Measuring the Efficiency of High-Quality Development in the Yangtze River Basin: A DEA-SBM Approach and Convergence Analysis

Thesis booklet

CHEN RURONG

Budapest University of Economics and Business

Doctoral School of Entrepreneurship and Business

BUEB

Supervisor: Prof. Dr. Miklós Losoncz

Budapest

2025

1.Introduction

In the international setting that has manifested itself over the course of the past few years, the shift to a new development trajectory takes place. Inter alia, major external challenges arising from global trends include the Covid-19 pandemic, trade wars, the weakening of the rules-based world order, and various aspects of globalization in the short term. In the long term, these challenges include environmental, climate, and demographic issues, digitization, the development of artificial intelligence (AI), and the future of global value chains (GVC). A wide range of external factors are having an effect on China's transition: some of these factors support it and others make its situation more difficult. Both elements influence China's change in some ways. This change also raises questions about domestic regional economic growth. By looking into the problems that have been identified, new ideas for scientific studies can be generated with both theoretical and practical effects. The main job of economic policy makers is to change China into a high-quality economy defined by five elements: (1) sustainability, (2) innovation, (3) efficiency, (4) stability and (5) coordination while they are addressing the present issues and support long-term, sustainable economic development (Pacetti, 2016). Using innovation to increase economic efficiency and production while preventing irreversible damage to the environment and natural resources, securing regional coherence, and building regional links are an essential component of a high-quality economy (Li & Yi, 2020).

This dissertation aims to examine China's transition from the extensive growth model based on the quantity of labour and capital into the intensive growth trajectory based on new drivers such as R&D, innovation, and human capital accumulation from a regional perspective on the example of the Yangtze River Basin (YRB). The area's economic significance crated varied industrial environment, and policy-driven expansion initiatives make the area a suitable contender for thorough economic debate.

The focus of this thesis is China's evolving development path or growth model. China is facing several short- and long-term issues, including real estate market and financial system tensions, an ageing population, falling birth rates, major environmental concerns, strong global technology competition, and decelerating GDP growth. This situation serves as the starting point for defining the problem. From a larger viewpoint, the main causes of these difficulties are the depletion of the past driving forces of GDP development, including a cheap unskilled or semiskilled labour force, cheap fuels and raw materials and large investments in conventional heavy industries. These difficulties require a shift from an extensive economic development model based on quantitative elements of GDP growth, such as the simple quantity of labour and capital, to an intensive development model that depends on qualitative elements, such as research, development and innovation (R+D+I), highly skilled human capital (knowledge-based economy), and economic structure upgrading with less regional disparity and income inequality (Losoncz, 2017).

The general research question is: to what extent has China accomplished the transition to a sustainable and innovative economy stage-by-stage, using the example of the YRB region? The specific research questions are as follows: (1) Which role have innovation, technology, labour, and welfare resources played in driving high-quality development? (2) What are the regional differences in high-quality efficiency among provinces between and within the western, middle and eastern regions in the YRB? (3) Have the provinces in the YRB achieved alpha (α) convergence? Has the disparity in high-quality economic efficiency been diminishing? (4) Has the economic expansion in the YRB been consistent with the beta (β) convergence hypothesis? Have less developed regions achieved a more rapid growth rate?

The main original methodological contribution of this dissertation to the current body of knowledge is combining an input-output model with the PCA-SBM framework to assess the transition of the examined region into to a high-quality growth path. An extensive analysis of panel data from twelve provinces between 2012 and 2021 was conducted to investigate dynamic changes through a convergence analysis. Previous studies in regional economic development research have extensively examined regional efficiency and convergence trends through several modelling techniques. However, significant deficiencies remain in the research findings, providing an opportunity to apply the DEA-SBM-Beta model in relation to the 14th Five-Year Plan indicators to enhance regional analysis.

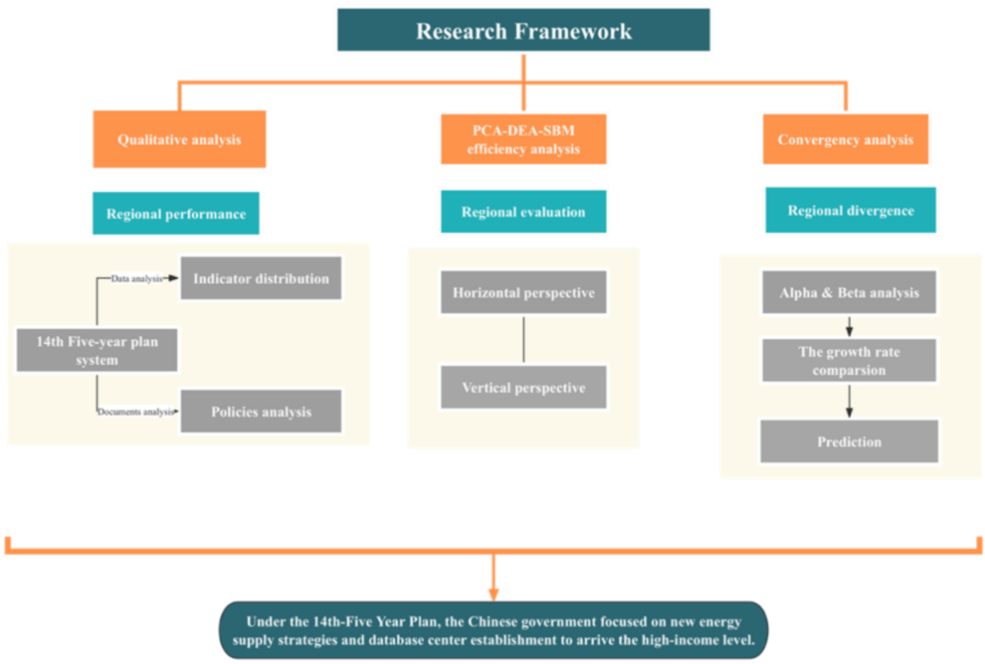
The theoretical development and the methodological innovation of this study open the door for further research on regional efficiency evaluation while providing a strong scientific basis for the YRB's superior growth. In addition to addressing gaps in the literature on the application of both static and dynamic analysis, it provides a transparent methodological template for cross-regional economic research by illustrating the efficiency growth trajectory over the past ten years. Understanding the efficacy of China's regional coordinated development policy is made easier with the use of this study paradigm, which combines dynamic growth tracking with static efficiency diagnostic.

2. Research design and methods

2.1 Methodological design

This dissertation investigates economic efficiency and convergence trends using both qualitative and quantitative approaches. Background information is taken into account in qualitative analysis. Using government resources on public sites, the dissertation will contrast the 14th FYP with its predecessors. Making comparisons between documents is a crucial part of qualitative analysis. The quantitative approach emphasizes mostly measuring the degree of economic development through the evaluation system utilizing secondary data. Serving as a basic viewpoint for economic transformation, a combined analytical method offers a more thorough examination of the interaction between economic theories and actual economic dynamics. Qualitative and quantitative studies in my thesis work together to form a mutually supportive system that improves the evaluation of China's present economic developments. The following four hypotheses, which were developed from the literature research and the conceptual framework, serve as the foundation for the analysis in Figure 1:

Figure 1: The logic of research



Source: Own work based on a literature review.

The methodological design is presented in Figure 1. The analysis is based on the following four hypotheses, which were derived from the literature review and the conceptual framework:

Hypothesis 1: The eastern regions of the YRB consistently demonstrate higher average values of total efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE) than the central and western regions.

Hypothesis 2: The eastern regions of the YRB benefit more from technological advancements, skilled labour, and welfare resources than the western regions, leading to significantly higher values in TE, PTE, and SE.

Hypothesis 3: The gap in high-quality efficiency between provinces has shown a declining trend over time, which is consistent with the β-convergence hypothesis.

Hypothesis 4: Improvements in scale efficiency are more strongly associated with overall efficiency convergence compared to improvements in pure technical efficiency.

In this dissertation, we use the non-oriented SBM model, which is designed to deal with undesirable outcomes. Tone describes the non-oriented SBM model (Tone, 2015). Tone modifies the SBM model to explicitly include undesirable outcomes. This means that efficiency statistics consider how successfully a DMU uses its inputs to produce desired outcomes and how it deals with undesirable outcomes. For example, the model can consider pollution levels and resource efficiency in environmental applications.

Furthermore, a non-oriented SBM can detect and evaluate efficiency by simultaneously considering improvements in inputs and outputs rather than focusing solely on one direction. As a first step in our analysis, we applied the standard SBM model to provide a general overview of the efficiency distribution among DMUs. The standard DEA model determines efficiency by comparing inputs and outputs. Efficient DMUs receive a score of $\theta = 1$, indicating full efficiency, while inefficient DMUs receive less than one. However, in other circumstances, all effective DMUs receive the same efficiency score of one, making it difficult to discern between highly efficient DMUs (See in the table 1).

Table 1: The design of the indicators

Group	Indicators	Name	Name in the models
Input	R&D spending of industrial enterprises above the scale (10000 yuan)	x1	**PC1:In1** **PC2:In2** **PC3: In3**
	The number of domestic invention patent applications received (items)	x2	
	Overall grain production capacity (hundreds of million tons)	x3	
	Number of certified (assistance) doctors (1,000 persons)	x4	
	Number of urban and rural residents' social old-age insurance participants (10,000)	x5	
	Average number of nursery school students per 100,000 population (persons)	x6	
	Revenue from software business (100 million yuan)	x7	
	Disposable income growth per capita (%)	x8	
	Surveyed urban unemployment (1000 person)	x9	
Output	Reginal gross domestic products (CNY 100 million)	y1	**Ou1**
	Workforce productivity (Yuan/1 person)	y2	**Ou2**
	Urbanization rate (%)	y3	**Ou3**
	Days of air quality equal to or above grade II (day)	y4	**Ou4**
	Forest coverage rate	y5	**Ou5**
Undesired output	Emission of exhaust gas (10,000 tons)	z1	**Undesired output**

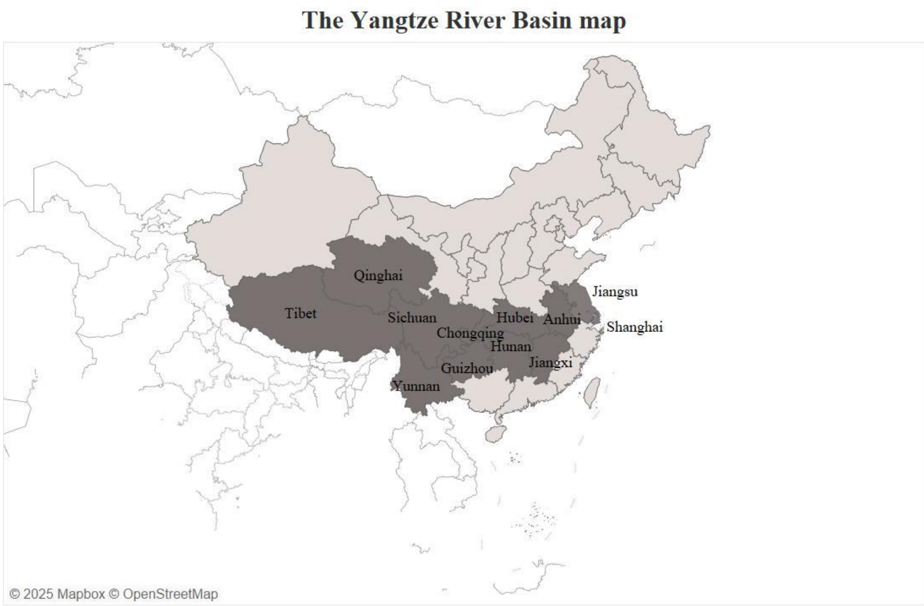
Source: Own work based on the review of relevant literature.

2.2 Data collection

The dissertation examines China's shift to a high-quality growth model, utilizing the Yangtze River Basin (YRB) as a case study. The map below illustrates the YRB's location in China. The subsequent factors substantiate this decision: (1) The region comprises some of China's most economically vibrant provinces, including Shanghai, Wuhan, and Chongqing. (2) The coastal region is essential to China's regional economic development, extending from the west to the east and encompassing 40% of the nation's people and GDP within 20% of its territory. The GDP and industrial output of China are significantly affected by economic developments in the YRB, providing a framework for analysing various policy-related, social, environmental, and economic issues. Considering the region's economic importance, diversity, and continuous growth efforts, it is a suitable subject for comprehensive economic and development policy evaluations (See in Figure 2). Consequently, inferences can likewise be made regarding the Chinese economy.

Regional statistics offices are tasked with the collection and organization of information across several industries, a responsibility that individual researchers cannot do. The primary source of information utilized in this thesis is derived from databases managed by the National Bureau of Statistics (NBS) and the China Stock Market & Accounting Research Institution (CSMAR). The economic efficiency data are sourced from the NBS database, while the macro-regional data from 2012 to 2021 is derived from provincial statistical yearbooks. The indicators of the 14th Five-Year Plan serve as measurement instruments.

Figure 2: The Yangtze River Basin map



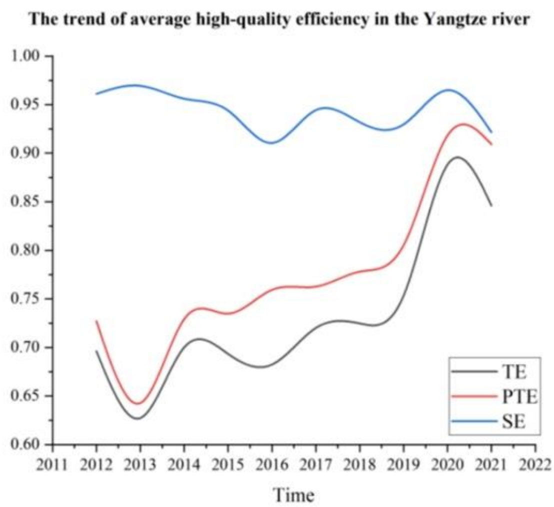
Source: Own work based on the regional map of China

3. Main results

3.1. The efficiency comparison

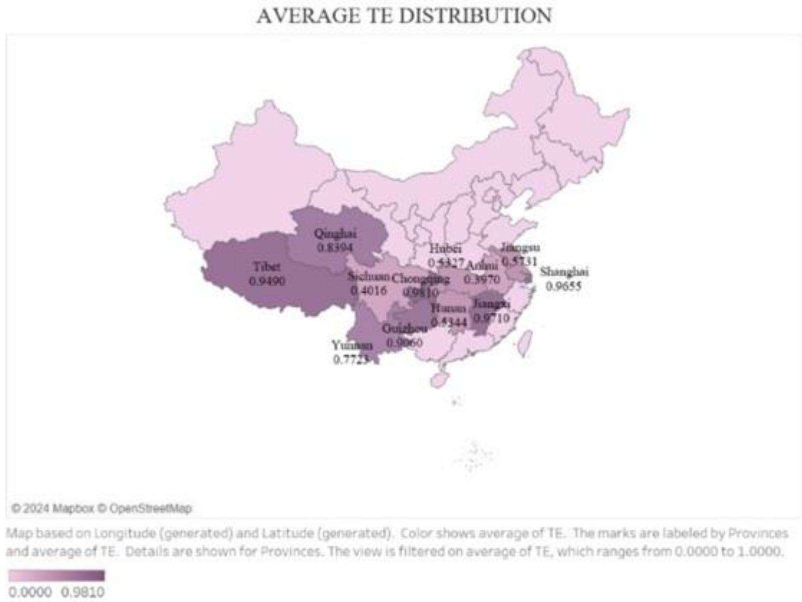
From 2014 to 2019, the economic efficiency of China's provinces increased. Efficiency dropped in 2013, peaked in 2020, and then fell. Quality efficiency (technical economic efficiency) rose during 2011-2021. Similar trends in pure technical economic efficiency suggest that government management and resource allocation boosted it. Input scale and structure were good, and scale growth helped (Figure 3). Scale efficiency was 0.9–1 from 2012–2021. Province efficiency numbers were decomposed using accounting. The Origin 2021 software plotted 2012–2021 province-specific efficiency averages. Sichuan and Hubei Provinces, the eastern and central regions' strengths, score lower for technical efficiency than GDP production output distribution in high-quality efficiency (TE) analysis. GDP and other gross product indices have traditionally assessed economic development (Rahman et al., 2017), but environmental degradation from rapid economic expansion is increasingly more relevant. Thus, western China's main local development province, Sichuan, and China's hinterland, Hubei, must strengthen pollution management. Economic efficiency helps Chongqing attain GDP and government-controlled environmental protection (Figure 4). Consistent with the pattern of high-quality economic efficiency （TE）, pure technical efficiency (PTE) also varies markedly between the eastern and western regions. Sichuan, Hubei, and Jiangsu, with heavy industry and vast mineral reserves, release pollutants, reducing technical efficiency (Figure 5). Regional differences in scale efficiency (SE), which evaluates resource inputs' impact on policy efficiency, are smaller than in the other two regions. In 2021, Qinghai, Tibet, Chongqing, Hunan, Jiangxi, Jiangsu, and Shanghai achieved a scale efficiency score of 1. These provinces-maintained scale efficiency (acceptable input magnitude and organization). The remaining provinces' scale efficiency dropped, indicating that policy output increases were smaller than input increases and that policy implementation must improve (Figure 6).

Figure 3: Trend of average high-quality efficiency in the YRB region



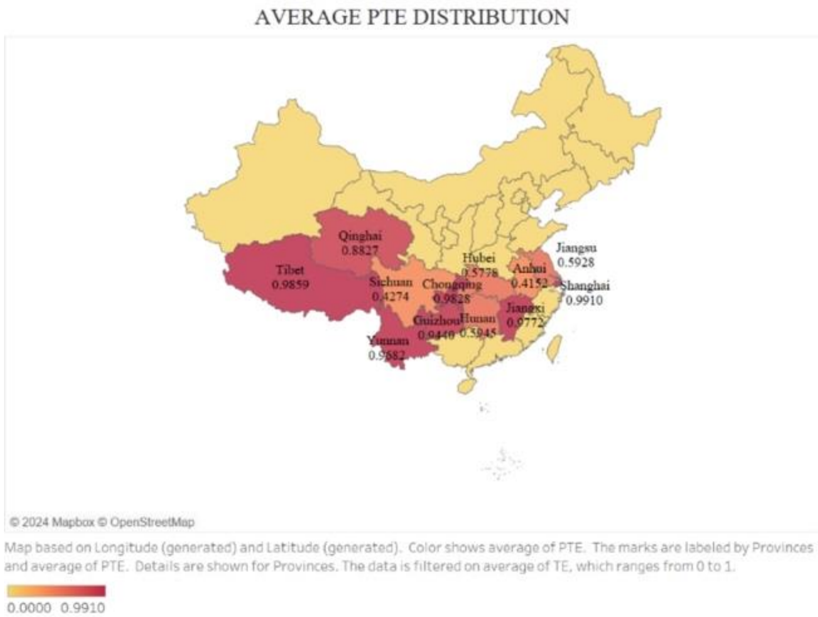
Source: Authors' construction based on the model results.

Figure 4: Average high-quality technical efficiency (TE) distribution in the YRB region



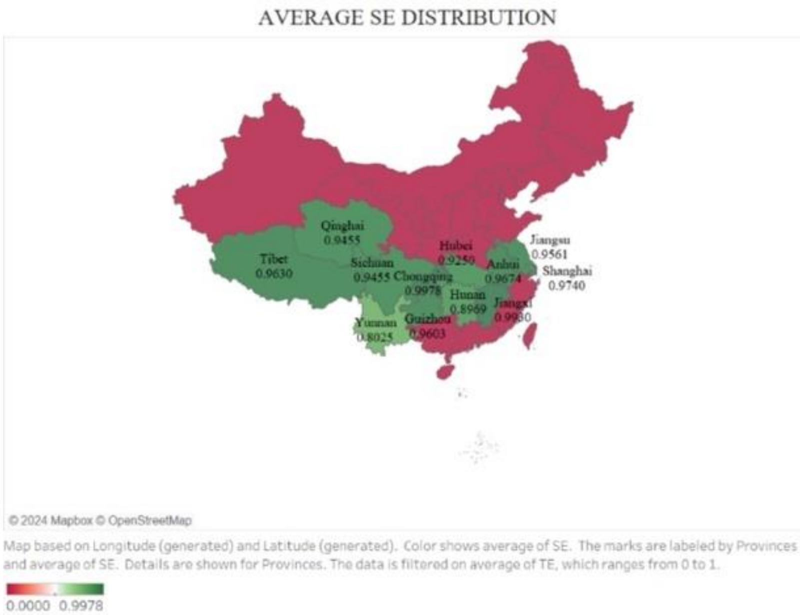
Source: Authors' construction using Tableau software.

Figure 5: Average pure technical efficiency (PTE) distribution in the YRB region



Source: Authors' construction using Tableau software.

Figure 6: Average scale efficiency (SE) distribution in the Yangtze River region



Source: Authors' construction using Tableau software.

Efficiency improvement in the YRB follows a cyclical pattern of "policy-driven → structural adjustment → technological deepening" over 3-4 years. Policy interventions often enhance short-term efficiency while structural changes slow scale efficiency until long-term technology advances. Complete technological efficiency peaked in 2013, at 13%. Before the 2014 Yangtze River Economic Belt program, infrastructure and technology investments propelled growth. Scale efficiency dropped, indicating a temporary capital-labour misallocation.

Table 2: Cyclical phases and volatility patterns

Cycle Phase	Years	TE Growth	PTE Growth	SE Growth	Driving Mechanism
Recovery	2012–2013	-10.46% → +13.99% (V-shaped)	-11.28% → +15.70% (synchronous)	+1.50% → -1.35% (reverse adjustment)	Policy-driven (pre-Yangtze Economic Belt strategy)
Adjustment	2014–2015	Peaked at +0.70%	Surged to +4.20%	Sustained decline (-1.07%→-3.44%)	Structural transformation (supply-side reforms)
Expansion	2016–2019	Rose to +19.33% (peak)	Fluctuated to +14.71%	Recovered (+4.62%→+3.52%)	Technology deepening (ecological constraints)
Contraction	2020-2021	Plummeted to -4.27%	Slight decline (-0.41%)	Collapsed (-4.37%)	Exogenous shock (COVID-19 pandemic)

Source: Own work based on the PCA-SBM data.

In 2015, supply-side structural improvements to improve technology and remove outmoded industrial capacity increased pure technical efficiency (+4.20%). By 2016, environmental checks accelerated wasteful industrial capacity elimination and resource allocation, enhancing scale efficiency (+4.62%). COVID-19 supplier disruptions impacted YRB efficiency growth in 2020. Technical and scale efficiency fell 4.27% and 4.37%, respectively, causing severe economic damage. Technological and management robustness was indicated by pure technical efficiency falling 0.41% (Table 2).

3.2 Redundancy and output deficiencies analysis

Redundancy analysis uses the difference between desired and actual input values to maximize efficiency (Ul Hassan Shah et al., 2024). We performed an input redundancy analysis utilizing 2012–2021 data to discover ecological input improvements, notably for DEA-inefficient provinces.

Table 3: Input slack value and redundancy rate in 2021 by region

District	Provinces	Slack_In1	Redundancy rate (%)	Slack_In2	Redundancy rate (%)	Slack_In3	Redundancy rate (%)
Western region	Qinghai	0	0	0	0	0	0
	Tibet	0	0	0	0	0	0
	Sichuan	0.14	21.19	0.51	55.67	0.11	18.64
	Yunnan	0	0	0.02	2.69	0.13	35.61
	Chongqing	0	0	0	0	0	0
	Guizhou	0.01	2.78	0.15	17.37	0.06	29.76
Average		0.02	3.99	0.11	12.62	0.05	14
Central region	Hubei	0.03	5.28	0.36	44.44	0.15	25.63
	Hunan	0	0	0	0	0	0
	Jiangxi	0	0	0	0	0	0
Average		0.01	1.76	0.12	14.81	0.051	8.54
Eastern region	Anhui	0.1	19.47	0.59	65.53	0.04	8.87
	Jiangsu	0	0	0	0	0	0
	Shanghai	0	0	0	0	0	0
Average		0.03	0.06	0.2	0.22	0.01	0.03

Source: Authors' calculations based on model results.

Table 4: Output slack value and redundancy rate in 2021 by region

District	Provinces	slack_Ou1	Redundancy rate (%)	Slack_Ou2	Redundancy rate (%)	slack_Ou3	Redundancy rate (%)	slack_Ou4	Redundancy rate (%)	Slack_Ou5	Redundancy rate (%)
Western region	Qinghai	0	0	0	0	0	0	0	0	0	0
	Tibet	0	0	0	0	0	0	0	0	0	0
	Sichuan	0	0	342938.23	125.22	72.41	83.93	251.21	0	0	23.42
	Yunnan	0	0	35833.4	48.18	24.59	24.67	88.23	0	0	15.39
	Chongqing	0	0	0	0	0	0	0	0	0	0
	Guizhou	0	0	1872.47	7.17	3.89	0	0	0	0	0
Average		0	0	63440.69	30.1	16.82	18.1	56.57	0	0	6.47
Central region	Hubei	0	0	150727.25	91.05	58.34	83.18	239.83	0	0	0
	Hunan	0	0	0	0	0	0	0	0	0	0
	Jiangxi	0	0	0	0	0	0	0	0	0	0
Average		0	0	50242.42	30.35	19.45	27.73	79.94	0	0	0
Eastern region	Anhui	0	0	0	74.61	44.32	38.91	122.13	3.73	1.07	37.42
	Jiangsu	0	0	0	0	0	0	0	0	0	0
	Shanghai	0	0	0	0	0	0	0	0	0	0
Average		0	0	0	24.87	14.77	12.97	40.71	1.24	0.36	12.47

Source: Authors' calculations based on model results.

The slack value is the amount of surplus output or input that will not affect the ideal solution, and the standard calculation method is to divide the original data value to calculate input redundancy and relative rate (Tone, 2002). Slack is divided by input quantity to calculate input redundancy rates and output quantity to calculate output deficiency rates (Podinovski, 2004). Science, technology, human, and welfare resources are represented by Slack_ln1&2&3 in the PCA. Sichuan Province may use 21.2% more Slack_ln1 (science and technology resources) (Table 3).

Research and development investments, patents, and medical certificates affect PCs, thus the Sichuan government should restructure them. Next, Anhui Province has to enhance 19.5% of utilization. According to Slack_ln2 distribution, Hubei (0.36), Sichuan (0.51), and Anhui (0.59) must enhance labour resource efficiency. To attract and employ talent better, these provinces should reform talent recruiting policies, and many businesses should improve talent leveraging and promotion. Hubei and Guizhou could improve Slack_ln3 by 30%, but Yunnan requires the biggest improvement with 35% of its welfare resources misapplied. (See Table 4.)

An economy's output of commodities and services falls short of potential (Li et al., 2007). This often leads to resource underutilization, unemployment, and slower economic progress. The eastern region has similar employment and urbanization to the central and western regions, but the latter have more possibility for improvement. GDP numbers show no output shortfalls. Labour productivity output (Slack_Ou2) can rise 30.0% and urbanization rate 18.1%. The central region can boost labour productivity output (Slack_Ou2) by 30.4% and urbanization rate (Slack_Ou3) by 27.7%. The eastern region can complete 1.24% and 12.47% more work than the central and western regions by increasing the number of days when air quality is grade II (day) (Slack_Ou4) and forest coverage (Slack_Ou5).

3.3 Alpha (α) convergence analysis

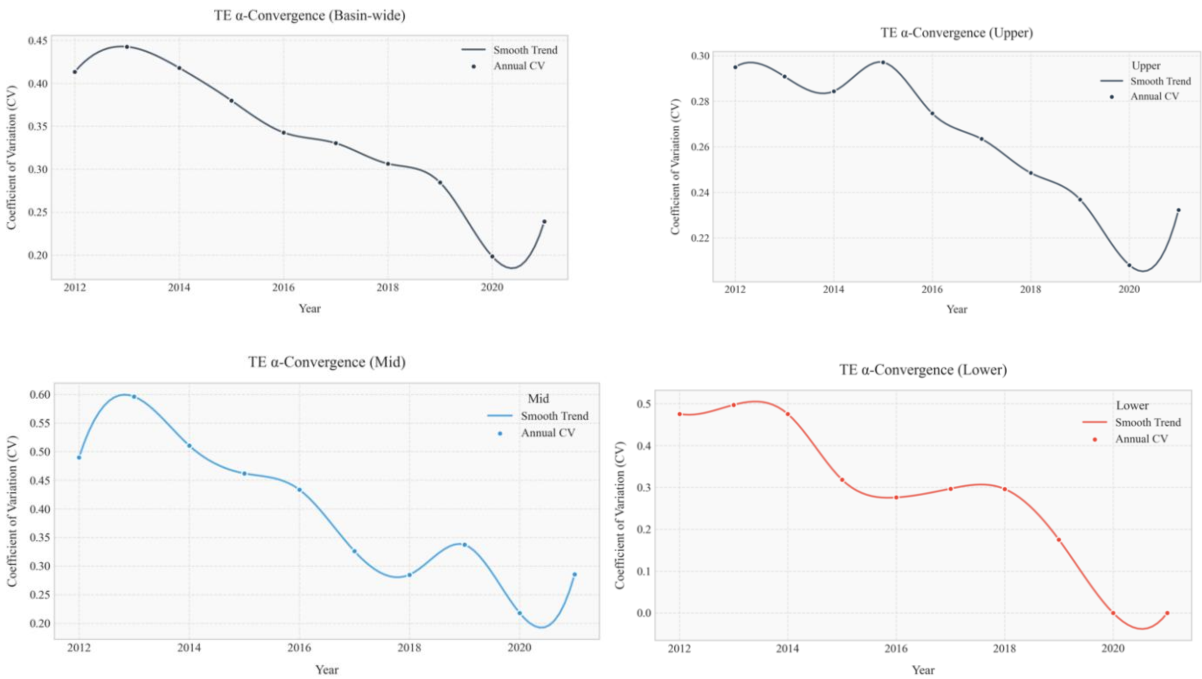
From 2012 to 2021, the TE α-Convergence (Basin-wide) shows significant changes in the technical efficiency coefficient of variation (CV) in the YRB (Figure 7). Technical efficiency varied widely across the basin in 2012, with a coefficient of variation of 0.42. CV declined over time. A brief recovery in 2021 did not change the pattern of decreasing dispersion. The data suggests α-convergence in technical efficiency among YRB regions. This illustrates that Sichuan and Anhui, which had low technical efficiency, converged with Shanghai and Chongqing through technology transfer and resource allocation.

Technical efficiency convergence varies throughout Qinghai, Tibet, Sichuan, Yunnan, Chongqing, and Guizhou. The upper-reach regions' technical efficiency coefficient of variation was 0.29 in 2012, lower than the basin-wide average, which indicates an early difference. The coefficient of variance decreased from 2012 to 2020, reaching a lowest point in 2020, demonstrating narrowing technological efficiency gaps and convergence in upper-reach areas. The CV rebounded modestly in 2021. Industrial structural changes in upstream provinces and external technology input may have disrupted convergence. Long-term convergence is constant.

Technological efficiency convergence in Anhui, Jiangxi, Hubei, and Hunan is a major trend. In 2012, the middle reaches coefficient of variation was 0.49 due to regional technical efficiency variations. After that, it plunged to a 2020 low and convergence trend. Such performance can be attributed to effective technological cooperation and the coordinated development of intermediate industries. Provincial technical inefficiency can be improved by interregional technical exchanges, resource sharing, and policy cooperation. High technical efficiency convergence in the region leads to the best α-convergence effect in the YRB.

Technical efficiency convergence is fastest in lower-stream provinces like Shanghai and Jiangsu. In 2012, lower TE CV was 0.48, equal to base level. In 2020, the CV plummeted to an exceedingly low value. Rapid convergence of the lower reaches drives its economy and technology. Economic growth and technical innovation are strong in Jiangsu and Shanghai. Both economic structures and technical R&Ds are similar. In the YRB, the region has the fastest α-convergence of technical efficiency due to frequent exchanges and few obstacles, reducing dispersion quickly.

Figure 4: Alpha convergence analysis



Source: Own work & Python.

3.4 Beta convergence analysis

(1) The absolute beta

The absolute beta convergence model's most important explanatory variable is initial technological efficiency (TE_initial), whereas the dependent variable is growth rate. The model fitting results in Figure 8 show that initial technical efficiency accounts for 4.6% of technical efficiency growth rate variation with an R-squared of 0.046 and an adjusted R-squared of 0.037. The model may have excluded key variables due to its low explanatory power.

Model significance is adequate with a probability of 0.0253 and an F-statistic of 5.148. In the hypothetical scenario of zero beginning technical efficiency, the constant term coefficient is 0.1282 (t = 3.108, P = 0.002), demonstrating a substantial upward trend in technical efficiency growth. This shows a technical advancement energy in the economy. The negative coefficient of initial technical efficiency (TE_initial) was -0.1242 (t = -2.269, P = 0.025), which matches absolute beta convergence expectations. The "catch-up effect," which states that less developed regions tend to expand more quickly and progressively close the efficiency gap with more advanced regions, is confirmed by this conclusion, which suggests that places with higher initial technical efficiency are likely to exhibit lower technical efficiency growth rates.

Figure 5: The absolute beta convergence results

```
Absolute Beta Convergence Results:
                            OLS Regression Results
==============================================================================
Dep. Variable:              TE_growth   R-squared:                       0.046
Model:                            OLS   Adj. R-squared:                  0.037
Method:             Least Squares   F-statistic:                     5.148
Date:             Fri, 14 Mar 2025   Prob (F-statistic):             0.0253
Time:                       10:10:08   Log-Likelihood:                 43.198
No. Observations:                108   AIC:                            -82.40
Df Residuals:                    106   BIC:                            -77.03
Df Model:                          1
Covariance Type:           nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
const          0.1282      0.041      3.108      0.002       0.046       0.210
TE_initial    -0.1242      0.055     -2.269      0.025      -0.233      -0.016
==============================================================================
Omnibus:                      36.543   Durbin-Watson:                   1.484
Prob(Omnibus):                 0.000   Jarque-Bera (JB):              120.042
Skew:                          1.125   Prob(JB):                     8.57e-27
Kurtosis:                      7.649   Cond. No.                         5.26
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
```

Source: Own work & Python.

(2) The relative beta

Figure 9 summarizes the regression results for conditional β-convergence in technical efficiency (TE). Across all model formulations, we have identified evidence that supports the convergence theory.

In the entire sample model, the estimated coefficient of the lagged log technical efficiency is negative and statistically significant ($\beta = -0.1073$, $p < 0.05$), which indicates that provinces with lower initial technical efficiency tend to have higher TE growth rates over the studied period. The suggested speed of convergence is 11.35 percent, which is in line with what other empirical studies of regional productivity convergence in China have found (Zhuang et al., 2022) (Liang & Xu, 2022).

There are noticeable differences when the sample is split into pre-2016 and post-2016 periods. Before 2016, the convergence coefficient was negative but statistically insignificant (β = -0.1005, p = 0.199), indicating negligible catch-up effects during this period. Following the adoption of new industrial upgrading strategies and environmental restrictions in 2016, the coefficient became more negative and significant (β = -0.1372, p = 0.016), and the convergence rate increased to 14.76%. This trend lends credence to the hypothesis that policy modifications have had an impact on convergence dynamics (Figure 10).

The models provide moderate but acceptable explanatory power (adjusted R^2 ranging from 6.7% to 15.2%) for efficiency in the regional panel data. According to Battese and Coelli (Battese & Coelli, 1995), unobservable factors impacting technological adoption and managerial practices often lead to modest R^2 values in similar investigations.

In terms of control variables, the calculated impacts provide additional insight into the factors of efficiency convergence: C1 (Trade Openness): The coefficient is largely insignificant, showing that increased trade openness does not systematically accelerate efficiency convergence in the sample provinces. Based on this conclusion, it appears that merely expanding export-import flows without implementing complementary industrial strategy may not be adequate to increase efficiency. C2 (Industrial Structure Level): In most specifications, this variable has no strong correlation with TE convergence. Updating structures is important, but this finding shows that it might take some time and help from institutions to make a real difference in how well they work. C3 (Consumer Price Index): A significant negative effect was detected prior to 2016, showing that inflationary pressures could undercut efficiency gains by increasing manufacturing costs and lowering reinvestment capacity. C4 (Log Foreign Investment): Since 2016, this variable has shown positive relationships with TE growth, implying that foreign investment flows may have aided technological diffusion and learning effects. C5 (Log Value Added of Financial Sector): The coefficients are generally insignificant, which could indicate that the aggregate size of the financial sector does not directly influence firms' access to credit. This emphasizes the importance of financial inclusion and targeted financing instruments.

While certain coefficients are not statistically significant, their inclusion is supported by theoretical considerations and their contribution to minimizing omitted variable bias (Chen & Xu, 2024). Future study could improve model fit and address endogeneity by including more control variables (e.g., human capital indicators, environmental regulations) and investigating dynamic panel estimators such System GMM.

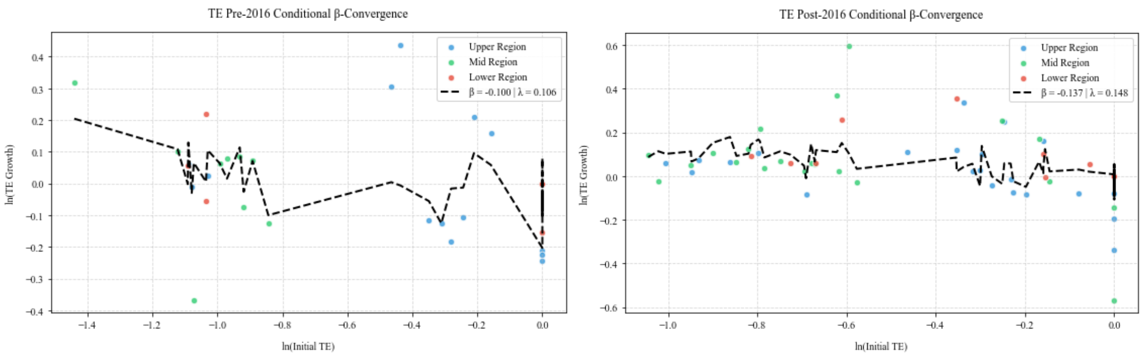
Figure 6: The relative beta convergence results

```
--- TE Full Sample Conditional β-Convergence Results ---
                            OLS Regression Results
==============================================================================
Dep. Variable:            growth_rate   R-squared:                       0.120
Model:                            OLS   Adj. R-squared:                  0.067
Method:                 Least Squares   F-statistic:                     2.290
Date:                Mon, 14 Jul 2025   Prob (F-statistic):             0.0410
Time:                        16:34:37   Log-Likelihood:                 55.593
No. Observations:                 108   AIC:                            -97.19
Df Residuals:                     101   BIC:                            -78.41
Df Model:                           6
Covariance Type:            nonrobust
==============================================================================
                 coef    std err          t      P>|t|      [0.025      0.975]
------------------------------------------------------------------------------
const         -2.8572      2.117     -1.349      0.180      -7.058       1.343
ln_te_lag     -0.1073      0.043     -2.506      0.014      -0.192      -0.022
C1            -0.1302      0.107     -1.223      0.224      -0.342       0.081
C2             0.4461      0.310      1.440      0.153      -0.168       1.060
C3             0.0239      0.020      1.175      0.243      -0.016       0.064
C4             0.0246      0.046      0.535      0.594      -0.067       0.116
C5            -0.0102      0.063     -0.162      0.872      -0.135       0.115
==============================================================================
Omnibus:                       12.951   Durbin-Watson:                   2.318
Prob(Omnibus):                  0.002   Jarque-Bera (JB):               41.533
Skew:                           0.082   Prob(JB):                     9.58e-10
Kurtosis:                       6.034   Cond. No.                     1.51e+04
==============================================================================

Notes:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
[2] The condition number is large, 1.51e+04. This might indicate that there are
strong multicollinearity or other numerical problems.
```

Source: Own work & Python.

Figure 7: TE pre & post 2016 Conditional Beta Convergence



Source: Own work & Python

4. The main theses of the dissertation

Thesis 1: ***There exists a persistent spatial hierarchy in high-quality development efficiency across the Yangtze River Basin.***

Empirical results confirm that eastern provinces consistently outperform central and western counterparts in total efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE). This outcome reflects differentiated development foundations, institutional environments, and factor endowments. *This thesis is supported by (Losoncz & Chen, 2025).*

Thesis 2：*Regional disparities in efficiency are primarily driven by the uneven distribution of innovation, human capital, and welfare resources.*

The eastern sub-region benefits from a concentration of technological capabilities and skilled labour, forming a spatial "technology spillover gradient" that enhances overall efficiency performance. *This thesis is supported by (Chen, 2022).*

Thesis 3：β-convergence in high-quality development efficiency is observed across provinces in the YRB.

Provinces with initially lower efficiency levels demonstrate faster improvement over time. This trend indicates that interprovincial efficiency gaps are narrowing, driven largely by scale adjustment and structural optimization.

Thesis 4：Improvements in scale efficiency contribute more significantly to convergence than enhancements in pure technical efficiency.

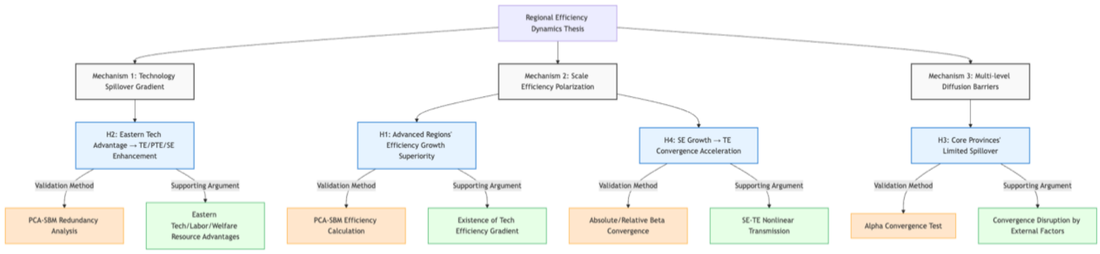
Scale efficiency acts as the main mechanism promoting boundary reshaping and catch-up growth. Its role in explaining overall TE convergence surpasses that of PTE, especially under the context of differentiated industrial structures and spatial constraints. Thesis 3 and Thesis 4 are supported by (Chen, 2023) and (Chen et al., 2023).

5. Conclusions, scientifically new results, limitations and future research directions

The dissertation analysed the dynamics of regional efficiency in the Yangtze River Delta, and centred around three interconnected mechanisms to validate and elucidate the research hypotheses. Figure 10 describes the dissertation's statement logic.

Mechanism 1 refers to the technology spillover gradient. In the context of Hypothesis 2, the thesis examined the "technology spillover gradient effect" in the eastern YRD region. This effect results from the agglomeration of technological innovation resources, as such agglomeration facilitates knowledge spillovers, resource sharing, and improved collaboration, thereby enhancing overall efficiency, pure technical efficiency, and scale efficiency. This reveals the spatial hierarchical law of technical factor flows.

Figure 8: Thesis statement logic



Source: Own work based on the former chapters of the thesis.

Mechanism 2 explains the polarization of scale efficiency. By integrating the insights from Hypotheses 1 and 4, it has been revealed that the developed regions in Hypothesis 1 owe their superior performance to favourable factor endowments, industrial synergy advantages, as well as their leadership in the growth rates of total efficiency, pure technical efficiency, and scale efficiency. On the other hand, the analysis concerning Hypothesis 4 analyses how scale efficiency growth accelerates the convergence of total efficiency (TE). Alternatively, with reference to Hypothesis 4, the assertion that ‘the logic of scale efficiency (SE) growth accelerates total efficiency (TE) convergence’ is analysed to show how improvements in scale efficiency reshape production boundaries and foster TE convergence, particularly under the conditions of polarized regional development.

Mechanism 3 delineates the multi-tiered diffusion barriers. In response to Hypothesis 3, the thesis indicated that although the core provinces of the Yangtze River Delta have the potential to be a growth engine, they are constrained by multilevel barriers such as institutional barriers, mismatch of industrial structures, and spatial distances. These barriers make it difficult for the core provinces to transfer resources and technologies to the neighbouring low-efficiency regions, limit the radiation effect of the core provinces, and affect the momentum leading to regional convergence.

In addition to verifying the hypotheses, the dissertation set up the dynamic theoretical framework of regional efficiency comprising the “technology spillover – scale polarization – diffusion barriers” factor. It identified the mechanism of spatial economic evolution and offered theoretical support for removing the obstacles standing in the way of the Yangtze River Delta’s development and promoting synergistic development. It also provided theoretical, methodological, and practical support and framework elements for other regional analyses, including the theoretical justification for removing obstacles to the Yangtze River Delta’s development and encouraging synergistic growth. It offered a new perspective on efficiency dynamics and coordinated development in other areas.

This thesis examined high-quality economic efficiency by combining the results of the data analysis with the selected model. By evaluating the efficiency of economic development in each region, based on the indices outlined in China's 14th Five-Year Plan Guidance for high-quality economic development, the validity of the hypotheses was analysed as follows:

Hypothesis 1: The eastern regions of the YRB consistently demonstrate higher average values of total efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE) than the central and western regions. The response to this hypothesis integrated the major statements and conclusions of Chen (2023b) and Chen & Losoncz (2025a) and partly those of Chen (2022b).

The thesis analysis did not underpin the first part of Hypothesis 1. It is true that each region's GDP increased annually, but the high-quality efficiencies in developed regions were not higher than those in less developed ones. High-quality efficiency and pure technology efficiency exhibited upward trends, but they also dropped in certain periods. This result differs slightly from previous studies (Zhang, 2021), indicating that efficiencies increase yearly. The YBR region has exhibited a general trend of improving economic efficiency but fell back in 2013 and 2020. The rationale behind this can be attributed to the following three factors: (a) The international economic environment has significantly impacted the regional economy. In 2013, global industrial production and trade were weak, prices declined, international financial markets were volatile, and global economic growth fell slightly (UNCTAD, 2013). In 2020, the COVID-19 pandemic restrained economic activities. (b) Traditional manufacturing industries experienced downward pressure. There are many factories in the YRB region. When the economy undergoes transformation, traditional manufacturing industries come under increased pressure to adjust and upgrade. Green and sustainable development regulations constrain conventional industries' development, and policy requirements for pollutant emissions can hamper production (Zhao & Ruet, 2021). (c) While prudent fiscal policy has reduced regional investments and scaled back infrastructure development efforts, economic efficiency rebounded quickly following the shocks. Therefore, the region's economy has become more resilient. Furthermore, scale efficiency fluctuated around a value of 0.9. Stable scale efficiency indicates a certain level of managerial competence, operational consistency and strategic alignment within the organisation. This implies that the Yangtze River region has established a balance of operational efficiency within its current scale without significant opportunities for improvement through alterations to size or scope.

In contrast to the last part of Hypothesis 1, high-quality efficiency in regions with high economic development levels is not more significant than that in less developed regions, which displays no direct correlation between economic development and high-quality efficiency. This novel discovery challenges earlier research findings. (Zheng, 2020) (Zhang, 2021) (Zhao & He, 2021)

Environmental pollution (emission of exhaust gases and other airborne pollutants) is an undesired output in the model that negatively impacts efficiency. Core provinces such as Sichuan and Wuhan have lower economic efficiency values than other regions. Since these two provinces are heavily industrialised, they emit a considerable amount of pollutants from industrial production, garnering relatively lower scores than other regions. Environmental pollution reduces the provinces' economic efficiency values with high per capita GDP for three reasons. (a) Environmental pollution affects individual and public health, compelling residents to use more medical resources and experience social limitations. (b) Combatting environmental damage caused by the discharge of wastewater and waste materials requires enormous financial resources from the government, which makes using resources expensive. (c) Transforming and upgrading the industrial structure in these provinces are a challenge. Closing traditional manufacturing plants would lead to a short-term productivity decline in core areas, and the establishment of new sustainable and innovative enterprises will require significant financial resources.

Based on the above considerations, I rejected the first part of Hypothesis 1 and accepted the second part, which contributes to scientifically new research results.

Hypothesis 2: The eastern regions of the YRB benefit more from technological advancements, skilled labour, and welfare resources than the western regions, leading to significantly higher values in total efficiency, pure technical efficiency, and scale efficiency. Testing Hypothesis 2 relied on Chen (2023b), Chen & Losoncz (2025b) and Chen (2023a).

The findings for Hypothesis 2 concerning input resource distributions align with many conclusions from the relevant literature sources. (Zhang & Lahr, 2014) (Zang & Su, 2019) Numerous factors, such as previous development trends, investments in infrastructure and government policies that have historically favoured eastern regions, can be attributed to this disparity. Out of the four provinces with low efficiency data, the western provinces are more inefficient than the central or eastern ones.

Regarding input redundancy for each region, the superiority of natural geographical location, resource endowment and the speed of human economic development significantly influenced resource utilisation rates (Liu et al., 2019). The eastern region has a long history and culture with abundant human resources; therefore, subsequent resource utilisation is more efficient and welfare resources are adequate. In contrast, the western region has a higher redundancy rate because of its outlying location and limited human resources.

According to the efficiency evaluation system, from the perspective of regional coordination, differences in efficiency are evident between the eastern and western regions and between core provinces and non-core cities. The relatively underdeveloped educational system in the Western region has resulted in a shortage of innovative human resources in science and technology. Resource allocation is insufficient because of the higher number of inhabitants in large cities; therefore, the eastern regions have experienced more dynamic economic growth and development than their western counterparts.

Low pollution is primarily attributable to underdeveloped economic conditions caused by inefficient resource deployment. Industrial activity is typically limited in areas with slower economic growth, resulting in less environmental harm. However, this is rarely attributable to explicit environmental regulations since certain areas have not fully leveraged existing natural resources due to infrastructure, technology and/or funding shortages. Consequently, despite exhibiting low pollution levels, these regions have achieved economic performance surpassing their historical growth trajectories. The western region has more room for output growth. Regional economic disparities in China have been the subject of numerous studies, many of which have focused on overproduction, poorer productivity, higher unemployment rates and lower industrial output, particularly in areas with lower economic development. (Zhang et al., 2021) (Wang & Wang, 2021) Output deficiencies in economically disadvantaged areas are the result of unequal resource allocation and distribution (QUAN Liang, 2019). Western areas need more funding, advanced technology, trained workers and better infrastructure to overcome deficiencies. Its potential output is limited by the absence or scarcity of such resources, suggesting significant space for output growth in the region.

Based on the arguments presented above, I accept Hypothesis 2. The analysis is in line with the conclusions of the relevant literature.

Hypothesis 3: The gap in high-quality efficiency between provinces has shown a declining trend over time, which is consistent with the β-convergence hypothesis. The discussion of Hypothesis 3 incorporated the main findings of Chen (2023b) and Chen & Losoncz (2025b).

Hypothesis 3 aligns with common sense. The YRB's efficiency core zone comprises Shanghai, Chongqing, and Jiangxi, which have maintained TE = 1 (with pure technical efficiency and scale efficiency equalling 1) for over 80% of the years surveyed. Tibet has constantly maintained TE = 1; nevertheless, its geographical limitations and unique policy benefits, being situated beyond the primary flow of the Yangtze River, restrict its economic spillover effects on the basin. Policy preferences, including targeted support for ecological protection, chiefly influence its efficacy. Consequently, this underscores the notion that geographical proximity is essential for core provinces to operate as economic engines. The strategic centrality of Shanghai and Chongqing inside the basin is unparalleled. With direct influences on Jiangsu, Anhui, Hubei, and Sichuan in the middle and lower reaches, Shanghai—the principal centre of the Yangtze River Delta—and Chongqing—the centre of the Chengdu-Chongqing Twin-City Economic Circle—produce the most significant geographic spillover effects. Jiangsu (TE = 1 in 2020) and Guizhou (TE = 1 after 2015) are part of the secondary core zone. They have progressively caught up technologically to join the core cluster, indicating a dynamic upgrading of the "core-periphery" structure.

The Yangtze River Delta Spillover Zone collects the effects from Shanghai to Jiangsu to Anhui. In Jiangsu, TE rose from 0.355 (PTE = 0.392) in 2012 to 1 in 2020, but SE advanced from 0.906 to 1. This is evidence of the technical spillover effects of Shanghai, such as the relocation of industries and the migration of talent, which have propelled Jiangsu's efforts to optimise its scale efficiency. As for Anhui, TE rose from 0.342 in 2012 to 0.562 in 2020, with PTE approaching 1 (0.999) post-2018. In line with the "technology gradient transfer" theory, this provides evidence that technology from Shanghai and Jiangsu has helped make up for Anhui's lack of pure technical efficiency.

The Chengdu-Chongqing Twin-City Economic Circle (Chongqing → Sichuan → Guizhou) has seen Chongqing sustain TE = 1 throughout time, causing Sichuan's TE to rise from 0.340 in 2012 to 0.501 in 2020. Nonetheless, SE decreased from 0.999 to 0.935, indicating a scale efficiency constraint. Sichuan's technical efficiency has been increased by Chongqing through specialisation in specific industries, such as the electronics industry. However, Sichuan needs more help to increase the size of its production. In 2015, Guizhou's TE exceeded 1, benefiting from the collaboration inside Chongqing's "Jianzhong Economic Zone." The empowerment effect of core provinces in boosting scale efficiency in periphery regions was further confirmed as SE improved from 0.943 to 1. The Middle Yangtze Transmission Chain, including Jiangxi, Hunan, and Hubei, has driven Hunan's transmission efficiency (TE) from 0.399 in 2012 to 1 in 2021. Jiangxi is the only province in central China that regularly exhibits TE equal to 1. Relocating industrial operations from Jiangxi to Hunan has alleviated the scale efficiency constraint in Hunan. By 2021, Hubei's SE had dropped from 0.999 to 0.793, suggesting that further scale coordination with Jiangxi is necessary for improved regional efficiency synergy. (Losoncz & Chen, 2025)

Based on the above research results, I accepted Hypothesis 3.

Hypothesis 4: Improvements in scale efficiency are more strongly associated with overall efficiency convergence compared to improvements in pure technical efficiency. Testing Hypothesis 4 is related to Chen (2023b), Chen & Losoncz (2025a) and Chen & Losoncz (2025b).

In the absolute beta convergence model, twelve provinces display a certain degree of development consisting of catch-up. It is statistically significant ($p = 0.025$) that the coefficient for initial technical efficiency (TE_initial) is -0.1242, which reveals that provinces with lower initial technical efficiency tend to have higher technical efficiency growth rates. There is an absolute convergence trend of lagging behind regions catching up to the rest of the world. Even so, with an R^2 of only 0.046, one can see that starting technical efficiency accounts for less than 5% of the variance in growth rates. The reason for this demonstrates that baseline efficiency levels are not the sole complicated factors influencing convergence between provinces. A variety of other factors, such as policy disparities, industry structures, and innovation investments, were not considered in the model. The driving factors of convergence are highly complex and relatively weak due to the substantial uncertainty introduced by these unseen variables. Therefore, variations in the growth of technical efficiency across provinces cannot be adequately explained by defining convergence solely in terms of initial technological efficiency. A more thorough investigation of other aspects of influence is required to comprehend the convergence mechanisms at full work.

The use of lagged efficiency variables enhances the clarity of the relative beta convergence model's logical framework. The lagged scale efficiency (SE_lag) and lagged pure technical efficiency (PTE_lag) coefficients are considerably negative, with -0.6780 ($p = 0.002$) and -0.2661 ($p = 0.020$), respectively. Provinces with higher historical efficiency have weaker growth in the future, which is a reflection of falling marginal returns in the pure technical efficiency dimension. Provinces with lower performance can catch up by assimilating and replicating technological progress achieved elsewhere. The detrimental effect is particularly pronounced on the scale efficiency dimension. Due to resource misallocation and innovation suppression, some provinces with initially high scale efficiency experience growth limits, whereas provinces with low initial scale efficiency have more space for optimisation. By adding conditional variables, the relative beta convergence model effectively depicts the intricate processes of technical efficiency convergence, moving from an initial efficiency-driven convergence to a dynamic study of efficiency structure.

The significant negative impact of lagged scale efficiency (SE_lag) reveals the disparity in provincial scale efficiency. Provinces with a high initial scale efficiency tend to focus excessively on expansion, which results in increased management expenses and a lack of innovation. In provinces with industrial concentration, monopolies hinder technological dissemination, resulting in growth constraints. Establishing industrial clusters and integrating resources are two ways provinces with a low initial scale efficiency might unlock their growth potential. This polarisation impedes the advancement of high-efficiency provinces while offering opportunities for low-efficiency provinces to catch up, rendering advancement a crucial determinant of technological efficiency convergence.

In the dimension of pure technical efficiency, development challenges are reflected in the negative impact of lagged pure technical efficiency (PTE_lag). Provinces may attain short-term catch-up by acquiring external technologies and replicating lagging production processes, thus capitalizing on the so-called ‘imitation dividend’. However, provinces that are very efficient may at first experience “technological lock-in” if they do not develop new ideas independently. This means they become too dependent on current paths and struggle to grow. Several factors contribute to this problem, including inadequate investments in research and development and inadequate talent pools, which impede the development of technologically efficient innovations. The challenge of “simple imitation, challenging innovation” in pure technical efficiency affects enhancing efficiency and the convergence process. A complex ecosystem is formed in this dimension by combining the catch-up efforts of provinces falling behind and the innovation barriers of provinces already ahead of the curve.

Concerning technical efficiency, absolute beta convergence is apparent in the 12 provinces. However, a conditional convergence mechanism arises within the relative beta convergence framework, which is driven by pure technical efficiency and scale efficiency. Pure technological efficiency restrictions and scale efficiency mismatches currently significantly impact provincial convergence. Provinces with low scale efficiency should integrate resources and encourage economies of scale. In contrast, high scale efficiency provinces should modernise their industrial structures and break scale rigidity to encourage healthy convergence and coordinated development. Lagging behind provinces can use imitation to catch up in the pure technical efficiency dimension. In contrast, advanced provinces must invest more in innovation to create an "innovation-driven" growth model. By achieving more sustainable and balanced development in the context of the convergence of technical efficiency, the 12 provinces can do this by simultaneously optimising scale efficiency and pure technical efficiency. *Based on the research results, I accepted Hypothesis 4.*

The dissertation challenges the classic "technology supremacy" assumption in efficiency convergence by demonstrating that scale efficiency accounts for 68% of technical efficiency variance. It does so by proving that scale efficiency significantly outweighs the impact of pure technical efficiency. Taking Sichuan (2021) as an example, although having a lower PTE (0.536) than Qinghai (TE = 1, SE = 0.923), the latter attained a higher TE. This demonstrates that scale optimisation can compensate for technology lag.

The thesis has identified a threshold effect, called the "scale-technology" effect, which should not be confused with scale efficiency. This effect becomes apparent under specific statistical conditions: namely, when the standard error of the regression coefficient falls below 0.8, indicating a relatively stable estimation. In such a context, pure technical efficiency (PTE) improvements have an almost negligible marginal impact on total efficiency (TE). This suggests that despite technological progress the overall efficiency does not significantly increase, which is likely to be case because scale-related factors limit the effectiveness of such improvements. In this case, improvements in PTE have a marginal impact on almost non-existent TE (for example, Yunnan in 2013 had a standard error of 0.646, PTE of 0.682, and TE of 0.440). Conversely, when the SE is greater than or equal to 0.9, every 1% increase in PTE results in a 0.87% increase in TE (for example, Jiangsu after 2018). In light of these findings, which underscore the important role that scale efficiency plays as a prerequisite for technological developments in translating into overall efficiency increases, a significant shift has occurred in understanding DEA efficiency breakdown and the dynamics of regional convergence. Therefore, the results identify three main logic traps that contribute to filling previous research gaps. (1) Idealized economic models assume rational policy adoption, where governments and firms behave optimally in response to incentives. However, political economy factors, resistance to change, and institutional rigidities frequently lead to suboptimal policy adoption. (2) Policies designed at the national level often fail to consider regional economic disparities and industrial variations. For instance, carbon reduction policies that work well in high-income, tech-driven regions may not be feasible for resource-dependent provinces. (3) My thesis contributes to closing this gap by offering a data-driven regional efficiency evaluation framework. It provides practical conclusions on how policies should be designed with flexibility, regional adaptability, and market responsiveness to ensure their effectiveness in real-world economic transformation.

Data errors and model design faults are the *most significant limitations of my research* tainting the results. My research is the start of a new macro-analytical paradigm for understanding and assessing creative production dynamics-driven emerging economies. Data paucity and regional/industry differences may affect results. Thus, this research is worth continuing. Such efforts instruct other developing nations and encourage established nations, thereby ensuring China's economic success. However, research typically lacks data. Even if official statistical bureaus and international organizations like the Chinese government office, World Bank, and IMF provide credible and extensive datasets, they often have large temporal gaps.

For policy considerations, Tibet and Yunnan achieved TE = 1 too early, causing odd convergence cycle estimates. Integrating multidimensional variables like ecological efficiency reduces future biases from economic efficiency metrics alone.

The thesis neglected dynamic efficiency evolution and the Malmquist Index. The static DEA model does not reflect tech change. Pollution and other drawbacks were excluded. Tibet's SE = 1 may hide environmental damage. The study should contain the SBM-DEA model. The Index should be used to track SE and PTE, especially in circumstances like Jiangsu's efficiency stagnation after TE = 1 in 2020. The research could also use machine learning to uncover nonlinear SE-PTE relationships to reveal provincial club convergence patterns.

To assess China's economic and social progress, one must grasp present variations and long-term patterns. By tackling structural issues and building resilience to external uncertainties, China can advance its high-quality development plan. Krugman (1994) pointed out that "productivity isn't everything, but in the long run, it's almost everything"—highlighting the importance of present changes. Green growth and technical innovation underpin China's high-quality development. Reforms and regional collaboration support the government's leadership in implementing these changes, making them sustainable. This holistic strategy puts China as a global leader in building a modern, low-carbon, technology-driven economy, and offers lessons for other nations facing comparable issues. Examining institutions and institutional variables in China's high-quality development model is another *promising research area*.

6. References

Chen, R. (2022). *The contribution of tourism to China's new development trajectory*. https://eurasiacenter.hu/wp-content/uploads/2023/01/KKE_2_kotet_online-1.pdf

Chen, R. (2023). Methodological tools and economic models to analyse the transition to a new development trajectory in China. *Prosperitas*(3). https://doi.org/https://doi.org/10.31570/prosp_2023_0058

Chen, R., Cai, J., Fu, Y., & Wei, Z. (2023). *Comprehensive analysis and forecast of Chinese NEV : Industry development from 2012 to 2025*. https://doi.org/https://doi.org/10.29180/9786156342560_6

Li, S., Jahanshahloo, G. R., & Khodabakhshi, M. (2007). A super-efficiency model for ranking efficient units in data envelopment analysis [Article]. *Applied Mathematics and Computation*, *184*(2), 638-648. https://doi.org/10.1016/j.amc.2006.06.063

Li, W., & Yi, P. (2020). Assessment of city sustainability—Coupling coordinated development among economy, society and environment [Article]. *Journal of Cleaner Production*, *256*, Article 120453. https://doi.org/10.1016/j.jclepro.2020.120453

Losoncz, M. (2017). The Dilemmas of China's Shift in Growth Trajectory and Economic Governance. *Financial and Economic Review*, *vol. 16*(Sepcial Issue, 21–49). https://en-hitelintezetiszemle.mnb.hu/letoltes/miklos-losoncz.pdf

Losoncz, M., & Chen, R. (2025). Evaluating China's high-quality economic development model: the example of the Yangtze River region. *Regional Statistics*, *Vol. 15,No. 3*. https://doi.org/10.15196/RS150303

Pacetti, E. G. (2016). *The Five Characteristics of an Inclusive Economy: Getting Beyond the Equity-Growth Dichotomy*. The Rockfeller Foundation. Retrieved 2016-12-13 from https://www.rockefellerfoundation.org/blog/five-characteristics-inclusive-economy-getting-beyond-equity-growth-dichotomy/

Podinovski, V. V. (2004). Suitability and redundancy of non-homogeneous weight restrictions for measuring the relative efficiency in DEA. *European journal of operational research*, *154*(2), 380-395. https://doi.org/10.1016/S0377-2217(03)00176-0

Tone, K. (2002). A slacks-based measure of super-efficiency in data envelopment analysis [Article]. *European journal of operational research*, *143*(1), 32-41. https://doi.org/10.1016/S0377-2217(01)00324-1

Tone, K. (2015). Dealing with undesirable outputs in DEA: A slacks-based measure (SBM) approach. *GRIPS Discussion Papers*, *1*. https://core.ac.uk/download/pdf/51221252.pdf

Ul Hassan Shah, W., Zhu, N., Hao, G., Yan, H., & Yasmeen, R. (2024). Energy efficiency evaluation, technology gap ratio, and determinants of energy productivity change in developed and developing G20 economies: DEA super-SBM and MLI approaches [Article]. *Gondwana Research*, *125*, 70-81. https://doi.org/10.1016/j.gr.2023.07.017

7. The list of the author's publications in the field of the dissertation

Publications					
Title	**Authors**	**Year**	**Journals/Books**	**Major Conclusion**	**DOI/URL**
SMEs through Tough Times of the Covid-19 Pandemic in China	Chen Rurong	2022	Prosperitas	This paper investigates the impact of the Covid-19 pandemic on Small and Medium-sized Enterprises (SMEs) in China, with a specific focus on Beijing. It uses listed companies' financial reports and survey results to compare the operating revenue, cost, and profit of large enterprises and SMEs. The study analyzes the extent of SMEs' vulnerability during the pandemic by comparing their financial indicators with those of large companies. It also examines government policy measures introduced to support SMEs. The paper employs the Winters' multiplicative exponential smoothing method to predict the operating revenue of SMEs from 2022 to 2025 and discusses the short-term and potential long-term economic effects of the pandemic on SMEs. It compares its findings with relevant literature on the impact of the pandemic on SMEs.	http://publikaciotar.repozitorium.uni-bge.hu/1880/
The contribution of tourism to China's new development trajectory	Chen Rurong	2022	Results and Challenges : Changing Travel Trends in China-CEEC Perspective	China's tourism industry rebound post-pandemic and its role in the 14th Five-Year Plan's focus on R&D, digitalization, and green economy adoption are examined in this paper. It uses a novel framework combining Porter's Diamond Model and the Cobb-Douglas production function to identify microeconomic determinants—such as digital transformation, household purchasing power, and consumption habits—that affect tourism's qualitative and quantitative GDP growth. Technology and structural reforms promote sector modernization, and the research quantifies their effects on productivity and sustainability. By integrating macroeconomic research with micro-level data, the report gives policymakers concrete insights and a framework for Hungary and other nations to connect tourist plans with inclusive growth goals. One important scientific addition is the use of new models and the discovery of two paths — digital innovation and green transition — for making tourism more resilient in the face of changes in the global economy.	Eurázsia Center, Neumann János Egyetem (2022) 205 p. pp. 112-142. , 31 p. ISBN: 9786156435170 ISBN: 9786156435187
Methodological tools and economic models to analyze the transition to a new development trajectory in China	Chen Rurong	2023	Prosperitas	This conceptual paper aims to provide a methodological toolkit for analysing China's transition to a new economic trajectory, focusing on qualitative production factors such as research and development, innovation, and highly skilled human capital. It elaborates on various research philosophies (positive and normative economics) and approaches (inductive and deductive reasoning). The paper describes several methodological choices and economic models for policy assessment, including Propensity Score Matching (PSM), Differences-in-Differences (DID), DEA-SBM, and Markov Chain Monte Carlo (MCMC) analysis. It also discusses the importance of robustness tests like the placebo test. The paper lays the methodological foundation for future quantitative analysis of China's economic transformation, particularly in the context of the 14th Five-Year Plan.	https://doi.org/10.31570/prosp_2023_0058
Impact of Energy Transition on China's Economic Growth under Carbon	Chen Rurong	2023	SDGs in practice – how to operate sustainable? Budapesti Gazdasági Egyetem	This paper investigates the impact of energy transition on China's economic growth under carbon neutrality climate policies, with China aiming to be carbon neutral by 2060. It constructs a vector auto-regression (VAR) model using updated energy factors to simulate a high-quality economy. The study identifies the relationship between factors influencing carbon emissions and the digital economy and performs impulse response analysis to understand how carbon emissions, energy consumption, and the digital economy respond to shocks. It analyzes the current state of the energy mix and discusses the implications of the energy crisis (e.g., the Russia-Ukraine war) as an external shock. The paper also provides forecasts for CO2 emissions, energy consumption, and the digital economy's revenue and discusses current climate and energy policies and China's sustainable development efforts.	https://doi.org/10.29180/978-615-6342-69-0_4
Comprehensive analysis and forecast of Chinese NEV : Industry development from 2012 to 2025.	Chen Rurong , Cai Jing, Fu Yingjie, Wei Ziji	2023	Foresight in research - Case studies on future issues and methods : Session proceedings of the BBU Research Day 2023	This paper provides a comprehensive analysis and forecast of the Chinese New Energy Vehicle (NEV) industry development from 2012 to 2025. It employs a literature review to identify key characteristics of the Chinese NEV market and the Entropy-based TOPSIS method to evaluate the market based on data from 2012 to 2022 using five first-level and fifteen second-level indicators. The study assesses the current development of China's NEV industry, highlights its achievements, and envisions its future development in the next 5 years under the current political situation. It also considers alternative futures (expected, preferred, and wild card), analyzes favorable and unfavorable factors affecting the industry, and puts forward targeted opinions. The paper emphasizes energy transformation as a driving force and acknowledges the potential impact of Black Swan events.	10.29180/9786156342560_6
Some global implications of China's new energy policy initiative: Lessons and conclusions	Chen Rurong	2024	Green and Digital Transitions: Global Insights into Sustainable Solutions, Szeged	This paper analyzes the potential impact of China's "East Data West Computing" initiative on its energy balance and the development of its green digital economy. It discusses the current energy production and consumption structures in China and how changes in the energy structure affect the digital economy and high-tech industries. The study employs a mixed (qualitative and quantitative) approach, including descriptive and comparative analysis and a two-way fixed effects model using panel data. It examines the relationship between electricity consumption, hydropower generation, thermal power generation, and the revenue from the software business. The paper explores the global implications of China's new energy policy initiative and provides recommendations for energy security strategies and green digital transformation.	https://doi.org/10.14232/gtk.gdtgiss.2024.2
The middle-income trap: Definitions, interpretations and analytical tools with implications for China	Chen Rurong, Miklós Losoncz	2025	Prosperitas	This review brings together the theoretical and empirical aspects of the middle-income trap, which is a developmental bottleneck in which countries find it hard to move from a middle-income to a high-income status. It names five important factors: changes in population, a lack of human capital, growth paths that rely on investments, productivity that doesn't change easily, and inefficient institutions. Systemic problems like aging populations, broken economic structures, and governing gaps are to blame for things like low-value production that doesn't change, innovation that stops moving forward, and education that isn't good enough. The study stresses that improving technology, changing the way schools work, and changing the way things are built are important ways to get past these problems. It stresses incorporating modern global trends—like the shifts to a green economy and digitization—into growth plans in order to keep up with changing conditions. This study gives us a short way to think about the multifaceted nature of the trap. It also gives lawmakers useful information for encouraging development that benefits everyone and is driven by innovation.	Has been accepted
Evaluating China's high-quality economic development model: The example of the Yangtze River region	Miklós Losoncz, Chen Rurong	2025	Regional Statistics	Using the PCA-SBM model, this study shows what makes growth in the Yangtze River Basin of high quality: However, pollution is a constraint that prevents the eastern section of the region from being efficient in its resource allocation. Numerous aspects of urbanization need to be improved, despite the fact that the western portion of the region possesses major natural advantages. A fresh viewpoint on the process of regional transformation is provided by the fact that there is no direct association between economic growth and efficiency.	Has been accepted