were expanded, and certain studies began combining correlation and regression analysis.
	Factor analysis	Applying factor analysis to propose and analyze the constraints of many real problems, as well as suggest countermeasures.	549	The application of these research methods was more scientific, and a growing number of studies began paying attention to the reliability and validity of questionnaires.
	Cluster analysis	Teaching quality assessment and college student evaluation.	179	Cluster analysis was combined with other methods such as factor analysis and data mining. In addition, two major submethods—hierarchical clustering and fuzzy clustering—were introduced.
	Discriminant analysis	Financial risk of higher education institutions and the risk of student loan default.	12	
	Regression analysis	Graduate education, the scale of higher education, and student achievement.	80	Simple linear regression and multiple linear regression were most commonly used in combination with correlation analysis.
	Logit model	Factors influencing the willingness to invest in education, employment, and financed entrepreneurship.	12	Using the nested logit model to analyze education-related choices.

(continued)

Table 4. (continued)

Category	Method	Primary research topics	Published papers	Comments
	Structural equation model	College students' employment, mental health, and subjective well-being.	42	
	Neural network analysis	Risk and early warning systems, teaching quality and evaluation indicators, the measurement and evaluation of student competency, and the predicting performance in college entrance examinations.	25	
	Data envelopment analysis	Evaluation of the allocation efficiency of school resources and performance evaluation of higher education institutions.	17	Used in conjunction with factor analysis.
New research methods	Cointegration analysis	The relationship between education and economic growth.	3	Econometric analysis of time series data.
	Instrumental variable	School efficiency, the rate of return of education, the effect of higher education on wages, as well as the relationship between education and regional economic differences.	5	Minimizing selection bias in measuring the rate of return on education.
	Spatial correlation analysis	The relationship between educational expenditure and tuition.	3	

(continued)

Table 4. (continued)

Category	Method	Primary research topics	Published papers	Comments
	Probit model	The relationship between education and the elimination of rural poverty.	2	Spatial regression model
	Multiple linear regression	The factors influencing student performance, school efficiency, and educational performance.	6	Probit model (a type of discrete choice model used to analyze data that respects a normal distribution).
	Quantile regression	The impact of education on different income groups.	1	
	Stochastic frontier analysis	Efficiency in school management.	1	

Note. ANOVA = analysis of variance; ANCOVA = analysis of covariance.

them with the necessary educational resources. In addition to improving social equity, such measures could increase the efficiency of investment in education.

During the growth spurt stage, Chinese education researchers intensified their use of statistical analysis and econometric regression methods. Moreover, younger scholars received improved training in the use of these tools, as statistical analysis and econometric regression methods were included in the compulsory courses for many graduate students in education. In terms of research data, Chinese education scholars took advantage of the household survey data collected by the National Bureau of Statistics. In addition, certain higher education institutions began conducting their own large-scale surveys. For example, in 2003, Renmin University launched the Chinese General Social Survey—the first national, comprehensive, and continuous large-scale social survey project in China. In 2008, Peking University launched the China Family Panel Studies (CFPS). The CFPS sought to reveal socioeconomic, demographic, health, and educational changes in China by collecting data at the individual, family, and community levels. The increased availability of statistical software packages—such as STATA, SPSS, SAS, Eviews, and Matlab—aided scholars in their quantitative research. Furthermore, the number of teachers holding doctoral degrees increased rapidly. These developments improved the ability of Chinese scholars to conduct quantitative research in the field of education.

The Integrated and Diverse Development Stage, 2009–2018

Review of quantitative studies on education in China

Between 2009 and 2018—the fourth decade since the reform and opening-up of China—419 Chinese education research papers used ANOVA. During this period, empirical research tended to combine the use of ANOVA with other quantitative research methods, such as factor analysis and regression analysis. The main research focus of Chinese scholars in the field of education remained the quality of teaching, the academic performance of college students, and mental health.

During this period, 1,047 papers applied correlation analysis. A third of these were published in core journals,¹ and the research focused primarily on college students. Researchers turned their attention to more specific topics. For example, in studying student mental health, researchers explored a number of subtopics, including self-esteem, self-consistency and congruence, self-efficacy, and subjective well-being. A growing number of studies began combining correlation analysis with regression analysis.

Approximately 2,187 empirical studies used factor analysis during this period. Factor analysis was often used in combination with cluster analysis and structural equation modeling. In addition, scholars not only focused on reliability and validity but also began focusing on the questionnaire development process. The research topics of these studies included teaching quality, student satisfaction, and comprehensive evaluation methods.

During this period, 559 papers applied cluster analysis. Additionally, other approaches—such as factor analysis, co-word analysis, multidimensional scaling, word frequency analysis, social network analysis, and data visualization—were applied in conjunction with cluster analysis when analyzing big data. Researchers also expanded their focus to cover new areas and developments. For example, in addition to studying the experiences of college students and the evaluation of higher education institutions, researchers explored topics such as bibliometrics and massive open online courses. Twenty-six papers employed a combination of discriminant analysis, cluster analysis, and factor analysis to investigate problems ranging from mental disorders among college students to occupational orientation and professional learning.

Approximately 219 empirical studies applied regression analysis. The application of regression analysis during this period placed more attention on model construction and researchers began utilizing a larger variety of analysis software packages. Moreover, researchers applied regression analysis in the study of a wider range of subjects, including high school and medical students. Of the collected papers, 57 used a logit model, as well as more targeted models such as sequential logit models and multinomial logit models. The research topics mainly centered on college students, migrant workers, vocational education, students at senior vocational schools, willingness to be an entrepreneur, propensity to invest, medical insurance, and employment.

Applied structural equation modeling and path analysis were used in 219 papers, which covered topics such as the academic achievements and satisfaction of college students, research on college teachers and teenagers, as well as macro research on universities and the informatization of education.

It was not until 2009 that the simultaneous equation model was used in educational research again. Only five papers used this method during this period, exploring topics such as research and innovation teams in higher education institutions, the impact of financial input, as well as the tuition and miscellaneous fees of higher education institutions. Several studies introduced simultaneous equations to the system of building innovation teams in higher education institutions. Multiple equation models were constructed to reflect the interactions between the main influential factors within a particular system.

Neural network models were used in 39 papers. Researchers continued to concentrate on the evaluation and indicator system of higher education institutions. Moreover, principal component analysis (PCA) was used in conjunction with neural networks.

Another 62 empirical studies used DEA. Combined with factor analysis, this method was used to analyze efficiency and performance.

Meanwhile, 83 studies applied finite difference analysis. This method was combined with the propensity score matching (PSM) method to explore topics such as school-enterprise cooperation, the effectiveness of teaching models, and educational fiscal policy.

During this decade, 76 papers adopted instrumental variable methods to solve endogenous problems presented within the studies. Scholars used methods such as quantile regression to analyze the rate of return of education, the relationship between education quality and economic growth, the expansion of enrollment in higher education, and the income gap.

Twenty-five papers employed spatial correlation analysis. Methods such as spatial spillover effect and spatial panel data models were adopted in analyzing the density of manpower inputs in education and regional differences, as well as evaluations of the effectiveness of education expenditure.

Probit models were used in 43 papers. Scholars applied ordered probit models to analyze the quality of employment, motivation of participating in postgraduate entrance exams, personal traits, participation behavior, and investment in education, and so on. Moreover, half of these papers were published in core journals, indicating the application of the method had further development potential.

Among the collected papers, 29 utilized multiple linear regression models for empirical study. The research topics of these papers included migrant children, academic achievements, gender differences, school backgrounds, and student psychology. The majority of these were longitudinal studies.

Eleven papers introduced stochastic production frontier models in the investigation of the effectiveness of higher education.

During this period, 255 papers used panel data, indicating an increased preference for panel data in educational research. Panel data were widely used in research topics such as higher education, economic growth, investment in education, human capital, fiscal expenditure, vocational education, and basic education, becoming an important data form for empirical research.

In 2009, the Tobit model began receiving attention from Chinese education scholars, and 28 papers applying this method were published during this period. The Tobit Model was utilized in combination with DEA to analyze the efficiency of resource allocation in higher education and compulsory education, thereby forming the DEA-Tobit model.

Of the collected papers, 44 applied the quantile regression method. This method was mainly applied in analyzing the rate of return on education, the income gap, and educational differences.

Chinese educational researchers began using fixed effect methods during this period. Such methods appeared in 67 published papers. Fixed effect analysis was mainly used to examine the relationship between higher education and economic growth, human capital and investment in education, as well as fiscal decentralization.

Chinese educational researchers began using PSM models in their research in 2012. During this period, 29 studies applied the PSM method. The main research topics included the rate of return on education under the expansion of higher education, migrant income, “left-behind children” in rural areas, and the effectiveness of various training programs.

The optimal means of conducting empirical causality analysis is the application of random experiments. However, conducting random experiments can be costly and time-consuming. A regression discontinuity design is the next best empirical method and can effectively use real constraints to analyze the causal relationship between variables. When random experiments are not a practical option, applying the regression discontinuity method enables researchers to avoid the endogeneity problem of parameter estimation, thereby better reflecting the causal relationship between variables. Of the collected articles, the first educational research paper that adopted the regression discontinuity method was published in 2014. Thereafter, seven studies utilized the method. Published in core journals, these papers covered research topics such as the impact of educational expansion, the rate of return on education, and school selection processes.

Table 5 summarizes the quantitative research methods that were only found in this period (2009–2018). Although these methods had long been in use elsewhere, they were only meaningfully applied in educational research in China during this period.

Between 2008 and 2018—the fourth decade following the reform and opening-up of China—Chinese education researchers applied the quantitative research methods used in previous periods with increasingly refinement. For instance, the ordered logit (Ologit) model, which is a refined

Table 5. Summary of the application of quantitative research methods, 2009–2018.

Methods	Published	
	papers	Primary research topics
Tobit model	28	The application of the Tobit model was combined with DEA to analyze the resource allocation efficiency of higher education and compulsory education, thereby forming the DEA-Tobit model.
Quantile regression	44	The rate of return on education, income gap, and educational differences.
Fixed effect	67	The relationship between higher education and economic growth, human capital and investment in education, and fiscal decentralization.
Propensity score matching	29	The rate of return on education under the expansion of higher education, the income of the migrant population, “left-behind” children in rural areas, and the effectiveness of various training programs.
Regression discontinuity	7	The impact of educational expansion, the rate of return on education, and school-selection processes.

Note. DEA = data envelopment analysis.

version of the logit model, was utilized during this period. In addition, new research methods—such as quantile regression, multiple linear regression, and PSM—emerged in Chinese educational research, while the causality inference method developed rapidly. Researchers also combined different quantitative methods with increasing frequency. Moreover, with researchers beginning to recognize the benefits of combining various methods, the methods used in each study became more diverse. Table 6 shows the number of published papers that used quantitative research methods during the third (1999–2008) and fourth (2009–2018) decades.

Analysis of representative papers

Chinese research on the capitalization of school quality has continued to develop in recent years. However, these studies have failed to solve the endogeneity issue between school quality and housing prices. Ha and Yu (2017) used quantitative methods to estimate real estate price premiums in certain school districts and examined the value of improving the quality of poor-performing primary schools. Their results demonstrate that average home prices in neighborhoods surrounding poor-performing schools that underwent reform between 2014 and 2016 increased by only 1.2%. In addition, this increase only manifested 1 year after the reforms were announced. However, this price transmission mechanism was more noticeable and occurred more swiftly in the housing prices of properties surrounding the first batch of primary schools that underwent reform, as well as apartments of less than 60 square meters in size. These results suggest that the high-quality

Table 6. Comparison between the number papers using quantitative research published in the third (1999–2008) and fourth (2009–2018) decades.

	Difference	Stochastic					Propensity				
		Instrumental variable	Spatial correlation	Probit models	Multiple linear regression	Stochastic frontier analysis	Tobit models	Quantile regression	Fixed effect	Propensity score matching	Regression discontinuity
The third decade	3	5	3	2	6	1	0	1	0	0	0
The fourth decade	83	76	25	43	29	11	28	44	67	29	7

educational resources generated by economic reform may have been obtained by certain advantaged groups. The findings of this study were valuable in the formulation of policies to promote the balanced development of compulsory education in China (Ha & Yu, 2017). Indeed, the study was granted the “The Second Outstanding Empirical Educational Research Achievements Award” by East China Normal University in October 2018.

During this period, statistical analysis and econometric regression methods were widely applied, while application techniques were further refined. A growing volume of large-scale questionnaire survey data emerged. Scholars also paid greater attention to the scientific nature of sampling methods. Laptops and smartphones became the most important tools in data collection. Meanwhile, new, more powerful software packages became available for statistical analysis—with software packages such as HLM (hierarchical linear model), AMOS (structural equation model), and the R language widely adopted. Finally, the majority of the key universities tended to recruit education professors with experience studying overseas. Moreover, the proportion of professors holding doctoral degrees increased greatly, with all teachers at Peking University and Tsinghua University having obtained PhD degrees.

On January 14, 2017, the heads of educational science schools at 14 universities from across the country, the chief editors of 32 educational research journals, representatives from the National Office for Education Sciences Planning, the Education Research Center of *Guangming Daily*, and the East China Normal University Press gathered at East China Normal University for the Forum on Empirical Educational Research. The forum discussed strategies to accelerate the development and improve the quality of educational research. As noted in the East China Normal University Declaration on Empirical Educational Research (2017), all participants agreed that improving empirical educational research and promoting the transformation of the research paradigm were necessary to improve the quality and influence of educational research in China. They also agreed that quantitative research constituted the most essential aspect of empirical research.

Conclusions and prospects for future research

In the 40 years following the reform and opening-up of China, the development of quantitative research methods in the field of education experienced sustained innovation and progress in numerous areas, including research methods, research data, statistical software packages, research topics, and the use of technology.

1. Research methods: The application of research methods transformed from simple application to extensive application, and from targeted application to the pursuit of rigorous, scientific methods. The statistical analyses applied in educational research between 1978 and 2018 included statistical descriptions, comparison of means testing, ANOVA,

correlation analysis, factor analysis, cluster analysis, to discriminant analysis. The econometric regression used in educational research included multivariate linear regression, categorical dependent variable models (logit and probit models), simultaneous equation models, multiple linear regression, stochastic frontier analysis, and quantile regression models. Moreover, endogeneity of explanatory variables, autocorrelation, and heteroscedasticity, as well as certain specific econometric analysis methods—such as PSM, regression discontinuity, and difference-in-differences—were applied by researchers to resolve issues of selection bias.

Quantitative research methods are diverse and varied, and social phenomena—including education—are complex. Social science research involves attempts to identify and summarize the patterns among complex phenomena, explain phenomena with existing theories, and establish new theories to enable better interpretation. The application of scientific research methods is of great significance in the field of education research. The selection of research methods should fit the research topics. In educational research, the majority of data at the micro level are hierarchical, as students come from different regions, schools, and academic groups. Hierarchical linear models are more suitable for the study of such data. When the research topic involves multiple inputs, outputs, and intermediate variables, a structural equation model is more appropriate. When studying the efficiency of education and its output as a single variable, the stochastic frontier model is appropriate; if the model involves multiple inputs and outputs, DEA is recommended. Meanwhile, when studying topics involving added values, the difference-in-differences model is usually applied. This method is also applicable when evaluating policy interventions (Yue, 2016).

2. Research data: In educational research, a growing amount of micro-survey data has become increasingly useful, as well as increasingly publicized and accessible. Various government and independent university surveys have provided sufficient information for the application of quantitative methods in educational research. These data sources include the *China Educational Finance Statistical Yearbook*, *Educational Statistics Yearbook of China*, *China Statistical Yearbook*, *China Labor Statistics Yearbook*, the door-to-door household surveys conducted by the National Bureau of Statistics of China, and the CFPS conducted by the Institute of Social Science Survey (ISSS) (Peking University). In addition, data from other countries—such as *Education at a Glance: OECD Indicators*, *World Education Indicators*, *Human Development Index*, and *World Development Indicators*—are also accessible and utilized by Chinese educational scholars. Scholars have begun paying closer attention to the representativeness of their sample data. Experimental research and quasi-

experimental research grows in popularity, while the sampling frame of traditional questionnaires becomes more scientific.

3. **Statistical software:** Over the course of 40 years, numerous software packages for statistical analysis were developed—from Excel, SPSS, SAS, STATA, MATLAB, and Eviews, to HLM, AMOS, R, and Python—and the research foundation became increasingly scientific. The scientific nature of the methods also improved, and a growing number of tests were developed to verify the quality of research design, such as reliability, validity, and applicability.
4. **Research topics:** Quantitative research tended to focus on higher education and college students, and approach the investigation from the perspective of learning, achievement, and evaluation; papers on middle and primary education remained limited. Earlier studies predominantly focused on teaching quality and students' classroom behavior and academic achievement. Thereafter, more attention was placed on macro-level factors, such as institutions and regions. Moreover, scholars expanded the scope of their research to cover new topics, including the informal education system.
5. **Development path:** Few empirical studies applied quantitative research methods in the first decade following China's reform and opening-up. The quantitative research methods that were used tended to be simple, with papers introducing the principles and theories of quantitative research methods. In the second decade, empirical papers using quantitative research methods increased significantly, although the methods used tended to be classical models. The coverage of research subjects began to expand, and the research topics started becoming more specific. Combining various methods became increasingly common in the third decade as researchers began recognizing the benefits of doing so. Methods that were scientific, practical, and highly scalable developed rapidly and the number of corresponding studies increased significantly. The research methods adopted during the fourth decade were more specific and targeted. During this period, an increasing number of studies began applying new research methods—such as quantile regression, multiple linear regression, and PSM—and the causality inference method developed rapidly. Combining various methods also became increasingly common, while the methods used became more diverse.
6. **Technology:** Chinese quantitative research in education has undergone significant technological changes since 1978. The rapid development of science and technology during this period created superior conditions for the development of educational research. More specifically, computer technology evolved rapidly in the first decade, while the second decade witnessed the growth of the Internet. There was a marked leap forward during the third decade with the development of smartphones, while the fourth decade saw the development of artificial intelligence. The advancement of information technology provided

unprecedented convenience and opportunities in regard to data surveys and big data acquisition for quantitative educational research.

Technological advancement has strongly influenced the development, utilization, and results of quantitative methods over the past four decades—and will continue to do so in the future. Looking ahead, with the rapid development of information technologies—such as the Internet, cloud computing, Internet of things, and artificial intelligence—big data are expected to become one of the main means of production on a level comparable to that of land, capital, and labor, and will provide richer and more extensive resources for educational research. Teachers can use big data and artificial intelligence technology to improve learning behavior. To be more specific, educational big data can record the learning processes of students throughout their life, from preschool to tertiary education, and even lifelong education. Artificial intelligence technology can be adopted to guide, supervise, and evaluate learning plans, statuses, and results. Big data and artificial intelligence are both necessary and favorable tools for quantitative researchers to improve efficiency and promote fairness in education.

However, despite the numerous development opportunities for educational research, certain challenges remain unaddressed. Various issues require further investigation, including methods to stimulate the interest and enthusiasm of students in learning, as well as the means of identifying valuable teaching resources in the massive—and growing—amount of data. Issues pertaining to accountability for the collecting, organizing, storing, and provision of educational big data also require attention, as do those concerning the utilization of artificial intelligence for deep mining and big data method innovation. As such, although data- and evidence-based educational quantitative research methods are important, other educational research methods should not be ignored.

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Note

1. Core journals refer to journals in the list of “Chinese Core Journals Overview.” It was an evaluation list including 1,800 selected core journals, which belong to seven major disciplines and 75 subject categories.

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