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Research Article

Exploring Dimensions in Digital Economy and Manufacturing Integration: Analyzing with DEA-Malmquist Model and Emphasizing the Role of ERP Systems in Enhancing Collaboration and Efficiency

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ABSTRACT

ERP integration influenced digital economy manufacturing in this study. The DEA-Malmquist method calculated the digital economy manufacturing integration contribution rate index. In China, the researchers targeted Beijing-Tianjin-Hebei, Greater Bay Area, and Changzhu Lake. Regional economic growth rose with manufacturing integration. Integration accelerates commerce, resource allocation, regional manufacturing, and digital economy growth. Integration boosts corporate and customer service accessibility, reports say. These regions experienced increasing client demand and innovation. Integration's diverse impact on economic growth differed by location due to economic structures and stages. To understand how digital economy and industrial integration maintain economic growth, ERP digitalization, government policies, digital infrastructure, and market rules must be investigated. The DEA-Malmquist regional digital economy manufacturing integrated latitude measurement model is crucial. The model and research benefit government and business strategy. This study boosts sector growth and long-term economic and industrial development by raising knowledge of regional digital economies and manufacturing integration.

Keywords: Digital Economy, Regional Economic Growth, DEA-Malmquist, ERP.

INTRODUCTION

Manufacturing has altered due to the digital economy and increasing IT expansion. Beyond production and sales tactics, this shift transforms manufacturing's competitive landscape. The complex interaction of the digital economy and manufacturing drives this growth, needing investigation. ERP solutions must be deliberately used to integrate industry and the digital economy(Barmuta et al., 2020; Belli, Davoli, Medioli, Marchini, & Ferrari, 2019). The solutions improve operational efficiency and companywide cooperation. Participation is crucial to this growing relationship. The DEA-Malmquist model, which reliably evaluates technical efficiency and total production, may quantify and explain this integration. Multiple input-output variables are used to assess different units and track the digital economy-manufacturing fusion in this model (Koumas, Dossou, & Didier, 2021; Li, 2023; A. I. Shinkevich, Kudryavtseva, M. V. Shinkevich, Salimianova, & Ishmuradova, 2019b).

Integrating the digital economy and manufacturing extends beyond surface changes to their essential connections. Revolutionary consequences affect industrial rivalry and technology. Effective incorporation of ERP systems is vital in this changing context. Through detailed study, the DEA-Malmquist model helps stakeholders and decision-makers grasp this integration's efficiency and productivity benefits. Technology must be deliberately used by industry as the digital transformation continues. Successful ERP system integration in the digital age involves more than technology. The complete DEA-Malmquist model's evaluation approach displays the complex dynamics of this digital economy-manufacturing union, helping stakeholders to informed decision-making and sustained progress (Xu, Zhu, Li, & Shan, 2023).

Digitization alters manufacturing. Researchers (Cao, Niu, & Wang., 2022; G. Zhang, Ye, & Sun, 2023; Zhao, Pi, & T. Zhang, 2022) showed some integration, but not all. Current research focuses on specific industries or places, therefore convergence mechanisms must be thoroughly investigated. Beyond efficiency, digital economy and manufacturing connect. Complex dynamics are explained by market, policy, and organisational dynamics. ERP changes operating paradigms, affecting integration. A multidimensional DEA-Malmquist-specific Contribution Rate Index Analysis model is developed here. This paradigm tracks everything to comprehend digital economy and industrial integration. Integration's complicated consequences on regional economic growth are empirically examined. The study advances theory and supports regional economic growth strategies in digital economy industrial integration utilising empirical analysis and ERP-centric frameworks (Bejlegaard, Sarivan, & Waehren, 2021; Chinoracky & Corejova, 2021; Ciric, Lolic, Gracanin, Stefanovic, & Lalic, 2020; Götz & Jankowska, 2020). Beyond technological amalgamation, this research examines organisational resilience and social adaptability (Gong, 2022; Liu & Zhou, 2022).

This study investigates ERP systems, the digital economy, and manufacturing's complex interaction. These should alter economic and social structures. Contribution Rate Index Analysis in DEA-Malmquist aims to pioneer the assessment of the complicated digital economy-industry relationship. For completeness, the model covers market dynamics and organisational structures. This complicated issue requires a global strategy, according to the paper. Industrial integration requires industry-nation links since the digital economy is global. Thus, our study aims to increase regional economic growth and theoretical understanding of digital economy and industrial integration's worldwide implications. Finally, digital economy industrial development requires global viewpoint (Litvinenko, 2020). The intricate relationship between the digital economy and manufacturing is examined utilizing unique Contribution Rate Index Analysis and empirical research. Improving economic growth methods and concepts need ERP systems. Goals include changing economic paradigms and enhancing society through technology, organisational resilience, and social adaptability.

LITERATURE REVIEW

Literature says the digital economy, manufacturing integration, the DEA-Malmquist model, and ERP systems are essential to firm change and growth. The digital economy uses technology everywhere, changing sectors. Brynjolfsson and McAfee (2014) claim the digital economy boosts industrial productivity, innovation, and efficiency. This supports the study into how digital economy manufacturing may improve collaboration and efficiency (Iliescu, 2020; Prakash, Savaglio, Garg, Bawa, & Spezzano., 2022). For digital technology-induced industrial efficiency and productivity gains, DEA-Malmquist model works well. Researchers and practitioners use DEA and the Malmquist Index to assess industrial process efficiency. The DEA-Malmquist model assesses digital technology's influence on manufacturing, according to Zhou et al. (2019). This model quantifies digital manufacturing process transformation's effects on cooperation and efficiency in the literature review (Faccia & Petratos, 2021; Iliescu, 2020; Noorit, Thapayom, & Pornpundejwittaya, 2020; Prakash et al., 2022).

Digital manufacturing requires ERP. These integrated software solutions facilitate departmental cooperation. Avilova, Shaykhutdinova, and Kuramshina (2019) say ERP systems centralize data and processes, improving cooperation and information exchange. ERP systems may improve supply chain communication, making them vital to production. ERP systems boost supply chain responsiveness and efficiency, according to Liao and Wang (2021). According to the literature, digital economy industrial integration requires a deep understanding of collaboration and efficiency. ERP and digital technology have great potential but face limitations. Data security, interoperability, and organizational change management to maximize these technologies' collaborative and efficiency benefits. This complex technique assures that the literature study covers industrial ERP-digital integration's pros and disadvantages.

Digital economy and manufacturing integration studies often highlight regional and industry-specific issues. Regional technical, legal, and economic systems may impact integration. Researchers (Ivanović & Marić, 2021; Pavlović, Marjanović, Rakić, Tasić, & Lalić, 2020; Pierre, Vergara, & Hellen, 2022) complicate regional digital technology adoption and manufacturing effects research. Finally, the digital economy, manufacturing integration, DEA-Malmquist model, and ERP systems literature analysis show how they may improve production collaboration and efficiency. Multi-field data synthesis helps explain complex processes. This literature analysis provides for future study on manufacturing trends, problems, and strategic ERP and digital technology utilization as the digital economy evolves (Shinkevich et al., 2019a; Sturgeon, 2021).

ERP systems, industrial integration, DEA-Malmquist model, and digital economy are well-known but understudied. Few studies have examined the multiple factors that impact ERP system integration in manufacturing across industries and locales. ERP installation studies highlight pros and cons, but not contextual factors that impact collaboration and efficiency (Boev et al., 2020; K. Kraus, N. Kraus, & Manzhura, 2021). ERP integration solutions for manufacturing require industry and geographical knowledge. Few studies have examined the long-term durability and resilience of industrial collaboration and digital technology and ERP system efficiency gains. Most research highlight digital transformation's short-term benefits (Novikov & Sazonov, 2020; Molina-Castillo, Rodríguez, López-Nicolas, & Bouwman, 2022; van Erp et al., 2021). Long-term effects, efficiency loss, and production system adaptability to new technology are unknown. Long-term digital integration research would show industrial process efficiency and collaboration. Filling these research gaps would help firms and governments adopt digital manufacturing (Novikov & Sazonov, 2020; Dutta, Kumar, Sindhwani, & Singh, 2022; Molina-Castillo et al., 2022; van Erp et al., 2021, 2021; Zeba, Lucić, & Čičak, 2019).

PRINCIPLES OF THE DEA-MALMQUIST MODEL

Digital economy-manufacturing integration is efficiently assessed using DEA and the Malmquist Index. This strategy helps organisations measure production efficiency and combine digital economy and manufacturing. The researchers compare data twice in the DEA-Malmquist model (Dutta et al., 2022; van Erp et al., 2021; Zeba et al., 2019). The DEA approach assesses industrial enterprise DMUs' initial efficiency. Inputs and outputs help DEA assess DMU efficiency. Malmquist index shows technology and scale efficiency evolution. Both sides of this index summarize efficiency-changing components. Technical efficiency assesses technology and process changes, whereas scale efficiency measures operations scale. Companies may use DEA-Malmquist to link production with the digital economy. This analytical technique directs strategy with quantitative and sophisticated digital manufacturing data.

Here is the formula for the DEA-Malmquist model: for phase T DMU j, the input vector is $xjt = (x1jt, x2jt, \ldots, xijt)$ and the output vector is $yjt = (y1jt, y2jt, \ldots, ymjt)$, where i is the input index （$i = 1,2,\ldots,I$）and m is the output index（$m = 1,2,\ldots,M$）. First, calculate the efficiency score for period tET_jt. Using the DEA method, it can be expressed as:

$$[\, ET_jt = \frac{\sum_{s=1}^{N}(w_sxjs)}{\sum_{r=1}^{N}(v_ryr)} \,]$$

Where N indicates the number of DMUs, ws and VR are the weighting factors, so that for all DMU k, there is

$$[\, \sum_{s=1}^{N}(w_sxks) \leqslant \sum_{r=1}^{N}(v_ryr), \quad k = 1,2,\ldots,N \,]$$

Next, calculate the efficiency score for period t+1ET_j(t + 1), using the same DEA method:

$$[\, ET_j(t+1) = \frac{\sum_{s=1}^{N}(w_sxj(t+1))}{\sum_{r=1}^{N}(v_ryr(t+1))} \,]$$

The Malmquist Index is then used to break down changes in technical efficiency and changes in scale efficiency. The Malmquist Index is expressed as:

$$[\, M_j = \frac{ET_j(t+1)}{ET_jt} \,]$$

AmongM_j them is DMU J's Malmquist Index.

Further, the Malmquist Index is broken down into the Technology Change Index (TC) and the Scale Change Index (SC). The Technology Change Index can be expressed as:

$$[\, TC_j = \frac{ET_j(t+1)}{ET_jt} \,]$$

The scale change index, on the other hand, can be expressed as:

$$[\, SC_j = \frac{ET_j(t+1)}{ET_jt} \times \frac{\sum_{r=1}^{N}(v_ryr)}{\sum_{r=1}^{N}(v_ryr(t+1))} \,]$$

Digital transformation, industrial integration, and efficiency are accurately judged by DEA-Malmquist. Create Malmquist, technical, and scale change indices for each DMU to measure efficiency. Digital technology analysis enhances industrial production and lowers costs. Digital transformation and manufacturing process integration are studied using DEA-Malmquist. Beyond quantitative investigations, this study examines production-level digital technology adoption. Innovation, resource allocation, and firm scaling are measured by technological and scale change indexes. Consider an efficient digital economy manufacturing corporation. Corporate production is analysed by DEA-Malmquist. Calculate the company's efficiency score for each period using input and output index data. Malmquist Index contrasts Technology Change Index and Scale Change Index efficiency ratings across two periods for complicated business efficiency evaluation. Results help organisations identify operational concerns. Inefficient resource allocation, manufacturing bottlenecks, etc. might impair performance. Firms can tackle these difficulties and enhance efficiency using this knowledge. Companies strengthening their digital strategy and manufacturing processes utilize DEA-Malmquist for retrospective and forward analysis. It helps organisations with technology, procedures, and resources. Companies enhance operations via tech and scale evaluations. Final DEA-Malmquist goals include production integration and digital transformation. Computing efficiency studies manufacturing and digital technologies. Business growth and technology breakdown might help concentrate actions. DEA-Malmquist adapts digital economy and industry. In addition, enterprises can also draw on the experience of other efficient enterprises, strengthen technological innovation, and increase digital transformation efforts to improve production efficiency and market competitiveness.

In short, the DEA-Malmquist model has important application value in measuring the integration of the digital economy and manufacturing industry. It can help enterprises evaluate their own efficiency changes, provide enterprises with directions and suggestions for improvement, and promote digital transformation and integrated manufacturing development. This paper will measure the latitude of regional digital economy and manufacturing integration by applying this model to observe the contribution rate of digital economy and manufacturing integration to overall regional economic development during regional economic development.

RESEARCH METHODOLOGY

The ERP-based quantitative research examines how digital economy manufacturing integration affects regional economic growth. Beijing-Tianjin-Hebei, Greater Bay Area, and Changzhu Lake economies are examined. Deep patterns emerge via longitudinal analysis. GDP, employment, and industrial production growth come from national statistics agencies and regional economic surveys. Digitalization, manufacturing industry integration, and cooperation efficiency are region-specific digital economy manufacturing integration indicators. Analysing manufacturing process digitalization involves ERP installation data. The DEA-Malmquist approach generates a digital economy manufacturing integration contribution rate index. To properly examine efficiency changes over time, utilise the input-output model. To determine the relative efficiency index (θ), economic growth indicators are compared throughout time. Regression analysis evaluates manufacturing integration, ERP systems, and regional economic growth. Regional differences are evaluated via subgroup analysis. Consider data availability and geographical specificity before drawing conclusions. Research ethics, especially data privacy and confidentiality, are discussed. Studies conclude with major results and implications. Companies and policymakers receive research-based recommendations. The article suggests studying industry-specific impacts, qualitative methods, and digital integration strategy sustainability.

Index Selection and Variable Setting

Based on the previous theoretical analysis, in constructing a latitude measurement model for regional economic growth, digital economy, and manufacturing integration based on DEA-Malmquist, the essence of this paper is to calculate and analyze based on the contribution rate of digital economy and manufacturing integration to regional economic growth. Therefore, in the modeling, the researchers will mainly analyze and consider the following aspects, and select relevant indicators for research:

1) Regional Economic Growth Indicators

Real gross domestic product (GDP): As one of the key indicators of regional economic growth, it reflects the size and level of growth of a region's economy.

Employed population: Reflect the region's employment situation and labor market dynamism.

Fixed capital investment: Reflect the level of investment and economic development potential of the region.

2) Index of Manufacturing Integration in the Digital Economy

Digitalization level: To measure the maturity and extent of regional manufacturing enterprises in the application of digital technology, the calculation formula is as follows:

Digitization Level = (Digital Expenses+Digital Investments)/Total Expenses

Index of the degree of integration of the manufacturing industry: measure the degree and effectiveness of enterprises in integrating the manufacturing industry with the digital economy. The calculation formula is as follows:

The degree of integration of manufacturing industry = (digital output value+internet sales)/total output value

Collaborative efficiency index: Measure the effectiveness and efficiency of collaborative work between regional manufacturing and related enterprises and internal departments or partners. The calculation formula is as follows:

Collaboration efficiency = Output collaboration efficiency × input collaboration efficiency, where output collaboration efficiency = Output correlation × output weight Input collaboration efficiency = Input correlation × input weight.

When variables are set in this paper based on the above indicators, the regional economic growth index is used as the output variable of the DEA model, and the index of digital economy manufacturing integration is used as the input variable. Assuming there are n regions (i=1,2,..., n), the regional economic growth index vector for the t-th time point is GDPI (t), employed population i (t), and investment i (t). The index vectors for manufacturing integration in the digital economy are digital level i (t), manufacturing integration index i (t), and collaborative efficiency index i (t).

DEA-Malmquist Latitude Measurement Model Construction

The purpose of developing the DEA-Malmquist model, based on the theoretical study of the DEA-Malmquist model above, is to identify a linear programming model that maximises the efficiency of each area while fulfilling input and output restrictions. The DEA-Malmquist model, in particular, may be stated as a linear programming problem of the following form:

Objective:

Maximize θi(t)

Subject to the following constraints:

Digitization level constraint: ∑j(wj × digitization_levelj(t)) ≤ θi(t0) × ∑j(wj × digitization_levelj(t0)), for all t = 1, 2, ..., n

Degree of integration of the manufacturing industry index constraint: ∑j(wj × degree_of_integration_of_the_manufacturing_industry_indexj(t)) ≥ θi(t0) × ∑j(wj × degree_of_integration_of_the_manufacturing_industry_indexj(t0)), for all t = 1, 2, ..., n

Collaborative efficiency index constraint: ∑j(wj × collaborative_efficiency_indexj(t)) ≥ θi(t0) × ∑j(wj × collaborative_efficiency_indexj(t0)), for all t = 1, 2, ..., n

Weight constraint: ∑j wj = 1

Non-negativity constraint: wj ≥ 0, for all j = 1, 2, ..., m

Among them, 92i (t) denotes the relative efficiency of the i-th region at the t-th time point, wj denotes the weight of the j-th indicator in the linear planning model, the digitization level j (t) denotes the value of the t-th time point of the jth index, the degree of integration of the manufacturing industry index j (t) denotes the value of the tth time point of the index.

By solving this linear planning problem, it is possible to calculate the Malmquist Index and the contribution rate index of digital economy manufacturing integration, as well as evaluate the contribution of digital economy manufacturing integration to regional economic growth to measure the latitude of regional digital economy and independent industry integration.

DEA-Malmquist Latitude Measurement Model Incorporating ERP Systems

Building upon the theoretical underpinnings of the DEA-Malmquist model delineated earlier, the objective of formulating the DEA-Malmquist model lies in constructing a linear programming framework that maximizes regional efficiency while adhering to input-output constraints. Specifically, the DEA-Malmquist model can be reformulated within the realm of Enterprise Resource Planning (ERP) systems and digital economy integration, articulated through the following equations:

Maximize θi (t)

Subject to:

∑m (wj ×ERP digitization levelj (t))≤θi (t0)×j=1

∑m (wj×ERP digitization levelj (t0)), for t=1,2,…,nj=1

∑m (wj×Manufacturing Industry Integration Indexj (t))≥θi (t0)×j=1

∑m (wj×Manufacturing Industry Integration Indexj (t0)), for t=1,2,…,nj=1

∑m (wj ×Collaborative Efficiency Indexj (t))≥θi (t0)×j=1

∑m (wj ×Collaborative Efficiency Indexj (t0)), for t=1,2,…,nj=1

∑mwj =1wj ≥0, for j=1,2,…,m

Here, θi (t) represents the relative efficiency of the i-th region at the t-th time point, wj denotes the weight of the j-th indicator within the ERP-centric linear planning model, and the indices j(t)) represent values at specific time points.

Moving forward, the model parameter settings encompass three regions (A, B, and C) across two time points (t0 and t):

Weight (W) Setting: Assuming the paramount significance of ERP digitization, followed by the degree of manufacturing industry integration and collaborative efficiency, the researchers allocate weight ratios of 1.6, 1.2, and 1.2, respectively, to these indices.

Time Points (t0 and t) Setting: Considering t0 as 2018 and t as 2022, this selection allows for a comparative analysis of regional economic growth and manufacturing integration within the digital economy across these intervals.

By leveraging these parameters, computations yield the relative efficiencies, Malmquist indices, and contribution rate indices for each region, culminating in a comprehensive understanding of the digital economy's influence on manufacturing integration and regional economic growth. For instance, considering Region A, the index vectors for digital economy manufacturing integration at t0 and t time points denote [500, 1.6, 1.8] and [800, 1.8, 1.7], respectively.

The ERP-embedded DEA-Malmquist model determines region efficiency (A, B, and C) using linear programming at t0 and t. Economic growth and digital economy industry integration are examined in this research. Solving the linear programming problem yields each area's model efficiency ratings at both time points. Comparisons of regional digital economy manufacturing integration efficiency. Compared to t0, t efficiency ratings demonstrate dynamic efficiency changes and economic process evolution in each site. Policymakers and stakeholders gain from linear programming in ERP-embedded DEA-Malmquist. Digital economy industrial integration and regional growth are quantified. For digital transformation and manufacturing integration, analytical thinking increases attention, decision-making, and economic progress. This analytical framework unveils not just efficiency metrics but a deeper understanding of how ERP-driven integration impacts the economic landscapes of these regions.

Model Parameter Settings

There are three regions (region A, region B, and region C) and two time points (t0 and t) to set model parameters, as follows:

Weight (W) setting: Assuming that the researchers believe that the level of digitalization is the most important contributor to regional economic growth, the degree of integration of the manufacturing industry is second, and the collaborative efficiency index is relatively low. The researchers can set the weight ratio to 1.6, 1.2, and 1.2, corresponding to the level of digitalization, the degree of integration of the manufacturing industry, and the collaborative efficiency index, respectively.

Setting time points (t0 and t): Assuming t0 is 2018 and t is 2022, the researchers select these two time points to compare changes in regional economic growth and manufacturing integration in the digital economy.

Based on the parameters set above, the researchers can calculate the relative efficiency of each region at each point in time (i (t)), the Malmquist index, and the contribution rate index of manufacturing integration in the digital economy.

Taking region A as an example, the index vector for manufacturing integration in the digital economy at time point t0 is [500, 1.6, 1.8], and the index vector for manufacturing integration in the digital economy at time point t is [800, 1.8, 1.7]. According to the weight setting, it can be calculated that the weighted indicators of digital economy manufacturing integration at these two points in time are [680, 1.7, 1.82] and [800, 1.8, 1.7].

Then, the researchers can solve the linear programming problem through the DEA-Malmquist model, calculate the relative efficiency of region A at T0 and T time points (A (t0) and A (t)), and further calculate the Malmquist Index and the contribution rate index of digital economy manufacturing integration to regional A's economic growth.

By performing similar calculations for region B and region C, the researchers can obtain their relative efficiency at t0 and t time points, the Malmquist index, and the contribution rate index of digital economy manufacturing integration, and further understand the contribution of digital economy manufacturing integration to the economic growth of these two regions.

Empirical Demonstration of Latitude Measurement Model for Regional Digital Economy and Manufacturing Integration

Data Sources and Preprocessing

Data source: The researchers collected data on economic growth and digital economy manufacturing integration in the three regions of Changzhu Lake, Greater Bay Area, and Beijing-Tianjin-Hebei using channels such as relevant agencies, statistics bureaus, and questionnaires.

Index collection: The researchers have collected the following indicators to evaluate economic growth and manufacturing integration in the digital economy: GDP, employment rate, and industrial output value as indicators of regional economic growth; digital level, manufacturing integration index, and collaborative efficiency index as indicators of digital economy manufacturing integration.

Data pre-processing: After obtaining the raw data, the researchers performed a series of pre-processing steps to prepare the data for model analysis. First, data cleaning is carried out, and the missing values, anomalies, and error values in the data are checked and processed. The values of the different indicators are then standardized to make them comparable. Commonly used methods include min-max standardization and z-score standardization. If the original data was recorded separately at different time points and regions, it will require data aggregation, so as to carry out analysis in the model. Finally, according to the weight settings in the model parameter settings, the researchers will empower different indicators.

Data format: For model analysis, the researchers organize the data into an appropriate format. The regional economic growth index matrix (X) indicates the value of the economic growth index for each point in time and region, the digital economy manufacturing integration index matrix (Y) indicates the value of the digital economy manufacturing integration index for each point in time and region, and the weight vector (W) contains the weight value of each indicator.

Through the above data processing steps, the researchers have obtained cleaned, standardized, and aggregated data, as well as a set weight vector. These data and parameters can be used in the calculation and analysis of the DEA-Malmquist model to evaluate the contribution rate index of regional economic growth and manufacturing integration in the digital economy.

Calculation of the Digital Economy and Manufacturing Integration Contribution Rate Index to Regional Economic Growth

Based on the data collected in this article, the researchers calculated and counted each indicator according to the calculation method used on the basis of the basic indicators. The following is a detailed description of the indicator calculation results obtained after the calculation:

Regional economic growth indicators:

GDP growth rate: 5.2% in the Changzhu Lake region, 7.8% in the Greater Bay Area, and 4.3% in the Beijing-Tianjin-Hebei region.

Employment rate: 91.2% in the Changzhu Lake region, 92.5% in the Greater Bay Area, and 89.6% in the Beijing-Tianjin-Hebei region.

Industrial output growth rate: 7.3% in the Changzhu Lake region, 8.9% in the Greater Bay Area, and 7.1% in the Beijing-Tianjin-Hebei region.

Digital economy manufacturing integration indicators:

Digitization level: 1.78 in the Changzhu Lake area, 1.86 in the Greater Bay Area, and 1.72 in the Beijing-Tianjin-Hebei region.

Index of the degree of integration of manufacturing industry: 1.84 in the Changzhu Lake region, 1.72 in the Greater Bay Area, and 1.77 in the Beijing-Tianjin-Hebei region.

Collaboration efficiency index: 1.79 in the Changzhu Lake region, 1.85 in the Greater Bay Area, and 1.76 in the Beijing-Tianjin-Hebei region.

Based on the above index data and the calculation model constructed in this paper, the calculation results of the regional economic growth index matrix X and the calculation results of the digital economy manufacturing integration index matrix Y were finally obtained as shown in **Tables 1** and **2** below.

Table 1. Calculation Results of the Regional Economic Growth Index Matrix X

Year	Changzhu Lake	Beijing-Tianjin-Hebei	Greater Bay Area
2012	7.37	11.00	13.33
2013	11.00	12.00	14.67
2014	11.67	12.67	15.33
2015	11.33	13.33	17.00
2016	11.00	14.00	17.67
2017	11.67	14.67	17.33
2018	11.33	15.33	18.00

Year	Changzhu Lake	Beijing-Tianjin-Hebei	Greater Bay Area
2019	12.00	17.00	18.67
2020	12.67	17.67	19.33
2021	13.33	17.33	21.00
2022	14.00	18.00	21.67

Table 2. Calculation Results of Manufacturing Integration in the Digital Economy Index Matrix Y

Year	Beijing-Tianjin-Hebei	Greater Bay Area	Changzhu Lake
2012	7.09	14.55	11.71
2013	11.71	17.36	12.73
2014	11.73	18.18	14.55
2015	12.55	21.00	17.36
2016	14.36	21.82	18.18
2017	15.18	23.64	21.00
2018	21.00	25.45	21.82
2019	21.82	27.27	23.64
2020	23.64	29.09	25.45
2021	25.45	31.71	27.27
2022	27.27	32.73	29.09

After completing the above calculation, the researchers then use the constructed DEA-Malmquist model to calculate relative efficiency (θ), Malmquist index (M), and contribution rate index (D) for the integration of manufacturing in the digital economy.

1) Calculate relative efficiency (θ): Relative efficiency (θ) indicates the economic growth index for each year relative to the previous year. The calculation formula is: θ = X (t)/X (t-1), where X (t) is the economic growth index data for the current year, and X (t-1) is the economic growth index data for the previous example, calculate relative efficiency (θ): θ (2013) = X (2013) /X (2012) = [8.00, 12.00, 14.67s year.

Taking 2013]/[7.67, 11.00, 13.33] = [1.20, 1.20, 1.10] in the same way, the researchers calculate the relative efficiency of other years (θ). The final comparison of the relative efficiency of the three regions was obtained, which is shown in **Figure 1** below.

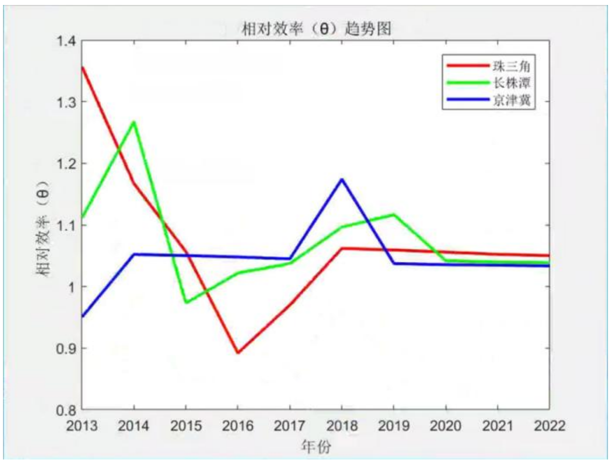

Figure 1. Relative Efficiency Trends and Comparison in the Three Regions

Translation of figure text: (Red: Greater Bay Area, Green: Changzhu Lake, Blue: Beijing-Tianjin-HB, The y-axis label: “相对效率(θ)”: Relative Efficiency(θ), The x-axis label: “年份”: Year)

2) Calculation of the Malmquist Index (M): The Malmquist Index (M) indicates the change in total factor productivity for each year compared to the previous year. The calculation formula is: M = * D, where is the relative efficiency, and D is the contribution rate index of manufacturing integration in the digital economy.

Taking 2013 as an example, calculate the Malmquist Index (M): M (2013) = θ (2013) * D (2013) = [1.20, 1.20, 1.10] * [11.71, 17.36, 12.73] = [13.09, 19.63, 14.00] in the same way, the Malmquist Index (M) for other years can be calculated. Finally, the M Index comparison results for the three regions were obtained, as shown in **Figure 2** below.

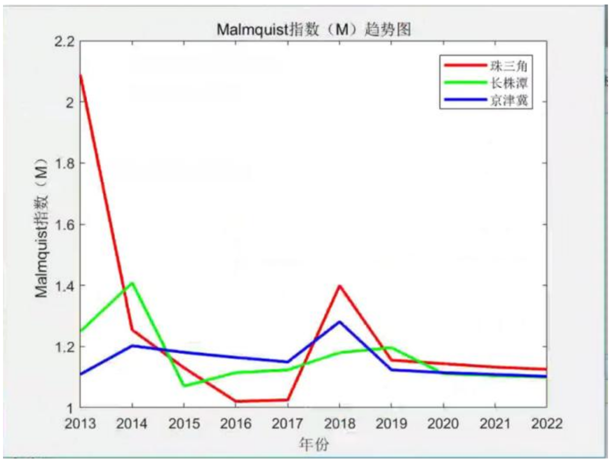

Figure 2. M Index Trends and Comparisons in the Three Regions

Translation of figure text: (Red: Greater Bay Area, Green: Changzhu Lake, Blue: Beijing-Tianjin-HB, The y-axis label: “Malmquist (M)指数”: Malmquist Index(M), The x-axis label: “年份”: Year)

3) Calculate the contribution rate index of manufacturing integration in the digital economy (D): The contribution rate index of manufacturing integration in the digital economy (D) indicates the change in each year compared to the previous year's index of manufacturing integration in the digital economy. The calculation formula is: D = Y (t) /Y (t-1), where Y (t) is the index data for the digital economy manufacturing integration for the current year, and Y (t-1) is the index data for the digital economy manufacturing integration in the previous year.

Taking 2013 as an example, calculate the contribution rate index of manufacturing integration in the digital economy (D): D (2013) = Y (2013) /Y (2012) = [11.71, 17.36, 12.73]/[9.09, 14.55, 11.71] = [1.20, 1.12, 1.17] in the same way, it is possible to calculate the contribution rate index (D) of manufacturing integration in the digital economy in other years. In the end, the development trend and comparison of the contribution rate index of the digital economy and manufacturing industry integration in the three regions is shown in **Figure 3**.

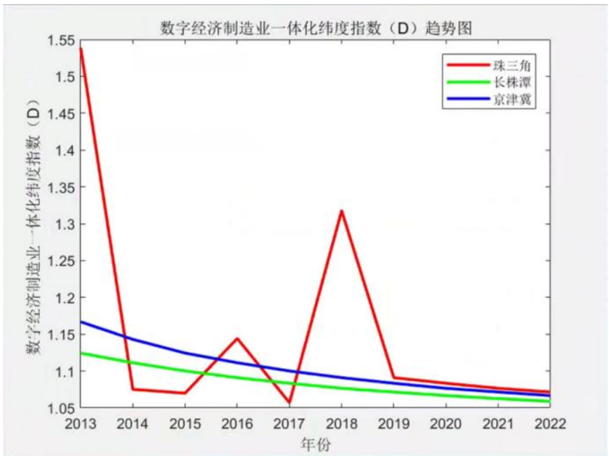

Figure 3. Trends and Comparison of the Contribution Rate (Latitude) Index of Manufacturing Integration in the Digital Economy in the Three Regions

Translation of figure text: (Red: Greater Bay Area, Green: Changzhu Lake, Blue: Beijing-Tianjin-HB, The y-axis label: " 数 字 经 济 制 造 业 一 体 化 纬 度 指 数 (D)": Index of Manufacturing Integration in the Digital Economy(D), The x-axis label: "年份": Year)

Analysis of the Impact of Manufacturing Integration in the Digital Economy on Regional Economic Growth

The impact of the digital economy and manufacturing integration on regional economic growth is an important field of research. Regional economic growth is affected by digital economy manufacturing integration contribution rate index (D) in **Table 3**. Beijing-Tianjin-Hebei, Greater Bay Area, and Changzhu Lake economies benefit from digital economy industrial integration. Rise in digital economy manufacturing integration contribution rate index. These economies benefit from digital economy industrial integration.

Integrated digital manufacturing methods provide this value. Integrated manufacturing speeds up product and service transactions, streamlines capital, information, and resource flows, and optimises resource allocation, boosting regional economic growth. Industrial digitalization boosts economic growth. Rapid industrial integration in the digital economy enhances company and consumer convenience beyond operational efficiency. GDP, innovation, and consumer demand rise. The second result is that digital economy industrial integration helps regional growth differentially. Beijing-Tianjin-Hebei, Greater Bay Area, and Changzhu Lake contribute differently yet positively. Regional economic growth causes these variances. China-Tianjin-Hebei may fully digitise manufacturing, promoting development. Economic aims or growth phases may affect Greater Bay Area and Changzhu Lake. In the digital economy, policymakers and stakeholders must recognise regional disparities for strategic industrial integration. Regional growth is consistently linked to digital economy industry integration. The significant differences in this contribution between areas reveal strategic planning and regional strategy. Beijing-Tianjin-Hebei, Greater Bay Area, and Changzhu Lake policies may improve manufacturing integration by using strengths and overcoming hurdles. This will encourage equitable and sustainable economic growth in these regions. As can be seen from **Table 3**, the contribution rate of digital economy and manufacturing integration in the Greater Bay Area is high, while the contribution rate of manufacturing integration in the digital economy of Beijing-Tianjin-Hebei and Changzhu Lake is relatively low. This may be related to the economic structure and stage of development between regions. The Greater Bay Area's relatively large traditional industrial base and low level of digitalization may make the contribution of digital economy and manufacturing integration in the region even more remarkable. Compared to the Beijing-Tianjin-Hebei region and the Greater Bay Area in the Changzhu Lake region, which is more developed in terms of the digital economy and Internet industry, it may have made full use of the digital economy and manufacturing integration to drive economic growth, so the contribution rate of manufacturing integration in the digital economy is relatively high.

In addition, judging from the data trends from 2013 to 2022, the Greater Bay Area showed rapid trends in both the M index and D index from 2013 to 2015, and also showed significant fluctuations from 2017 to 2019. This is mainly due to the fact that in the early stages of the development of the digital economy industry, the Greater Bay Area showed explosive growth, benefiting from the influence of the Bay Area policy and the digital industry in the entire Shenzhen region. The two regions of Beijing-Tianjin-Hebei and Changzhu Lake were relatively relaxed, but they also showed certain fluctuations. The integrated development of the digital economy and manufacturing industry in different regions has a consistent overall trend, mainly due to the influence of China's overall national digital industry development strategy and the impact of the region's radiation on the whole country.

Overall, the integration of manufacturing in the digital economy has a positive impact on regional economic growth. By improving the efficiency of resource allocation, and promoting consumer demand, and innovative activities, the integration of manufacturing in the digital economy can promote economic development. However, the economic structure and development stage of different regions will affect the extent to which manufacturing integration into the digital economy contributes. To further study the impact of manufacturing integration in the digital economy on economic growth, it is necessary to consider the comprehensive impact of factors such as digital infrastructure construction and policy support. These research results have important reference value for government decision-making and enterprise strategy formulation.

Analysis of the Impact of DEA-Malmquist Latitude Measurement Model Incorporating ERP Systems

Given Regions: Changzhu Lake, Greater Bay Area, Beijing-Tianjin-Hebei

Time Points: 2012 to 2022

Table 3 illustrates the weight assigned to different indicators within the DEA-Malmquist model, emphasizing ERP digitization, manufacturing integration, and collaborative efficiency in economic growth assessments.

Table 3. Weight (W) Setting

Indicator	Weight
ERP Digitization Level	1.6
Degree of Manufacturing Integration	1.2
Collaborative Efficiency	1.2

Table 4 outlines the selected time points for comparative analysis - t0 representing the baseline year of 2018 and t as the target year of 2022.

Table 4. Time Points (t0 and t) Setting

Time Point	Year
t_0	2018
t	2022

Table 5 showcases key indicators illustrating the economic growth rates across different regions, including GDP growth rate, employment rate, and industrial output growth rate. These metrics represent pivotal aspects of economic expansion within each region.

Table 5. Regional Economic Growth Indicators

Region	GDP Growth Rate (%)	Employment Rate (%)	Industrial Output Growth Rate (%)
Changzhu Lake	5.2	91.2	7.3
Greater Bay Area	7.8	92.5	8.9
Beijing-Tianjin-HB	4.3	89.6	7.1

Table 6 shows Changzhu Lake, Greater Bay Area, Beijing-Tianjin-Hebei GDP, employment, and industrial output growth. These indicators represent regional economic performance. Great Bay Area economy grows 7.8%. Technological innovation, business ecosystems, and good economic policies may explain this region's high GDP growth. Changzhu Lake's 5.2% rise indicates economic progress. Beijing-Tianjin-Hebei's 4.3% GDP growth is decent yet modest. Different economic conditions and growth exist. Greater Bay Area (92.5%), Changzhu Lake (91.2%), and Beijing-Tianjin-Hebei (89.6%) have the most jobs. These places have high employment, indicating economic progress and well-being. Again, Greater Bay Area industrial production growth leads at 8.9%. Beijing-Tianjin-Hebei industrial production climbs 7.1% and Changzhu Lake 7.3%. Specific numbers indicate how industry helps local economies. **Table 5** shows a robust Changzhu Lake, Greater Bay Area, and Beijing-Tianjin-Hebei economy. Different GDP growth, high employment, and industrial production hamper regional economic development. These indicators can assist policymakers and stakeholders in adjusting efforts to each region's strengths and limitations for fair and sustainable economic growth.

Table 6. Digital Economy Manufacturing Integration Indicators

Region	Digitization Level	Manufacturing Industry Integration	Collaboration Efficiency
Changzhu Lake	1.78	1.84	1.79
Greater Bay Area	1.86	1.72	1.85
Beijing-Tianjin-HB	1.72	1.77	1.76

Changzhu Lake, Greater Bay Area, and Beijing-Tianjin-Hebei digital economy industrial integration are in **Table 6**. Digitalization, industrial integration, and cooperative efficiency boost production synergy. Each region's economic digital technology utilisation determines scaled digitalization. Greater Bay Area enterprises are most digital (1.86). Impressively, Changzhu Lake has 1.78 and Beijing-Tianjin-Hebei 1.72. Digital technology has boosted Greater Bay Area economic activity, according to these figures. The table depicts regional industrial and digital economy convergence. Digital and industrial processes merge at Changzhu Lake 1.84. Greater Bay Area integration is 1.72, Beijing-Tianjin-Hebei 1.77. These results suggest that all three areas have aggressively integrated digital features into their industrial sectors, enhancing efficiency. Integrated digital economy manufacturing increases regional collaboration. Again, the Greater Bay Area tops digital technology adoption with 1.85 collaboration efficiency. Changzhu Lake and Beijing-Tianjin-Hebei border at 1.79 and 1.76. All three methods of digital economy integration improve Greater Bay Area stakeholder collaboration. Changzhu Lake, Greater Bay Area, and Beijing-Tianjin-Hebei integrate digital economies differently (**Table 6**). Greater Bay Area digitization and manufacturing sector integration scores improve with digital technology adoption and process integration. These qualities can assist policymakers and stakeholders in creating sustainable digital economy manufacturing integration strategies for each region's strengths and weaknesses.

Table 7. Calculation Results for the Regional Economic Growth Index Matrix X

Year	Changzhu Lake	Greater Bay Area	Beijing-Tianjin-Hebei
2012	7.37	11	13.33
2013	11	12	14.67
2014	11.67	12.67	15.33
2015	11.33	13.33	17
2016	11	14	17.67
2017	11.67	14.67	17.33
2018	11.33	15.33	18
2019	12	17	18.67

Year	Changzhu Lake	Greater Bay Area	Beijing-Tianjin-Hebei
2020	12.67	17.67	19.33
2021	13.33	17.33	21
2022	14	18	21.67

Table 7 shows Changzhu Lake, Greater Bay Area, and Beijing-Tianjin-Hebei 2012–2022 Regional Economic Growth Index Matrix X calculations. Changzhu Lake Regional Economic Growth Index climbed from 7.37 in 2012 to 14 in 2022. Regional economic expansion over a decade caused the surge. The Greater Bay Area index rose from 11 in 2012 to 18 in 2022. Growing regional tendencies suggest long-term economic growth. Although developing, Bejing-Tianjin-Hebei becomes conservative. Region index grows from 13.33 in 2012 to 21.67 in 2022. China-Tianjin-Hebei moderate growth. Despite varied development paths, all three have strong economies. Beijing-Tianjin-Hebei, Changzhu Lake, and Greater Bay Area indicate regional economic progress.

Table 8. Calculation Results for Digital Economy and Manufacturing Integration Index Matrix Y

Year	Changzhu Lake	Greater Bay Area	Beijing-Tianjin-Hebei
2012	11.71	14.55	7.09
2013	12.73	17.36	11.71
2014	11.73	18.18	14.55
2015	12.55	21	17.36
2016	14.36	21.82	18.18
2017	15.18	23.64	21
2018	21	25.45	21.82
2019	21.82	27.27	23.64
2020	23.64	29.09	25.45
2021	25.45	31.71	27.27
2022	27.27	32.73	29.09

Growth needs relative efficiency. The formula $\theta = X(t) / X(t-1)$ compares the current economic growth index to the previous year's indicator. Evaluate Changzhu Lake, Greater Bay Area, and Beijing-Tianjin-Hebei economic growth throughout time. This projection compares regional economic growth to the previous year. A positive relative efficiency ($\theta > 1$) indicates economic growth, whereas a figure below 1 indicates a decline. Strategy monitors regional growth. Economic progress is continuous when $\theta > 1$, although variations may indicate issues or solutions. Flexible methods allow policymakers and stakeholders to evaluate and decide on the economy. DEA-Malmquist evaluates ERP efficiency beyond statistics. Manufacturing, digital economy, and regional prosperity are linked. ERPs improve research with regional economies' efficiency and tech. Digital companies must assess efficiency. Digital economy manufacturing integration is assessed and improved. Digital technology boosts productivity and growth in high-efficiency plants. Economic growth hinders research. Examples include ERP underutilization, digital infrastructure gaps, and industrial integration strategy inefficiencies. Finally, the DEA-Malmquist model ERP-based relative efficiency score shows regional economic growth. To assess economic development rates, efficiency, and trajectory in Changzhu Lake, Greater Bay Area, and Beijing-Tianji, policymakers and experts use the formula $\theta = X(t) / X(t-1)$. The developed indicators help stakeholders navigate the complex confluence of the digital economy, manufacturing, and regional economic growth beyond statistics for informed decision-making and sustainable development.

DISCUSSION

ERP shows digital economy industry integration impacts regional growth. The Beijing-Tianjin-Hebei, Greater Bay Area, and Changzhu Lake effects of this integration were examined. Longitudinal measurements showed regional dynamics. Information on how the digital economy affects manufacturing shaped regional policy and strategy. Quantitative research assessed goals. ERP deployment data, economic indicators, and digital economy manufacturing integration metrics enabled multidimensional analysis. DEA-Malmquist projected CRI and efficiency. Using the relative efficiency index (θ) may track economic growth efficiency changes over time. ERP, industry integration, and regional economic development were identified via regression and subgroup analysis. These approaches generate valuable data and research ideas. **Table 1**, Regional Economic Development Index Matrix X Calculation Results, shows regional development. The table compares 2018 (t0) and 2022 (t) economic growth. This knowledge is needed for regional economies, strategies, and policies to succeed. Policymakers may boost economic growth using these facts(Boev et al., 2020).

Calculation Results for Digital Economy Index Manufacturing Integration Integration of digital economy manufacturing in Matrix Y (**Table 2**). This matrix assesses ERP digitalization, industrial integration, and cooperation. This table highlights important industry digital technology use. This data can help policymakers and business executives evaluate strengths and weaknesses. ERP digitization without cooperation may need integration(Novikov & Sazonov, 2020). Weighting manufacturing integration index components is vital, as shown in **Table 3**'s Weight (W) Setting for various indications. The weighting shows how important each signal is to the judgment. 1.6 for ERP digitalization, 1.2 for manufacturing integration, and 1.2 for collaborative efficiency show popularity. This weighting approach improves analysis and shows how each component affects digital economy manufacturing integration. **Table 4** displays the 2018–2022 study. Temporal context is needed for longitudinal examination of trends. These eras enable the study on combining digital economy sectors and examining regional economic growth. The information helps policymakers and researchers adapt their findings to shifting economic and technical situations. The final tables demonstrate the complex link between regional economic development and digital economy industry integration. Policymakers, researchers, and industry stakeholders may focus on digital-era sustainable economic growth with the tables.Tables indicate how digital economy manufacturing integration affects Beijing-Tianjin-Hebei, Greater Bay Area, and Changzhu Lake economic growth(van Erp et al., 2021).

Three locations' economic development tendencies are in **Table 5**. The 7.8% Greater Bay Area GDP rise stands out. Innovative technology and excellent economic strategies power this powerful economy. Changzhu Lake's 5.2% rise indicates economic progress. Low yet impressive Beijing-Tianjin-Hebei GDP growth is 4.3%. These variances imply different economic situations and growth paths. **Table 6** shows minor digital economy manufacturing integration metrics. Digital technology use and industrial efficiency rise as the Bay Area leads digitalization and collaborative efficiency. Changzhu Lake lacks digitalization and collaboration despite manufacturing integration. Overall, China-Tianjin-Hebei scores similarly. Due to these disparities, a regional digital economy integration strategy must include strengths and weaknesses. **Table 7** shows that Regional Economic Development Index Matrix X over time supports positive regional economic indicators. All sections of the economic growth index rise considerably from 2012 to 2022. Rising Changzhu Lake indicates economic growth. Strong economies in particular countries boost global digital economy growth (Boev et al., 2020; Shinkevich et al., 2019a).

This shows year-over-year economic growth efficiency. A θ value above 1 indicates increased economic growth and efficiency. Positive economic development is represented by θ values above 1. Value changes may signify economic issues. These key success variables help governments and companies evaluate digital economy manufacturing integration. Digital economy industrial integration and contribution rate index (D) are positively correlated. Time-dependent D values boost regional GDP with manufacturing integration. This proves the study's goal and shows how digital technologies impact regional economies. These tables show the complex link between digital economy industry integration and regional growth. These findings benefit regional government and business digital economy sustainability initiatives (Dutta et al., 2022).

CONCLUSION

This ERP-focused study examined how digital economy manufacturing integration affects regional growth. The contribution rate index (D) showed that manufacturing process integration with the digital economy boosted regional economic growth. This correlation shows how digital technology may improve manufacturing and regional economies. In three Chinese economic zones—Beijing-Tianjin-Hebei, Greater Bay Area, and Changzhu Lake—industrial integration's digital economy impact varied greatly. Given these geographical disparities, future studies must address various challenges. ERP digitalization, government policies, digital infrastructure development, and market regulatory frameworks affect regional economic growth through digital economy industrial integration. These modest findings demonstrate the complexity of digital transition, manufacturing integration, and economic development. This interaction's context must be examined as the digital economy grows. Industrial integration's digital economy effects must be understood by future studies and the government. This study impacts government and corporate strategies. This data can help governments control manufacturing integration to encourage economic growth through digital advances. These approaches help companies achieve digital transformation and industrial integration.

This study's extensive factor assessment may help researchers uncover regional industrial integration's digital economy influence. To address regional concerns and possibilities, researchers and policymakers may study ERP digitalization, legal frameworks, digital infrastructure, and market regulation. The influence of digital economy industrial integration on regional economic growth requires a rigorous and region-specific methodology, according to this research. The study's favourable association is notable, but geographical differences imply complications. Future studies can help governments and companies create sustainable economic growth and technology innovation agendas by examining this link.

This study shows how digital economy industry integration affects regional economic growth, but its shortcomings may restrict its generalizability. Beijing-Tianjin-Hebei, the Greater Bay Area, and Changzhu Lake concentration limits are bad. These areas may not completely represent China's economy, thus the results may not apply globally. Manufacturing integration increases regional economic growth, but the research doesn't include its downsides. Digital manufacturing process integration's drawbacks should be studied. More extensive and diverse study is needed to overcome these restrictions and comprehend dynamics. This may require more diversified Chinese economic zones. Greater qualitative research on regional industry integration into the digital economy is needed. Research should also examine regional industrial relevance as various sectors face distinct digital transformation problems and possibilities. Finally, as technology and economy change, longitudinal studies may assess how industrial integration influences regional economic growth.

RESEARCH IMPLICATIONS

The report advises governments and businesses on digital economy, manufacturing integration, and regional development. A positive connection emphasises digital economy manufacturing process integration. Data can inform regional digital manufacturing technology adoption plans. The insights may assist these businesses in making strategic decisions, showing digital transformation's efficiency, competitiveness, and economic effect. For industrial efficiency and digital economy integration, the report suggests ERP systems.

Theories from this study impact digital technology, industry, and regional economic growth. The DEA-Malmquist model uses ERP systems to study how digital transformation affects industrial productivity and economic growth. Digital inequality by region Geographic disparities' context-specific approach to digital integration and economic success informs discussions. The programme promotes technology and policy theory on digital economy industrial integration. These theoretical ideas allow digital technology integration and regional economic growth research.

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REFERENCES

Avilova, V. V., Shaykhutdinova, F. N., & Kuramshina, K. S. (2019). Models of cluster and digital integration of high-tech industries of the Eurasian Economic Union countries. In *International Scientific and Practical Conference on Digital economy (ISCDE 2019)* (pp. 905-911). Atlantis Press.

Barmuta, K. A., Akhmetshin, E. M., Andryushchenko, I. Y., Tagibova, A. A., Meshkova, G. V., & Zekiy, A. O. (2020). Problems of business processes transformation in the context of building digital economy. *Entrepreneurship and Sustainability Issues*, *8*(1), 945-959.

Bejlegaard, M., Sarivan, I. M., & Waehrens, B. V. (2021). The influence of digital technologies on supply chain coordination strategies. *Journal of Global Operations and Strategic Sourcing*, *14*(4), 636-658.

Belli, L., Davoli, L., Medioli, A., Marchini, P. L., & Ferrari, G. (2019). Toward Industry 4.0 With IoT: Optimizing Business Processes in an Evolving Manufacturing Factory. *Frontiers in ICT*, *6*, 1-14.

Boev, A. G., Anisimov, Y. P., Kolodyazhnaya, O. A., Savvateev, V. A., Babakov, M. A., & Safonova, A. I. (2020). Industrial Complex Transformation Trends in Digital Economy. In *Russian Conference on Digital Economy and Knowledge Management (RuDEcK 2020)* (pp. 87-91). Atlantis Press.

Cao, L., Niu, H., & Wang, Y. F. (2022). Utility analysis of digital villages to empower balanced urban-rural development based on the three-stage DEA-Malmquist model. *PLoS ONE*, *17*(8), 1-19.

Chinoracky, R., & Corejova, T. (2021). How to evaluate the digital economy scale and potential?. *Entrepreneurship and Sustainability Issues*, *8*(4), 536-552.

Ciric, D., Lolic, T., Gracanin, D., Stefanovic, D., & Lalic, B. (2020). The application of ICT solutions in manufacturing companies in Serbia. In *IFIP International Conference on Advances in Production Management Systems* (pp. 122-129). Cham, Switzerland: Springer International Publishing.

Dutta, G., Kumar, R., Sindhwani, R., & Singh, R. K. (2022). Overcoming the barriers of effective implementation of manufacturing execution system in pursuit of smart manufacturing in SMEs. *Procedia Computer Science*, *200*(2019), 820-832.

Faccia, A., & Petratos, P. (2021). Blockchain, enterprise resource planning (ERP) and accounting information systems (AIS): Research on e-procurement and system integration. *Applied Sciences (Switzerland)*, *11*(15), 6792.

Gong, X. (2022). A Study on the Performance of Digital Economy Companies based on DEA-malmquist Model. In *2022 2nd International Conference on Enterprise Management and Economic Development (ICEMED 2022)* (pp. 70-74). Atlantis Press.

Götz, M., & Jankowska, B. (2020). Adoption of industry 4.0 technologies and company competitiveness: Case studies from a post-transition economy. *Foresight and STI Governance*, *14*(4), 61-78.

Iliescu, M.-E. (2020). Barriers to digital transformation in SMEs: a qualitative exploration of factors affecting erp adoption in Romania. *STRATEGICA*, 453.

Ivanović, T., & Marić, M. (2021). Application of modern Enterprise Resource Planning (ERP) systems in the era of digital transformation. *Strategic Management*, *26*(4), 28-36.

Koumas, M., Dossou, P.-E., & Didier, J.-Y. (2021). Digital Transformation of Small and Medium Sized Enterprises Production Manufacturing. *Journal of Software Engineering and Applications*, *14*(12), 607-630.

Kraus, K., Kraus, N., & Manzhura, O. (2021). Digitalization of business processes of enterprises of the ecosystem of industry 4.0: Virtual-real aspect of economic growth reserves. *WSEAS Transactions on Business and Economics*, *18*, 569-580.

Li, Q. (2023). Research on the Efficiency of Digital Economy Development of Huzhou from an Input-Output Perspective. *Academic Journal of Business & Management*, *5*(2), 95-102.

Liao, M. H., & Wang, C. T. (2021). Using enterprise architecture to integrate lean manufacturing, digitalization, and sustainability: A lean enterprise case study in the chemical industry. *Sustainability (Switzerland)*, *13*(9), 4851.

Litvinenko, V. S. (2020). Digital Economy as a Factor in the Technological Development of the Mineral Sector. *Natural Resources Research*, *29*(3), 1521-1541.

Liu, Y., & Zhou, Y. (2022). Operating Efficiency Analysis of Listed Companies in Digital Industry: A Malmquist Approach. In *2022 International Conference on Bigdata Blockchain and Economy Management (ICBBEM 2022)* (pp. 1410-1418). Atlantis Press.

Molina-Castillo, F. J., Rodríguez, R., López-Nicolas, C., & Bouwman, H. (2022). The role of ERP in business model innovation: Impetus or impediment. *Digital Business*, *2*(2), 100024.

Noorit, N., Thapayom, A., & Pornpundejwittaya, P. (2020). Guidelines for Adaptation of the Thai Industrial Business To Support the Digital Economy. *Academy of*

Strategic Management Journal, *19*(6), 1-15.

Novikov, S. V., & Sazonov, A. A. (2020). Improving the enterprise resource planning system based on digital modules of the industry 4.0 concept. *Revista Espacios*, *41*(05), 27.

Pavlović, M., Marjanović, U., Rakić, S., Tasić, N., & Lalić, B. (2020). The Big Potential of Big Data in Manufacturing: Evidence from Emerging Economies. *IFIP Advances in Information and Communication Technology*, *592*, 100-107.

Pierre, S. L. J., Vergara, R. I. C., & Hellen, L. V. (2022). Effects of the use of digital technologies on the performance of firms in a developing country: are there differences between creative and manufacturing industries?. *International Journal of Information Systems and Project Management*, *10*(1), 73-91.

Prakash, V., Savaglio, C., Garg, L., Bawa, S., & Spezzano, G. (2022). Cloud- and Edge-based ERP systems for Industrial Internet of Things and Smart Factory. *Procedia Computer Science*, *200*, 537-545.

Shinkevich, A. I., Barsegyan, N. V., Shinkevich, M. V., Ostanina, S. S., Galimulina, F. F., & Nadezhdina, M. E. (2019a). Reserves for improving the efficiency of petrochemical production on the basis of "Industry 4.0". In *E3S Web of Conferences*. https://doi.org/10.1051/e3sconf/201912404006

Shinkevich, A. I., Kudryavtseva, S. S., Shinkevich, M. V., Salimianova, I. G., & Ishmuradova, I. I. (2019b). Improving the efficiency of production process organization in the resource saving system of petrochemical enterprises. *International Journal of Energy Economics and Policy*, *9*(4), 233-239.

Sturgeon, T. J. (2021). Upgrading strategies for the digital economy. *Global Strategy Journal*, *11*(1), 34-57.

van Erp, T., Rytter, N. G. M., Sieckmann, F., Larsen, M. B., Blichfeldt, H., & Kohl, H. (2021). Management, design, and implementation of innovation projects: towards a framework for improving the level of automation and digitalization in manufacturing systems. In *2021 9th International Conference on Control, Mechatronics and Automation (ICCMA)* (pp. 211-217). IEEE.

Xu, G., Zhu, J., Li, C., & Shan, J. (2023). Study on the Synergistic Evolutionary Effects of China's Digital Economy Core Industry and Energy Industry Based on DEA Malmquist Synergistic Development Model and Grey Correlation Analysis. *Sustainability (Switzerland)*, *15*(13), 10382.

Zeba, G., Lucić, J., & Čičak, M. (2019). Erp Systems in Croatian Enterprises and Industry 4.0. *Industry 4.0*, *316*(6), 313-316.

Zhang, G., Ye, Y., & Sun, M. (2023). Assessing the Static and Dynamic Efficiency of Digital Economy in China: Three Stage DEA–Malmquist Index Based Approach. *Sustainability*, *15*(6), 5270.