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Medical Imaging Technologies and Healthcare Infrastructure: Artificial Intelligence-Based Analysis of Global Trends

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ABSTRACT Medical imaging technologies have a critical role in improving healthcare efficiency, diagnostic accuracy, and patient outcomes. This study investigates the global distribution of advanced medical imaging devices such as computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and mammography across OECD countries between 2015 and 2023 using OECD health data. Using correlation and regression analyses, this research explores the relationships between imaging device density, healthcare infrastructure capacity, population size, and healthcare expenditures. The analysis reveals a strong positive correlation between imaging device availability and healthcare infrastructure capacity ($\rho = 0.77$), as well as a robust association with population size ($\rho = 0.87$). In contrast, healthcare expenditures demonstrate a weaker relationship with these variables ($\rho \approx 0.41 - 0.55$), indicating that strategic planning is essential beyond mere budget increases. K-Means clustering and Principal Component Analysis (PCA) categorize countries into distinct groups according to imaging technology availability and infrastructure capacity. Integration of artificial intelligence (AI) within medical imaging is highlighted as a promising approach for enhancing early diagnosis, reducing unnecessary healthcare utilization, and improving operational efficiency. Findings emphasize that effective healthcare policies should focus not only on increasing budgets but also on targeted resource allocation, infrastructure optimization, and adoption of advanced AI technologies.

KEYWORDS
Artificial intelligence
Medical imaging technologies
Healthcare infrastructure
Regression analysis
OECD health data
CT
MRI
PET
Healthcare expenditures
Clustering analysis
Principal component analysis

INTRODUCTION

Medical imaging technologies are foundational elements of contemporary healthcare systems, playing a critical role in enhancing diagnostic precision, clinical decision-making, and treatment planning. The widespread use of advanced imaging modalities such as computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and mammography has substantially improved early disease detection and patient outcomes across many developed nations (Lei *et al.* 2024; Deng *et al.* 2024). However, significant disparities remain in access to these technologies, particularly between high-income and lower-income countries.

In recent years, the integration of artificial intelligence (AI) into medical imaging has introduced transformative capabilities that go beyond conventional imaging. AI-powered tools, including deep learning algorithms, convolutional neural networks, and computer-aided diagnosis (CAD) systems have enhanced lesion detection, reduced noise in low-dose CT (LDCT) images, and improved diagnostic efficiency (Zubair *et al.* 2024). Countries such as South Korea, Germany, and the Netherlands have pioneered the deployment of AI-supported imaging workflows, demonstrating the potential of AI to elevate diagnostic quality and streamline radiology operations. Despite these advances, global adoption of AI-enhanced imaging remains uneven and often limited by infrastructure, budgetary constraints, and policy readiness.

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Effective utilization of imaging technologies depends not only on equipment acquisition but also on the broader healthcare infrastructure in which these technologies are embedded. Numerous studies have confirmed that medical imaging device availability correlates strongly with healthcare infrastructure indicators, including hospital bed density, intensive care unit (ICU) availability, and qualified personnel (Rhodes *et al.* 2012; Phua *et al.* 2020). In countries with well-developed healthcare systems, access to high-performance imaging is facilitated by complementary investments in institutional capacity, workforce, and information systems. In contrast, infrastructure deficiencies often constrain device utilization in lower-resourced settings (Murthy *et al.* 2015).

Although previous research has explored the associations between population size, healthcare expenditures, and imaging technology distribution (Jones 2024; Hou *et al.* 2020), the role of AI integration and strategic planning in shaping such distributions remains underexplored. Existing studies rarely assess how technological readiness and digital health policies intersect with economic and demographic factors to influence the deployment of imaging technologies. Furthermore, healthcare expenditures alone have proven insufficient to explain the variability in imaging device density, highlighting the importance of targeted infrastructure planning and resource optimization.

This study aims to investigate the global distribution of advanced medical imaging devices across OECD countries over the period 2015 to 2023. This time frame was selected based on data availability and completeness in the OECD Health Statistics database, as well as to capture critical developments during the COVID-19 pandemic, which significantly impacted healthcare investments and imaging needs. By employing multivariate statistical techniques, correlation analysis, regression modeling, K-Means clustering, and principal component analysis (PCA), this research examines the relationships between imaging device density, healthcare infrastructure capacity, population dynamics, and healthcare spending. Additionally, it evaluates the strategic implications of AI integration in improving imaging accessibility and infrastructure efficiency. The findings aim to provide evidence-based recommendations for health policymakers to support equitable, efficient, and AI-informed imaging infrastructure planning across diverse healthcare contexts.

LITERATURE REVIEW

Recent literature from 2015 to 2024 has examined the evolving relationship between medical imaging technologies and healthcare infrastructure, focusing on two main dimensions: (1) the integration of artificial intelligence (AI) into advanced imaging modalities such as CT, MRI, and PET, and its impact on clinical effectiveness; and (2) the influence of demographic variables, population structure, income distribution, healthcare spending, and digital capacity on the equitable distribution of imaging technologies.

AI-Based Medical Imaging Applications

Artificial intelligence has fundamentally reshaped diagnostic imaging, particularly in radiology. Convolutional neural networks (CNNs) and deep learning algorithms have been shown to enhance lesion detection, classification, and segmentation in CT and MRI images, significantly improving diagnostic workflows (Deng *et al.* 2024; Hwang *et al.* 2024). In the context of PET imaging, AI-based models have improved molecular image analysis and contributed to advanced applications in drug development and immunotherapy (McGale *et al.* 2024). Countries like South Korea, Germany, and the Netherlands have led large-scale initiatives to incorporate AI-supported imaging systems into clinical practice, reflecting both technical maturity and policy-driven strategies (Hwang *et al.* 2024). However, gaps in infrastructure and workforce readiness remain critical barriers in middle- and low-income settings.

Hybrid Imaging Technologies: PET/CT and PET/MRI

Hybrid imaging modalities such as PET/CT and PET/MRI integrate anatomical and functional imaging to enhance diagnostic precision. While PET/CT remains dominant due to speed and cost-efficiency, PET/MRI offers superior soft tissue contrast, especially valuable in oncology (Lei *et al.* 2024). The incorporation of AI into hybrid imaging technologies remains an emerging but promising trend, offering benefits such as enhanced image reconstruction, faster processing times, and improved targeting for personalized therapy (McGale *et al.* 2024).

Low-Dose CT (LDCT) and Deep Learning Techniques

Growing concern over radiation exposure in CT imaging, particularly in lung cancer screening has driven the adoption of low-dose CT (LDCT). However, the reduced image quality in LDCT can hinder accurate diagnosis. Recent studies have demonstrated that deep learning-based denoising algorithms significantly enhance LDCT image clarity, enabling safer, high-frequency screenings without compromising diagnostic reliability (Zubair *et al.* 2024). These AI-driven solutions are particularly critical in resource-constrained environments where cost-effective yet accurate imaging is required.

Healthcare Infrastructure and Device Distribution

The distribution of medical imaging devices is strongly associated with national healthcare infrastructure metrics such as ICU capacity, hospital bed density, and trained personnel availability (Rhodes *et al.* 2012; Phua *et al.* 2020). High-income countries typically exhibit higher device density due to their established institutional frameworks and sustained investments. In contrast, countries with infrastructure deficits face limited diagnostic reach, regardless of healthcare spending levels (Murthy *et al.* 2015). Recent models suggest that capital investment, not merely operational expenditure, better predicts device acquisition trends across countries (Organisation for Economic Co-operation and Development (OECD) 2023).

Optimal Infrastructure Planning and Socioeconomic Determinants

Healthcare capacity planning increasingly incorporates variables such as population aging, chronic disease prevalence, mortality rates, and epidemiological transitions (Hou *et al.* 2020). However, emerging research emphasizes the role of income inequality, urban–rural divide, and health service accessibility in determining whether technological investments translate into actual clinical usage (Jones 2024). Countries with similar income levels often exhibit vastly different imaging accessibility outcomes due to differing investment priorities and policy efficiency. AI-based predictive modeling tools are increasingly utilized to optimize device placement, hospital capacity, and staff allocation (Hwang *et al.* 2024).

Digital Transformation and Health Information Technologies

The integration of information technology into healthcare systems has transformed operational management, diagnostics, and resource optimization. Tools such as electronic health records (EHR), health information exchanges (HIE), and AI-enhanced analytics platforms enable data-driven decision-making across both clinical and administrative domains (Agarwal *et al.* 2010). IT integration has been linked to reduced operational costs, better inventory control, improved service coverage, and ultimately, improved patient outcomes (Fichman *et al.* 2011). These systems form the backbone for AI deployment, ensuring that technological advances are embedded within an actionable infrastructure.

MATERIAL AND METHODS

This study adopts a quantitative research design to analyze the global distribution of medical imaging devices and their relationship with healthcare infrastructure capacity across OECD countries. The selected time frame, 2015–2023, was determined based on the completeness and consistency of OECD Health Statistics data across countries. This period also encompasses the COVID-19 pandemic years (2020–2022), which significantly influenced healthcare investment priorities, diagnostic demand, and infrastructure strain.

The dataset includes detailed indicators on the number of imaging devices per country, including computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and mammography units, as well as national population size, total healthcare expenditures, and general healthcare infrastructure indicators (e.g., hospital bed availability and ICU capacity). To explore the relationships between variables and underlying structures, the following analytical techniques were applied:

Correlation analysis was used to evaluate linear associations between device density, infrastructure capacity, population, and healthcare expenditure. Linear regression analysis assessed the predictive strength of these variables on imaging device availability, focusing on statistical significance and R^2 values. K-Means clustering was implemented to categorize countries based on similarity in device density and infrastructure. The optimal number of clusters (k=5) was identified using the elbow method, minimizing within-cluster sum of squares. Principal Component Analysis (PCA) was applied to standardized variables using Python's scikit-learn library. PCA helped identify latent dimensions, such as population-driven demand versus infrastructure-driven supply, that explain cross-national variability in device deployment. All statistical analyses were performed using SPSS version 28 and Python (pandas, numpy, matplotlib, scikit-learn) to ensure reproducibility and analytical robustness.

RESULTS

Growth Trends in Medical Imaging Devices

Between 2015 and 2023, the total number of medical imaging devices increased substantially across most OECD countries. CT and MRI devices experienced steady growth, driven by technological advancements, expanded clinical applications, and the increasing adoption of AI-supported diagnostic workflows. In contrast, PET device growth was more gradual, constrained by higher costs and limited specialist use cases (Figure 1).

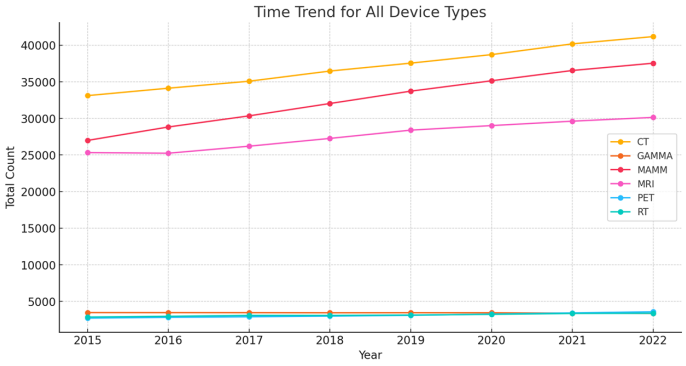

Figure 1 Annual Growth Trend of Medical Imaging Devices

Device availability showed pronounced variation among OECD nations. Countries such as Germany, Italy, South Korea, and Australia recorded the highest availability of CT scanners. MRI and PET scanners were predominantly concentrated in high-income countries such as Italy, France, Germany, and South Korea. In contrast, lower-income countries, including Mexico, Romania, and Turkey, exhibited significantly lower device densities, often limited by capital investment and workforce constraints (Figure 2).

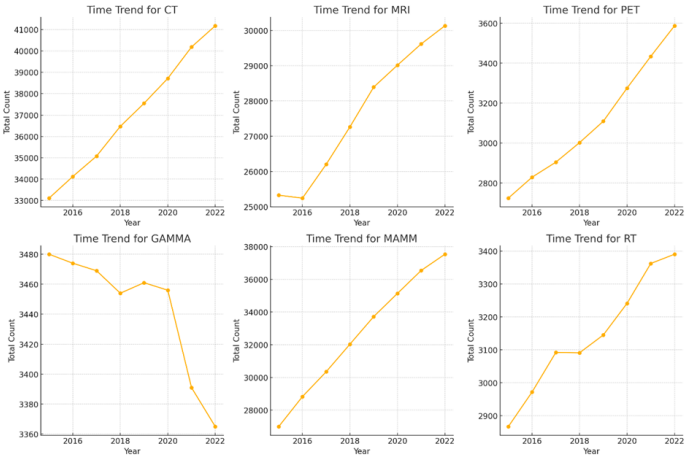

Figure 2 Time Trend of Medical Devices

Per Capita Medical Device Distribution

An analysis of per capita device density revealed that smaller, high-income countries such as Iceland, Denmark, and South Korea maintained the highest device availability per 100,000 population. Conversely, countries with large populations, such as Turkey and Mexico, displayed lower per capita values, despite possessing high absolute numbers of devices. This suggests that national population size can obscure disparities in accessibility when using total counts alone.

Correlation and Regression Analysis

Correlation analysis revealed strong positive associations between imaging device density and healthcare infrastructure capacity ($\rho = 0.77$), as well as population size ($\rho = 0.87$). In contrast, healthcare expenditures exhibited weaker correlations with device density ($\rho \approx 0.41 - 0.55$), indicating that fiscal inputs alone are not sufficient to explain technology diffusion.

Linear regression modeling confirmed that infrastructure capacity was the most significant predictor of device density ($R^2 = 0.827$,

$p < 0.01$), reinforcing the importance of investment in physical and institutional capacity alongside procurement strategies.

Clustering Analysis and PCA

Using K-Means clustering ($k = 5$), countries were grouped based on similarities in imaging device density and healthcare infrastructure. The highest-density cluster included the United States, Germany, and Japan, while mid-tier clusters featured countries such as Turkey, Poland, and Hungary. Low-density clusters encompassed Romania, Mexico, and Lithuania.

PCA results showed that the first two principal components explained a substantial portion of the variance. The first component was driven primarily by population size and device availability, while the second reflected infrastructure indicators such as hospital beds per capita. Interestingly, healthcare expenditure did not load heavily on either component, further supporting the idea that structural capacity and policy prioritization—rather than spending levels—are primary determinants of imaging availability (Figure 3).

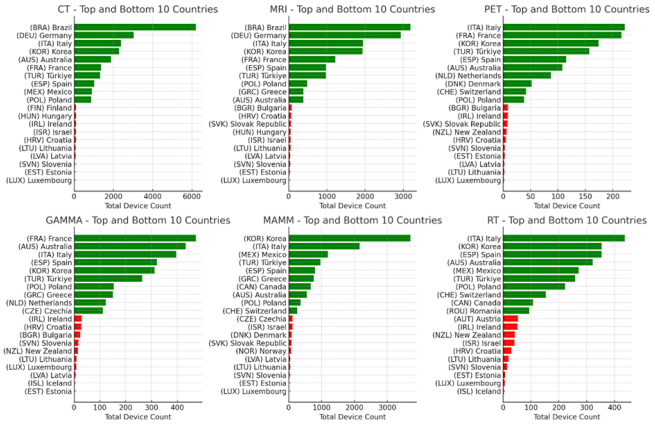

Figure 3 Comparison of Medical Imaging Device Availability: Top and Bottom 10 Countries

Medical Device Distribution by Population

Detailed device distribution analysis by population and income level highlighted structural inequities. Countries such as Australia, Greece, and South Korea ranked highest in per capita CT availability, while South Korea, Finland, and Germany led in MRI density. PET device access was highest in Denmark, the Netherlands, and Switzerland, while Romania, Lithuania, and Mexico ranked lowest.

Mammography distribution followed similar patterns: wealthier countries demonstrated higher access, while lower-income nations lagged behind. Gamma devices (e.g., gamma cameras for nuclear medicine) were found predominantly in Western Europe, with significantly limited availability in Turkey, Romania, and Mexico. Radiotherapy device distribution was similarly uneven, Italy, South Korea, and Spain exhibited the highest per capita RT density, while Estonia, Slovenia, and Luxembourg ranked lowest.

These variations are closely tied to health policy strategies, income distribution, and national investment models. Countries with strong healthcare governance and capital planning maintained high per capita access, even when overall population size was small (Figure 4).

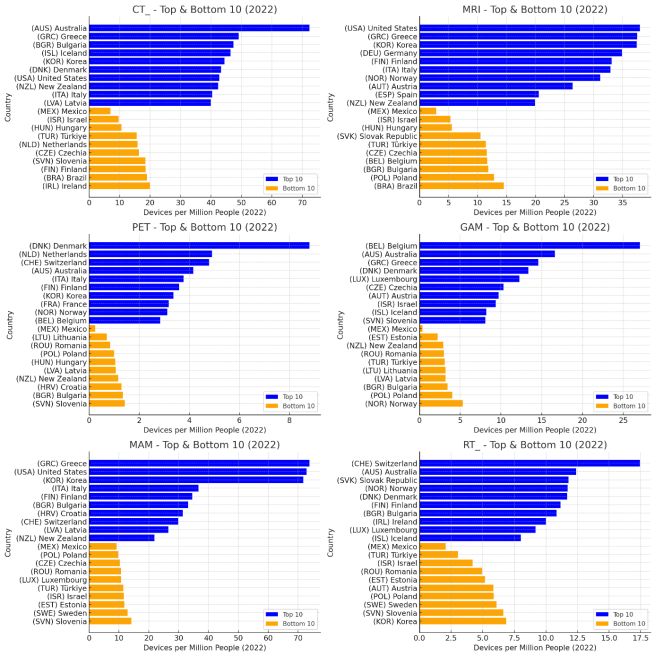

Figure 4 Medical Device Distribution by Population

K-Means Clustering and PCA Results

To further explore patterns of similarity among OECD countries regarding imaging technology deployment and healthcare infrastructure, both K-Means clustering and Principal Component Analysis (PCA) were conducted.

K-Means Clustering Results: K-Means clustering was applied to standardized data including imaging device density (CT, MRI, PET, Mammography), hospital bed availability, and population size. The elbow method was used to determine the optimal number of clusters, with $k = 5$ selected based on minimization of within-cluster sum of squares (WCSS). The resulting five clusters showed clear stratification by healthcare development levels:

Cluster 1 – High Density, High Infrastructure: Countries such as Germany, Japan, and the United States showed both high imaging device density and robust infrastructure, reflecting sustained investment and mature healthcare systems.

Cluster 2 – High Per Capita but Small Population: Iceland, Denmark, and Finland stood out for their extremely high per capita device availability, despite relatively small populations. These countries have high health expenditure per capita and strong national planning frameworks.

Cluster 3 – Mid-Range Device Availability with Strong Infrastructure: South Korea, France, and Italy had relatively balanced device distributions, supported by universal health coverage and active AI adoption in radiology.

Cluster 4 – Moderate Density, Growing Capacity: Countries like Turkey, Hungary, and Poland fell into this intermediate category. They showed moderate device availability and growing infrastructure, often supported by recent health transformation programs.

Cluster 5 – Low Density, Limited Capacity: Mexico, Romania, and Lithuania were clustered due to limited imaging infrastructure, low device-per-capita ratios, and overall constrained healthcare budgets.

This analysis reveals that imaging device distribution is not solely dependent on healthcare expenditure, but rather on broader

institutional capacity, policy prioritization, and long-term capital investment strategies.

Principal Component Analysis (PCA) Results: PCA was conducted on the same standardized dataset to uncover the underlying structure influencing imaging technology distribution. The first two principal components (PC1 and PC2) explained 78.5% of the total variance.

PC1 (Population-Infrastructure Component): Heavily loaded with population size, hospital bed density, and overall device counts, this component reflects the scale and institutional readiness of national healthcare systems.

PC2 (Technology Efficiency Component): Primarily associated with per capita device availability and mammography coverage, this component differentiates between high-efficiency systems and those with uneven or resource-constrained allocation. Interestingly, healthcare expenditure did not significantly load onto either component, supporting earlier regression findings that spending levels alone are insufficient predictors of imaging technology diffusion. Instead, structural indicators, such as population health demand and infrastructure scale, emerged as more critical.

Countries such as South Korea and Germany showed strong performance across both components, while Turkey, Mexico, and Romania loaded high on PC1 (population) but low on PC2 (per capita efficiency), suggesting challenges in translating investment into accessible services.

DISCUSSION

This study offers comprehensive insights into the global landscape of medical imaging technologies, revealing the extent to which their availability is shaped by healthcare infrastructure, demographic realities, and policy direction. Consistent with prior research (Rhodes *et al.* 2012; Phua *et al.* 2020), the results confirm a strong association between imaging device density and hospital bed capacity, signifying that physical infrastructure remains a foundational determinant of technology diffusion. High-income countries with mature institutional frameworks, such as Germany, South Korea, and Japan, demonstrate higher imaging accessibility, while resource-constrained nations lag behind, despite increasing healthcare budgets (Murthy *et al.* 2015).

Importantly, the findings challenge the assumption that healthcare expenditure alone ensures equitable technology access. Regression and PCA analyses clearly illustrate that spending levels have weaker explanatory power than infrastructure indicators and population-driven demand (Hou *et al.* 2020; Jones 2024). This underscores the necessity of incorporating capital investment data and strategic planning variables into future assessments. A system may invest heavily in healthcare, yet without operational efficiency or infrastructure readiness, the impact on imaging accessibility remains limited.

The study also highlights the transformative potential of artificial intelligence in medical imaging, particularly in enhancing diagnostic precision and reducing operational burden. AI-supported low-dose CT and PET/MRI modalities, as discussed in recent literature (Lei *et al.* 2024; Zubair *et al.* 2024), exemplify the shift towards data-driven, personalized diagnostics. Countries with advanced digital ecosystems (e.g., South Korea) are actively integrating AI tools into radiology workflows, but adoption remains uneven across the OECD, often constrained by infrastructure, workforce readiness, and policy frameworks.

Moreover, the COVID-19 pandemic, covered within the study's 2015–2023 timeline served as an inflection point, prompting urgent diagnostic capacity expansion in several countries. However, those with pre-established infrastructure and coordinated planning responded more effectively, reinforcing the idea that system resilience stems from long-term investment, not crisis-driven funding alone.

The intersection between imaging technologies and healthcare economics is deeply mediated by information technology integration. Tools like EHR systems, AI-based analytics, and digital hospital infrastructure enhance not only decision-making but also cost-efficiency and outcome optimization (Fichman *et al.* 2011). The synergy between physical infrastructure and digital capabilities will be essential as healthcare systems transition toward more predictive, preventive, and personalized models.

CONCLUSION

Ensuring equitable access to advanced medical imaging technologies requires more than increasing healthcare expenditure. Evidence presented in this research points to the primacy of infrastructure development, population-based planning, and capital investment over general budget growth. Countries with effective alignment between these domains tend to achieve both higher device availability and more balanced per capita distribution. The role of artificial intelligence is becoming increasingly central, particularly in improving diagnostic precision, operational efficiency, and healthcare outcomes. However, technological integration must be accompanied by investments in digital infrastructure, workforce readiness, and ethical governance to be effective. The disparity in AI readiness among OECD countries reflects broader systemic differences in healthcare strategy and innovation adoption.

Future policy efforts should prioritize the creation of AI-compatible healthcare environments where imaging technologies are part of a broader ecosystem, combining hardware, data infrastructure, and clinical intelligence. In addition, upcoming research should expand on this work by incorporating longitudinal device usage data, national capital investment indicators, and digital health maturity indices. Such multidimensional analyses will better inform strategic decisions and foster more resilient, inclusive, and technologically adaptive healthcare systems.

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Ethical standard

The author has no relevant financial or non-financial interests to disclose.

Availability of data and material

Data used in this study are publicly available through the OECD Health Statistics database.

Conflicts of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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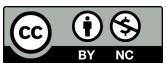

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The Dynamic Impact of Gold and Oil Uncertainty on XU100, CDS, and Exchange Rate in Türkiye: A Wavelet Analysis

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ABSTRACT Geopolitical tensions and macroeconomic fluctuations in global markets have significantly influenced investor behavior and the direction of financial markets. In this turbulent environment, strategic commodities such as gold and oil have emerged as prominent safe-haven assets. The price volatility of these assets is considered a key indicator of market uncertainty and is measured through implied volatility indices, namely the GVZ (Gold Volatility Index) and OVX (Oil Volatility Index). In this respect the relationship between these indices and financial indicators becomes particularly critical during periods of economic distress. This study examines the effects of GVZ and OVX indices on the main financial variables in Türkiye, namely XU100 index, USD/TRY exchange rate and CDS spreads, in the time-frequency domain using wavelet analysis method. The analyses are conducted through wavelet power spectrum, wavelet coherence, and phase difference techniques. The findings reveal that GVZ exerts strong and persistent influences on exchange rates and CDS spreads, particularly over medium to long term horizons, often acting as a leading indicator. OVX also demonstrates a leading role, with more pronounced effects in the short to medium term. In contrast, the XU100 index exhibits a weaker and more fragmented response to these uncertainties, mostly limited to short-term episodes. In conclusion, implied volatility indices represent significant indicators for both investment decisions and macroeconomic policymaking, particularly in economies like Türkiye that are vulnerable to external shocks. This study underscores the necessity of analyzing uncertainty financial market interactions within a time frequency framework and offers meaningful policy implications for uncertainty management.

KEYWORDS
Uncertainty
Gold
Oil
Wavelet analysis
GVZ
OVX

INTRODUCTION

Global financial markets have undergone a significant transformation in recent years due to rising geopolitical tensions, volatility in energy supply, and growing macroeconomic uncertainty. Within this context, strategic commodities such as gold and oil have played a pivotal role in shaping investor decisions and financial market dynamics, both through their price levels and inherent volatility. Historically, these two commodities have been considered safe-haven assets, often used by investors seeking protection against inflation and uncertainty (Gokmenoglu and Fazlollahi 2015; Bouri *et al.* 2017). Implied volatility indices developed by the Chicago Board Options Exchange (CBOE) provide a quantifiable measure of investors' short term uncertainty perceptions about these assets.

The OVX index captures the volatility of oil prices, while the GVZ index reflects the expected volatility of gold prices. These indices offer forward looking insights into market expectations and have become increasingly relevant in understanding the interactions between commodity markets and financial indicators particularly in emerging economies where macro financial vulnerabilities are more pronounced (Chen *et al.* 2018; Luo and Qin 2017).

The literature examining the relationship between uncertainty indices and stock markets highlights the role of these indices in risk transmission channels. Several studies utilizing implied volatility indices have shown that the impact of commodity market fluctuations on financial systems intensifies during periods of crisis (Xiao *et al.* 2018; Alqahtani and Chevallier 2020). Moreover, implied volatility indices are found to possess greater predictive power compared to traditional volatility models (Dutta 2017). This study explores the effects of gold (GVZ) and oil (OVX) market uncertainty on Türkiye's financial markets. Specifically, the relationships between these uncertainty indices and the XU100 stock index, CDS spreads, and the USD/TRY exchange rate are examined using time-frequency decomposition via wavelet analysis. This method enables the identification of how these relationships evolve across different time horizons and frequency bands. The wavelet based approach facilitates a simultaneous assessment of both short term fluctuations and long term trends (Jain and Biswal 2017).

The primary aim of this study is to investigate the time-frequency dependent effects of implied volatility indicators on Türkiye's financial system. In particular, the dynamic interactions between macro financial variables such as exchange rate volatility,

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credit risk, and capital market performance are examined within the context of a developing economy. This approach enables a more comprehensive understanding of the transmission mechanisms through which uncertainty influences investment behavior. This study contributes to the literature both in terms of scope and methodology. While previous research has largely focused on developed markets or relied on conventional time series models, this study adopts a wavelet based analytical framework specifically tailored to the Turkish context. The methodology allows for a joint analysis of short term shocks and long term dependencies, offering more robust insights for policymakers and investors during periods of heightened uncertainty (Bouri *et al.* 2017; Xiao *et al.* 2018).

The empirical findings reveal that the effects of GVZ and OVX on Türkiye's financial indicators are both time varying and frequency dependent. GVZ exerts a strong and persistent influence particularly on the CDS spreads and exchange rate, predominantly at medium to long term scales, and often leads their movements. On the other hand, OVX, also displays a leading role, especially in the short to medium term, affecting both the exchange rate and CDS spreads. In contrast, the XU100 index exhibits a more fragmented and less pronounced reaction to these volatility shocks, with limited coherence concentrated in shorter time horizons. These findings suggest that global volatility indicators should be systematically considered in the formulation of portfolio diversification strategies, the interpretation of investor risk perception, and the design of macroeconomic and financial policies in Türkiye.

LITERATURE REVIEW

Gold and oil volatility indices (GVZ and OVX) have emerged as prominent measures of uncertainty over the past decade, particularly in the context of their impact on financial markets. Numerous studies have investigated the relationship between these indices and various financial variables in both developed and developing economies. Gokmenoglu and Fazlollahi (2015) analyzed the relationship between the S&P500 index and gold and oil prices using the VAR model, concluding that the three variables exhibit long-term cointegration. Aloui *et al.* (2015) employed wavelet coherence analysis to examine the time dependent relationship among gold, oil, and stock markets, finding strong interdependence, particularly during crisis periods.

Maghyereh and Awartani (2016) used implied volatility based models to explore the causal dynamics between gold, oil, and stock markets, suggesting that volatility indices contain more informational value than prices. Ji *et al.* (2016) analyzed interactions between stock markets and commodity volatility indices through a dynamic conditional correlation model, noting that volatility spillovers intensify during crises. Bouri *et al.* (2017) investigated the Indian market, identifying nonlinear causality and cointegration between GVZ, OVX, and stock indices, with bidirectional and time varying linkages. Dutta (2017) analyzed the effect of oil volatility on clean energy stock returns using GARCH-type models and found a significant negative impact.

Jain and Biswal (2017) applied a wavelet approach to examine frequency domain causality between GVZ and stock returns in China and India, revealing stronger long-term relationships. Chen *et al.* (2018) evaluated the predictive power of the CBOE oil volatility index and found it superior to traditional volatility models. Xiao *et al.* (2018) assessed the asymmetric impact of OVX on Chinese stock returns under different market conditions, identifying direction-dependent responses. Wen *et al.* (2018) emphasized the persistent effects of oil volatility on financial stability, especially in emerging markets. Alqahtani and Chevallier (2020) studied the influence of oil and gold volatility indices on stock markets in Gulf Cooperation Council countries using VAR and spillover index methods, identifying both short and long term directional effects. Li and Yoon (2022) applied wavelet decomposition and Granger causality to examine the effects of GVZ and OVX on emerging markets, highlighting the frequency sensitive nature of uncertainty transmission. Overall, this literature highlights the importance of time-frequency analytical techniques in evaluating the financial implications of implied volatility indices. In particular, wavelet analysis has proven effective in capturing dynamic relationships between uncertainty and financial indicators, especially during periods of economic turbulence.

MATERIAL AND METHODS

In this study, the wavelet analysis used is a powerful spectral decomposition method that allows the simultaneous examination of time series in both frequency and time domains. This method, which differs in operation from Fourier transformation and traditional time-series models stands out especially in the analysis of non-stationary data (Gençay *et al.* 2001; Zhao *et al.* 2004; Rua and Nunes 2009; Mariani *et al.* 2020). Wavelet analysis decomposes signals at different resolutions through small, localized waves to detect time-varying frequency structures. In this respect, it differs from the classical Fourier transformation; while Fourier transformation reveals only the frequency components of the signal, it does not show the time intervals in which these components occur (Graps 1995; Arı *et al.* 2008). On the other hand, wavelet transformation enables the simultaneous analysis of these two dimensions and allows a detailed examination of short- and long-term relationships in the time-frequency plane (Crowley 2007).

In the analytical process, the Continuous Wavelet Transform (CWT) is first applied to decompose the time series data into frequencies. Then, with the help of Wavelet Coherence (WTC), the correlation between two different time series is analyzed in both time and frequency dimensions. This analysis reveals in which frequency bands and time intervals there are significant relationships between the variables (Adebayo *et al.* 2021; Kalmaz and Kirikkaleli 2019). The coherence coefficient ranges between 0 and 1; the closer to 1, the stronger the relationship is considered, while values closer to 0 indicate a weak relationship. The theoretical foundations of the wavelet method were laid by Goupillaud *et al.* (1984). The variables k and f represent time and frequency, respectively, allowing the relationship between time and frequency dimensions to be revealed (Adebayo *et al.* 2021).

$$\psi_{k,f}(t) = \frac{1}{\sqrt{f}}\psi\left(\frac{t-k}{f}\right), \quad k, f \in \mathbb{R}, f \neq 0 \tag{1}$$

As stated by Alola and Kirikkaleli (2019), the key variables in the wavelet approach are k and f. Therefore, the main factor for revealing the relationship concerning time-frequency is the continuous wavelet transition (CWT). Accordingly, the CWT approach is preferred to relate two variables expressed in time series format. The CWT approach is expressed as follows:

$$W_p(k,f) = \int_{-\infty}^{\infty} p(t)\frac{1}{\sqrt{f}}\psi^*\left(\frac{t-k}{f}\right)dt \tag{2}$$

Here, p(t) represents the past time series and can be expressed as follows (Adebayo *et al.* 2021).

$$p(t) = \frac{1}{C_\psi}\int_0^{\infty}\int_{-\infty}^{\infty}|W_p(a,b)|^2\frac{dadb}{b^2} \tag{3}$$

The variance of the wavelet power spectrum (WPS) of the time series is expressed as follows (Adebayo *et al.* 2021).

$$WPS_p(k,f) = |W_p(k,f)|^2 \tag{4}$$

Wavelet coherence (WTC) estimates the cross-spectrum ratio of each spectrum of the time series by combining their frequencies (Kalmaz and Kirikkaleli 2019). The wavelet transformation of two time series is expressed as follows:

$$W_{pq}(k,f) = W_p(k,f)W_q^*(k,f) \tag{5}$$

Here, $W_p(k,f)$ and $W_q(k,f)$, represent the CWT of p(t) and q(t), respectively. The squared value of WTC is expressed as:

$$R^2(k,f) = \frac{|S(f^{-1}W_{pq}(k,f))|^2}{S(f^{-1}|W_p(k,f)|^2)S(f^{-1}|W_q(k,f)|^2)} \tag{6}$$

If $R^2(k,f)$ is close to 0, it indicates zero or weak correlation between the two series; if it is close to 1, it shows a correlation between the examined variables at a specific scale (Shahbaz *et al.* 2015).

In light of the above, wavelet analysis examines the multidimensional relationships of the time series over time and reveals the dynamic structure of the relationship between variables in relation to time and frequency.

The data for this information was obtained weekly from the "investing" website. The data covers the time period between 01.01.2013 and 31.05.2025. Data belonging to the times that were missing or did not match with different situations in this date range were cleaned. Prior to the empirical analysis, the series were subjected to an outlier detection process. Outliers were adjusted following the methodology of (Bodart and Candelon 2009), which entails replacing the outlier value with the mean of a centered 10 day window around the affected observation. This approach facilitated the refinement of the dataset and improved the reliability of the subsequent econometric analysis.

DISCUSSION AND RESULTS

In this section, the relationship between GVZ (Gold Volatility Index) and OVX (Oil Volatility Index) and the key indicators of the Turkish economy namely XU100, the USD/TRY exchange rate, and CDS spread is analyzed using wavelet-based methods in the time-frequency domain. The analysis employs continuous wavelet spectra, component decompositions, as well as wavelet coherence, correlation, and covariance techniques.

The wavelet coherence analysis reveals the time frequency interaction between the XU100 index and the Gold Volatility Index (GVZ). Significant coherence regions are observed particularly in the short and medium term frequency bands (scale range of 4–32). In these regions, most of the arrows point to the left, with a predominance of upper left and lower left directions, indicating a negative phase relationship and suggesting that GVZ tends to lead XU100. This implies that increases in global gold market uncertainty are followed by inverse movements in the Turkish stock market index. Such a pattern may reflect capital outflows from equities due to rising risk perception, thereby exerting downward pressure on the index. In the longer term frequency bands (64–128), some meaningful but less pronounced coherence zones are also present, again with predominantly leftward arrows. Overall, the analysis suggests that the GVZ may exert leading and negative influences on the XU100 over multiple time horizons (Figure 1).

The wavelet coherence analysis illustrates the dynamic interaction between the USD/TRY exchange rate and the Gold Volatility Index (GVZ) across time and frequency domains. Notably, strong coherence regions emerge predominantly within the long term frequency band (scale 64–128), particularly in the later periods of the sample. In these zones, arrows are mostly directed to the left, especially upper left, suggesting a negative phase relationship and indicating that GVZ tends to lead the exchange rate. This pattern implies that increases in global gold market uncertainty are followed by depreciations in the Turkish lira, reflecting a transmission mechanism from international risk sentiment to domestic currency markets. In earlier segments of the graph, rightward pointing arrows in some lower frequency areas suggest temporary positive and synchronous co-movements, but these instances are weaker and less persistent. Overall, the findings indicate that GVZ plays a leading and inversely correlated role in shaping the dynamics of the USD/TRY exchange rate, particularly over longer time horizons (Figure 2).

The wavelet coherence analysis between the Credit Default Swap (CDS) spread and the Gold Volatility Index (GVZ) reveals distinct patterns of time frequency dependence. Strong and persistent coherence is particularly evident in the long term frequency bands (scales 64–128), where leftward pointing arrows, especially lower left and upper left, dominate. These directions indicate a negative phase relationship, suggesting that increases in gold market volatility tend to be followed by declines in Türkiye's perceived sovereign creditworthiness, as captured by CDS spreads. Moreover, the consistent orientation of these arrows toward the left confirms that GVZ leads the movements in CDS. In contrast, coherence in shorter frequency bands is more fragmented, with occasional high coherence regions exhibiting mixed arrow directions. Overall, the results suggest that global gold volatility plays a leading and inversely correlated role in shaping Türkiye's sovereign risk spreads over longer time horizons (Figure 3).

The wavelet coherence analysis between the XU100 index and the Oil Volatility Index (OVX) demonstrates notable time frequency variations in their co-movement structure. Strong and sustained coherence is observed particularly in the medium to long term frequency bands, where most arrows point to the left, especially in the lower left direction. This configuration reflects a negative phase relationship, indicating that OVX tends to lead XU100 and that increases in oil market volatility are followed by declines in the Turkish stock market index. This relationship suggests a flight to safety behavior by investors in response to rising global uncertainty in energy markets. Additionally, short term coherence areas with similar arrow orientations reinforce the inverse and anticipatory influence of OVX on XU100. Overall, the results imply that the oil volatility index serves as a leading and negatively correlated factor influencing equity market dynamics in Türkiye, especially over longer time scales (Figure 4).

The wavelet coherence analysis between the USD/TRY exchange rate and the Oil Volatility Index (OVX) reveals significant time frequency dependencies, particularly in the medium and long term scales. Notably, strong coherence regions emerge within the scale range of 64–128, especially in the early and late parts of the sample. In these regions, leftward pointing arrows, including lower left and upper left directions, dominate indicating a negative phase relationship and suggesting that OVX leads the exchange rate dynamics. This implies that increased oil market volatility is typically followed by a depreciation of the Turkish lira, likely reflecting the spillover effects of global energy related uncertainty into domestic currency markets. In some shorter frequency episodes, transient coherence patches are observed with mixed directional arrows, indicating more complex and possibly

bidirectional short term effects. Overall, the results underscore OVX's role as a leading and negatively associated factor in the determination of exchange rate movements over longer horizons (Figure 5).

The wavelet coherence analysis between the Credit Default Swap (CDS) spreads and the Oil Volatility Index (OVX) reveals significant and persistent interactions across time and frequency domains. High coherence is particularly visible in the medium to long term frequency bands, where most arrows point to the left, predominantly in the upper left and lower left directions. This pattern indicates a negative phase relationship, suggesting that increases in oil market volatility are followed by rising CDS spreads, i.e., a perceived deterioration in sovereign creditworthiness. The leftward orientation of the arrows further implies that OVX tends to lead movements in CDS spreads, underscoring its role as an early indicator of rising country risk. In shorter time scales, coherence is weaker and more fragmented, though some brief co-movement episodes are still visible. Overall, the results highlight OVX as a leading and inversely associated factor influencing the dynamics of Türkiye's sovereign credit risk, particularly over longer horizons (Figure 6).

Taken together, the wavelet coherence analyses underscore the significant and dynamic influence of global volatility indicators namely GVZ and OVX on key financial and macroeconomic variables in Türkiye, including the XU100 index, USD/TRY exchange rate, and CDS spreads. Across most pairings, strong coherence is observed in medium and long term frequency bands, with directionality patterns consistently revealing negative phase relationships and lead lag structures, where global volatility indices frequently act as leading indicators. These findings suggest that heightened uncertainty in global gold and oil markets tends to propagate into the Turkish economy through various channels, exerting downward pressure on equity prices, upward pressure on sovereign risk spreads, and causing depreciation of the local currency. Overall, the results emphasize the vulnerability of emerging market economies like Türkiye to external volatility shocks and highlight the importance of incorporating global uncertainty measures into financial stability and risk management frameworks.

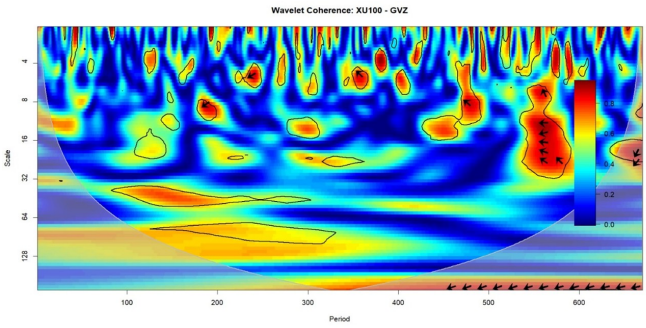

Figure 1 Wavelet Coherence between the Gold Volatility Index (GVZ) and XU100 Index.

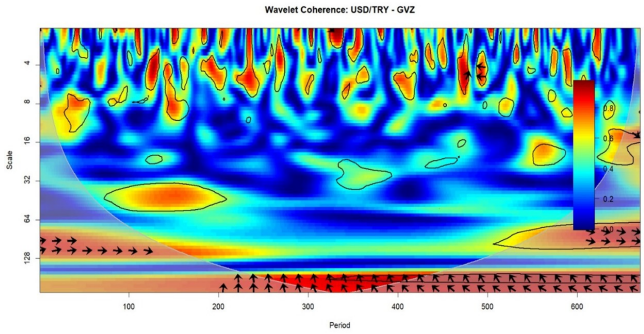

Figure 2 Wavelet Coherence between the Gold Volatility Index (GVZ) and USD/TRY Exchange Rate.

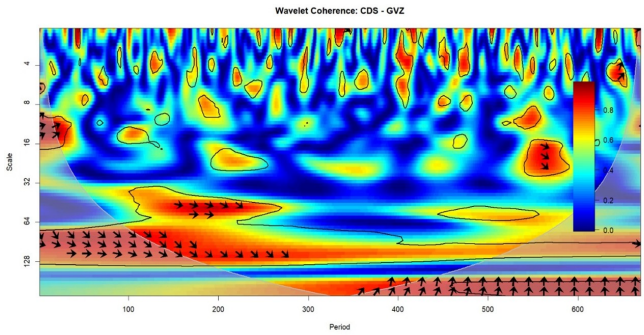

Figure 3 Wavelet Coherence between the Gold Volatility Index (GVZ) and CDS Spread.

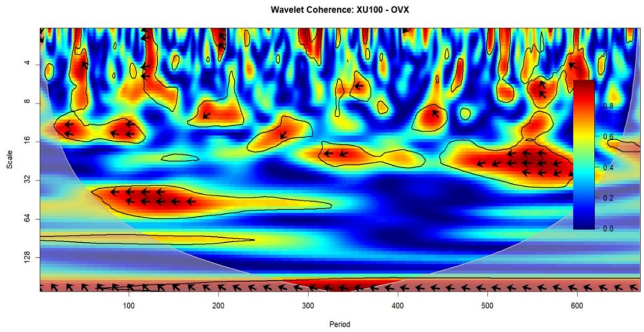

Figure 4 Wavelet Coherence between the Oil Volatility Index (OVX) and XU100 Index.

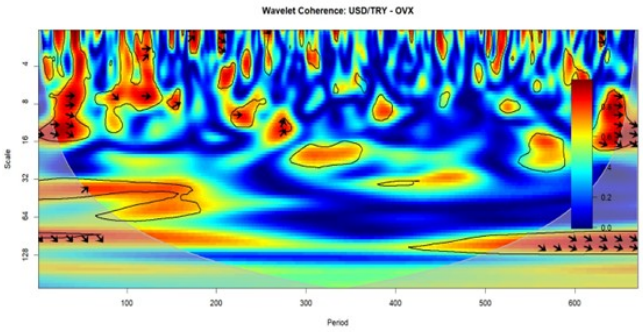

Figure 5 Wavelet Coherence between the Oil Volatility Index (OVX) and USD/TRY Exchange Rate.

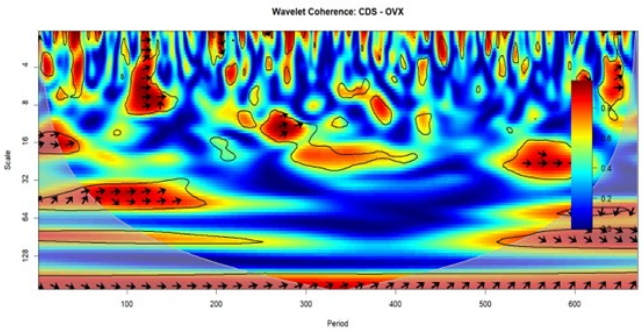

Figure 6 Wavelet Coherence between the Oil Volatility Index (OVX) and CDS Spread.

CONCLUSION

This study comprehensively examines the time–frequency interactions between Türkiye's key financial indicators namely the XU100 index, the USD/TRY exchange rate, and CDS spread and global volatility indices GVZ (Gold Volatility Index) and OVX (Oil Volatility Index), using wavelet coherence methodology. The findings clearly demonstrate that the effects of GVZ and OVX on Türkiye's financial markets are both frequency dependent and time varying.

The analyses reveal that GVZ exerts a strong and persistent influence particularly on the CDS spread and exchange rate, with the gold volatility index leading movements in these variables across medium to long-term frequency bands. On the other hand, OVX also shows a leading role but has relatively more pronounced effects in short to medium term frequencies, especially on the exchange rate and CDS spreads. In contrast, the XU100 index displays a weaker and more fragmented relationship with both GVZ and OVX, indicating that capital markets react less consistently and less immediately to global volatility shocks than do currency and sovereign risk indicators.

These results suggest that GVZ and OVX are not merely speculative or sentiment based indices, but function as early warning indicators of macro financial stress, particularly in emerging markets that are highly sensitive to global risk transmission channels. The lead–lag structures and phase differences observed across all variables further underscore the necessity for dynamic and proactive policy responses.

1. GVZ and OVX should be systematically monitored by economic policymakers and central banks as part of Türkiye's financial stability and macroprudential surveillance frameworks.

2. Given the asymmetric impact of global volatility on different market segments, monetary and fiscal policy responses should be differentiated with more responsive instruments aimed at exchange rate and CDS volatility, and longer-horizon strategies for capital market resilience.

3. To mitigate the effects of external volatility, Türkiye should reassess its reserve adequacy, external borrowing structure, and FX risk management strategies, particularly during periods of rising global uncertainty.

4. Since market perceptions respond rapidly to volatility spikes, transparent communication and expectation management should be prioritized during periods of stress to reduce herd behavior and overshooting in exchange and credit markets.

In conclusion, this study not only enhances the understanding of the dynamic interlinkages between global volatility and Türkiye's financial system but also contributes valuable policy relevant insights to support macro financial stability and crisis resilience efforts in emerging markets.

Availability of data and material

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Ethical standard

The author has no relevant financial or non-financial interests to disclose.

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Bibliometric Analysis of the Impact of Big Data Technology on Business and Management

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ABSTRACT Businesses are established with the aim of generating more profit and remaining in operation for longer periods of time. Various practices contribute to ensuring the sustainability of businesses. One of these practices is big data technology. The application of big data technology, which has taken the whole world by storm and affected all sectors, is based on digital transformation. As a technology-based development, Industry 4.0 applications interact with many scientific fields such as sociology, economics, biological systems, and computer systems. Industry 4.0 applications bring about strategic transformations and paradigm shifts in all scientific fields and sectors. A bibliometric study is being conducted to observe and analyze the development of Industry 4.0 applications in the field of business, which enables important developments. The data for studies related to big data technology in the field of business and management was obtained from the Web of Science database, consisting of 2011 studies. The data obtained was analyzed using the Bibliometrix software in the R Studio program via the Biblioshiny database. The results show that 5,568 authors conducted research between 2020 and 2025. Additionally, it was found that the most frequently used keywords are “big data,” “big data analysis,” “digital transformation,” and “artificial intelligence.” Another important finding is that Bag and Papa are the authors who have conducted the most research in this field. Big data technology will make significant contributions to business and management, especially in 2024. The journal Technological Forecasting and Social Change contains the most studies related to this research topic. This research output serves as a guide for researchers interested in this field.

KEYWORDS
Big data
Sustainability
Innovation
Supply chain
Digital transformation

INTRODUCTION

With the acceleration of digitalization, the concept of big data has emerged and become one of the most valuable organizational resources of today. Today, data production is rapidly increasing in many areas, from manufacturing to finance, health to education, and this data plays an important role in strategic decision-making processes (Franke and Hiebl 2023; Abdelhalim 2024). Big data refers not only to the sheer volume of data but also to the high speed at which it is produced, its diverse sources, and its complex structure, making it impossible to process using traditional methods (Sardi *et al.* 2023).

Big data refers to large volumes of data produced in structured, semi-structured, and unstructured formats that are difficult to process using traditional methods (Baig *et al.* 2020). This data is obtained from various sources such as social media posts, learning management systems (LMS), sensor data, and log files (Michalik *et al.* 2014). The ’5V’ framework (volume, variety, velocity, veracity, value) frequently used to define big data reflects both technical and operational challenges (Luan *et al.* 2020). These are: **Volume**: The size of the data (terabytes/petabytes), **Variety**: The presence of different types of data (text, visual, audio, unstructured content), **Velocity**: The speed at which data is produced and processed, **Veracity**: The reliability of the data, **Value**: The contribution of the information obtained to decision-making processes (Gärtner and Hiebl 2018). These data sets require new-generation analysis techniques and information technologies because they cannot be processed using traditional data processing systems (Ward and Barker 2013; Sardi *et al.* 2023). In this context, big data has become an important source of information and a decision support tool for organizations.

Big data is used in a wide variety of sectors. It has an impact in many areas, from disease prediction to resource management in the healthcare sector and quality control and supply chain optimization in the manufacturing sector (Fanelli *et al.* 2023). It is also used to support decision-making processes in areas such as public administration, marketing, education, and environmental sustainability (Nisar *et al.* 2021; Abdelhalim 2024). The opportunities offered by big data are particularly prominent in the digital transformation of public services such as healthcare and education. The main benefits of big data include more accurate and faster decision-making, cost reduction, increased customer satisfaction, and competitive advantage (Franke and Hiebl 2023).

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Furthermore, big data enables organizations to perform real-time analysis and significantly increase their operational efficiency (Sardi *et al.* 2023; Abdelhalim 2024). A knowledge-based decision-making culture paves the way for strategic transformations, particularly in areas such as accounting and finance. Big data is not merely a technological advancement but also a tool for organizational change and strategic management. A company's ability to remain competitive is directly linked to its capacity to make data-driven decisions. In this context, investing in big data is the key to sustainable growth for both the private sector and public institutions.

The importance of big data is directly related to the transformation it brings to business decision-making processes. Information that could take days to obtain using traditional data analysis methods can now be obtained in real time thanks to big data analytics (BDA). This enables businesses to not only analyze the past but also predict the future and develop proactive strategies (Ajah and Nweke 2019). In particular, predictive and prescriptive analysis techniques make it possible to model customer behavior, optimize the supply chain, predict risks, and increase operational efficiency.

Big data technologies also contribute to the restructuring of business processes. Fosso Wamba and Mishra (2017) reveal a strong integration between big data analytics and business process management (BPM), business process reengineering (BPR), and business process innovation (BPI). This integration enables businesses to improve process performance, optimize resource utilization, and gain a competitive advantage. Furthermore, big data analytics enriches decision support systems, thereby improving the quality of managerial processes. In particular, big data-driven decisions yield higher success rates in areas such as customer relationship management, pricing strategies, product/service development, and marketing campaign effectiveness (Pizło *et al.* 2023). For example, Wal-Mart uses big data analytics to develop product recommendation systems, while American Express conducts successful analyses to predict customer churn (Ajah and Nweke 2019). However, big data management requires not only technological but also organizational transformation. Successful big data projects require accurate problem definition, access to data, collaboration among multidisciplinary teams, and integration of analysis results into systems (Pizło *et al.* 2023). Additionally, issues such as security, privacy, and ethics must also be considered.

Kalantari *et al.* (2017) evaluates publications on big data technology. A comprehensive analysis of publication trends is presented, including document type and language, year of publication, country contributions, journal analysis, research area analysis, Web of Science category analysis, author analysis, author keywords, and keyword plus analysis. Additionally, the innovative aspect of this study is that it presents a formula derived from multiple regression analysis for citation analysis based on the number of authors, number of pages, and number of references.

Liu *et al.* (2020) includes a bibliometric study on big data technology.In recent years, the rapid growth of big data has offered tremendous potential for business applications and has also attracted considerable attention in academia. In response to this emerging phenomenon, this article aims to provide a comprehensive literature review on big data. The number of studies on big data is increasing, and it is considered an intensively researched field worldwide. Chawla and Goyal (2022) conducted a bibliometric study on digital transformation. This study reveals a general upward trend in terms of annual publications, author performance, publishing journals, affiliated institutions, and countries driving the research, along with important insights obtained from co-citation network analysis. Additionally, the study evaluates four research areas (institutional impacts, applied applications and insights, operational processes, and social aspects) comprising eighteen research streams that comprehensively address research in the DT field.

The research question is: What are the implications of big data technology applications in the field of business and management? The research is conducted based on this question, and big data provides many contributions in the application field.

On the other hand, in order to reveal the reflections of big data in the field of business and management, the interaction in the literature is revealed by using the document analysis technique. The study uses the document review technique from the qualitative research method. The study will examine the implications of big data technology in the fields of business and management between 2020 and 2025 using the Web of Science database. The research is conducted based on five main questions. The research questions to be answered in this study are as follows:

1. What is the distribution of articles according to the years they were published?
2. What is the distribution of articles according to the journals in which they were published?
3. What are the most frequently used keywords by authors?
4. Who are the most prolific authors?
5. What are the most trending topics?

The most important outcome of this study is that it offers recommendations to authors who will conduct research in this field. Indeed, it identifies the latest developments in the literature. By identifying gaps in the literature related to this topic, it guides new studies.

MATERIALS AND METHODS

The research was conducted by evaluating scientific studies on big data technology in the fields of management and business based on specific parameters. In the research, the document review technique was used as a qualitative research method. The data was collected between May 20, 2025, and June 20, 2025. The Web of Science database was used to collect the data. The search criteria focused on the keywords "big data" and "management." Studies from the last five years were targeted, and the period between 2020 and 2025 was selected. The field of study was business and management. Only articles were selected as the data type. The search yielded 2011 documents. The documents were filtered to include only those published between 2020 and 2025 and related to the fields of business and management. The 2011 documents were analyzed using the IR Studio program and Biblioshiny.

RESULTS AND DISCUSSION

After analyzing the study, various findings were obtained. Table 1 presents the general information of the study.

Table 1 General Information Summary

Main Information About Data	
Timespan	2020–2025
Sources (Journals, Books, etc.)	400
Documents	2011
Annual Growth Rate (%)	214.77
Document Average Age	1.88
Average Citations per Document	17.84
References	115170
Document Contents	
Keywords Plus (ID)	2722
Author's Keywords (DE)	5963
Authors	
Total Authors	5568
Authors of Single-Authored Docs	156
Authors Collaboration	
Single-Authored Documents	168
Co-Authors per Document	3.61
International Co-authorships (%)	43.06
Document Types	
Article	1780
Article; Book Chapter	20
Article; Early Access	205
Article; Proceedings Paper	2
Article; Retracted Publication	4

According to Table 1, all of the 2011 documents retrieved from the Web of Science database were categorized as articles. The data covers the period between 2020 and 2025. These studies were produced using 115,700 references, and a total of 5,568 authors contributed to the topic of big data. Additionally, 5,963 keywords were used by the authors. The proportion of studies utilizing big data technology in the fields of management and business is reported as 214%.The first research question is: *What is the distribution of articles according to the years they were published?* The findings addressing this question are presented in Table 2.

Table 2 Distribution of Articles by Publication Year

Year	Number of Articles
2020	245
2021	319
2022	408
2023	467
2024	572

According to Table 2, the highest number of studies was conducted in 2024 with 572 studies, and when looking at the distribution over the last five years, it can be seen that the number of studies has increased year by year. The increasing interest in this field can be understood from the number of documents. The second research question is:

What is the distribution of articles according to the journals in which they were published? The findings of this research question are presented in Table 3 below:

Table 3 Most Relevant Journals in the Field of Management and Big Data (2020–2025)

Source	No. of Documents
Technological Forecasting and Social Change	133
IEEE Transactions on Engineering Management	84
Journal of Business Research	81
Benchmarking – An International Journal	50
Business Strategy and the Environment	45
Journal of Enterprise Information Management	38
Business Process Mgmt Journal	32
European Journal of Innovation Management	31
TQM Journal	30
Cogent Business & Mgmt	28

According to Table 3, most studies were published in *Technological Forecasting and Social Change*. *IEEE Transactions on Engineering Management* ranked second, and *Journal of Business Research* ranked third.

The third question of the study was: *What are the most frequently used keywords by authors?* The findings of this study are presented in Figure 1.

Figure 1 Most frequently used keywords by authors

Figure 1 shows the most frequently used keywords. Words such as *big data*, *big data analytics*, *digital transformation*, *artificial intelligence*, and *sustainability*, which are expressed in large font, are frequently used. The fourth question of the research is: *Who are the authors who produce the most work?* The findings of this research question are presented in Table 4.

Table 4 Most Frequently Cited Authors (Local Citations)

Author	Local Citations
BAG S	83
PAPA A	78
CIAMPI F	76
DEMI S	76
GIACOMO G	76
MAGRINI A	76
MARZI	76
KUMAR A	51
DHAMIJA P	45
LUTHRA S	45

According to Table 4, Bag is the author who produced the most studies with 83 studies, followed by Papa with 78 studies. Ciampi and Demi come next with 76 studies.The fifth question of the study is: *What are the most trending topics?* The answer to this question is presented below:

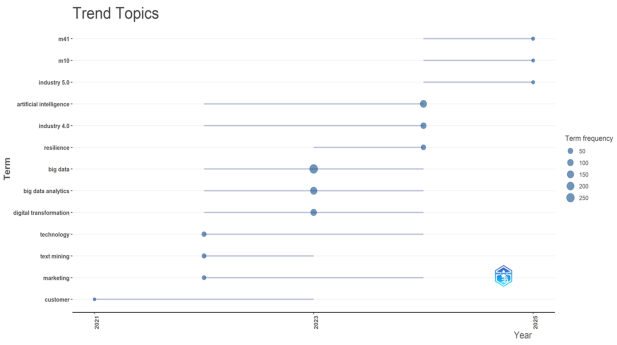

Figure 2 Trend Topics Identified Between 2021 and 2025

As seen in Figure 2, *big data*, *big data analytics*, *digital transformation*, *artificial intelligence*, and *Industry 4.0* are considered to be the most trending topics. They are frequently mentioned in connection with big data.

CONCLUSION

This study was conducted using bibliometric analysis techniques to reveal the general trends in the literature and the structural map of knowledge accumulation. The findings were comprehensively evaluated in terms of citation data, keyword usage, author impact, and source journal density at both global and local levels. Firstly, concepts such as 'big data,' 'big data analytics,' 'artificial intelligence,' and 'digital transformation' stand out among the most frequently recurring keywords. This shows how management and organization studies are integrated with current technological trends and that data-driven decision-making processes are at the forefront. In addition, concepts such as 'sustainability,"innovation', 'performance,' and 'supply chain' reveal that strategic governance and operational efficiency dimensions are also intensively discussed in the studies. In author-based analyses, authors with both high local and global impact levels were identified. In particular, Bag S. has established a leading position in the literature, ranking among the authors with the most local citations and the most publications. He is followed by Ciampi F. and Papa A. The contributions of these authors are related to the themes of digital transformation, sustainability, and innovation.

In journal-based analyses, the *Journal of Business Research* and *Technological Forecasting and Social Change* journals form the main axis of the literature in terms of both citations and publication volume. This highlights the interdisciplinary nature of the study and its strong links with both social sciences and engineering-based literature.

The co-citation network has enabled us to understand the theoretical foundation of the knowledge structure. Blue clusters, where classic strategy authors such as Porter, Teece, Barney, and Wernerfelt are concentrated, show that the resource-based view (RBV) and dynamic capabilities theory are still central reference points. On the other hand, the works of contemporary authors such as Bag, Belhadi, and Mikalef on artificial intelligence, digitalization, and sustainability indicate current research trends. The list of most cited documents includes publications such as Mikalef *et al.* (2021); Belhadi *et al.* (2021), which have received over 500 citations. These publications are thought to be related to themes such as digital transformation, data analytics, and green supply chain management. In addition, studies such as Ciampi *et al.* (2021); Usai *et al.* (2021) have become reference texts in the field, particularly through their publication in the *Journal of Business Research*.

In light of all these analyses, it has been observed that there has been a significant paradigm shift in the literature in the areas of strategic management, digitalization, and sustainability. Traditional resource-based strategy approaches are being reinterpreted in light of concepts such as big data, artificial intelligence, and digital transformation. In this context, the literature is increasingly taking on an interdisciplinary structure, and new research opportunities are emerging at the intersection of management science, information technology, and environmental sustainability. This study not only provides researchers with a map of the current state of the literature but also identifies potential gaps and trends that may guide future work. As a recommendation, it is suggested that future research should focus on restructuring conceptual frameworks around key themes identified through bibliometric analysis and integrating theoretical approaches with the requirements of the digital age.

Ethical standard

The author has no relevant financial or non-financial interests to disclose.

Availability of data and material

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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An Assessment of the Concept of Competitiveness through Postgraduate Thesis Studies in Türkiye

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ABSTRACT The understanding of the concept of competitiveness and its transformation into a subject of research has become an interesting field both in practice and in theoretical frameworks. As emphasised in academic articles, textbooks, and papers, competitiveness also emerges as an evaluation and comparison tool in reports prepared for the analysis of local and regional areas, as well as in comparisons made at the global and national levels. In this study, we sought to investigate how the concept is approached in postgraduate programs, in which areas studies on competitiveness are conducted, whether the concept is addressed with a correct positioning, and what the method-output relationship is for the results obtained. It was observed that the concept is used in place of concepts such as 'competitive advantage' and 'competitive superiority,' and that the Porter Five Forces Model is predominantly used for the outputs obtained. It was also noted that the outputs are included in the recommendations related to the thesis topic within the context of competitiveness, and that these are mostly encountered in doctoral theses, while certain gaps and evaluations regarding competitiveness are not made.

KEYWORDS
Competitiveness
Postgraduate thesis
Competitive advantage
Strategic analysis

INTRODUCTION

While the concept of competition is built on establishing superiority, different interpretations, methods, and tools come to the fore in determining what constitutes superiority (Heseltine 1994). Competitive conditions in sports do not lead researchers to the same conclusions as competition between companies in the market. Competition arises from living beings' dependence on resources, describing a distinct interaction with their environment. Competition in the political arena (Stigler 1972), competition within the extended family, or competition among students within a class is a type of competition that must be understood in its own context. Their common feature is the achievement of superiority, but the legal context of these relationships is the subject of considerable debate (Peter 2009).

To understand how the process can be defined and what results can be achieved by going beyond competition, it is necessary to analyse the relationships between actors. In other words, it is necessary to learn and measure competitiveness (Talani 2017; Klein and Newby 2017). Competitiveness demonstrates the level of success of actors in achieving goals or objectives, which include sustainability and are defined by the power to compete while using methods and tools (Bredrup 1995). Competitiveness includes utilising innovation, effectiveness, and transformation. In this context, it is easier to understand why Porter (Porter 1985, 1990) focused on competitiveness at the national and firm levels, why De Bono (De Bono 2019) linked the success of a rising company to competitiveness, and why competitiveness is considered more important than growth and/or development in measuring success in the global world.

While competition reveals the existence of a race, competitiveness describes the actors who know why the race is taking place and who take action to achieve a goal by considering the nature of the arena. Competition is inherent in the nature of existence. Competitiveness manifests itself through abilities, skills, methods, and tools (Vlcek *et al.* 1997). Competition brings superiority, and competitiveness brings leadership. This explains why the economies and companies of countries that neither act on the nature of competition nor are competitive are performing poorly. Indeed, when growth figures or economic development rankings in global reports are evaluated on a country-by-country competitive scale, interesting differences emerge (Mytelka 1999; Turkey 2021; Ilchenko *et al.* 2021). If being the largest does not imply competitiveness, meaning when rankings related to economic size are compared with those of competitive countries, success in terms of sustainability is more prevalent among competitive countries than large ones. The same is true for companies. Especially in globalisation, the value of competitiveness in terms of how companies should act has attracted the attention of many researchers. While those who are effective in methods and tools surpass larger competitors' success, those who believe that growth is a necessity are forced to exert more effort to keep up with the competitive ones (Ernst and Haar 2019; Rudianto 2009; Chaudhuri and Ray 1997).

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When considering competitiveness as a measure, it is argued that it should be considered in five different dimensions (Chaudhuri and Ray 1997; Gutium 2018):

1) **Firm level:** The evaluation of firm competitiveness involves a complex evaluation process considering many factors. Porter (Porter 1990; Ketels 2006) explains this through cost and differentiation, while also revealing how a firm should formulate a strategy for competitiveness through these two concepts. In addition, an analysis based on the value chain can be used to examine how various variables such as product, price, technology, innovation, international marketing power, human resources, structural characteristics, production technologies affect the market advantages and disadvantages for a company, thus impacting competitiveness (Fagerberg 1988; Erkut and Albayrak 2010; Hult 2012; Lado and Wilson 1994; Lekovic and Cvetanovic 2012; Do *et al.* 2021).

2) **City:** Cities have historically been pioneers of productivity, progress, and growth. They will continue to be of vital importance for the growth and competitiveness of countries and regions in the future. This is particularly true in the context of rapid and mass urbanisation in developing markets, therefore, it should be recognised that cities have become the new focus of competitiveness. Six global 'megatrends' are particularly important for cities: (1) urbanisation, demographics and the emerging middle class; (2) increasing inequality; (3) sustainability; (4) technological change; (5) industrial clusters and global value chains; and (6) governance. Led by urbanisation, these trends are shaping the overall operating environment of cities worldwide. It is the responsibility of cities to capitalise on these megatrends and mitigate their negative effects, such as increasing inequality, pressure on natural resources and the environment, and declining trust in public authorities. This brings the competitiveness of cities to the forefront.

   The competitiveness of cities is defined as the factors (policies, institutions, strategies, and processes) that determine a city's level of sustainable productivity. Sustainability encompasses economic, environmental, and social issues. Efficiency refers to the effective use of existing resources to achieve economic growth. However, efficiency must be sustainable and maintained in the long term, reconciling economic, environmental, and social goals rather than in the short term. A four-part classification of city competitiveness has been developed: (1) institutions, (2) policies and regulations related to the business environment, (3) 'hard connections,' and (4) 'soft connections' (Begg 1999; Forum 2014; Kamiya and Pengfei 2021).

3) **Regional level:** Numerous examples, such as Third Italy, Bavaria, Sophia Antipolis, Shenzhen, and Tennessee Valley, demonstrate what it means to address competitiveness at the regional level using different models. The specialisations or development models of regions are giving competitiveness a new meaning, highlighting the quality of regional capabilities, human resources, social capital accumulation, and various forms of cooperation for competitiveness. Researchers working in many different fields, such as economics, business, sociology, urban and regional planning, and political science, examine the relationship between these concepts using different methods and tools, and make important recommendations for policymakers. One of the most well-known examples is Putnam's study, which sought to understand development in northern Italy and presented a new model of development and competitiveness. Porter, on the other hand, has examined regional competitiveness, particularly through cluster models, in many of his studies. The studies conducted seek to discover new examples using different criteria and evaluations, learn about new actors playing a role in development and growth, and discuss what needs to be learned and done for competitiveness based on the new models discovered or proposed. This also facilitates the development and use of indices that enable comparisons across multiple topics (OECD 1997; Dijkstra *et al.* 2023; Commission 2022; Enright 2000; Maskell and Malmberg 1999).

4) **At the sectoral level:** Sectoral comparison can be approached in two dimensions. The first involves comparing the same sector across different countries, while the second aims to compare different sectors based on parameters that constitute the sectors (labour force, energy, exports, purchasing power, etc.). Both are important for competitiveness assessments. The former contributes to comparative advantage as a well-known method for national competitiveness, while the latter contributes to determining which sectors will make the city, region, and even the nation competitive. In other words, sectoral competitiveness reveals which sectoral dynamics provide advantages over others and how disadvantaged sectors can be improved. In this context, sectoral competitiveness analyses serve as a guide for dynamic strategies (Kancs and Kielyte 2001; Esposito and Collignon 2017).

5) **At the national level:** When examining the origins of competitiveness, it is likely that national competitiveness is the oldest domain for measurement and the area where the most research has been conducted. The competitiveness of nations and competitive economies, which have come to the fore with the process of globalisation, is expected to become more prominent, providing a rich field of study for academic researchers. The World Competitiveness Forum's thesis that "An economy's competitiveness cannot be reduced to just its GDP and productivity; political, social and cultural dimensions are a reality for enterprises, too. Governments play a crucial role by providing an environment characterised by efficient infrastructure, institutions and policies that can encourage sustainable value creation on the part of enterprises." This thesis is now accepted by all global actors. At the same time, this thesis reveals which competitive skills nations must possess and how to achieve a priority that is independent of economic size and noteworthy (Center 2024; Deloitte 2024; Schwab and Zahidi 2020).

In this context, it is important to understand what academic studies and researchers are investigating through the concept and what they have achieved, as this helps to establish context. The aforementioned distinction provides specific guidance on understanding and approaches to competitiveness in that country. In this study, thesis studies related to competitiveness were examined from the Thesis Database in Türkiye, and we attempted to understand the perception, evaluation, and interpretation of competitiveness in Türkiye, through content analysis.

MATERIAL AND METHODS

Analysis of Postgraduate Theses on Competitiveness in Türkiye

Postgraduate theses were utilised and analysed based on a conceptual examination, literature review of the theoretical framework, identification of objectives/problems, research and recommendations, following a search of the thesis database.

Research Objective

The purpose of this study is to analyse the context in which the concept of 'competitiveness' in Türkiye is perceived, valued, and analysed in the academic field, based on postgraduate studies conducted on 'competitiveness.'

Research Method, Scope, and Sample

The thesis studies examined in the research were analysed in terms of conceptual structure, literature and application context, within the framework of the solutions reached and the recommendations presented. Descriptive content analysis was used. Descriptive content analysis method means that qualitative and quantitative studies conducted independently from each other in a particular subject or field are examined and organized in depth. Thus, general trends in that subject or area are determined. The results obtained in this method are expected to guide the planned studies in the future towards the targeted subjects. The main purpose of this study is to solve the questions about how to analyze the descriptive content analysis method, which is frequently used in the field of educational sciences, in order to be used in other social sciences.

The study aims to guide academicians who want to use descriptive content analysis in the field of social sciences and to be a basic resource. In the descriptive content analysis, especially in the analysis of the aims, reasons, results and suggestions of the studied studies, creating a code pool in accordance with the qualitative analysis approaches and using the appropriate theming/categorization method will ensure that the descriptive content analysis studies are enriched in terms of quality. In addition, in the descriptive content analysis studies to be carried out, the studied studies should be analyzed from different aspects in order to distinguish them from other descriptive content analysis studies on similar topics, apart from the standardized analysis stages (Ültay *et al.* 2021). The results obtained were classified. The conceptual structure, application correspondence, realism, and analysis of the recommendations presented were analyzed. Additionally, the meaningfulness of the postgraduate studies was explored.

The following questions were sought to be answered in order to interpret the studies:

- How are the main problems/issues perceived?
- How were the solutions/solutions, suggestions/recommendations and context established?

To this end, data (all postgraduate theses) were collected and included in the analysis. A search was conducted using the keyword 'competitiveness' in the Higher Education Council (YÖK) National Thesis Centre. Since the aim was to have the same population and sample, 57 of the 57 registered postgraduate (master's and doctoral as of 01.05.2025) theses were accessed. 66.6% of the postgraduate studies examined are master's theses, while the remaining 33.3% are doctoral theses. Research on the concept began relatively late, in 2007, with a noticeable increase in 2019 and thereafter. When considering the fields of study, Business Administration, Economics, and Tourism stand out, along with Industrial Engineering, Urban and Regional Planning, and International Trade.

Although the studies reveal different sectoral distributions, it is seen that competitiveness is most researched, analysed, and understood in the tourism sector. Apart from this, the textile sector is considered interesting, and the competitiveness of the construction sector has also attracted attention. From a regional perspective, studies have been conducted in the Southeast and Mediterranean regions, Mediterranean, Black Sea, and outside Istanbul, and research has been carried out on the international competitiveness of sectors and with the aim of reaching conclusions through comparisons. The studies also highlight the work of foreign students pursuing postgraduate studies in Türkiye on their own regions and focus on the accuracy of the models. Additionally, structural analyses of clustering and competitive models are among the primary research tools used in the studies.

In the analysis, the Diamond Model developed by Porter is widely used, along with the Balassa Model, AHP, Statistical and Econometric models, and Panel Data Analysis. Three studies, one on political history, another on education, and finally on women's competitiveness, were excluded from this study as they fall outside its scope. While primary sources based on field research are widely used, secondary data sources, particularly reports and indices developed on competition, form the dataset for studies on competitiveness.

ANALYSIS AND EVALUATION

As can be seen, a comprehensive field study on the status of thesis topic within the context of competitiveness in Türkiye has emerged. The issues focused on in the theses studied, and the results and recommendations obtained, constitute the focus of our study in terms of the academic perspective on family businesses.

Evaluation of the Geography-Based Analysis Process of Competitiveness

When the thesis studies are evaluated based on the classification made regarding the understanding, measurement, and evaluation of competitiveness, one study indicates that a single study conducted on the TOGG example provides an analysis at the firm level. In addition, there are 14 analyses conducted primarily based on sectors, 5 region-based studies, 10 sectoral studies, 5 studies on national competitiveness, and 20 studies in other categories without distinction between master's and doctoral studies).

Firm-based competitiveness appears to be approached based on the premise that the brand and the firm are the same. Yılmazcam (2022) examined TOGG's competitiveness through Porter's Diamond Model (Porter 1985, 1990). Various thesis studies have attempted to examine how a city's sectoral capabilities determine its competitiveness (Begg 1999; Forum 2014; Kamiya and Pengfei 2021). These studies focus on the assumed capabilities of cities and the nature of sectors believed to provide a competitive advantage.

Although region-based studies are limited (Dijkstra *et al.* 2023; Commission 2022), it is also observed that there is no common standard in the selection of regions. Studies conducted by Development Agencies may serve as a guide; however, it should not be forgotten that these studies were conducted within a specific time frame and should be considered in light of changing environmental conditions, including earthquakes, COVID-19, and other similar factors.

When studies are examined in a sectoral context, researchers such as Baran (2021) in the olive oil sector, Kayan (2021) in defence, and others have conducted studies on competitiveness in various

Table 1 Distribution of Postgraduate Theses on Competitiveness in Türkiye (2007-2025)

Year	Master's	Doctoral	Total	Field(s)
2007	2	0	2	Business Admin. / Architecture
2009	1	0	1	Industrial Engineering
2010	0	1	1	Econometrics
2011	1	0	1	Economics
2013	1	0	1	Economics
2014	2	1	3	Construction / Tourism / Urban and Regional Planning
2015	2	1	3	Tourism / Business Admin. / Tourism
2016	1	2	3	Economics / Business Admin. / Tourism
2017	1	2	3	Geography / Urban and Regional Planning / Economics
2018	2	1	3	Political Science / Business Admin. / Business Admin.
2019	7	2	9	Public Admin. / Business Admin. / Tourism / Industrial Eng. / Business Admin.
2020	2	1	3	Business Admin. / Business Admin. / Business Admin.
2021	4	2	6	Urban / Civil Aviation / Economics / Tourism / Business Admin. / Economics
2022	5	0	5	Economics / Business Admin. / Economics / Economics / Economics
2023	1	3	4	Economics / Business Admin. / Tourism / Economics
2024	4	2	6	Int. Trade / Business Admin. / Industrial Eng. / Econometrics / Industrial Eng. / Business Admin.
2025	2	1	3	Int. Trade / Education / Business Admin.
TOTAL	**38**	**19**	**57**	

sectors (Kancs and Kielyte 2001; Esposito and Collignon 2017). To answer the question of in what context Türkiye has a competitive advantage, works by Özçalık (2010), Dalkıran (2019), and Ülken (2007) were analyzed (Porter 1985, 1990; Dijkstra *et al.* 2023; Schwab and Zahidi 2020). Among various studies on competitiveness, the effects of culture and innovation, econometric studies, and the relationship between education, per capita income, and other variables with competitiveness have been analyzed (Gutium 2018; Ketels 2006; Fagerberg 1988).

A Critical Approach to Analyses and Searches

Master's and doctoral theses conducted during the specified period (2007-2025) were examined, specifically analyzing how the concept was analysed, how it was addressed according to classification, and how the context was determined.

The transformation of the concept of competitiveness and its historical development in relation to various parameters and variables has not been sufficiently examined in many studies. The question of how competitiveness should be approached in relation to competition and defined in various contexts concerning economic, political, and social developments has not been discussed in a multidisciplinary manner. For example, the impact of resource dependence on competitiveness or how competitiveness varies across the globe through organizational ecology has not been sufficiently studied. When limited studies with specific themes are not taken into account, the transformation of competitiveness through events like the impact of the 1973 oil crisis or liberalisation, the acquisition of a new dimension with globalisation, the emergence of a new form of competitiveness among global companies, how the ethical and legal forms of competitiveness should be interpreted in the new economy, the place of the concept in the search for a new balance in the world after the 2001 crisis, and the search for the counterpart of competitiveness during and after the Covid process remain unexamined. Even when searching for 'competitiveness and Covid' on Scholar 413,000 results are obtained however, the absence of any research on this correlation is striking (accessed on May 16, 2025).

When examining methods for measuring competitiveness, it is observed that certain methods defined in the literature stand out, while innovative methods are not widely used. No studies have been found that develop methods for competitiveness from the perspectives of sectoral and city competitiveness.

In urban competitiveness, the relationship between a sector and other sectors within the city has not been examined. The analyses

conducted on cities do not fully reflect city-based competitiveness studies. On the other hand, the fact that the analyses do not include a strategy proposal, either that comparisons with other cities regarding city-sector relations are not made in a complete or sufficient manner, reveals the shortcomings of competitiveness studies. Furthermore, the reasons for selecting the sector in the city, the references related to this, and the past performance of this sector have not been presented.

The studies conducted for the region and carried out on a sectoral basis contain similarities to these criticisms. It is evident that the extremely limited number of studies, regardless of the model and method used, requires more in-depth interpretations of the assessments related to national and regional activities. In other words, it would be useful to assess the future of the sector in terms of competitiveness and to highlight its contribution to the country's economy.

The analyses under this heading go beyond assessing competitiveness in a specific area and include suggestions to enhance competitiveness. The impact of factors such as culture, innovation, participation, decision-making, and specific institutional approval on competitiveness can be considerable. In addition, studies have been conducted on regions such as Gaza, Sub-Saharan Africa, and the Commonwealth of Independent States and mathematical and econometric models have been used to measure international competitiveness, as well as the competitiveness of clusters within countries.

CONCLUSION

Seeking answers to practical problems in academic studies is important for concretising the ongoing debate between these two dimensions. In this context, a search of the YÖK Thesis Database using the keyword 'competition' reveals that 2,568 theses have been conducted since 1993. When searching for '"competitive strength"', it was found that 476 studies were initiated in 1989. It was determined that two thesis studies on 'competitive advantage' were conducted in 2007, and 152 thesis records on the same topic were found starting in 1999. Competitiveness appears in only 57 thesis titles, and it is noteworthy that studies began as late as 2007.

Although the concept has been researched and measured by Porter, its being addressed so late seems to be related to the existence of other concepts used in its place. This points to a problem in conceptualisation. In particular, the use of the term 'competitive power' instead of 'competitiveness' indicates a shift in terminology. This is a situation that arises from the translation. For example, for 'global competitive power,' the term 'global competitive power' is used, while "competitiveness" and 'competitive power' are used as synonyms in Turkish. To be clear, the difference between them is not very significant or easy to understand. Competitive power refers to the ability and accumulated resources of a structure to achieve superiority in competition to establish an objective or geographical measurement value Competitiveness can be considered as the power to create an effect that will enable multiple actors to sustain their abilities to achieve defined goals in the competitive arena. While competitive strength contributes to explaining the cause of a result, competitiveness reveals the alignment and sustainable power of a company's or an organisation's capabilities.

In this context, city competitiveness is also emphasized, with a particular focus on the city's functions and economic characteristics in terms of competitive strength or advantage. Regional studies are generally based on classifications such as the TR-IBS distinction or KOP regions; however, these efforts are deemed insufficient. Notably, only one example directly examines companies, and even though these companies strive to become national and international brands, their competitiveness does not appear to attract significant academic interest. A similar lack of focus is observed in studies on national competitiveness. While research in fields such as business, economics, and tourism is more prominent, many studies from other disciplines primarily concentrate on methods and approaches related to competitiveness. Importantly, there is a clear absence of independent studies analyzing how the concept of competitiveness has evolved since the advent of Industry 4.0 in 2011 or the onset of the COVID-19 pandemic in 2020, and how this evolution should reshape the current discourse on competitiveness.

However, in addition to all these findings, the studies also include, albeit to a limited extent, efforts to produce effective solutions; discussions that critically question the practical meaning of concepts and offer suggestions by approaching competitiveness with a holistic understanding; theoretically comprehensive frameworks; and contributions to quantitative research through modeling and statistical evaluations. Postgraduate thesis studies, in particular, interrogate the concept of competitiveness along with its outputs and ontological foundations. The multidisciplinary nature of the concept further offers significant opportunities for expanded and in-depth future research.

Availability of data and material

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of interest

The author declares that there is no conflict of interest regarding the publication of this paper.

Ethical standard

The author has no relevant financial or non-financial interests to disclose.

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