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Corporate Social Responsibility for Sustainable Development: A Systematic Review of Business Contributions to Address Global Challenges

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ABSTRACT

This systematic review aims to analyze the contributions of Corporate Social Responsibility (CSR) to sustainable development by examining how businesses address critical global challenges such as zero hunger, health and well-being, gender equality, clean water and sanitation, sustainable cities, life on land, and peace and justice. **Purpose:** The study seeks to identify gaps in the existing literature and propose future research directions. **Method:** A comprehensive literature search was conducted across multiple bibliometric databases, yielding 2,520 studies. After applying stringent inclusion and exclusion criteria, 100 relevant studies were selected for analysis. The review synthesized empirical and theoretical findings, focusing on the effectiveness of CSR initiatives and their alignment with the United Nations Sustainable Development Goals (SDGs). **Results:** The findings reveal that while CSR initiatives significantly contribute to addressing global challenges, there are critical gaps in their long-term sustainability and effectiveness, particularly in developing regions. The review highlights the importance of integrating stakeholder engagement, addressing systemic inequalities, and measuring the impact of CSR practices to enhance their effectiveness. **Contributions:** This study provides valuable insights into the role of CSR in fostering sustainable development, contributing to existing theories and offering practical applications for industry and policymakers. It identifies underexplored areas for future research, emphasizing the need for robust frameworks that ensure CSR initiatives are equitable, inclusive, and sustainable.
Keywords: corporate social responsibility; CSR; sustainable development goals; SDG; sustainability; zero hunger; gender equality; clean water; health and well-being; sustainable cities; life on land; peace and justice; stakeholder engagement

Корпоративная социальная ответственность в интересах устойчивого развития: систематический обзор вклада бизнеса в решение глобальных проблем

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АННОТАЦИЯ

Данный систематический обзор направлен на анализ вклада корпоративной социальной ответственности (КСО) в устойчивое развитие с помощью изучения того, как компании решают важнейшие глобаль-

ные проблемы, такие как борьба с голодом, здоровье и благополучие, гендерное равенство, чистая вода и санитария, устойчивое развитие городов, экосистемы суши, мир и справедливость. **Цель:** исследование направлено на выявление пробелов в существующей литературе и предложение направлений будущих исследований. **Метод:** был проведен комплексный поиск литературы по нескольким библиометрическим базам данных, что позволило выявить 2520 исследований, относящихся к теме обзора. После применения строгих критериев включения и исключения для анализа было отобрано 100 релевантных исследований. В обзоре были синтезированы эмпирические и теоретические выводы, с акцентом на эффективность инициатив КСО и их соответствие целям устойчивого развития (ЦУР) Организации Объединенных Наций. **Полученные результаты** показывают, что, хотя инициативы КСО вносят значительный вклад в решение глобальных проблем, существуют критические пробелы в их долгосрочной устойчивости и эффективности, особенно в развивающихся регионах. В обзоре подчеркивается важность интеграции взаимодействия с заинтересованными сторонами, устранения системного неравенства и измерения воздействия практик КСО для повышения их эффективности. **Научный вклад:** в данном исследовании получена ценная информация о роли КСО в содействии устойчивому развитию, которая вносит вклад в существующие теории и предлагает практические приложения для промышленности и политиков. В обзоре определены недостаточно изученные области для будущих исследований, а также подчеркивается необходимость создания надежных структур, обеспечивающих равноправный, инклюзивный и устойчивый характер инициатив в области КСО.

Ключевые слова: корпоративная социальная ответственность; КСО; цели устойчивого развития; ЦУР; устойчивость; отсутствие голода; гендерное равенство; чистая вода; здоровье и благополучие; устойчивые города; экосистемы суши; мир и справедливость; взаимодействие с заинтересованными сторонами

1. Introduction

Corporate Social Responsibility (CSR) has become an essential strategy for firms to foster sustainable development while preserving revenue and reputation. CSR beyond mere charity, including ethical labor practices, environmental sustainability, stakeholder participation, and company governance [1]. The escalating significance of CSR is propelled by heightened public expectations, regulatory demands, and the acknowledgment that enterprises are pivotal in tackling global issues such as poverty, climate change, and social disparities [2]. The United Nations' (UN) Sustainable Development Goals (SDGs) have emphasized the need for corporations to include CSR in their plans to achieve enduring economic, social, and environmental sustainability [1]. Sustainable development entails fulfilling current need without jeopardizing the capacity of future generations to satisfy their own needs. The business sector significantly contributes to sustainability by implementing responsible practices in resource management, urban development, environmental preservation, and social equity [2]. Global organizations have started the implementation of sustainability-oriented CSR efforts, including carbon footprint reduction, fair pay promotion, ethical sourcing assurance, and community development engagement. Despite the increasing recognition of CSR's role in sustainable development, agreement remains elusive about its efficacy, impact assessment, and optimal practices across many sectors and geographies [1].

1.1. Aim of the paper

CSR has garnered heightened attention as enterprises encounter increasing demand to synchronize their operations with sustainable development objectives. The incorporation of CSR into company plans has transitioned from a voluntary activity to a fundamental element of corporate governance and sustained competitiveness. Considering escalating global difficulties like climate change, resource depletion, wealth disparity, and rapid urbanization, corporations are anticipated to actively engage in mitigating social and environmental concerns. Despite the expanding literature on CSR and sustainability, a complete synthesis that systematically assesses the efficacy of CSR programs in addressing significant global concerns remains absent. This study seeks to perform a comprehensive analysis of the contributions of CSR to sustainable development by

critically examining how companies tackle essential global issues, such as well-being, equality, resource management, urban development, environmental conservation, and social justice. This study synthesizes previous empirical and theoretical studies to provide a comprehensive view on the role of CSR in promoting sustainable development, while also noting research gaps and methodological limitations in the current literature. The study examines the degree to which CSR initiatives correspond with global sustainability agendas, including the UN SDGs, and assesses their effects on diverse stakeholders, such as employees, consumers, local communities, and policymakers. This study analyzes historical and contemporary CSR contributions while emphasizing upcoming themes in corporate sustainability, such as digital transformation in CSR practices, stakeholder-driven sustainability models, and legislative changes affecting CSR adoption. The study seeks to delineate explicit research trajectories for future researchers, concentrating on domains such as industry-specific CSR initiatives, longitudinal impact evaluation, and the influence of legislative frameworks in enhancing CSR efficacy. This study provides a systematic and evidence-based assessment of CSR's contribution to sustainable development, enhancing the dialogue on corporate responsibility and ethical business practices.

1.2. Background
1.2.1. Evolution of CSR and sustainability
The notion of CSR has significantly transformed over the decades, shifting from a charitable approach to an integrated strategy that aligns company objectives with SDGs. In the early 20th century, CSR was mostly voluntary and centered on corporate philanthropy, with enterprises participating in charity endeavors to assist local communities [3]. As industrialization progressed and firms increasingly influenced society, expectations for corporate responsibility changed. In the mid-20th century, CSR was seen as an ethical imperative rather than a voluntary option. The rise of stakeholder capitalism, influenced by Freeman's Stakeholder Theory (1984), underscored the need for firms to consider the interests of many stakeholders, including workers, customers, suppliers, governments, and communities. The expanding impact of globalization and tech-

nical progress has expedited the implementation of CSR initiatives, as multinational corporations encounter heightened scrutiny regarding their social and environmental effects [2, 3].

1.2.2. Business engagement in sustainable development
Businesses significantly contribute to sustainable development via many CSR efforts, such as the adoption of renewable energy, ethical labor standards, sustainable supply chain management, and inclusive economic growth [3]. As global focus on sustainability intensifies, companies are incorporating green technologies, circular economy principles, and carbon neutrality objectives into their strategic frameworks to minimize environmental impacts and promote long-term economic and social welfare [2]. A major aspect of business involvement in sustainability is the deployment of renewable energy. Numerous enterprises have adopted solar, wind, and hydroelectric energy sources to decrease their dependence on fossil fuels and mitigate greenhouse gas emissions [4, 5]. Corporations such as Tesla, Apple, and Unilever have pledged to use 100% renewable energy in their operations, exemplifying how enterprises may spearhead the worldwide transition to sustainable energy solutions [5]. Ethical labor practices are a vital component of corporate involvement in sustainable development. This includes the provision of equitable remuneration, secure work environments, diversity and inclusion initiatives, and anti-discrimination regulations [2]. Companies that emphasize ethical labor standards not only adhere to international labor legislation but also improve employee happiness and productivity. By using circular economy models, enterprises may minimize waste, recycle resources, and enhance resource efficiency, thereby promoting sustainability across sectors.

1.2.3. CSR and the fight against zero hunger
CSR is pivotal in combating global hunger and food insecurity, in accordance with UN SDG 2. Businesses, especially in the food, agricultural, and retail industries, have progressively integrated sustainable food production, waste minimization, and nutrition-oriented community programs into their CSR plans [6]. These initia-

tives are essential for guaranteeing fair access to healthy food and fostering long-term food security. Businesses primarily contribute to Zero Hunger via sustainable agriculture and food production. Corporations like Nestlé and Unilever have used regenerative agricultural techniques that boost soil vitality, promote biodiversity, and guarantee sustainable food production in the long run [2]. Moreover, several multinational food firms have engaged with smallholder farmers by offering training, financial resources, and technological access to improve production and uphold fair trade norms. A crucial CSR program is the decrease of food waste. The Food and Agriculture Organization (FAO) estimates that over one-third of all food produced worldwide is squandered, intensifying food insecurity and environmental deterioration [7].

1.2.4. CSR and the promotion of good health and well-being

CSR has emerged as a significant tool for advancing health and well-being, in accordance with UN SDG 3. Companies in many sectors are allocating resources towards healthcare accessibility, workplace wellness initiatives, illness prevention, and mental health assistance to improve public health outcomes and foster healthier communities [8]. Companies primarily enhance global health by bolstering healthcare infrastructure and accessibility. Numerous multinational firms, especially in the pharmaceutical and healthcare industries, undertake efforts that provide medical supplies, vaccinations, and healthcare services to marginalized people. Johnson & Johnson and Pfizer have developed CSR initiatives concentrating on vaccine distribution and maternity health care in economically disadvantaged areas [9]. These initiatives facilitate the elimination of disparities in healthcare access and decrease death rates from avoidable illnesses. Workplace wellness initiatives constitute a notable CSR effort.

1.2.5. CSR and the advancement of gender equality

CSR is essential in advancing gender equality, in accordance with UN SDG 5. Global enterprises have acknowledged the significance of cultivating inclusive environments, promoting female leadership, guaranteeing equitable compensa-

tion, and tackling gender-based discrimination. Corporations are implementing targeted CSR programs to provide fair opportunities for women and disadvantaged gender groups, both in the workplace and beyond. A primary CSR strategy for gender equality is the development of diverse and inclusive work environments. Numerous firms have instituted gender diversity policies, anti-discrimination initiatives, and leadership development programs to facilitate women's professional progression. Corporations like Unilever and IBM have pledged to enhance female participation in senior positions via the establishment of mentoring initiatives and the enforcement of impartial hiring and promotion protocols. A vital component of CSR regarding gender equality is the elimination of the gender wage gap. Consequently, several firms have performed pay equality audits and implemented transparent wage frameworks to eradicate discrepancies [10]. Salesforce and Starbucks have pledged to attain equitable compensation across all job tiers, establishing a benchmark for other firms to emulate [11].

1.2.6. CSR and the commitment to clean water and sanitation

Access to clean water and sanitation is a basic human right and an essential element of sustainable development, in accordance with UN SDG 6. CSR programs have increasingly concentrated on tackling global water issues by advocating water conservation, enhancing sanitary infrastructure, and guaranteeing equal access to clean drinking water. Companies, especially in the beverage, agricultural, and manufacturing industries, have acknowledged their responsibility in effective water management and have included sustainable water-use policies in their CSR plans. Corporations significantly contribute to clean water projects via water stewardship programs. Numerous multinational firms have initiated programs aimed at diminishing water usage, mitigating pollution, and rehabilitating freshwater habitats [12].

1.2.7. CSR and the development of sustainable cities and communities

The rapid growth of metropolitan regions has generated considerable issues concerning infrastructure, pollution, housing, and resource management. Resolving these difficulties re-

quires collaborative efforts from governments, enterprises, and civil society. CSR has become an essential catalyst for advancing sustainable urban development via investments in environmentally sustainable infrastructure, affordable housing, intelligent technology, and community development initiatives [13]. Companies, via CSR activities, aid in fulfilling UN SDG 11 by promoting inclusivity, resilience, and environmental sustainability in urban areas. A principal CSR strategy for urban sustainability is the development of green infrastructure and smart city technology. Numerous firms have invested in energy-efficient structures, renewable energy integration, and waste management strategies to reduce the environmental impact of urban growth. Siemens and Tesla have led the development of sustainable urban solutions, including electric mobility, smart grids, and energy-efficient transportation systems to enhance urban sustainability [14].

1.2.8. CSR and the protection of life on land

The deterioration of terrestrial ecosystems presents a substantial risk to biodiversity, climatic stability, and human livelihoods. CSR has emerged as an essential mechanism for enterprises to alleviate deforestation, save endangered species, and advocate for sustainable land-use practices [15]. In accordance with the UN SDG 15, several firms are allocating resources to reforestation, sustainable agriculture, and wildlife conservation initiatives to reduce their ecological impact. Businesses significantly contribute to terrestrial ecosystems via forest protection and replanting efforts. Numerous major firms, like Microsoft and Nestlé, have pledged to achieve net-zero deforestation by implementing sustainable sourcing practices and financing extensive tree-planting initiatives [16].

1.2.9. CSR and the promotion of peace, justice, and strong institutions

The significance of CSR in advancing peace, justice, and robust institutions has garnered heightened focus in recent years, in accordance with UN SDG 16. Businesses are acknowledging the need to function within ethical frameworks that enhance transparency, combat corruption, safeguard human rights, and ensure legal compliance

to cultivate stable and equitable communities [17]. CSR programs in this domain emphasize corporate governance, legal responsibility, and community participation to foster trust and institutional resilience. A significant contribution of CSR to peace and justice is the implementation of ethical corporate practices and anti-corruption initiatives. Numerous global firms have implemented anti-bribery procedures, open financial reporting, and independent audits to guarantee adherence to legal and ethical norms. Organizations such as Microsoft, Unilever, and IBM have established whistleblower protection initiatives and anti-corruption training to foster ethical corporate practices [18].

1.2.10. CSR and global challenges

CSR activities have increasingly concentrated on tackling urgent global issues, such as climate change, social justice, poverty reduction, and urban development. The pressing nature of these concerns has compelled corporations to implement more sustainable practices and establish ambitious objectives that correspond with global sustainability initiatives, like the UN SDGs. A major concern for corporations is climate change, which endangers the environment, economy, and global societies. In response, several firms have pledged to attain net-zero carbon emissions by certain deadlines, adopt renewable energy sources, and improve energy efficiency in their operations [19]. For example, Microsoft intends to attain carbon negativity by 2030, while Unilever aspires to net-zero emissions across its value chain by 2039 [20]. These ambitious objectives not only advance global climate initiatives but also establish corporations as leaders in sustainability, promoting innovation in green technology and practices. A critical domain for CSR projects is social justice. Businesses are increasingly acknowledging the significance of fostering equality and diversity within their operations and the communities they serve. Numerous firms have implemented diversity and inclusion policies to establish equal workplaces and empower marginalized groups [19]. Moreover, firms are participating in community outreach projects that assist vulnerable groups via education, healthcare, and economic empowerment activities.

2. Method

This study employs a systematic review methodology to examine the role of CSR in advancing sustainable development, concentrating on critical global challenges including zero hunger, health and well-being, gender equality, clean water and sanitation, sustainable cities, life on land, and robust institutions. The methodological approach aims to guarantee extensive literature coverage, transparency, and replicability in the review process. The research procedure includes the selection of relevant bibliometric databases, the implementation of a systematic search strategy, and the application of stringent inclusion and exclusion criteria to guarantee the capture of high-quality data. The research adheres to PRISMA principles to evaluate and filter methodological rigor, ensuring the inclusion of only empirical and theoretical works that significantly contribute to CSR and sustainability. Data extraction emphasizes essential CSR activities, theoretical frameworks, and industry-specific contributions, succeeded by qualitative content analysis to discern trends, research deficiencies, and prospective trajectories.

2.1. Selection of bibliometric databases

This research utilizes several bibliometric databases to provide a thorough and high-quality evaluation of peer-reviewed journal articles, conference proceedings, and gray literature pertaining to CSR and sustainable development. The choice of databases is determined by their reliability, multidisciplinary scope, and comprehensive citation monitoring, guaranteeing a wide and well-rounded dataset for the research [21, 22]. Scopus was chosen for its comprehensive multidisciplinary scope, providing a wide collection of high-quality journal articles and citations across business, social sciences, and environmental studies. The inclusion of Web of Science (WoS) provides access to high-impact, peer-reviewed research, facilitating a more thorough evaluation of CSR's contribution to sustainability. Google Scholar was used to get company reports, conference papers, and institutional studies, since it provides access to gray literature sometimes neglected in conventional bibliometric analysis. Furthermore, ScienceDirect was selected for its robust emphasis on CSR-related research, especially studies tackling sustainability issues across several industries. Emerald Insight was established for its extensive collection of research papers on CSR and sustainability, especially those analyzing business initiatives for environmental and social accountability. This research integrates data from many high-impact sources to provide a complete literature assessment, including a holistic picture of CSR's contributions to sustainable development across diverse sectors, geographic locations, and theoretical frameworks.

2.2. Search strategy

A systematic search method was used to obtain pertinent papers on CSR and its impact on sustainable development. The search procedure included Boolean operators (AND/OR) to narrow results and guarantee a thorough selection of literature. Keyword combinations were used across several bibliometric databases, including Scopus, Web of Science, Google Scholar, ScienceDirect, and Emerald Insight. The search parameters were formulated to include research pertaining to CSR's function in tackling global issues, including zero hunger, health and well-being, gender equality, clean water and sanitation, sustainable cities, terrestrial ecosystems, and robust institutions.

The search identified 229 articles related to "Zero Hunger" AND "CSR", while 388 studies explored the intersection of CSR and Good Health and Well-being. Additionally, 577 articles examined CSR's impact on Gender Equality, and 424 studies investigated CSR and Clean Water and Sanitation. The topic of Sustainable Cities and Communities in the context of CSR yielded 372 articles, whereas Life on Land had 294 relevant studies. Finally, CSR and Peace, Justice, and Strong Institutions were covered in 281 articles. The initial database search yielded a substantial number of articles that were further subjected to a screening process based on relevance, methodological rigor, and alignment with the study's objectives. The results were filtered to remove duplicates and non-peer-reviewed sources, ensuring a robust dataset for the subsequent stages of analysis.

2.3. Inclusion and exclusion criteria

A stringent inclusion and exclusion strategy was used to create a focused and high-quality dataset for systematic review. This phase was cru-

cial for preserving the reliability, validity, and relevance of the study outcomes. The inclusion criteria included research published from 2015 to 2025, guaranteeing the contemporaneity of findings about CSR and its contributions to sustainable development. Only peer-reviewed journal papers, book chapters, and conference proceedings were included to guarantee legitimacy. The chosen papers either experimentally or conceptually investigated the role of CSR in advancing sustainability. Furthermore, research focusing on CSR activities related to significant global challenges such as eradicating hunger, promoting health and well-being, advancing gender equality, ensuring clean water and sanitation, developing sustainable cities, protecting the environment, and strengthening institutions was emphasized. Conversely, papers were omitted if they were non-English publications, since linguistic hurdles might impede accessibility and comprehension. Articles devoid of empirical or theoretical contributions, including opinion pieces, editorials, or commentary articles, were also removed. Furthermore, duplicate entries from several databases were eliminated to prevent duplication. Upon applying the specified inclusion and exclusion criteria, a final compilation of 100 articles was chosen for comprehensive examination, guaranteeing that the research is found on reliable, varied, and methodologically robust literature.

2.4. Methodological quality assessment

A systematic quality evaluation was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria [23] to guarantee the rigor, reliability, and validity of the chosen studies. PRISMA offers a systematic framework for assessing the methodological quality of studies included in systematic reviews, guaranteeing that only rigorous and significant research informs the final evaluation [6, 24]. A key quality evaluation criterion was the relevance of study aims, particularly assessing the alignment of the research with CSR and SDGs. Research specifically investigated the role of CSR in tackling global issues such as eradicating poverty, promoting health, advancing gender equality, and ensuring environmental sustainability was emphasized. A significant compo-

nent was the research technique, evaluating whether the studies used qualitative, quantitative, or mixed-method methods. Preference was given to research using rigorous statistical approaches, case studies, or theoretical frameworks, since these methodologies guarantee dependability and depth in analysis. Moreover, the trustworthiness of the data was a crucial factor. Research was evaluated according to its publication in peer-reviewed, indexed journals such as Scopus, Web of Science, and Science-Direct, therefore assuring high-impact and reputable sources. Articles demonstrating robust theoretical contributions, empirical rigor, and significant citation effect were favored over those relying on anecdotal evidence or possessing weak empirical support. The findings and contributions of each study were assessed, especially regarding their implications for sustainable business practices, corporate policies, and strategic CSR initiatives. Studies providing policy recommendations, innovative CSR frameworks, or industry-specific sustainability strategies were considered more influential. This study employs stringent methodological evaluation criteria to guarantee that the final dataset comprises high-quality, evidence-based research that offers significant insights into the role of CSR in sustainable development.

2.5. Selection of studies

The selection of papers for this systematic review was executed using a systematic methodology to guarantee the inclusion of relevant and high-caliber research. The procedure included many screening phases, according to PRISMA recommendations. The preliminary search produced 2,520 papers from several academic databases. Following the identification of 834 relevant studies using titles and abstracts, the elimination of duplicates removed 251 records, resulting in a total of 583 studies. A title and abstract screening were thereafter performed to evaluate the pertinence of the papers concerning the study goals. This phase led to the classification of 258 studies as pertinent, while 325 were considered non-pertinent and consequently eliminated. The subsequent step included a comprehensive review of the 258 pertinent papers. This evaluation emphasized methodological rigor, data reliability, and coherence with the study's topic emphasis.
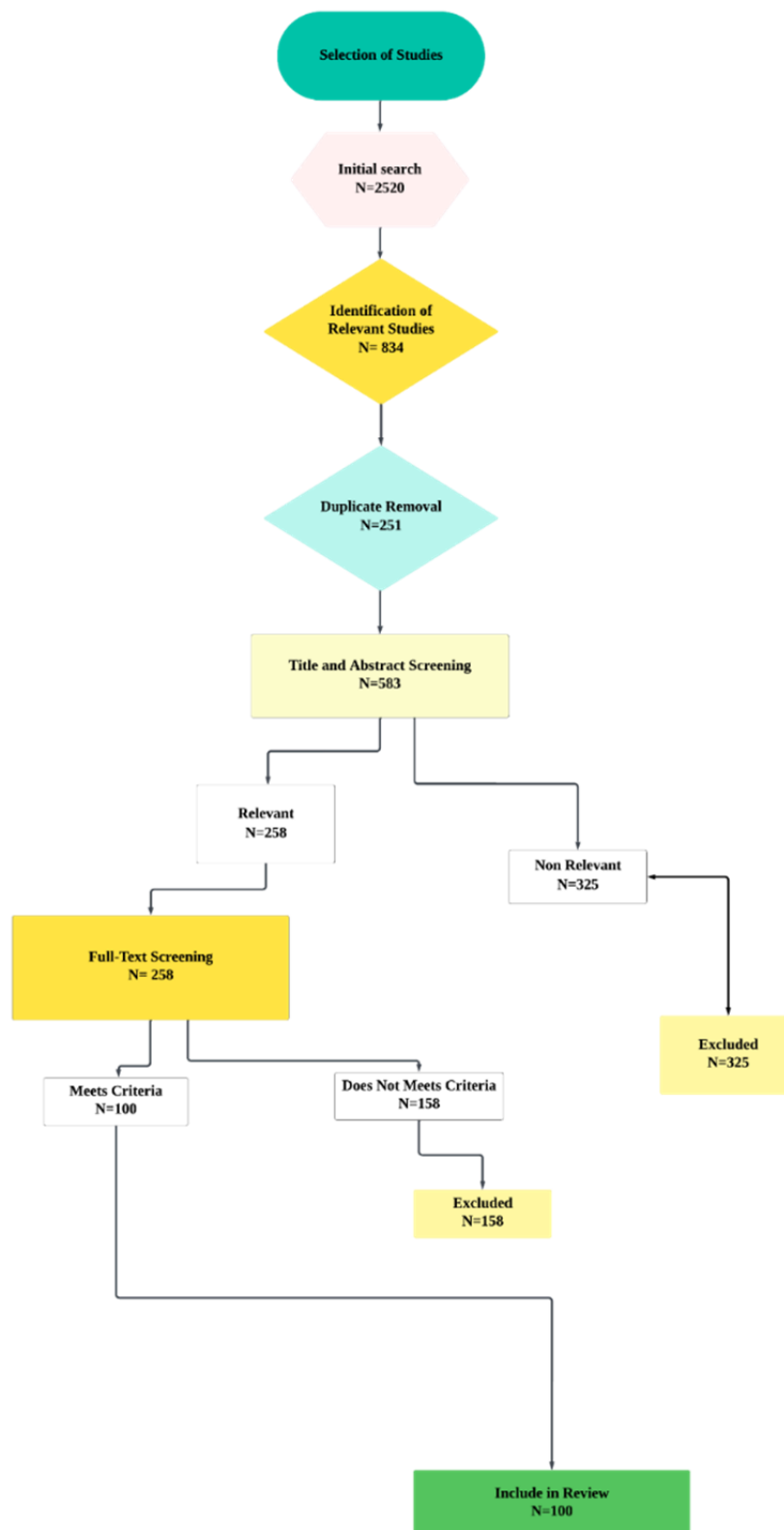
Fig. 1. **Search strategy, outlining the subsequent identification and screening of appropriate sources**

Source: Developed by the authors.

At this stage, 158 research failed to satisfy the established inclusion criteria and were eliminated, resulting in the inclusion of 100 high-quality studies in the final evaluation. This systematic screening methodology guaranteed a thorough and transparent method for finding research that substantially enhances the knowledge of CSR and sustainable development. *Figure 1* delineates the search approach, including the following discovery and evaluation of suitable sources.

2.6. Data extraction and analysis

The data extraction procedure was rigorously executed to classify the principal results from the final selection of 100 research, guaranteeing a systematic and thorough examination of CSR activities in sustainable development (see *Table* at the end of the Discussion section). The extracted data concentrated on several essential aspects, including the influence of CSR on diverse sustainable development themes such as zero hunger, good health and well-being, gender equality, clean water and sanitation, sustainable cities and communities, life on land, and peace, justice, and robust institutions. Each research was evaluated for the distinct methods by which CSR activities impact different domains, revealing patterns and trends in corporate involvement with sustainability efforts. The categories of CSR efforts were delineated, differentiating between corporate philanthropy, sustainable business models, ethical labor practices, and community development programs. This categorization offered insights into the various tactics used by organizations to attain sustainability objectives. A geographical analysis was undertaken to identify the nation or continent of each research, providing a comparative view on the variation of CSR's involvement in sustainable development across diverse economic and cultural situations. Additionally, sector-specific accomplishments were recognized, with a focus on CSR projects in industries like energy, healthcare, finance, manufacturing, and technology.

2.7. Rationale for selecting the SDGs in this study

This study examines SDGs 2, 3, 5, 6, 11, 15, and 16 because of their essential importance to CSR and their urgent worldwide relevance. These Sustainable Development Goals comprise fundamental domains where enterprises can exert quantifiable social and environmental influence. SDG 2 (Zero Hunger) and SDG 3 (Good Health and Well-being) pertain to essential human requirements, with studies indicating that CSR-driven innovations and initiatives in food systems and mental health help mitigate hunger and enhance well-being. SDG 5 (Gender Equality) is essential due to ongoing gender-based inequalities in workplaces and communities, where CSR may enhance women's empowerment through inclusive poli-

cies and transparency. SDG 6 (Clean Water and Sanitation) is emphasized because of the business responsibility in sustainable water utilization and pollution management, particularly in sectors with significant ecological impacts. SDG 11 (Sustainable Cities and Communities) corresponds with corporate initiatives in urban planning, housing, and social inclusion, whereas SDG 15 (Life on Land) illustrates the effects of corporate land utilization, deforestation, and biodiversity practices. Ultimately, SDG 16 (Peace, Justice, and Strong Institutions) is essential to Corporate Social Responsibility in conflict areas and government transformation. Collectively, these SDGs signify critical areas where corporate activities significantly align with sustainable development results.

2.8. Identification of research gaps and future research directions

The literature study on CSR and its correlation with sustainable development identifies significant gaps and prospects for further investigation. A significant constraint in contemporary study is the excessive emphasis on CSR activities in rich countries, resulting in the insufficient exploration of the contextual realities in developing nations. This regional bias impedes a thorough understanding of how CSR functions across varied socio-economic and cultural situations. Considering the distinct developmental constraints and institutional frameworks in developing nations, forthcoming research should investigate the role of CSR in these contexts to identify distinctive dynamics and obstacles to implementation. Literature indicates a deficiency in transdisciplinary approaches to analyzing CSR impacts. Current research often analyses CSR through singular disciplinary lenses, including business ethics, environmental science, or social development, neglecting the interrelatedness of various fields. Future research should employ integrative frameworks that amalgamate sociology, economics, environmental studies, and information systems to accurately represent the intricacies of sustainable development challenges. A notable deficiency exists in the insufficient examination of technical advancements in CSR procedures. Despite the discourse surrounding emerging technologies such as blockchain, artificial intelligence, and big data in individual

studies, their strategic capacity to improve transparency, stakeholder involvement, and social accountability has not been adequately explored. Future research may concentrate on how these technologies might be utilized across other sectors to address sustainability concerns more efficiently. A significant amount of the literature is cross-sectional, providing only snapshots of CSR impacts. Longitudinal study is essential to evaluate the sustainability and enduring effects of CSR projects, especially in domains such as community development, resource management, and employee welfare. This temporal depth will allow researchers to assess how prolonged CSR actions facilitate the attainment of SDGs over time.

This study highlighted specific SDGs where CSR research has been concentrated, justifying their inclusion considering these gaps. For instance, SDG 2 is examined in research pertaining to technical innovations in food supply chains, including blockchain and AI for traceability and transparency. Nonetheless, whereas environmental issues are extensively documented, the social and economic dimensions of food security are inadequately addressed, highlighting the necessity for a more comprehensive study focus. SDG 3 has garnered increasing focus, especially concerning mental health and occupational stress. Nonetheless, emerging pressures from virtual work environments and socio-demographic factors affecting well-being necessitate a more thorough contextual examination, especially in low-income or rural areas. SDG 5 is a significant focus, with research indicating systemic obstacles in employment and corporate social responsibility; however, feminist theories and gender mainstreaming are insufficiently employed. Future studies should examine how corporate social responsibility might facilitate structural transformation, particularly for marginalized and intersectional communities. The literature highlights the significance of circular economy innovations and corporate social responsibility in water governance related to SDG 6, especially within the mining and tourism industries. However, the integration of policies and the involvement of local stakeholders require additional empirical validation. SDG 11 underscores the disjointed character of urban corporate social responsibility programs, especially concerning housing, infrastructure, and community interactions. Research may further explore inclusive urban design and

the contribution of corporate social responsibility to promoting social integration in fast urbanizing areas. SDG 15 examines the relationship between land use, biodiversity, and economic development, although frequently neglects the long-term ecological trade-offs associated with policies such as forest-to-farm conversions. Further efforts are necessary to establish integrated frameworks that reconcile environmental conservation with community livelihoods. Research highlights the shortcomings of corporate social responsibility in conflict-affected regions, particularly within the extractive sector, in relation to SDG 16. Inadequate governance, insufficient stakeholder involvement, and the co-optation of corporate social responsibility by elites are persistent issues. Research must emphasize ethical accountability, culturally attuned CSR frameworks, and systems for institutional legitimacy in vulnerable areas. Common elements appear across these SDGs that underscore the identified research needs. A paradigm changes from corporate to human social responsibility is advocated, emphasizing enhanced integration of social components into circular economy models and a more profound engagement of cultural and community viewpoints in CSR planning. Interdisciplinary techniques and hybrid methods are widely acknowledged as vital for elucidating the complexity of CSR's contribution to sustainable development. The forthcoming research agenda should concentrate on geographical inclusion, longitudinal effect evaluation, theoretical advancement beyond conventional frameworks such as Stakeholder Theory, and the strategic incorporation of emerging technology. This congruence between recognized research deficiencies and prospective trajectories guarantees that CSR research can more efficiently aid in the attainment of the SDGs and the promotion of global sustainability initiatives.

3. Results

This section delineates the results of a systematic review of 100 selected papers that examine the impact of CSR on sustainable development across diverse themes, including zero hunger, health and well-being, gender equality, clean water and sanitation, sustainable cities, life on land, and peace and justice. The report examines the alignment of CSR programs with global sustainability goals and their effects on diverse stakeholders.

3.1. Corporate Social Responsibility and Its Alignment with Sustainable Development Goals: A Keyword Co-Occurrence Analysis

Figure 2 illustrates a term co-occurrence network visualization of research pertaining to CSR and its correlation with several SDGs, highlighting the multidisciplinary character of sustainability studies. The study reveals a profound connection between CSR initiatives and SDG 2 (Zero Hunger), especially in relation to research on food security, malnutrition, sustainable agriculture, and hunger elimination. These themes underscore the responsibility of companies in mitigating global food shortages, enhancing agricultural methods, and aiding communities in attaining sustainable nutritional stability. Moreover, SDG 3 (Good Health and Well-being) is widely represented throughout the network, including essential ideas like healthcare access, illness prevention, mental health, and universal health coverage. This relationship highlights how CSR programs improve public health systems, guarantee fair healthcare services, and foster workplace well-being as a fundamental component of corporate responsibility. A notable area of study is SDG 5, which examines gender discrimination, women's empowerment, gender-based violence, and equitable compensation. These themes underscore the significance of CSR in advancing gender-inclusive policies, enhancing diversity in business leadership, and tackling structural disparities within the workforce. Moreover, SDG 6 represents a vital domain of CSR involvement, highlighting water quality, sanitation, hygiene, and wastewater management. Corporations are progressively allocating resources to sustainable water management, pollution mitigation, and sanitation initiatives, exemplifying their corporate duty towards environmental preservation and public health. The graphic demonstrates significant links to SDG 11, highlighting studies on urbanization, smart cities, housing affordability, and climate resilience. CSR initiatives in this sector foster sustainable urban development, infrastructure planning, and the establishment of resilient communities via eco-friendly policies and social investment programs. SDG 15 is a crucial subject, emphasizing biodiversity protection, deforestation, land degradation, and ecosystem restoration within the context of CSR-driven environmental sustainability. Organizations involved in conservation initiatives, reforestation projects, and sustainable resource management synchronize their activities with enduring ecological stability. Furthermore, SDG 16 is reflected in studies concerning human rights, governance, corruption, and conflict resolution, illustrating how CSR initiatives foster ethical corporate practices, transparent governance, and institutional accountability. The emergence of governance-related topics in the keyword network indicates the growing significance of CSR in promoting regulatory compliance, anti-corruption initiatives, and corporate ethics across both private and public sectors. These observations demonstrate that CSR research encompasses not just business ethics but is also intricately linked to the overarching sustainability goal, highlighting the need for ongoing corporate involvement in realizing the SDGs.

3.2. Key insights from the systematic review of CSR initiatives

The systematic assessment revealed numerous CSR activities associated with specific SDGs, including addressing SDG 2, SDG 3, SDG 5, SDG 6, SDG 11, SDG 15, SDG 16. Although their beneficial contributions, numerous shortcomings in existing CSR methods and studies have constantly surfaced. SDG 2, CSR efforts often emphasize the promotion of sustainable agriculture, enhancement of food supply chains, and provision of technology resources to farmers. Research underscores the advantages of corporate partnerships with local farmers to improve productivity and food security [29]. Nevertheless, there is scant research evaluating the long-term effects of these activities. Although they may provide temporary relief from hunger, many do not tackle fundamental structural concerns such as poverty, disparities in land ownership, and policy obstacles. This suggests that CSR initiatives often emphasize immediate, quantifiable results rather than enduring, systemic transformation. Future studies should concentrate on amalgamating agricultural assistance with comprehensive socio-economic reforms to attain enduring food security. Concerning SDG 3, CSR initiatives typically focus on employee wellness, community health outreach, and mental health assistance. These activities can augment public health out-
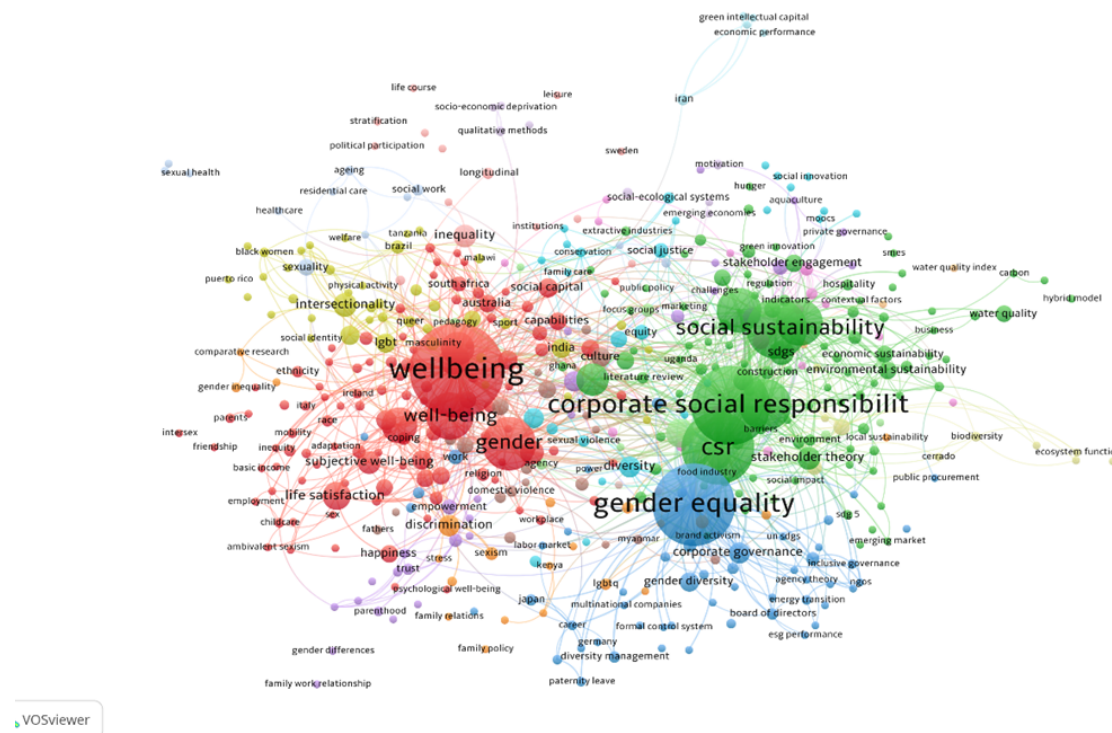
Fig. 2. **Keyword Co-Occurrence Network of CSR Research Aligned with Sustainable Development Goals (SDGs)**

Source: Developed by the authors.

comes and elevate business reputation. However, there is a lack of longitudinal research assessing the lasting impacts of health-related CSR actions. Many assessments are confined to immediate or short-term results, hindering a comprehensive knowledge of how CSR might foster long-term health equity [92]. SDG 5, CSR projects frequently advance women's empowerment via education, skills development, and workplace inclusion programs. Despite firms reporting advancements, a disparity often exists between pledges and actual execution. In numerous instances, gender initiatives are predominantly symbolic rather than substantive, motivated by reputational concerns rather than authentic ethical commitment [75]. Furthermore, monitoring frameworks frequently lack robustness, hindering the evaluation of actual impact. This underscores the constraints of CSR when gender equality is not integrated into fundamental corporate strategies and governance.

SDG 6 is prioritized through investments in water infrastructure and partnerships with local communities. Although these projects may enhance water accessibility in the near term, their long-term sustainability frequently remains dubious due to inadequate follow-up and insufficient

local capacity development [12]. The lack of participative methods and thorough preparation compromises the sustainability of many CSR initiatives. In relation to SDG 11, corporations contribute by enhancing urban infrastructure, managing trash, and preserving the environment. Nevertheless, numerous initiatives concentrate on discrete projects without tackling comprehensive urban sustainability. This disjointed methodology obstructs the capacity to assess collective advancement and formulate cohesive responses [13].

Regarding SDG 15, CSR programs frequently participate in conservation, reforestation, and biodiversity efforts. Although these initiatives exhibit ecological advantages, little focus is directed towards the social aspects, especially the effects on local communities reliant on natural ecosystems. Neglecting socio-economic connections may result in community marginalization or opposition, hence diminishing the overall efficacy of CSR [15].

Finally, SDG 16 is tackled by CSR initiatives focused on conflict resolution, equitable resource allocation, and community development in vulnerable environments. Although CSR has the capacity to enhance social cohesiveness, some programs fail to adequately address systemic inequities or structural violence. Corporate initiatives may often

serve more as instruments for reputation control rather than authentic endeavors to enhance institutional resilience [102]. The lack of multi-stakeholder governance diminishes credibility and efficacy. Whereas CSR programs increasingly correspond with several SDGs, their efficacy is frequently hindered by a short-term perspective, insufficient systemic integration, and inadequate participatory methods. Future study must employ critical and interdisciplinary methodologies to more effectively assess the long-term effects and inclusivity of CSR contributions to sustainable development.

3.3. Global barriers to effective CSR implementation

Comprehensive studies underscore the essential function of CSR in promoting sustainable development, yet various international obstacles hinder the successful execution of CSR efforts. Identifying these obstacles is essential for augmenting CSR's influence on vital global concerns, including hunger elimination, health advancement, gender equity, access to potable water, sustainable urban development, environment conservation, and social justice. A primary difficulty is the dearth of robust legislative frameworks and institutional support in most places, especially in developing nations. Inadequate regulatory frameworks frequently compel firms to prioritize legal compliance above authentic corporate social responsibility commitments, yielding cosmetic initiatives that fail to tackle essential social and environmental issues. Moreover, inadequate governance frameworks diminish the capacity of stakeholders such as local communities, regulators, and civil society to ensure corporate accountability for their CSR commitments. Economic constraints present further obstacles, particularly for SMEs that may be deficient in the financial resources required to initiate and maintain extensive CSR initiatives. During periods of economic instability, companies frequently emphasize immediate financial gains at the expense of long-term sustainability objectives, thereby jeopardizing the prospects for significant and lasting CSR results. Cultural considerations significantly impact the uptake and efficacy of CSR. In many communities, CSR initiatives may be viewed with skepticism, seen primarily as marketing strategies rather than genuine efforts to enhance social welfare. Cultural conventions and cultural views can further con-

strain the popularity or efficacy of CSR projects; for instance, programs promoting gender equality may face opposition in communities with entrenched gender roles. Effective corporate social responsibility necessitates substantial contact with a diverse array of stakeholders, encompassing employees, local communities, and civil organizations. Nevertheless, numerous CSR programs inadequately integrate stakeholder viewpoints, resulting in projects that fail to comprehensively meet community needs or expectations. The absence of authentic conversation can cultivate distrust and undermine the validity and efficacy of CSR initiatives. An additional obstacle is the inadequate knowledge and skills within organizations to formulate and execute effective CSR programs. Numerous organizations, especially SMEs, lack the expertise or understanding of CSR's potential advantages, leading to insufficient investment in responsible activities. The lack of standardized measurements and evaluation methods obstructs proper measurement of CSR performance, hence constraining evidence-based decision-making and ongoing stakeholder support.

4. Discussion

This systematic review of 100 meticulously chosen studies provides significant insights into the complex function of CSR in promoting sustainable development (see *Table*). The findings highlight CSR's essential role in tackling significant global issues, such as hunger elimination, health enhancement, gender parity, access to clean water and sanitation, sustainable urban development, terrestrial ecosystem conservation, and the promotion of peace and justice. A recurring topic in the literature is the acknowledgement that CSR programs are vital instruments for promoting sustainable practices and strengthening community resilience. Although, despite this widespread recognition, the research uncovers significant deficiencies in the efficacy and long-term viability of numerous CSR initiatives. Although many firms officially endorse CSR values, their practical implementation frequently fails owing to financial limitations, cultural obstacles, and insufficient governmental backing. This disconnection underscores the intricacy of converting CSR objectives into significant, enduring effects. The study findings validate the study questions outlined in the methodology, illustrating CSR's capacity as a mechanism for sustainable

Table
Characteristics of the studies included in the review

Sl.	Authors	Methodology	Country / Continent	Findings	SDGs Addressed in the Study	SDGs Matched with This Review's Focus
1	[6]	Systematic review, bibliometric analysis, topical analysis, SAFA approach	Italy; Germany; Qatar	Environmental aspects in AFS are well addressed, but social, economic, and political dimensions are often neglected. Suggests a 4P holistic framework	2, 8, 12, 17	2
2	[25]	Survey, Decision Matrix Analysis, Pearson's Correlation	Thailand	SEP shows strong consistency with SDGs across environmental, economic, and social dimensions, supporting sustainable development. A 42.33% positive correlation with SDGs was found	2, 8, 12, 17	2
3	[26]	IoT integration, LEACH protocol, App-based monitoring, Blockchain	Pakistan; China	Blockchain and IoT improve transparency and sustainability in agriculture. Enhance food security through traceability and informed consumer choices	2, 9, 12, 13	2
4	[27]	Literature review, Case study	New Zealand; Canada	ISO standards potentially support SDG 2 goals, especially targets 2.3 and 2.4. However, challenges include limited smallholder adoption and governance issues	2, 8, 12	2
5	[28]	Case study, Secondary data, Technological assessment	Australia	Uses tech-based logistics (AI, blockchain) to deliver meals efficiently. Aims to combat child malnutrition via large-scale school lunch programs	2, 8, 12, 17	2
6	[7]	Literature review, Policy analysis	Saudi Arabia; Bahrain; Pakistan; Sudan	Identifies major food waste issues and suggests zero hunger strategies and circular bioeconomy approaches to improve food waste management	2, 12	2

Sl.	Authors	Methodology	Country / Continent	Findings	SDGs Addressed in the Study	SDGs Matched with This Review's Focus
7	[29]	Systematic literature review, Thematic analysis	India; United States	Nutraceuticals can address hunger and malnutrition but operational challenges in developing countries limit accessibility and affordability	2, 9, 12, 17	2
8	[30]	Empirical analysis, Sustainability reporting review	Italy	Companies with inclusive reporting contribute more to SDG 2. Advocates dialogic sustainability reporting for corporate social impact	2, 8, 9, 10, 12	2
9	[31]	Institutional theory, Sociological analysis, Policy framework	Colombia	Calls for CSR and institutional change in the food industry to combat obesity and promote healthy diets. Emphasizes responsible practices and nutrition policy alignment	2, 3, 9, 17	2, 3
10	[32]	Participatory demonstrations, scaling-up, multi-country initiatives	India; Asia	Demonstrated that "seeing is believing" approach improved technology adoption; over 10 million farmers benefited in Asia	2, 11, 13	2, 11
11	[33]	Comparative analysis, benchmarking, SDG analysis	Czech Republic; Ukraine	Found inequality in financial access; proposed responsible investment as a key tool to improve SDG outcomes	2, 9, 12, 17	2
12	[10]	Survey, Healthy Workplaces Tool, quantitative analysis	Portugal; Spain	Organizational culture was linked to stress management and healthy environments during the pandemic	5, 8, 10, 17	5
13	[34]	Online survey, conservation of resources theory	Belgium	Virtual meetings increased stress and fatigue but also enhanced perceived work influence	3, 8	3
14	[35]	Longitudinal survey, JD-R model	Netherlands	Wellbeing declined over six months; job demands harmed wellbeing while autonomy and support helped	3, 8	3

Sl.	Authors	Methodology	Country / Continent	Findings	SDGs Addressed in the Study	SDGs Matched with This Review's Focus
15	[36]	Systematic literature review, thematic analysis	United States	Civic engagement's impact on mental health is mixed; further study is needed on marginalized youth	16	16
16	[11]	Qualitative survey, feminist analysis	Australia	Unpaid placements create significant financial and mental health stress, disproportionately impacting women	5, 10	5
17	[37]	Program evaluation, qualitative insights	New Zealand	NLH improved holistic well-being by integrating adaptable goals in stress, nutrition, and self-care	3, 4	3
18	[38]	Cross-sectional, hierarchical regression, PISA data	Turkey	SES had a stronger impact than wellbeing on academic achievement; demographic factors had weak predictive power	3, 4, 10	3
19	[39]	Descriptive design, multistage sampling, interviews	India	Marital quality and life satisfaction varied across urban and rural groups; socio-demographics influenced wellbeing	3, 5	3, 5
20	[9]	Survey, Moderator model, Cross-cultural	Pakistan; UK	Stronger links between gender role beliefs and wellbeing in Pakistan vs UK. Patterns differ by gender and country	3, 5, 10	3, 5
21	[40]	Systematic review, Thematic analysis	Italy	Coworking spaces enhance quality of working life and wellbeing by offering flexible, collaborative environments	3, 8	3
22	[41]	Qualitative, Interviews, Ethnography	UK	Religious communities provide vital wellbeing resources in deprived areas; wellbeing paradox and multi-level factors identified	16	16
23	[42]	Longitudinal, Survey, Mental health	UK	Females without prior mental health issues showed similar or worse wellbeing decline, highlighting new vulnerable	3, 5	3, 5

Table (continued)

Sl.	Authors	Methodology	Country / Continent	Findings	SDGs Addressed in the Study	SDGs Matched with This Review's Focus
24	[43]	Qualitative, Thematic analysis, Focus groups	Mexico	IPV-exposed women face intrapersonal, structural, and social barriers; empowerment and community support are key facilitators	3, 5, 16	3, 5, 16
25	[44]	Quantitative, Survey, Regression	Belgium; Spain	Adolescents in youth care show high QOL in self-determination but low in emotional well-being; female and residential care linked to lower QOL	5, 10	5
26	[45]	Quantitative, Multilevel path analysis	Hong Kong; China	Teacher well-being positively influences student life satisfaction and affects, controlling for SES and gender	3	3
27	[46]	Qualitative, Thematic analysis	Finland	Mindfulness and character strengths training improve parental wellbeing and family dynamics, though some stress reported	3	3
28	[47]	Meta-analysis, Correlational	China	Moderate positive correlation between trust and wellbeing; social wellbeing is strongest linked to trust	3	3
29	[48]	Qualitative, Thematic analysis	United Kingdom	Personal academic tutors experience wellbeing challenges related to burden, mental health, and resilience	3	3
30	[49]	Quantitative, Predictive analysis	Italy; Spain	Social support predicts life satisfaction, sense of community, and resilience. Different support sources vary in impact	3, 10	3
31	[50]	Quantitative, Survey, Regression	Malaysia	Family-to-work conflict significantly reduces job and life satisfaction. Practical implications for organizations	3, 8	3

Table (continued)

Sl.	Authors	Methodology	Country / Continent	Findings	SDGs Addressed in the Study	SDGs Matched with This Review's Focus
32	[51]	Cross-sectional, SEM, Path analysis	Ghana	Social participation predicts health literacy, influencing health and well-being. Volunteer activities can have negative effects	3, 10	3
33	[52]	Quantitative, Survey, Moderation	UK	Ethnic identity centrality intensifies negative effects of harassment on well-being; gender identity centrality buffers impact	3, 5, 10	3, 5
34	[8]	Longitudinal, Quantitative	Ireland	Lower parental expectations partly explain poorer self-concept and academic outcomes in disabled children	1, 3, 10	3
35	[53]	Systematic review, Bibliometric	Global	Studies lack diversity in methods; focus mainly on governance body gender diversity; gaps in reporting identified	5, 8, 10	5
36	[54]	Quantitative, Propensity score matching, Logit	Nigeria; South Africa	CSR by oil companies positively affects gender equality and social equity in coastal communities; promotes women's empowerment	5, 10, 14	5
37	[55]	Qualitative, Theoretical analysis	Australia	NGOs face barriers in CSR governance; inclusion is vital for equality	5, 10, 16	5, 16
38	[56]	Bibliometric, Systematic review	Global	Research focused on board diversity, financial performance, women on boards	5, 10, 12	5
39	[57]	Qualitative, Case study, Interviews	Sweden	Corporations find unpaid care work difficult to justify economically; governance techniques repurposed for political aims	5, 10	5
40	[58]	Mixed methods, Case study	Nigeria	CSR initiatives impact capacity building for women entrepreneurs; GMoU plays a critical role in empowerment efforts	1, 4, 5, 8, 10, 12	5

Sl.	Authors	Methodology	Country / Continent	Findings	SDGs Addressed in the Study	SDGs Matched with This Review's Focus
41	[59]	Experiment, Survey, Reactance theory	Switzerland	CSA messages with call to action harmed corporate reputation due to reactance. Effects persisted after controlling for alignment and politics	5, 10	5
42	[60]	Bibliographic analysis, Literature review	Global	Feminist theory integration in BE/ CSR is limited; better integration suggested to strengthen research and propose new directions	5	5
43	[61]	Qualitative, In-depth interviews (20)	Australia	Female leaders face challenges in board power dynamics; use rhetorical strategies to influence CSR decisions	5	5
44	[62]	Content analysis, Exploratory study	Spain	Gender equality standards lack uniformity and gender mainstreaming; mainly driven by business case; need for common terminology and indicators	5, 8, 10, 12, 17	5
45	[63]	Quantitative, Legal reforms analysis	France; China; UK	Gender quota reforms increased board diversity and improved CSR, stronger effects with legislation-based regulations and in high-equality countries	5, 10	5
46	[64]	Content analysis, Interpretivist approach	Saudi Arabia	Gender disclosures driven by legislation and international frameworks; disclosures increased but lack systematic adoption	5, 9, 10, 12, 17	5
47	[65]	Literature review, Conceptual analysis	Global	Identifies problem areas in gender equality education; proposes strategies aligned with UN 2030 goals to improve gender equality in education	4, 5, 10	5

Sl.	Authors	Methodology	Country / Continent	Findings	SDGs Addressed in the Study	SDGs Matched with This Review's Focus
48	[66]	Case study, Semi-structured interviews	Japan	Formal and cultural management control systems support gender equality; cultural MCS foster norms enhancing formal MCS effectiveness	5, 10	5
49	[67]	Managerial approach, Regulatory analysis	Italy	Low female board representation linked to social background and culture; CSR commitment needed beyond regulations for true gender balance	5, 10, 12	5
50	[68]	Literature review, Policy analysis	United Arab Emirates	CSR linked to gender equality and HRM policies; calls for organizational and government policies promoting equality recognizing women's agency	5, 10	5
51	[69]	Qualitative research, Case study	Bangladesh	Banks focus gender commitments more on economic and political gains rather than societal or ethical demands	5, 10, 16	5, 16
52	[70]	Conceptual	China; United Kingdom; Ireland	Gender strategies differ by CSR orientation; models propose 4 strategies linking doing/ undoing gender and CSR	5, 10, 12	5
53	[71]	Case study	United Kingdom	CSR frames gender equality as synergistic with profit, promoting corporate-led development without challenging corporate power	5, 10	5
54	[72]	Quantitative, logit model, survey	Nigeria	CSR supports education but lacks female-specific targeting; without gender focus, CSR may delay women's economic and social progress	4, 5, 8, 9, 10, 12	5

Sl.	Authors	Methodology	Country / Continent	Findings	SDGs Addressed in the Study	SDGs Matched with This Review's Focus
55	[73]	Case study	United States	Evidence is necessary but insufficient for SDG 5; recommends public-private partnerships and new tools for corporate CSR strategy	5, 10, 12, 17	5
56	[74]	Conceptual, feminist theory, human rights	Australia	Extends CSR to sexual violence issues; radical feminist and human rights approaches offer more effective solutions than prior strategies.	5, 10, 12, 16	5, 16
57	[75]	Theoretical	United States	Proposes mandatory gender education integrating feminist and sustainability studies to equip students for equitable workplaces	4, 5, 10	5
58	[76]	Qualitative, content analysis, survey	Turkey	CSR efforts include women as stakeholders but remain limited, mostly in private sector; findings not generalizable beyond context	5, 10	5
59	[77]	Mixed methods, DEA, survey	Colombia	Combines qualitative and quantitative data; identifies drivers of sustainable perceptions, guiding balanced sustainability policies	7, 9, 11, 17	11
60	[12]	Semi-systematic review, qualitative	Latin America	Highlights circular economy pathways and policy gaps in the water sector; calls for integrating CE innovations to support SDG 6	6	6
61	[13]	Framework development, integrative model	Iran; United States	Proposes integrating CSR with SDGs for a strategic and measurable approach, especially crucial post-COVID-19 for sustainable impact	8, 12, 11, 17	11

Table (continued)

Sl.	Authors	Methodology	Country / Continent	Findings	SDGs Addressed in the Study	SDGs Matched with This Review's Focus
62	[78]	Conceptual, CSR, sustainability	Pakistan	Argues CSR alone is insufficient; human social responsibility by individuals and firms is essential for sustainability goals	9, 12, 16, 17	16
63	[79]	Content analysis, Sustainability and Annual reports	Indonesia	CSR activities align mostly with SDGs like good health and education. Annual reports show limited disclosure on other SDGs	4, 5, 6, 8, 9, 10	5, 6
64	[14]	Case analysis, Conceptual exploration, Stakeholder engagement	Global	Partnerships amplify SDG efforts by combining diverse strengths. Success depends on aligned objectives and transparent collaboration	8, 10, 11, 12, 13, 17	11
65	[80]	Mixed methods, Chi-square, Multivariate analysis	Uganda	A strong link was found between housing quality and social integration. Infrastructure and social interaction jointly enhance sustainability	11, 10	11
66	[81]	Quantitative, Structured survey, Case study	Turkey	Park excels in identity and cohesion but lacks safety and comfort. Low-income users feel higher satisfaction and identification	11	11
67	[82]	Content analysis, VOSviewer text analysis	India	Social concerns like worker welfare are underrepresented in plans. Community is most salient stakeholder; delivery type affects SS focus	9, 11	11
68	[83]	Mixed methods, Composite indicators, Key informant interviews	Zambia	Social sustainability ranges from weak to moderate in mining areas. Proposed indicators can realign CSR and governance strategies	8, 9, 11, 12, 16	11, 16

Sl.	Authors	Methodology	Country / Continent	Findings	SDGs Addressed in the Study	SDGs Matched with This Review's Focus
69	[84]	SLCA, Multi-stakeholder, Inventory analysis	Afghanistan	Scavenger overwork and poor local engagement weaken the system. Improved infrastructure and communication can enhance social outcomes	9, 11, 12	11
70	[85]	TISM, MICMAC, Literature review	India	Equal employment is key to sustainable HRM. Social trust highly depends on other SS factors, offering improvement pathways	5, 8, 9, 10, 11	5, 11
71	[86]	Online survey	Egypt	Residents of gated communities in Cairo rarely value social interaction, preferring isolation. Enhancing shared spaces can improve social sustainability	11	11
72	[87]	Structured interviews, Gap analysis, Attribute ranking	Malaysia	A notable gap exists between perceived and actual practices in social sustainability. Stakeholder engagement and education require immediate focus	4, 16	16
73	[88]	Policy analysis, Historical contextualization	Sweden	The shift from centralized governance to fragmented networks weakened coordinated social sustainability outcomes. Government still steers via indirect mechanisms	7, 10, 11, 16	11, 16
74	[89]	Theoretical discussion, Case-based insights	United Kingdom	Stakeholder inclusion is vital for achieving social sustainability in projects. Aligning interests fosters sustainable and cohesive organizational impact	8, 9, 16, 17	16
75	[15]	Field survey, Statistical modeling, multi-scale analysis	China	Biodiversity in urban green spaces is shaped more by surrounding landscapes than local conditions. Multi-scale filtering enhances ecosystem service understanding	11, 15	11, 15

Sl.	Authors	Methodology	Country / Continent	Findings	SDGs Addressed in the Study	SDGs Matched with This Review's Focus
76	[16]	Field data collection, Soil analysis, Species mapping	Brazil	Species diversity varies greatly across watershed sectors, demanding localized restoration models. Avoiding homogenization ensures biodiversity and ecological resilience	6, 11, 15	6, 11, 15
77	[17]	Document analysis, Interviews, Workshop with stakeholders	Brazil	Using an ecosystem services framework aligned community and corporate interests in mine closure. This approach supports inclusive and sustainable land use outcomes	11, 16	11, 16
78	[90]	Semi-systematic literature review, topic modeling, qualitative analysis	Global	Circular economy contributes to social well-being but literature inconsistencies persist. Suggests rethinking economic models and integrating social dimensions into CE strategies	8, 11	11
79	[91]	In-depth interviews, qualitative perception study	Botswana	Land acquisitions shaped by tourism and subsistence agriculture. Power dynamics influence access and governance of resources	6, 7, 8, 11, 15	6, 11, 15
80	[92]	Content analysis, semi-structured interviews	Vietnam	Mining boosts jobs and infrastructure but leads to environmental degradation and social problems. Economic resilience is stronger in non-mining communities	1, 3, 6, 8, 9, 10	3, 6
81	[18]	Econometric analysis, nonlinear cointegration	Developing Economies	Resource rent has mixed effects: negative in some countries, positive in others. Findings support the 'resource curse' in certain contexts	8, 16	16
82	[93]	Ecological-economic valuation, soil value analysis	Russia	Societal land value captures environmental benefits. Soil components significantly contribute to ecological-economic damage estimates	11, 12, 15	11, 15

Sl.	Authors	Methodology	Country / Continent	Findings	SDGs Addressed in the Study	SDGs Matched with This Review's Focus
83	[94]	Directional distance function, shadow price analysis	Spain	Positive shadow prices show high value of social outputs. Farm efficiency improves under better crop conditions	2, 17	2
84	[95]	Panel data analysis, marginal effect estimation	Brazil	Forest-to-farm conversion yields small short-term income gains but boosts long-term asset accumulation. Opportunity costs of forest conservation must consider long-term effects	2, 8, 13, 15	2, 15
85	[96]	Survey, institutional analysis, stakeholder theory	South Asia	Social sustainability depends on GVC governance and local institutional alignment. Cultural and institutional factors shape suppliers' adoption	11, 17	11
86	[97]	Case study, historical analysis, qualitative comparison	Brazil	Changing CSR strategies have influenced community conflict dynamics. Failure to address past legacies undermines trust and CSR effectiveness.	8, 12, 16	16
87	[98]	Qualitative research, case analysis	Nigeria	CSR can mitigate harder-farmer conflicts, but effectiveness hinges on community involvement and local context sensitivity	9, 10, 16	16
88	[99]	Mixed methods, survey, key informant interview, logit model, propensity score matching	Nigeria	CSR reduces inter-communal violence by addressing poverty, land and resource access. Expanded CSR can deter violence through improved livelihoods	1, 10, 16	16
89	[100]	Case study analysis, literature review	Global	Nationalization is often driven by state interest in welfare and sovereignty. State ownership aligns with social responsibility during crises or nationalist waves	11, 16, 17	11, 16

Sl.	Authors	Methodology	Country / Continent	Findings	SDGs Addressed in the Study	SDGs Matched with This Review's Focus
90	[101]	Thematic literature analysis, case-based discussion	Papua New Guinea	CSR in PNG has largely failed due to poor compensation, weak state regulation, and local resistance. Deeper frameworks are needed for peace and development	4, 15, 16	15, 16
91	[102]	Empirical evaluation, qualitative analysis	Nigeria	CSR based on Western models fails in regions with weak state control. Pro-West approaches hinder sustainable development in local contexts	1, 9, 11, 12, 16	11, 16
92	[103]	AI data mining, Bayesian correlation, root cause analysis	USA, Australia, Albania	ESG ratings lack correlation with real misconduct. Legal violations often go reflected in ESG scores, indicating flawed index design	8, 9, 10, 13, 16, 17	16
93	[104]	Critical discourse analysis, case study	Canada, Guatemala	Canadian CSR policy promotes «dialogue» that legitimizes elite repression. It undermines indigenous rights and stifles opposition	10, 16	16
94	[105]	Document analysis, case study, counter-insurgency theory	Canada, Guatemala	Internal documents expose corporate coordination in violent land evictions. Corporate and elite collusion enables human rights abuses	5, 16	5, 16
95	[106]	Multi-method comparative analysis, case studies	USA	Private regulations often fail due to weak domestic governance. Global norms are reshaped by local politics, limiting CSR impact	8, 9, 12, 15, 17	15
96	[107]	Theoretical analysis, secondary data, environmental peacebuilding theory	Nigeria	Unregulated oil activities drive degradation and conflict. Lack of genuine dialogue and poor stakeholder engagement fuel insecurity	10, 16, 17	16

Sl.	Authors	Methodology	Country / Continent	Findings	SDGs Addressed in the Study	SDGs Matched with This Review's Focus
97	[108]	Critical review, conceptual analysis	Global	Neoliberal ideology undermines effective CSR. Shareholder value orientation conflicts with developmental goals in CSR	8, 11, 13, 15	11, 15
98	[109]	Qualitative, Semi-structured interviews, Expert opinions	Canada, Spain	Employee involvement and tacit knowledge are crucial for internalizing biodiversity practices. Key barriers include lack of training, corporate commitment, and externalization of initiatives	12, 15, 16	15, 16
99	[110]	Case study, Stakeholder perception analysis, Comparative analysis	China	Managers and village leaders share similar perceptions due to local knowledge. The study reveals gaps between expert and local views on sustainability and ecosystem services	9, 12, 15, 17	15
100	[111]	Delphi method, Remote sensing, Benefit transfer approach	Iran	Cultural services ranked highest in national parks, while regulating services dominated by wildlife refugees. Provisioning services have the highest estimated economic value	11, 15	11, 15

Source: Developed by the authors.

development while also revealing substantial barriers that hinder its wider effectiveness. An examination of the literature indicates both agreement and disagreement among experts over the efficacy of CSR programs. Studies [97] and [101] highlight the beneficial societal effects of CSR, especially in advancing gender equality and public health. Conversely, several studies criticize CSR initiatives as superficial marketing strategies rather than genuine endeavors to effect social change. Moreover, the strength of evidence is inconsistent, with numerous studies advocating for longitudinal study to enhance comprehension of the enduring effects of CSR initiatives. Despite the frequent documentation of immediate advantages, there exists a nota-

ble absence of comprehensive frameworks to assess the long-term efficacy of CSR, highlighting a significant gap for future research.

This review's insights bolster and expand upon established theoretical frameworks, including Stakeholder Theory and the Triple Bottom Line. They emphasize the significance of embracing a comprehensive approach to CSR that equally values social, environmental, and economic sustainability. The practical ramifications of these discoveries are extensive. Businesses must design CSR plans that transcend mere regulatory compliance to actively engage stakeholders and tackle the fundamental socio-economic concerns underlying global issues. Governments can utilize these insights to build regu-

latory frameworks that promote authentic corporate responsibility and transparency. Furthermore, the incorporation of digital technology in CSR projects presents a great opportunity to enhance data collection, transparency, and stakeholder interaction. These technical improvements can improve monitoring and reporting systems, promoting more accountable and effective CSR operations. Notwithstanding these advancements, numerous inadequately invested domains necessitate additional inquiry. There is an imperative to examine the contextual efficacy of CSR in emerging economies, where distinct socio-economic and cultural factors affect results. Future study enquiries may encompass: How may CSR programs be customized to address the specific requirements of local communities within varied cultural contexts? What are the enduring effects of CSR initiatives on community development and environmental sustainability? Furthermore, investigating how emerging digital technologies might enhance stakeholder engagement and refine effect evaluation is a vital area of inquiry for CSR research.

5. Conclusion

This comprehensive review has shown that Corporate Social Responsibility (CSR) is essential in tackling several sustainable development issues, such as hunger, health, gender equality, conservation of the environment, and social justice. Although CSR initiatives have demonstrated encouraging short-term advantages and have proven essential to company governance and competitiveness, substantial deficiencies persist, especially about the long-term impact and efficacy of these programs across various cultural and economic situations. The results highlight the necessity for more stringent, longitudinal studies and the creation of comprehensive frameworks to assess CSR's enduring impact on sustainable development. Moreover, the incorporation of digital technology and the promotion of inclusive stakeholder interaction are essential measures for improving transparency and accountability in CSR operations. Policymakers and corporations must transcend mere compliance to adopt comprehensive and contextually aware CSR policies that adequately tackle socio-economic and environmental intricacies. This study essentially establishes a core comprehension of CSR's present accomplishments and shortcomings, delineating explicit pathways for future research to enhance the congruence between corporate responsibility and global sustainability objectives.

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Volatility Spillovers Between BRIC and South African Stock Markets: Evidence from the COVID-19 and Russia-Ukraine Crises

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ABSTRACT

The aim of this study was to assess how global crises influenced volatility spillovers between BRIC and South African stock markets. In conducting the study, **the methods employed** are the generalized autoregressive conditional heteroskedasticity (GARCH) framework and the time-varying parameter vector autoregressive (TVP-VAR) Diebold-Yilmaz approach, based on a sample period segmented into pre-crisis, COVID-19, and Russia-Ukraine conflict phases. **The study results** revealed that volatility spillovers intensified during the COVID-19 pandemic due to economic disruptions and uncertainty. At the same time, the Russia-Ukraine conflict saw reduced spillovers due to geopolitical isolation and risk aversion. South Africa consistently emerged as a key volatility transmitter, particularly during crises. **The study concludes** that different global crises have distinct impacts on volatility transmission and should, therefore, be treated distinctly. **The key contribution** lies in enhancing the understanding of crisis-driven market integration, providing valuable insights for risk management and policy-making in interconnected financial systems.
Keywords: volatility spillovers; stock market; BRICS; Diebold-Yilmaz; COVID-19; Russia-Ukraine conflict

Перетоки волатильности между фондовыми рынками БРИК и Южной Африки: на примерах кризиса COVID-19 и российско-украинского конфликта

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АННОТАЦИЯ

Целью данного исследования была оценка влияния глобальных кризисов на перетоки волатильности между фондовыми рынками стран БРИК (Бразилия, Россия, Индия, Китай) и Южно-Африканской Республики (ЮАР). При проведении исследования использовались **методы** обобщенной авторегрессии с условной гетероскедастичностью (GARCH) и подход Дибольда-Йилмаза с векторной авторегрессией с переменными во времени параметрами (TVP-VAR), основанные на периоде выборки, сегментированном на фазы докризисного периода, COVID-19 и российско-украинского конфликта. **Результаты** исследования показали, что перетоки волатильности усилились во время пандемии COVID-19 из-за экономических потрясений и неопределенности, в то время как российско-украинский конфликт сократил перетоки из-за геополи-

тической изоляции и неприятия риска. Южная Африка неизменно оказывалась ключевым передатчиком волатильности, особенно во время кризисов. **Выводы** исследования свидетельствуют о том, что мировые кризисы оказывают неодинаковое влияние на передачу волатильности и, следовательно, должны рассматриваться по-разному. **Ключевой вклад** работы заключается в улучшении понимания рыночной интеграции, вызванной кризисом, что дает ценные знания для управления рисками и разработки политики во взаимосвязанных финансовых системах.

Ключевые слова: перетоки волатильности; фондовый рынок; БРИКС; Diebold-Yilmaz; COVID-19; российско-украинский конфликт

1. Introduction

Globalisation is an instance where international markets become more interconnected. This web of connectivity wields a substantial impact on volatility spillovers across markets [1]. Volatility, the fluctuations in asset prices over time, readily spills over to other markets as they become more connected, propelled by factors such as increased trade, cross-border investments, and the flow of information. Consequently, volatility spillovers, defined as the transmission of instability and risks from one market to another, have raised concerns for investors and policymakers [2].

Volatility spillovers can occur between distinct stock markets or different assets in a single market [3], where fluctuations in one market or asset can swiftly reverberate across others, amplifying market-wide volatility and risk perceptions. Such was the case during the 2008–2009 global financial crisis, as shocks from one market triggered reactions in related markets [1]. This illustrates how volatility spillovers can exacerbate market turmoil, highlighting the need for robust risk management strategies and coordinated policy responses to mitigate systemic risks and stabilise financial markets.

Thus, studying volatility and its spillovers is crucial for gaining insights into financial market behaviour, especially for emerging markets that are more sensitive to external shocks [2]. Despite their potential, emerging markets face challenges like weak financial institutions, limited financial depth, and high external debt. These challenges expose emerging markets to heightened vulnerability, particularly during periods of market turbulence and economic uncertainty, where their resilience is put to the test, often leading to significant market disruptions.

This vulnerability was apparent during the COVID-19 pandemic when financial markets experienced significant uncertainty and disruptions [4]. Similarly, markets were plagued by heightened geopolitical tensions and economic instability during the Russia-Ukraine conflict, exacerbating the already fragile situation initiated by the pandemic. Although not to the extent of the 2008–2009 global financial crisis, both periods highlight the interconnectedness of international markets and the critical role of understanding how volatility transmits across borders [1]. Accordingly, this study assessed the volatility spillovers between the South African and BRIC (Brazil, Russia, India, China) markets during the COVID-19 pandemic and the Russia-Ukraine conflict crises, juxtaposed with stable periods. The selection of BRICS (Brazil, Russia, India, China, South Africa) markets as the subjects of the analysis was driven by their growing prominence in the global economy and their significant impact on international financial markets [5]. Moreover, the focus on South Africa stemmed from its distinctive economic characteristics and market dynamics that render its markets unique and influential within the BRICS framework.

Further, while the pandemic and the Russia-Ukraine conflict crises resulted in disruptions, their effects may have differed. The pandemic primarily impacted global markets through widespread lockdown measures, supply chain disruptions, and economic slowdowns, leading to broad-based volatility and uncertainty [6]. Conversely, the conflict introduced geopolitical tensions and instability, potentially affecting specific industries and regions more acutely. Thus, understanding the nuanced differences is crucial for comprehending the intricacies of volatility spillovers across BRICS.

The rest of this study is organised as follows: Section 2 presents the theoretical framework employed as the foundation of the study, while Section 3 provides the empirical literature review of studies conducted on market connectedness and

volatility spillovers before and during crises. Section 4 describes the methodology, while Section 5 contains the results and discussion. Section 6 concludes the study and provides implications of findings and recommendations for future studies on the subject.

2. Theoretical framework

In traditional finance, few theories have garnered as much attention as the efficient market hypothesis, which posits that markets are efficient due to the rapid assimilation of all available information into asset prices [7]. Investors are presumed rational, processing information per rational expectations [8]. This ensures that market prices adjust promptly to incorporate new information, leading to the accurate pricing of assets at any given time. Consequently, investors cannot consistently outperform the market through trading strategies based on publicly available information, as market participants swiftly correct any potential mispricing.

Various financial market phenomena, such as volatility spillovers, would not be expected to occur in efficient markets because all available information is rapidly and accurately incorporated into asset prices [9]. As a result, asset prices reflect their true underlying value. Any temporary imbalances are quickly corrected by rational arbitrageurs who exploit them. This process ensures that market prices remain efficient and any potential mispricing is promptly rectified across markets. Therefore, in theory, the hypothesis implies that volatility spillovers should be minimal or non-existent in truly efficient markets [8].

Yet, volatility spillovers have been ubiquitously reported across markets [10]. They present opportunities for profit-making that contradict the efficient market hypothesis. Volatility spillovers can only occur if markets are not perfectly efficient, as they entail delayed or incomplete incorporation of information into asset prices in these markets. If a group of investors can discern patterns or trends in volatility spillovers between connected markets, they can consistently outperform the market by leveraging the volatility information from one market to inform their trading decisions in another connected market.

Thus, volatility spillovers may be direct evidence against the efficient market hypothesis, like other abnormal patterns such as value, growth, size, momentum, and reversal effects [11]. They align with behavioural finance theory, a burgeoning strand of finance wherein market participants' psychological biases and irrational behaviours are acknowledged. Investors exhibit cognitive biases, leading to suboptimal decision-making and market inefficiencies. This perspective suggests that market inefficiencies can arise due to behavioural biases, leading to deviations from rational decision-making and the emergence of predictable patterns [12].

In this context, volatility spillovers reflect market interconnectedness and irrational investor behaviour, highlighting the limitations of the efficient market hypothesis in capturing the complexities of real-world markets [11]. Much evidence demonstrates that psychological biases such as herding behaviour and investor sentiment drive market volatility. Additionally, studies examining the relationship between market uncertainty and investor decision-making further underline the influence of behavioural factors on volatility spillovers, revealing the intricate interplay that exists in shaping financial market outcomes [13, 14].

Studies that provide evidence of intensified volatility spillovers during crises also fortify the argument about behavioural bias [15, 16]. During highly volatile periods, investors are more prone to emotional reactions such as fear and panic, which exacerbate market instability and amplify the transmission of volatility across interconnected markets [15, 17]. Additionally, heightened uncertainty and risk aversion may lead investors to overreact to new information or engage in irrational trading behaviour, further fuelling the propagation of volatility spillovers. This supports the notion that behavioural biases play a significant role in markets.

Overall, volatility spillovers and their alignment with behavioural finance theory challenge the rational expectations theories, signifying the need for a better understanding of market dynamics. This is more needful now since markets are increasingly getting connected. Investigating volatility spillover patterns in crises characterised by heightened uncertainty and stress provides valuable insights into the underlying mechanisms driving market behaviour. Understanding how volatility spillovers manifest during such extreme events can inform risk management strategies and enhance market participants' ability to navigate turbulent financial markets.

3. Empirical literature
3.1. Volatility spillovers before the crises

Several studies examined volatility spillovers and market interconnectedness across diverse markets. For example, [18] scrutinised BRIC countries' integration in regional and global equity markets between 1995 and 2004, uncovering significant integration within BRIC and other international markets. [19] explored BRICS capital markets post-2008 global crisis until 2013, revealing volatility spillovers with the US market, indicating the region's interconnectedness with international capital markets. [20] assessed volatility spillovers between the US and Latin American stock indexes from 2003 to 2016, identifying Brazil as a net transmitter of volatility in Latin American markets.

[21] investigated volatility spillovers between BRICS and G7 countries due to volatile oil prices from 1992 to 2015, highlighting the sensitivity to higher volatility and shocks in the oil market. [22] analysed spillover dynamics between the US and BRICS stock markets from 1998 to 2016, revealing shifts in the importance of net spillover in the different countries from the historical status quo. [23] examined volatility spillovers between BRICS and Japan from 2009 to 2019, discovering two-way relationships between foreign exchange and stock markets and emphasising the role of foreign exchange markets in influencing stock market volatility spillovers across different markets.

[3] explored volatility spillovers in BRICS countries from 2002 to 2019, highlighting increased spillovers during crises. [4] investigated returns and volatility spillovers in Indian markets compared to other countries from 2008 to 2019, revealing more significant volatility spillovers among Indian and Asian countries during expansion life cycles. [2] examined volatility spillovers in BRICS stock and foreign exchange markets from 1997 to 2018, identifying interdependence among BRICS markets, particularly during the 2008 global crisis, suggesting implications for coordinated policy responses and risk management strategies.

3.2. Volatility spillovers during the crises

Some other studies conducted similar studies, focusing on crisis periods. For instance, [10, 15] analysed volatility spillovers among BRIC and G7 countries, finding that G7 countries exported risk to BRIC countries, especially during crisis periods.

[24] found heightened risk spillovers transmitted by China to its BRICS partners during the COVID-19 pandemic. [25] investigated volatility spillover effects influenced by COVID-19 on India's stock market. They found significant negative spillovers received by India from various global stock markets, particularly the US market. [24] found that connectedness and spillovers across China, America and Europe increased during the Russia-Ukraine conflict.

[26] revealed the significant roles played by the UK, Germany, the US, and France in transmitting risk to Japan and China during the Russia-Ukraine conflict. [27] noted an increase in total spillovers across markets during the Russia-Ukraine conflict, highlighting the influence of Russia in the volatility transmitted to global markets. [27] found that during the COVID-19 pandemic, the US, China, and Brazil exhibited the highest own volatility spillovers, with the US and Russia displaying the strongest long-term spillover effect. [28–30] noted that the Russia-Ukraine conflict had widespread global impacts observed since the 2008 financial crisis. Their study revealed intense interconnectedness among G7 and BRICS countries.

[31] revealed India and China as significant transmitters and receivers of stress spillovers during the COVID-19 pandemic. [32] found stronger connectedness and spillover effects among BRICS equity markets during the COVID-19 pandemic and the Russia-Ukraine conflict crises. [33] found notable contagion effects among BRICS countries, particularly heightened during the COVID-19 pandemic and the Russia-Ukraine conflict, notably with increased contributions from Russia. [34] found that volatility spillover among G7 and BRICS stock markets indexes increased during the Russia-Ukraine conflict and the pandemic. Additionally, the effect of geopolitical risk on spillovers varied over time.

Overall, the literature highlights the importance of examining volatility spillovers across markets. These studies consistently showed significant volatility spillovers among markets, including those involving BRICS countries, with crisis events amplifying these spillovers. Before the crises, some studies demonstrated dynamic shifts in spillover patterns influenced by economic phases. In contrast, heightened volatility transmission and interconnectedness were evident during crisis periods. These findings provide a compelling rationale for investigating volatility spillovers between BRIC and South African markets during the COVID-19 and Russia-Ukraine crises and stable periods.

4. Data and methodology
4.1. Data description

Daily closing prices on the BRICS broad market indices from January 2013 to 30 June 2023 from Bloomberg[1] were employed. Daily data offers a more efficient assessment of short-term price movements compared to lower frequencies, allowing for early detection of market trends [35]. The selection of broad market indices, as depicted in *Table 1,* ensured a good representation of a diverse range of stocks within each respective market [3, 2]. The returns on the broad market indices were then calculated as follows:

$$R_t = \ln\left(P_t \,/\, P_{t-1}\right) \times 100 \,, \qquad (1)$$

where: R_t are the index returns on day t, and P_t and P_{t-1} are the index prices on day t and $t-1$, respectively, in line with [35] and [3].

The study's sample, consistent with [2], excluded weekends and holidays for uniformity across BRICS economies, covering pre-crisis periods [25] and major events such as COVID-19 and the Russia-Ukraine conflict. It was divided into pre-crisis, CO-VID-19, and Russia-Ukraine conflict periods [36, 37], with the division justified by the distinct impacts each phase likely had on volatility spillovers between BRIC and South African stock markets. The pre-crisis period serves as a baseline of market behaviour under stable conditions, while the COVID-19 pandemic, marked by global economic disruptions and heightened uncertainty, may have amplified volatility spillovers.

In contrast, the Russia-Ukraine conflict, driven by geopolitical tensions, may have reduced spillovers due to market isolation and risk aversion. Thus, this segmentation allows the study to provide insights into the varying nature and transmission mechanisms of shocks across markets, captured using dummy variables for each period. Preliminary data analysis included stationarity tests [36], the Jarque-Bera test for normality, skewness, kurtosis statistics, and mean and standard deviation calculations. Autocorrelation and ARCH effects were assessed using the Ljung-Box [37] and the ARCH-LM tests, ensuring the GARCH model's suitability [23].

4.2. Method of analysis
4.2.1. GARCH models

To examine spillovers across the BRICS, this study employed both the GARCH (1,1), the TGARCH (1,1) and the EGARCH (1,1) in line with [23] and [2] to produce residuals to use in subsequent estimations. The GARCH models were chosen based on their ability to capture and model the time-varying volatility and leverage effects in financial markets. GARCH models are widely employed because they provide a robust framework for estimating volatility based on past values and errors. These are critical for understanding how market conditions evolve [36].

TGARCH and EGARCH models extend the standard GARCH by incorporating asymmetry and leverage effects, which are particularly relevant during periods of financial stress, as these models account for the fact that negative shocks may have a different impact on volatility compared to positive shocks [36]. These models allow the study to capture the complex and dynamic volatility patterns within the BRIC and South African markets, ensuring that the analysis reflects the true nature of market interconnections and spillovers during stable and crisis periods [2, 23].

The best model was selected using the Schwarz-Bayesian Information Criterion (SBIC) because it provides a reliable measure for model selection by balancing model fit and complexity. SBIC penalises the inclusion of unnecessary parameters, thus preventing overfitting while ensuring that the chosen model adequately captures the underlying volatility structure of the data. This criterion is particularly effective when comparing multiple models, as it consistently selects the model that optimises the trade-off between goodness of fit and parsimony, making it well-suited for choosing the most appropriate GARCH-based model for the study [36].

The mean equation — standard across the three models — was specified as:

$$y_t = \mu + \theta\left(\sigma_{t-1}\right) + \vartheta\left(y_{t-1}\right) + \nu\left(u_{t-1}\right) + u_t \,, \qquad (2)$$

where:

ϑ captures the effect of previous returns, y_{t-1}, on current returns,

ν indicates the effect of past shocks, u_{t-1}, on current returns, and represents the risk premium on the standard deviation, σ_{t-1}.

Equations (3), (4), and (5) represent the variance equation specifications for the GARCH (1,1),

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Table 1
BRICS broad market indices, 2013– 2023

Countries	Index
Brazil	BOVESPA-Brazil Sao Paulo Equity Index
Russia	Russia Trading System Index
India	National Stock Exchange NIFTY 50 Index
China	Shanghai Stock Exchange Composite Index
South Africa	FTSE Johannesburg Stock Exchange All Share Index

Source: BRICS broad market indices, Bloomberg Terminal. URL: https://www.bloomberg.com (accessed on 21.04.2023).

TGARCH, and EGARCH models. Equation (3) improves on the ARCH model by reducing the likelihood of violating the non-negativity property, while Equations (4) and (5) go further by incorporating terms to capture leverage effects [2]. Of note is that the possibility of violating the non-negativity constraints on variance is entirely mitigated by the EGARCH. The specifications are as follows:

$$\sigma_t^2 = \omega_0 + \alpha_1 u_{t-1}^2 + \beta\sigma_{t-1}^2, \tag{3}$$

$$\sigma_t^2 = \omega_0 + \alpha_1 u_{t-1}^2 + \beta\sigma_{t-1}^2 + \delta u_{t-1}^2 I_{t-1}, \tag{4}$$

where $I_{t-1} = 1$ if $u_{t-1} < 0$; and $= 0$ otherwise

$$\ln(\sigma_t^2) = \omega_0 + \alpha_1 \left[\frac{|u_{t-1}|}{\sqrt{\sigma_{t-1}^2}} - \sqrt{\frac{2}{\pi}} \right] + \beta \ln\sigma_{t-1}^2 + \delta \frac{u_{t-1}}{\sqrt{\sigma_{t-1}^2}} \tag{5}$$

where:

σ_t^2 is the conditional variance,

u_{t-1}^2 is the information about volatility in the previous period (the ARCH term) with

α_1 as the coefficient. The long-term mean is given by

ω_0 and the GARCH term is shown by

σ_{t-1}^2 with

β as the coefficient. Terms ⸲capture the leverage effects in Equations (4) and (5), respectively.

Subsequently, the models were examined to determine if they satisfy the stationarity and non-negativity conditions. The SBIC was then utilised to obtain the best models, and the residuals obtained from the selected models were transferred to the Diebold-Yilmaz model to examine volatility spillovers across BRICS markets.

4.2.2. Diebold-Yilmaz index

To explore spillover effects within BRICS, the study employed the Diebold-Yilmaz index [37, 38], known for its capability to quantify total and directional spillovers among financial markets. This index captures the overall interconnectedness of markets and distinguishes between the influence of individual markets as transmitters or receivers of volatility. Its dynamic framework allows for a comprehensive analysis of how shocks propagate across markets, particularly during periods of heightened uncertainty, thus ideal for examining the complex interrelations within the BRICS economies.

[28] and [1] advocate for incorporating a time-varying variation of the TVP-VAR model, as pioneered by [39]. The TVP-VAR model, which utilises Kalman filter estimation, effectively captures the evolving nature of spillovers over time, eliminating the constraints associated with fixed rolling window sizes and offering robustness against outliers. This approach allows for a more precise and flexible analysis of dynamic spillover effects, making it particularly suitable for assessing the interconnectedness of financial markets in this study. Therefore, the TVP-VAR model was specified as follows:

$$Y_t = \beta_t Y_{t-1} + \varepsilon_t,$$

$$\varepsilon_t \sim N\left(0, S_t\right) \tag{6}$$

$$\beta_t = \beta_{t-1} + \upsilon_t, \quad \upsilon_t \sim N\left(0, R_t\right), \tag{7}$$

where: The variable vectors Y_t and $Y_t - 1$ are $N \times 1$, as is the error terms ε_t vector. Time-vary-

ing coefficients β_t, v_t, and S_t are represented by $N \times N$ matrices, while the error variance-covariance matrix R_t has dimensions $N\,2 \times N\,2$. For connectedness measures, the TVP-VAR is transformed into a TVP-VMA as:

$$Y_t = \sum_{j=0}^{\infty} A_{jt}\varepsilon_{t-j}, \tag{8}$$

where: A_{jt} is a $N \times N$ matrix.

4.2.3. Generalised impulse response and variance decompositions

After that, the generalised impulse response function (GIRPF) and the generalised forecast error variance decomposition (GFEVD) were estimated to analyse how variables in the system respond to shocks, as they provide a comprehensive understanding of the dynamic relationships within the model [26]. GIRPF allows for assessing the magnitude and direction of variable responses to specific shocks without requiring orthogonalisation, thus maintaining the system's structural integrity. Meanwhile, GFEVD quantifies the proportion of each variable's forecast error variance attributed to shocks in other variables, offering insights into the influence and connectedness within the system.

Thus, together, these techniques enable a detailed exploration of the pathways and impacts of shocks across the variables, capturing the full extent of spillover effects in the studied financial markets. Following [40], the GIRPFs and GFEVDs were determined as:

$$\begin{cases} GIRF_t\left(h, \delta_{j,t}, F_{t-1}\right) = E\left(Y_{t+h} \mid \varepsilon_{j,t} = \delta_{j,t}, F_{t-1}\right) - E\left(Y_{t+h} \mid \varepsilon_{j,t} = F_{t-1}\right) \\ \\ \psi_{j,t}^{g}\left(h\right) = S_{jj,t}^{-\frac{1}{2}} A_{h,t} S_t \varepsilon_{j,t}, \end{cases} \tag{9}$$

$$\begin{cases} GFEVD : \theta_{ij,t}^{\tilde{g}}\left(h\right) = \sum_{t=1}^{h-1} \psi_{ij,t}^{2,g}\left(h\right) / \sum_{j=1}^{N} \sum_{t=1}^{h-1} \psi_{ij,t}^{2,g}\left(h\right) \\ \\ with \sum_{j=1}^{N} \theta_{ij,t}^{\tilde{g}}\left(h\right) = 1 \quad and \quad \sum_{i,j=1}^{N} \theta_{ij,t}^{\tilde{g}}\left(h\right) = N, \end{cases} \tag{10}$$

where:

h indicates the forecast horizon for equations (9) and (10), $\psi_{j,t}^{g}(h)$ shows variable j's GIRPFs and the selection vector is given by

$\delta_{j,t}$ which equals one for the element j and zero otherwise, and the information set is indicated by F_{t-1} until $t-1$.

The net spillovers of individual markets were assessed to ascertain whether they have acted as net receivers or transmitters of spillover effects. The total influence of shocks from all variables on the forecasted total error variance is referred to as the total spillover index (2:6). Additionally, the GFEVD, utilised in calculating the Total Connectedness Index (TCI), is provided by [25] as:

$$S_t^{g}\left(h\right) = \sum_{\substack{i,j=1 \\ i \neq j}}^{N} \theta_{ij,t}^{\tilde{g}}\left(h\right) / \sum_{i,j=1}^{N} \theta_{ij,t}^{\tilde{g}}\left(h\right) \times 100, \tag{11}$$

where:

$S_t^{g}(h)$ denotes the total connectedness across the system.

In addition, per [1], directional spillovers are either transferred (Equation 12) or received (Equation 13) by the market i in the model in relation to the other markets, with the net spillovers being the difference (Equation 14). The latter determines whether a market is a net transmitter or receiver. The net pairwise directional spillovers are given by Equation 15, with a positive value indicating that *i* influences *j*, and vice versa for a negative value.

$$S_{,i}^{g}(h) = \sum_{\substack{j=1 \\ i \neq j}}^{N} \theta_{ji,t}^{\sim g}(h) \Big/ \sum_{j=1}^{N} \theta_{ji,t}^{\sim g}(h) \times 100, \tag{12}$$

$$S_{i,}^{g}(h) = \sum_{\substack{j=1 \\ i \neq j}}^{N} \theta_{ij,t}^{\sim g}(h) \Big/ \sum_{i=1}^{N} \theta_{ij,t}^{\sim g}(h) \times 100, \tag{13}$$

$$S_{i,t}^{g}(h) = S_{,i}^{g}(h) - S_{i,}^{g}(h), \tag{14}$$

$$NPDC_{ij}(h) = \theta_{ji,t}^{\sim g}(h) - \theta_{ij,t}^{\sim g}(h), \tag{15}$$

where: $NPDC_{ij}(h)$ indicates the net pairwise directional connectedness between market i and market j.

Overall, these estimations, primarily done in EViews, Excel and the David Gabauer online estimation platform, allowed for examining volatility spillovers among BRICS markets during the COVID-19 and Russia-Ukraine crises, providing insights into total, directional, and net spillovers, enabling a comprehensive analysis of BRICS interconnections.

5. Results and analysis
5.1. Preliminary data analysis

Figure 1, depicting the BRICS broad market indices, reveals a notable trend of volatility clustering during two major crises. This phenomenon, characterised by periods of heightened market fluctuations and sharper price movements, indicates a substantial increase in market uncertainty and risk. These findings align with those of [26], who observed increased volatility spillovers among BRICS markets during the COVID-19 pandemic due to economic disruptions and heightened investor uncertainty. Similarly, the pronounced impact of these crises on BRICS markets is consistent with [24], who found that geopolitical tensions during the Russia-Ukraine conflict led to significant market volatility, albeit with a differing spillover pattern due to the isolating effects of sanctions.

The observed volatility clustering underscores the interconnectedness and vulnerability of global financial systems to external shocks, as highlighted in previous studies on crisis periods [27]. Unlike earlier findings that suggested uniformly increased spillovers during crises, our results indicate that while the COVID-19 pandemic intensified interconnectedness, the Russia-Ukraine conflict led to reduced spillovers due to regional isolation, aligning with the conclusions of [17] that geopolitical disputes often result in market segmentation rather than integration. These insights emphasise the importance of robust risk management strategies to monitor and mitigate potential vulnerabilities in the face of such disruptions.

A preliminary analysis of BRICS broad market indices in *Table 2* reveals distinct characteristics. India boasts the highest mean daily return (0.0533%), while Russia experienced negative returns (−0.0217%) amidst geopolitical tensions. Russia also displays the highest volatility, followed by China, while India exhibits the least. Skewness and kurtosis values indicate non-normal return distributions, further confirmed by Jarque-Bera statistics. All indices exhibit stationarity in levels and significant ARCH effects, suggesting volatility clustering and serial correlation in residuals. These findings necessitate using GARCH models for accurate volatility analysis in the BRICS markets. These findings align with [20] in supporting the use of GARCH models.

The analysis of various GARCH models with different error distributions indicated that the optimal model varied among the BRICS nations. Although the EGARCH model with Student's t error distribution initially appeared suitable due to its low SBIC value, it failed to meet the stationarity condition. Consequently, TGARCH models were selected for Brazil and Russia, while standard GARCH models were deemed most appropriate for China, India, and South Africa, all utilising Student's t error distribu-
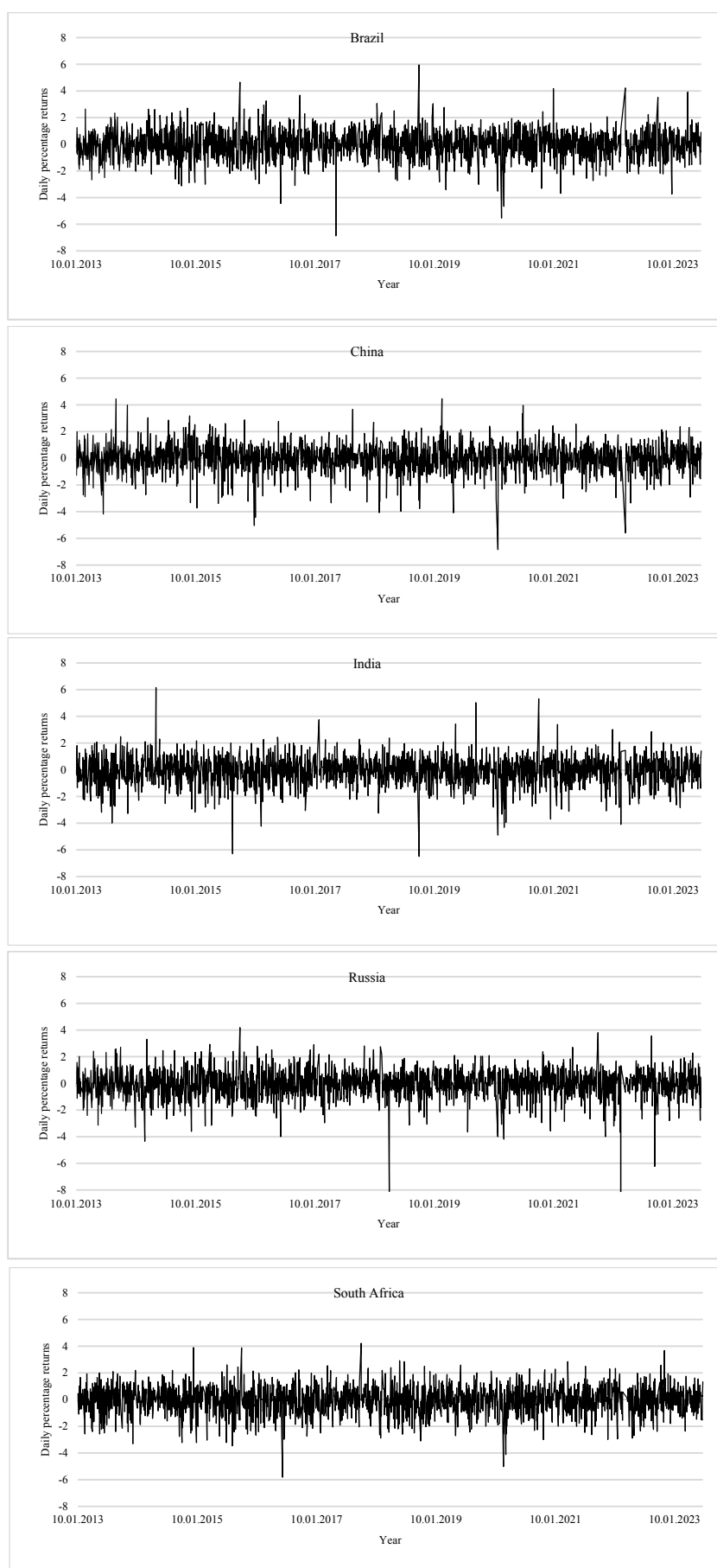
Fig. 1. **Broad market returns over the sample period**

Source: Authors' own depiction (2023).

Table 2
Preliminary tests and descriptive statistics

Test	rBzl	rRus	rInd	rChn	rSaf
Observations	2180	2180	2180	2180	2180
Mean (%)	0.0302	0.0217	0.0533	0.0157	0.0293
Std dev%	1.7154	2.3391	1.1688	1.4240	1.1697
Skewness	−0.7079	−4.0731	−1.1290	−0.8768	−0.5524
Kurtosis	15.2266	93.2108	18.5255	11.4267	10.2961
Jarque-Bera	13760.63*	745228.1*	22357.67*	6729.294*	4946.183*
ADF t-stat	−49.0978*	−48.6743*	−46.4755*	−44.7242*	−45.6468*
KPSS lm-stat	0.0563	0.0555	0.02868	0.0417	0.0258
ARCH F-stat	985.5808*	115.0954*	83.1222*	69.7706*	156.4986*
Ljung-Box Q-stat	2119.9	148.92	1381.5	820.14	2277.7
Ljung-Box Q2-stat	59.882	52.644	80.017	48.652	28.454

Source: Authors' own computations (2023).

Note: * indicates the rejection at a 1% significance level.

tion. The residuals derived from these models were then employed to further analyse spillover effects and market interconnections within the BRICS countries using the Diebold-Yilmaz spillover index. The use of these tailored GARCH models allowed for a more precise capture of the unique volatility dynamics in each market.

5.2. Volatility spillover analysis

Table 3 reveals significant shifts in market dynamics across the sub-periods, as reflected in the TCI values. Before the crises, only 35.13% of market risk was attributed to spillovers, indicative of low interconnectedness, aligning with findings from previous studies that noted lower spillover levels during stable periods [15, 20]. However, during the pandemic, it surged to 54.14%, likely due to heightened correlations and contagion effects, as observed by [15, 26], who reported increased volatility transmission among BRICS markets during COVID-19. Conversely, it dropped to 22.05% during the Russia-Ukraine conflict, potentially due to sanctions imposed on Russia, which isolated the conflict's impact, consistent with [27]. These fluctuations highlight the sensitivity of financial markets to global events, a recurrent theme in the literature on crisis periods [24].

In the pre-crisis period, South Africa emerged as the primary transmitter at 36.46%, while China exhibited the lowest spillover transmission at 16.81%. South Africa also led in spillover reception at 35.03%, with China receiving the least at 20.50%, which aligns with findings that suggest regulatory frameworks significantly influence market dynamics during stable periods [13]. During the pandemic, total directional spillovers surged, with South Africa maintaining its dominance as the largest transmitter at 57.50% and China as the least transmitter at 23.06%, consistent with literature highlighting China's resilience due to strict capital movement restrictions during crises [26]. India exhibited increased transmission compared to Brazil, mirroring the findings noting India's growing interconnectedness during the pandemic [32].

Contrary to expectations, the Russia-Ukraine conflict decreased proportional connectedness and spillovers, with Russia transmitting and receiving minimal spillovers, reflecting findings by [28], who documented how sanctions created barriers that reduced Russia's market impact. Consequently, Russia became the lowest transmitter, while South Africa retained its status as the highest, a pattern similarly reported in studies on emerging markets' reliance on global trade [21]. South Africa's position as the largest receiver of shocks was likely due to its heavy dependence on international trade and commodity prices, highlighting the complexities of geopolitical conflicts on market dynamics, as supported by [32]. However, the analysis of net spillovers also unveils the shifting behaviour of BRICS markets in the subperiods.
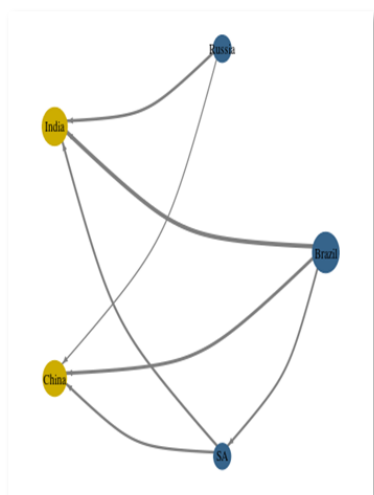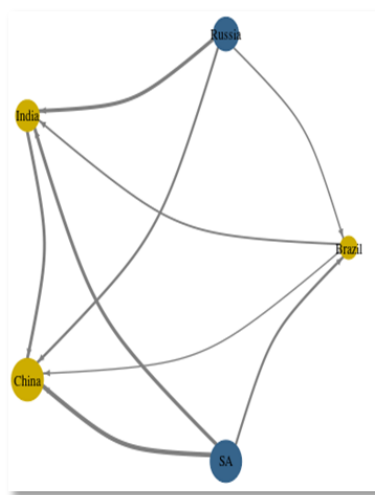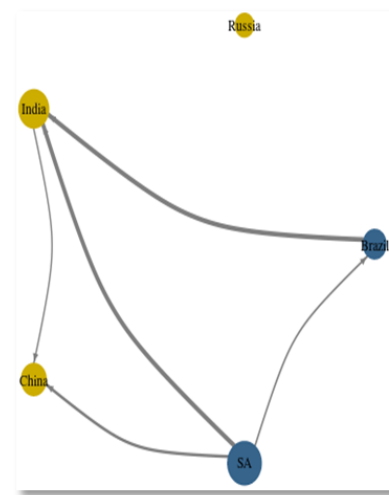
| *Fig. 2.a* | *Fig. 2.b* | *Fig. 2.c* |

Fig. 2. **Volatility spillover networks**

Source: Authors' own depiction (2023).

During the pandemic, Brazil shifted from being a net transmitter to a net receiver of volatility, likely due to its healthcare vulnerabilities and trade dependence, aligning with findings by [20]. In contrast, South Africa remained the largest net transmitter, consistent with findings by [3]. This pattern continued during the Russia-Ukraine conflict, where Russia, impacted by sanctions, became a net receiver, as observed by [17]. Pre-crisis, South Africa and Russia exhibited strong pairwise volatility spillovers. South Africa emerged as the most interconnected BRICS country during the pandemic, transmitting the most volatility to other members, as highlighted by studies on South Africa's role [32]. The Russia-Ukraine conflict saw Brazil, India, and China receiving more volatility from South Africa, reflecting its growing importance in global trade [28].

The net pairwise spillovers among BRICS countries during crises, analysed through volatility spillover networks in *Fig. 2*, reveal distinct patterns of volatility transmission across different periods. Before the crises (*Fig 2.a*), Brazil was the dominant source of volatility spillovers, while Russia and South Africa exhibited similar spillover behaviours, indicating a balanced yet interconnected market environment. During the COVID-19 pandemic (*Fig 2.b*), the dynamics shifted, with Russia and South Africa emerging as the primary transmitters of volatility, consistent with [26]. South Africa's significant role in transmitting shocks, particularly to India and China, stresses its growing influence within the BRICS bloc [16].

In contrast, Russia's role in volatility transmission was markedly diminished during the Russia-Ukraine conflict (*Fig 2.c*), likely due to trade restrictions and sanctions that isolated its market impact [27]. This shift left Brazil and South Africa as the primary drivers of volatility, with both countries significantly influencing India's market dynamics, which aligns with the findings by [17] and [13]. Overall, these findings emphasise the evolving nature of market interconnectedness within BRICS, demonstrating how South Africa, in particular, can exert substantial influence on the regional market landscape during periods of economic turbulence.

The limitations of static analysis in capturing the evolving nature of volatility spillovers prompted the adoption of a dynamic approach, as recent literature recommends, emphasising the importance of time-varying measures for understanding market interconnections [39]. Figure 3 below illustrates the dynamic TCI, which provides a better view of changes in market linkages over time. It notably surged above 50% during 2015–2016, coinciding with China's market crash, a period characterised by heightened global uncertainty and increased financial contagion, consistent with findings from [26]. The index peaked above 60% in early 2020, reflecting the severe impact of the COVID-19 pandemic on global financial interconnectedness, in line with documentation of significant increases in correlations during the pandemic [10].

Table 3
Static spillovers

	Market	Brazil	Russia	India	China	SA	FROM
Pre-crises	Brazil	76.66	11.11	3.80	1.59	6.84	23.34
	Russia	11.37	66.74	5.78	4.14	11.98	33.26
	India	5.70	7.11	71.62	5.13	10.44	28.38
	China	3.10	4.84	5.36	79.50	7.19	20.50
	SA	8.02	11.87	9.18	5.96	64.97	35.03
	TO	28.19	34.94	24.11	16.81	36.46	140.51
	Including Own	104.85	101.68	95.73	96.31	101.43	TCI =35.13
	NET	4.85	1.68	−4.27	−3.69	1.43	
	NPDC	4.00	2.00	1.00	0.00	3.00	
COVID-19 pandemic	Brazil	58.93	12.97	10.28	4.07	13.74	41.07
	Russia	11.82	52.21	11.12	4.91	19.94	47.79
	India	11.55	13.33	53.08	7.49	14.55	46.92
	China	5.02	6.60	9.66	69.45	9.28	30.55
	SA	12.07	19.30	12.26	6.59	49.78	50.22
	TO	40.46	52.21	43.32	23.06	57.50	216.55
	Including Own	99.39	104.42	96.41	92.51	107.27	TCI =54.14
	NET	−0.61	4.42	−3.59	−7.49	7.27	
	NPDC	2.00	3.00	1.00	0.00	4.00	
Russia-Ukraine conflict	Brazil	81.34	1.14	5.92	2.79	8.81	18.66
	Russia	1.29	95.47	0.20	2.13	0.92	4.53
	India	8.38	0.25	77.00	0.57	13.80	23.00
	China	3.19	1.77	1.52	84.89	8.62	15.11
	SA	7.75	0.81	11.31	7.04	73.09	26.91
	TO	20.61	3.98	18.95	12.53	32.15	88.22
	Including Own	101.95	99.44	95.95	97.42	105.24	TCI =22.05
	NET	1.95	−0.56	−4.05	−2.58	5.24	
	NPDC	3.00	1.00	1.00	1.00	4.00	

Source: Authors' own computations (2023).

Note: All figures in this table are percentages (%) and have been displayed without the % sign for brevity.
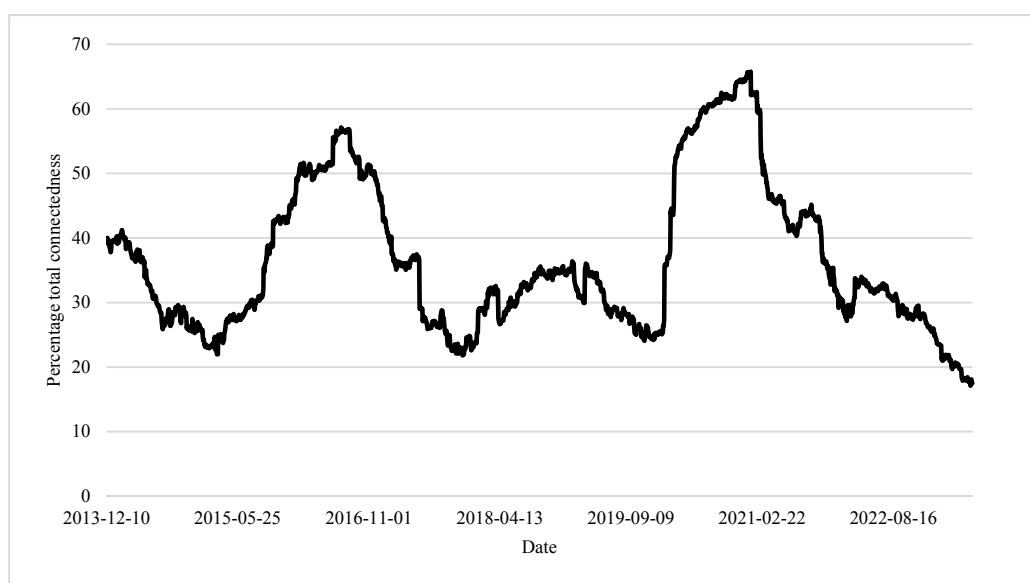
Fig. 3. **Dynamic total connectedness index**

Source: Authors' own depiction (2023).

Following the initial pandemic shock, the TCI gradually declined, likely due to improved pandemic management, economic adjustments, and monetary policy interventions aimed at stabilising markets, as observed by [29]. A renewed increase in the TCI in February 2022, followed by a gradual decline, underscores the impact of the Russia-Ukraine conflict on BRICS market interconnectedness, aligning with the literature that highlights how geopolitical events can abruptly alter market dynamics and volatility spillovers [1]. These findings reaffirm the critical need for dynamic analysis to capture better the temporal fluctuations in market connectedness driven by global economic and geopolitical developments. Otherwise, relying solely on static measures risks missing the real-time market behaviour and response shifts.

The dynamic directional spillovers in *Fig. 4* provide critical insights into the interactions between BRICS markets. During the crises, markets exhibited increased spillovers and connectedness, indicating contagion effects similar to those documented in previous studies [30]. China and India experienced predominantly negative net spillovers, likely due to their relatively insulated financial systems and stringent regulatory measures [10, 32]. In contrast, Brazil, Russia, and South Africa showed varying patterns, with South Africa frequently displaying positive net spillovers, particularly during the pandemic, demonstrating its role as a major volatility transmitter within the BRICS network, as shown by [16].

In *Fig. 5*, the net pairwise analysis reveals fluctuating volatility transmission between Brazil and Russia. Brazil generally received from Russia during the pandemic and the conflict, aligning with findings emphasising Russia's role as a volatility source during crises [32]. Brazil consistently transmitted volatility to India and China while receiving from South Africa, consistent with [32]. Russia transmitted volatility to India and China but was a net receiver from South Africa, particularly during the pandemic, aligning with [34]. The conflict marked a shift, with India and China transmitting to Russia and South Africa emerging as a net receiver, showcasing the dynamic nature of market linkages [35].

India consistently transmitted volatility to China and received it from South Africa. At the same time, China remained a net receiver from South Africa across both crises, highlighting their interconnected yet distinct roles within the network. These dynamics are further emphasised in *Fig. 6*. The continued economic integration means such patterns may become more prominent in future crises, reinforcing the necessity for vigilant market monitoring. A slight increase in connectedness observed following the Russia-Ukraine conflict reflects the broader impact of geopolitical tensions on global market dynamics, consistent with findings highlighting the ripple effects of geopolitical shocks on interconnected markets [1].

Spikes in connectedness also align with significant market events, such as the market crash in China, highlighting the heightened sensitivity of BRICS
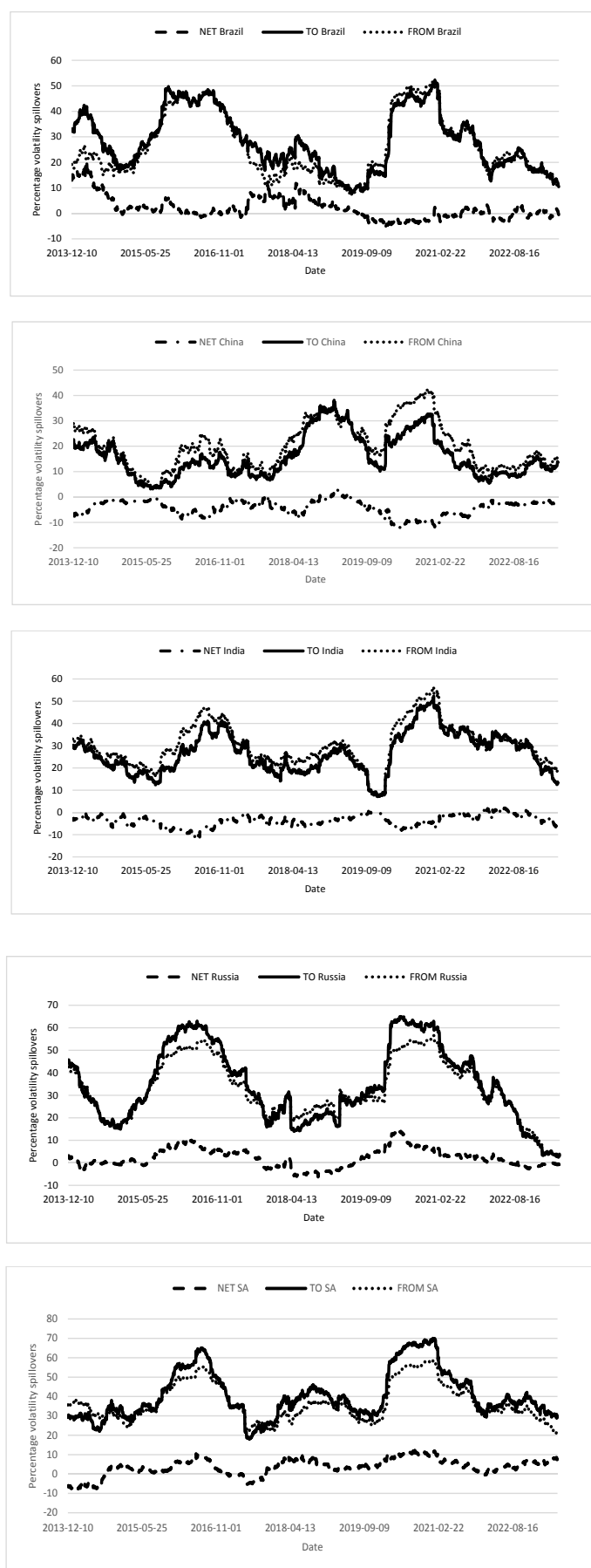
Fig. 4. **Directional dynamic spillovers**

Fig. 5. **Dynamic net pairwise spillovers**

Source: Authors' own depiction (2023)
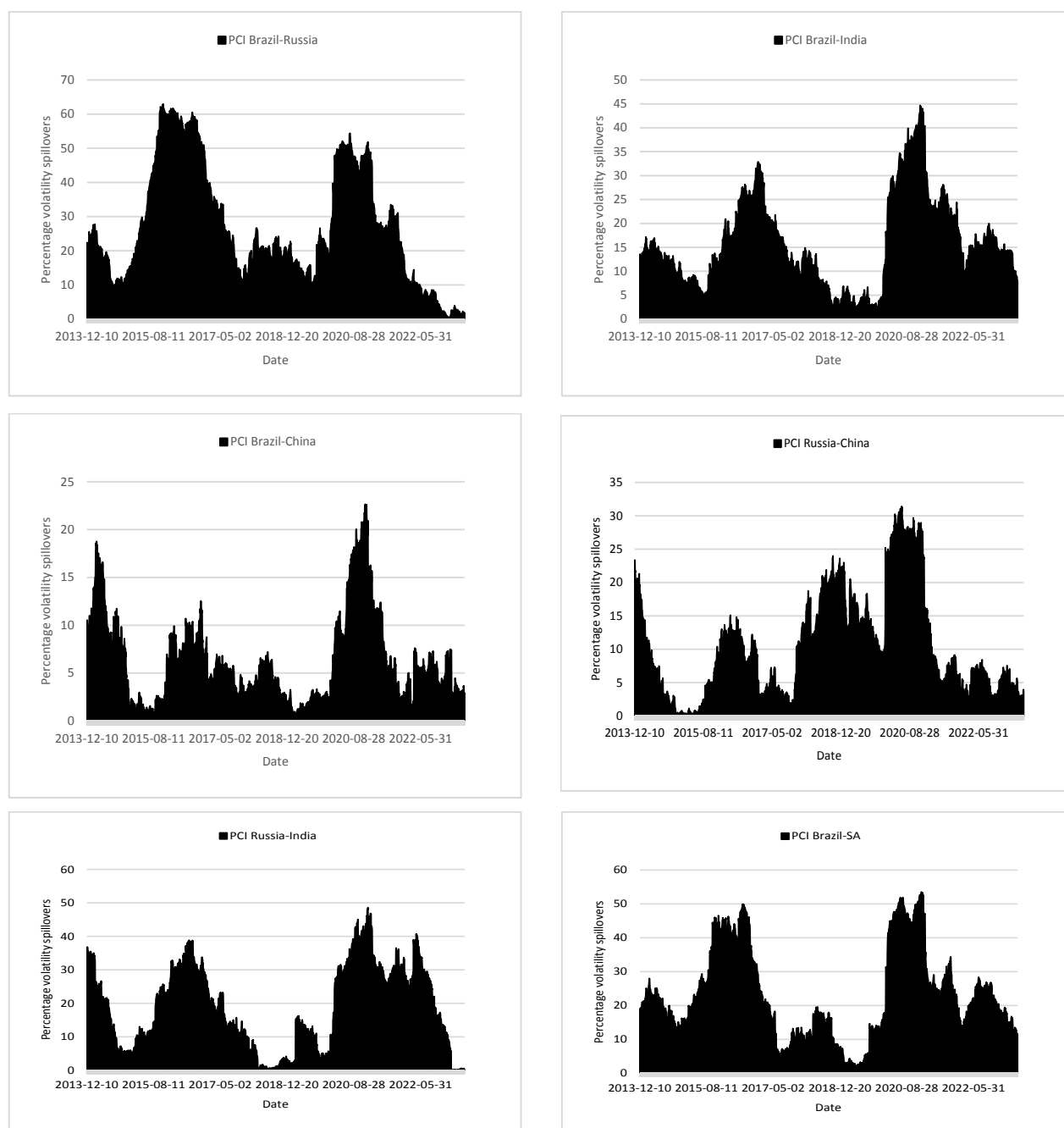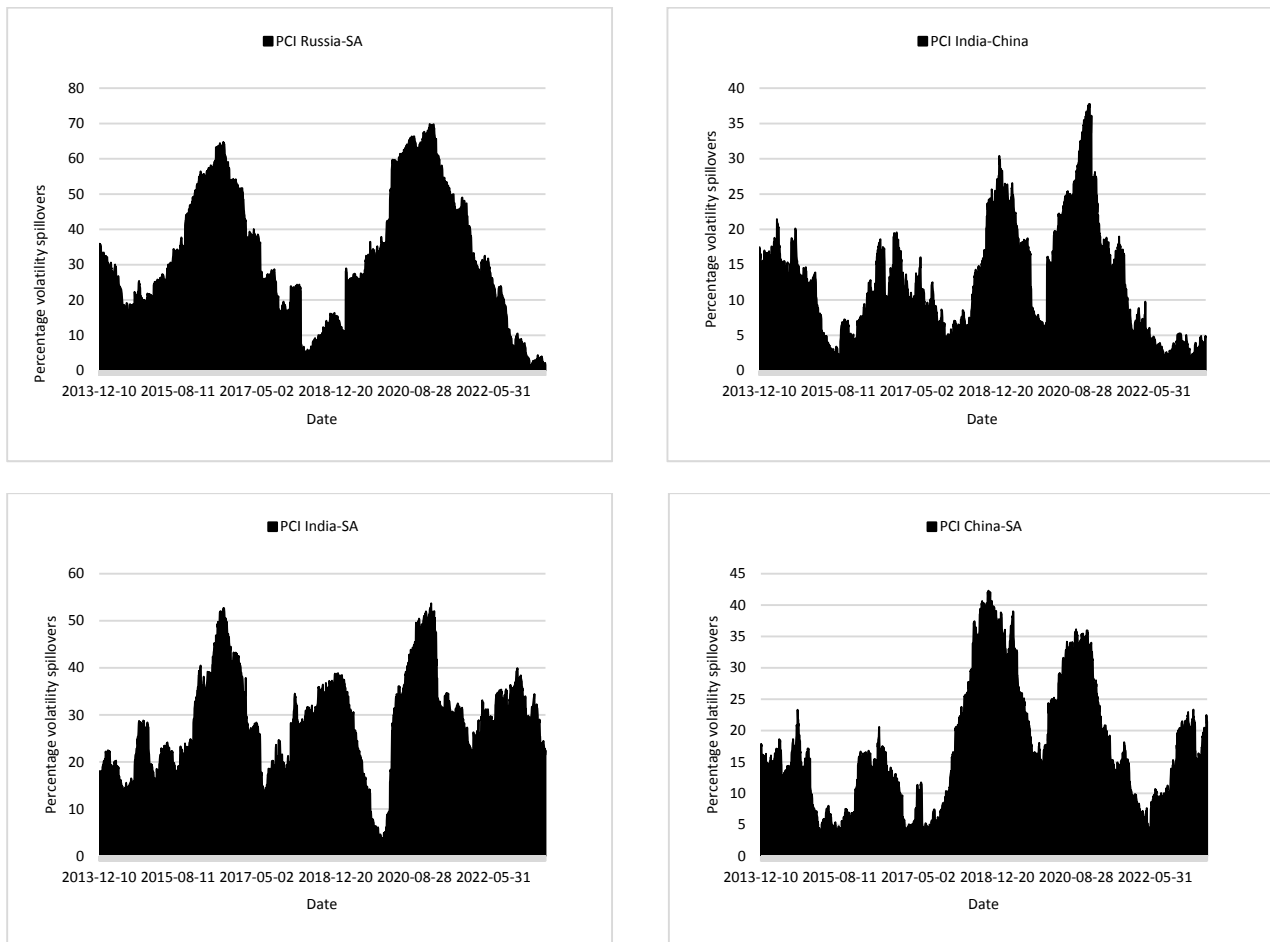
Fig. 6. **Pairwise Connectedness Index between BRICS countries over time**

Source: Authors' own depiction (2023).

markets to global disruptions and external shocks. These periods of increased volatility transmission underscore how quickly economic and geopolitical events can ripple through interconnected markets, affecting investor sentiment and market stability. Looking forward, it will be crucial to compare the impacts of the Russia-Ukraine conflict with those of ongoing geopolitical tensions, such as the current Middle East conflict, to understand how different types of crises influence market dynamics and interconnectedness.

Overall, the analysis reveals South Africa's consistent role as a transmitter of volatility across various crises. This prominence was particularly evident during the COVID-19 pandemic, where South Africa remained the top transmitter even as interconnectedness among BRICS nations declined. Interestingly, even the Russia-Ukraine conflict, which caused a decrease in overall spillovers, couldn't diminish South Africa's role as a primary transmitter. The reasons behind South Africa's unique role as a volatility transmitter warrant further investigation but could include its heavy reliance on global trade and possession of a financial system that might be more open and deregulated relative to the other BRICS.

6. Conclusion

This study examined the dynamics of volatility spillovers between the BRIC and South African stock markets across pre-crisis, COVID-19, and the Russia-Ukraine conflict periods. It highlighted substantial variations in spillover intensity across these phases, illustrating that crises and non-crisis periods impact market interconnectedness differently. These findings highlight the context dependency of market dynamics. Furthermore, different crises, such as the COVID-19 pandemic and the Russia-Ukraine conflict, also demonstrated unique impacts on market behaviours, reflecting the varying nature of economic disruptions and geopolitical tensions on volatility spillovers in interconnected markets.

During the COVID-19 pandemic, volatility spillovers increased significantly among BRICS

markets, aligning with previous studies highlighting heightened contagion effects during global crises [3]. This spillover increase can be attributed to the widespread economic disruptions, lockdown measures, and heightened uncertainty that characterised the pandemic period [26]. In contrast, the Russia-Ukraine conflict saw a general decline in cross-market spillovers, mainly due to geopolitical isolation, sanctions on Russia, and reduced cross-border financial interactions, reflecting findings by [24] and [28].

South Africa consistently emerged as a key transmitter of volatility, especially during the COVID-19 pandemic. This dominant role may be attributed to its significant exposure to global commodity markets and relatively open financial system compared to other BRICS countries [16]. These findings suggest that market characteristics, such as openness to international trade and financial regulation, significantly influence the extent of spillover effects during crises. The persistent role of South Africa as a volatility transmitter aligns with [13], who found that emerging markets with higher integration into global financial systems are more likely to transmit shocks during periods of heightened uncertainty.

Interestingly, the study challenges initial assumptions that the Russia-Ukraine conflict would lead to heightened spillovers across BRICS markets, especially given the global economic disruptions typically associated with such geopolitical events. Contrary to expectations, spillover transmission decreased, indicating that geopolitical factors such as sanctions and regional isolation can reduce interconnectedness rather than intensify it [27]. This outcome aligns with the findings of [17], who noted that geopolitical conflicts often cause market segmentation rather than increased integration, highlighting how political tensions can disrupt regular market linkages and dampen cross-border volatility transmission.

These results have significant implications for policymakers, investors, and scholars. Policymakers should acknowledge that the nature of a crisis significantly influences market interconnectedness and the magnitude of spillover effects. Investors need to understand that financial markets react differently to various shocks, highlighting the importance of dynamic risk assessments. For scholars, these findings emphasise the need for continued research into crisis-specific market responses to refine predictive models. Overall, the evidence calls for tailored risk management and policy strategies that account for the unique characteristics of each crisis, enabling more effective navigation of market turbulence.

This study provides a valuable foundation for significant future research. Future studies could build on these findings by investigating sector-specific spillovers or incorporating additional variables, such as investor sentiment, to better capture the complex nature of volatility. Additionally, as BRICS expands and discussions about a new BRICS currency gain momentum, further research into these evolving market interconnections will be crucial for managing financial stability in an increasingly interconnected global economy. Such insights would deepen our understanding of crisis-driven market behaviour and inform strategies for risk management, investment decision-making, and policy formulation.

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The Influence of Empty Container Depots on Container Repositioning in Tanzania: Implications for Port Efficiency

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ABSTRACT

Empty Container Depots (ECD) and container repositioning play pivotal roles in optimising the efficiency of global supply chains, especially within strategic facilities such as port terminals. **This study aims** to assess the influence of ECD on container repositioning within the context of Tanzanian ports. Specifically, it explores how ECD and repositioning processes are essential for managing container traffic and ensuring effective port operations in Tanzania. **Methods:** This study employed a survey design, targeting a population of 95 respondents. A stratified sampling technique was used to determine the sample size. Data were collected through questionnaires. Multiple regression analysis was employed to show the statistical relationships between the variables. **The results** revealed that investments in modern infrastructure and equipment at ECD significantly enhance container repositioning efficiency and reduce operational costs to alleviate congestion. The study underscores the importance of stakeholder collaboration in improving logistical performance. **The study recommends** improving the road network along transit routes to minimise delays in transporting empty containers.
Keywords: empty container depots; infrastructure; stakeholders; repositioning; port efficiency; Tanzania

Влияние складов пустых контейнеров на перемещение контейнеров в Танзании: последствия для эффективности порта

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АННОТАЦИЯ

Склады пустых контейнеров (СПК) и перемещение контейнеров играют ключевую роль в оптимизации эффективности глобальных цепочек поставок, особенно в рамках стратегических объектов, таких как портовые терминалы. **Цель** данного исследования — оценить влияние СПК на перемещение контейнеров в контексте портов Танзании. В частности, в нем рассматривается, насколько процессы СПК и перемещения контейнеров важны для управления контейнерными перевозками и обеспечения эффективной работы портов в Танзании. В данном исследовании использовался **метод** опроса, в котором приняли участие 95 респондентов. Для определения размера выборки использовался метод стратифицированной выборки. **Данные** были собраны с помощью анкетирования. Для демонстрации статистических связей между переменными использовался множественный регрессионный анализ. **Результаты** показали, что инвестиции в современную инфраструктуру и оборудование СПК значительно повышают эффективность

перемещения контейнеров и снижают эксплуатационные расходы, что позволяет избежать перегрузок. Исследование подчеркивает важность сотрудничества заинтересованных сторон в улучшении логистических показателей. Исследование **рекомендует** усовершенствовать дорожную сеть вдоль транзитных маршрутов, чтобы минимизировать задержки при транспортировке пустых контейнеров.

Ключевые слова: склады пустых контейнеров; инфраструктура; заинтересованные стороны; перемещение контейнеров; эффективность порта; Танзания

1. Introduction

Empty container repositioning (ECR) is one of the most significant subjects in the liner shipping industry [1]. ECR has both economic effects on the stakeholders in the container transport chain and environmental sustainability impacts on humanity. ECR lessens empty container schedules and, henceforward, reduces fuel consumption, overcrowding, and emissions. Additionally, Empty Container Depots (ECD) play a crucial role in the repositioning of containers in ensuring the containers are sent where required at a particular time. Moving empty containers costs the industry more than $ 20 billion every year. That's more than 12% of operating costs for shipping lines [2].

Inland transport of cargo and empty containers plays a key role in the efficiency of global supply chains, particularly at strategic facilities such as port terminals, intermodal rail stations, warehouses, or customs storage areas. The container transport chain starts when the shipping company takes empty containers from their depot to be loaded by the consignor. Every third container being moved is empty. That's at least 60 million empty container moves every year. To break the numbers down even further, 170 million containers are being moved around the world via different methods of freight transport, and of that number, an additional 50 million containers are empty.

In response to reducing pressure and as a decongestion strategy for major ports, the development of dry port concepts such as Empty Container Depots (ECD) has been initiated to assist the operational performance of prime ports [1].

There has been an increase in the need for ECD to reduce cargo congestion at the port [3]. However, less has been done by extant studies on how ECD influences container repositing; therefore, this study intended to assess how ECD has an influence on container repositing by employing ECD

infrastructure, ECD stakeholder perspective and ECD handling equipment.

2. Literature review
2.1. Theoretical foundation

Empty container repositioning (ECR) is the movement of empty containers from an area with a surplus of containers to a location with a deficit. Additionally, ECR is the last movement in intermodal freight transportation of containers in door-to-door shipments, where empty containers are returned to depots or moved to shippers for exportation [4]. Containers can either be returned to a depot for storage in the hinterland of a port or directly to the port depot for global repositioning. Furthermore, empty repositioning can refer to the movement of empty containers between inland depots, port depots, or port terminals to decrease empty container imbalance [5].

It has been noted that international trade has been a key factor in developing world economies, increasing the need for efficient supply chains to distribute products and services in global markets. "Although the responsiveness of trade to the Gross Domestic Product (GDP) growth has been moderate over the recent years, demand for maritime transport services and seaborne trade volumes continues to be shaped by global economic growth and the need to carry merchandise trade" [1].

This study has been guided by two theories (the street turns theory and stakeholders' theory). The essence of using two theories is to overcome one theory's weaknesses and increase the likelihood of having many constructs to explain the problem under investigation.

A street turn theory expounds on an operational strategy that shortens the distance travelled to a port terminal. Instead of returning an import container stripped at a consignee/importer to a port terminal, the empty container is directly

transported to a shipper/exporter, stuffed with export cargo there, and subsequently transported to a port. Finding an export request for an imported container before it returns to the port is referred to as a match-back, resulting in a container's street turn. That strategy eliminates two types of empty container movements from the importer to the terminal and from the terminal to the exporter while adding only one empty container movement, namely between the importer and the exporter [6].

From a local and regional perspective, the street turns reduce the number of empty trips and thereby the distance travelled by trucks [6]. The study [7] on empty container repositioning in ports concluded that street turns can significantly reduce costs and congestion, hence emissions, noise, and drive times for truck drivers, all depending on the geographical proximity between the importer and the exporter. However, identifying suitable street turns is quite difficult.

Existing studies reveal several barriers to street turns, including timing and location mismatch, ownership mismatch, container type mismatch, and legal issues [6–8]. Identifying suitable situations with geographical proximity also complicates street turns due to the trade imbalances that exist between regions that are usually import- or export-dominated. Further barriers include limited free time, repair charges, inconsistent procedures for interchange, inspection and paperwork requirements, and commercial, insurance, and liability hurdles [5]. Studies in the literature have mostly approached street turns from the perspective of shipping lines [6]. More recently, however, [9] has considered the perspective of the importer[1].

Stakeholder theory, on the other hand, emphasises the view of capitalism that stresses the interconnected relationships between a business and its customers, suppliers, employees, investors, communities and others who have a stake in the organisation [10]. The stakeholder approach identifies and models the groups that are stakeholders of a corporation, and both describes and recommends methods by which management can give due regard to the interests of those groups. "A *stakeholder is any individual or group of individuals that can influence or be influenced by the achievement of the organisation's objectives"*. The theory argues that a firm should create value for all stakeholders, not just some shareholders. The stakeholder approach is well applied in both seaports and dry ports studies and identifies some of the stakeholders with their interests.

The study [11] categorised these stakeholders into three main groups based on various interests, i.e., seaport-based players, dry port users, and the community. The seaport-based group includes port operators and port authorities. These players' interests are to expand their seaports' hinterland to further inland locations. Dry port users include shipping lines, local shippers, logistics providers, economic zone operators, transporters, and forwarders, which tend to enhance logistics performance for cargo movements between seaports and the local economic areas, and the community has an interest in the regional social economy impacts of dry port operations such as regional trade development, traffic congestion and accident rates, job creation and environmental issues. In the context of this study, stakeholders are ECD users, including clearing and forwarding agents and shipping line companies that receive services to enhance their access to maritime and minimise operational costs. As each stakeholder group has an interest in dry port development, it is necessary to have a framework to evaluate their various benefits in empty container repositioning. Therefore, the street turns theory and stakeholders' theory form a basis to study how ECD relates to ECR to enhance port operations.

2.2. Empirical perspective

The review of empirical literature was based on ECD infrastructure, empty container repositioning, ECD stakeholders' perspectives, and ECD handling equipment.

2.2.1. ECDs infrastructure

Container depot infrastructure significantly influences empty container repositioning processes by providing temporary storage, examination facilities, and centralised documentation handling, facilitating efficient empty container repositioning. For instance, the study [12] highlights the importance of integrated port and logistics infrastructure in enhancing supply chain efficiency and competitiveness, emphasising the role of container depots as crucial nodes for customs clearance activities. By offering secure storage spaces and examination facilities, emp-

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[1] UNESCAP. Guidelines for Port Stakeholders: Managing for Efficiency. Bangkok: UNESCAP; 2017.

ty container depots enable depot authorities to conduct inspections and repairs.

Furthermore, when a container has been returned to a depot, it must be inspected before being reused for an export shipment [13]. Inspection of empty containers is carried out to categorise and assess the quality or cleanliness of the container. Containers can be either operational and ready for reuse or damaged and in need of repairs [14]. Hence, contributing to the smooth flow of goods across borders. Overall, container depot infrastructure plays a vital role in optimising the repositioning of empty container processes, ensuring compliance with import/export regulations, and facilitating seamless trade operations within global supply chains. Generally, port infrastructure is divided into physical and soft elements. Physical infrastructure includes not only the operational facilities, such as the number of cranes, yards, and the area of storage space, but also transport, such as roads and railways. Whereas, the soft infrastructure refers to the manpower employed. Maximum deployment of both types will assist in reducing truck turnaround, thereby increasing the terminal capacity to accommodate more containers. Ships are continually increasing their carrying capacity, and containers made for large transport units in overseas container transport are under consideration. This scale enlargement requires new and capital-intensive transshipment facilities in gateway ports. Particularly, intermodality is essential for the speedy transport of cargo into and out of a gateway port. Without proper linkages, the efficiency of container terminal operations may decline due to congestion and delays [8]. The study [15] on reducing redundant empty container repositioning indicated that container repositioning relates to the role played by seaports and inland terminals' infrastructure in reducing cargo congestion at the seaport. The empirical findings recounted that the role of seaports and inland terminals is largely to facilitate intermodal transport. Supplementary, several stimuli and barriers for reducing empty container repositioning were identified. Therefore, we hypothesise that **Ha1**: *ECD infrastructure positively influences container repositioning.*

2.2.2. ECDs stakeholders' perspectives
Stakeholder cooperation serves as the glue that supports organisational workflow and opera-

tional efficiency. A stakeholder is a party interested in a company and can either affect or be affected by the business [16]. According to the international standard guiding social responsibility, ISO 26000, a stakeholder is defined as an individual or group that has an interest in any decision or activity of an organisation. Numerous parties are engaged in the dry ports in Tanzania. These parties must pull together towards a unified goal of supporting optimal port performance to avoid conflicts and inefficiencies. This study will examine the involvement of the various stakeholders, namely the Government of Tanzania, clearing and forwarding agents, port operators, terminal operators, the Tanzania Ports Authority, and shipping line companies in empty container depots in Tanzania.

Studies reveal that stakeholders have diverse interests in efficiently managing empty containers, impacting port congestion, transportation costs, and environmental sustainability [17]. Effective stakeholder engagement strategies are crucial for managing depot operations and addressing concerns such as land use, noise pollution, and traffic congestion while promoting sustainable practices and enhancing operational efficiency [18]. Research emphasises the need for collaborative governance frameworks and policy interventions to optimise depot utilisation, mitigate environmental impacts, and ensure equitable distribution of benefits among stakeholders [19]. Case studies highlight successful practices in stakeholder collaboration and regulatory frameworks that facilitate the integration of empty container depots into broader port logistics strategies.

The results from the study [20] on improved transport efficiency through reduced empty positioning of containers — transport buyers' perspective — revealed that Empty Container Depots (ECD) stakeholders such as freight forwarders have proven to play an important role in reducing empty container repositioning among the transport buyers mainly because of their knowledge within container transport management. ECD stakeholders play a substantial role in reducing cargo congestion at the port by managing the empty containers to be used from surplus to deficit areas. From these arguments, we hypothesise that **Ha2:** *ECD stakeholders' perspective positively influences container repositioning.*

2.2.3. ECDs handling equipment

Container handling equipment is one of the important operations for container terminal logistics, which involves loading a container from a truck to a vessel or unloading a container from a vessel to a truck [21]. Several major container terminal operations influence the efficiency of the container terminal, which include the vessel berthing operation, the crane unloading/loading operation, the container delivery operation by trucks, the inspection operation, and the container storage operation. The crane operation is the key factor that determines the efficiency and effectiveness of a container terminal [22]. When a container vessel is moored at berth, several cranes are arranged to load or unload containers for that vessel. Unloaded containers are transported by trucks and then go through other terminal operations. After finishing all unloading jobs, cranes will start loading containers from the land side onto the container vessel [22].

Improved container handling systems attract larger tonnage, thereby offering competitive international transport distribution services. Failure to improve container handling systems will encourage ship owners and shippers to use other ports with full operational capacity due to the absence of underutilisation resulting from low mechanisation, manual handling, and improper cargo handling equipment [3].

According to [8], one of the most basic requirements of any organization is to be able to transport or move materials, equipment and spare parts from one point to another. Material handling is of vital importance and is indicated by the range and high cost of the equipment that each organization has. Handling materials, which is a major activity in storehouses and stockyards, is a costly operation, and therefore the methods and equipment should be efficient. Poor equipment handling leads to shoddy work, making an organization unable to handle the required load on time, causing delays, congestion, and inefficiencies along the supply chains. A study conducted by [21] examined the impacts of cargo handling equipment on government revenue collection, a case of the Tanzania Ports Authority (TPA). The results showed a relationship between cargo-handling equipment and government revenue collection. That is, cargo handling equipment affects government revenue collection positively. Therefore, we hypothesise

that *Ha3*: *ECD handling equipment positively influences container repositioning.*

2.2.4. Empty container repositioning

Empty container repositioning, also known as container redistribution, is the process of moving empty shipping containers to locations where they are needed. This is necessary because containers often end up in locations where there is less demand for imports compared to exports, leading to imbalances in container availability. Repositioning helps to ensure that containers are available in the right places to meet the demand for shipping goods. It's a crucial aspect of global logistics management, aimed at optimising container utilisation and reducing costs in the shipping industry.

Empty container repositioning is a fundamental concept in maritime logistics and supply chain management, extensively discussed in academic literature and industry publications (see *Fig. 1*) [23].

Variables for ECD infrastructure include transport, storage capacity, and ICT system. Variables from ECD stakeholders' perspective include: logistics providers, importers and exporters, and depot operators and variables for ECD handling equipment are unloading and loading, automated mechanics, and modern equipment.

3. Material and methods

A survey research design was used by this study due to its ability to produce statistical information about aspects of ECD influence and its impact on empty container repositioning. Data were collected at once (cross-sectional time horizon). The use of survey design was of paramount significance due to its suitability to ensure minimum bias and maximum reliability of the evidence collected. Data collected quantitatively enabled the researchers to generalise findings from samples to populations, test hypotheses, and make predictions based on data analysis [24]. Study [25] defines a population as an entire group of people or things of interest that the researcher aims to assess. Additionally, [26] presumes a population is an entire group of individuals or objects having common observable characteristics.

3.1. Study participants

The target population is specified as a large group of many cases from which a researcher
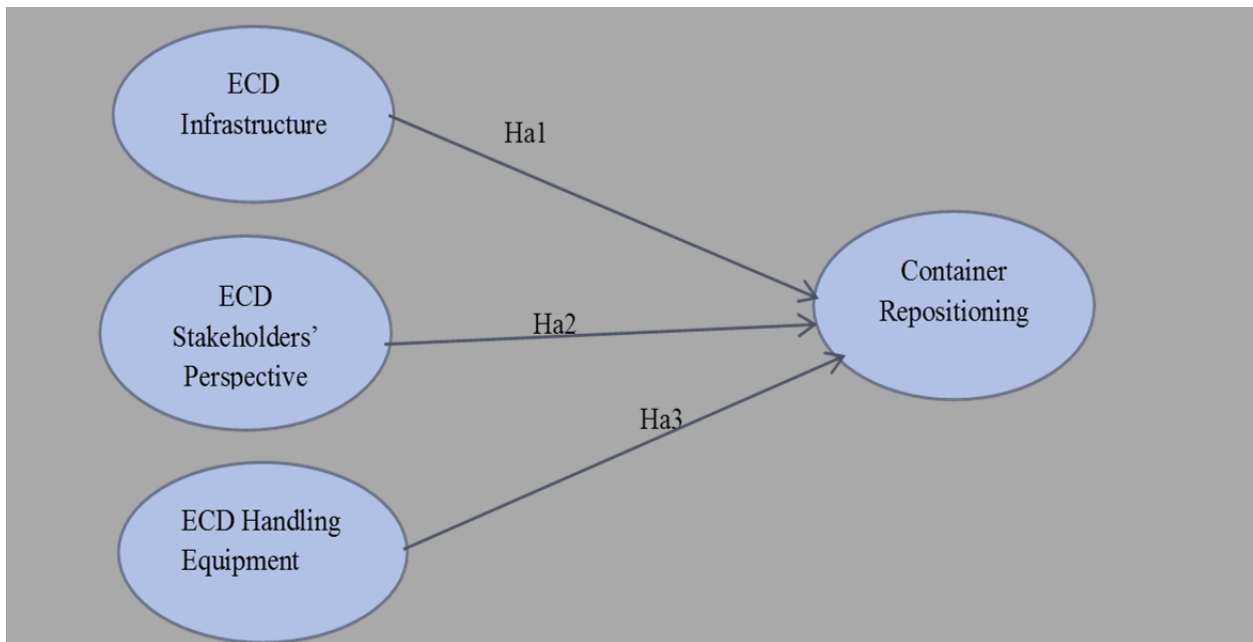
Fig. **Conceptual model of the study**

Source: Authors' conceptualisation from literature and theories.

draws a sample, and to which results from the sample are generalised. The target population for this study covered three groups of respondents identified as shipping line companies based on ECD operations of 20 major companies in Tanzania, 70 clearing and forwarding agents, and 5 companies registered both as shipping lines and clearing and forwarding, based on Fantuzzi and Kurasini empty container depots.

A stratified random sampling was used, through which the researcher identified the target population and then defined the criteria for stratification. Respondents were chosen randomly from the strata based on sample size to give an equal probability [27]. This sampling technique was used because it has a minimal sampling error. All based on Fantuzzi Investment Ltd and Kurasnini Container Terminal CFAs had equal chances to participate in the study. The sample size was computed by solving a formula to draw the sample size [28–29].

$$n = \frac{N}{\left(1 + Ne^2\right)}$$

n = sample size, N = population size, e = error, Confidence level = 95% p- value = 0.05

Then; Sample size, $n = \dfrac{95}{\left(1 + 95\left[0.05^2\right]\right)} = 77.$

Therefore; the total sample size used is 77.

The above assessments are based on Slovin's formula for sampling technique.

3.2. Data collection procedures and analysis

The questionnaire (Appendix 1) was applied to collect data in which closed-ended questions on a Likert point scale ranging from 1 to 5 were involved. To increase the understanding of the problem and create a logical base for the research gap, researchers have to review other documents such as books, laws, regulation papers, conference reports and theses. The purpose of reviewing previous studies was grounded on generating concepts and theoretical knowledge available and preparing research instruments and field observation.

Data were analysed descriptively, and to some extent, a multiple linear regression technique was adopted to provide statistical significance on the relationship between independent variables and dependent variables. Descriptive and inferential statistics were used to analyse the data. Descriptive statistics include percentages, frequency distribution and measures of central tendencies (mean). The data was presented in the form of tables, graphs and charts. Inferential statistics was used out of the fact that sampling naturally incurs sampling error, and thus a sample

Table 1
Gender of Respondents

Gender		Frequency	Per cent
Valid	Male	61	79.2
	Female	16	20.8
	Total	77	100.0

Source: Authors' field data, 2024.

Table 2
Levels of education of the respondents

Education		Frequency	Per cent
Valid	Masters' Degree	17	22.1
	Bachelor's degree	50	64.9
	Diploma	9	11.7
	Certificate	1	1.3
	Total	77	100.0

Source: Authors' field data (2024).

is not expected to perfectly represent the population. The methods of inferential statistics were used to estimate the parameter(s) and the testing of statistical hypotheses. Data (Appendix 2) were analysed using the IBM SPSS Statistics version 20.

4. Results and discussion
This part describes the results and links the findings with the previous empirical studies.

4.1. Respondents' profiles
This section provides an overview of the study respondents' profiles in their respective fields. It is described using respondents' profiles, which include the variables for gender, education level and field of work of respondents, respectively.

4.1.1. Gender of the respondents
The study collected data on the gender of the respondents of the study. *Table 1* shows the results as follows.

The findings in *Table 1* reveal that 79.2 percent of the respondents are male, while 20.8 percent of the respondents are female. This asserts that many respondents involved in this study were males. This is because women make up a small fraction of the workforce in the logistics and supply chain sector. Globally, women comprise only about 2% of seafarers, reflecting deep gender imbalances within the shipping industry [30]. Similarly, in freight forwarding, only 16% of placements were female across Europe, Africa, and Asia [31]. The barriers for women include not only traditional gender roles but also industry-specific challenges, such as physical demands and long hours, which are perceived as unsuitable for women in conservative societies [32].

4.1.2. Level of education of the respondents
The study collected data on the level of education of respondents of the study (*Table 2*).

The findings in *Table 2* show that 22.1 percent of the respondents had a master's degree, 64.9 percent of the respondents had a bachelor's degree, 11.7 percent of the respondents had a diploma, and 1.3 percent of the respondents had a certificate. This makes the total number of 77 respondents (100 percent). The results show that the logistics sector in Tanzania employs people with all levels of education. The findings further indicate that a large number of respondents of this study have bachelor's degrees, 50 (64.9%).

Recent research demonstrates that bachelor's degree holders, particularly in supply chain management and logistics, predominate in the shipping line, clearing, and forwarding industries. Because of the complexity of international trade and the necessity for a specialist understanding of customs, freight operations, and compliance, a degree in these subjects is becoming an increasingly important prerequisite. Furthermore, the

Table 3
Field of work of respondents

	Field of work	Frequency	Percent
Valid	Clearing and forwarding	59	76.6
	Shipping Line	15	19.5
	Clearing and forwarding	3	3.9
	Total	77	100.0

Source: Authors' field data (2024).

Table 4
Descriptive statistics

Variables	N Statistic	Min Statistic	Max Statistic	Sum Statistic	Mean Statistic	Std. Deviation Statistic	Skewness Statistic Std. Error	Kurtosis Statistic	Std. Error
ECD_ Infrastructure	77	1.00	5.00	274.00	3.5584	0.90715	−0.367 0.274	−0.221	0.541
ECD _Stakeholders' Perspective	77	1.33	5.00	297.67	3.8658	0.087067	−1.164 0.274	1.055	0.541
ECD_Handling Equipment	77	1.00	5.00	288.67	3.7489	0.87218	−0.548 0.274	0.245	0.541
Empty_ Container_ Repositioning	77	2.00	5.00	293.67	3.8139	0.86601	−0.322 0.274	−0.931	0.541
Valid N (Listwise)	77								

Source: Authors' field data (2024).

introduction of specialised degrees, such as the Bachelor of Commerce in Freight Forwarding and Customs Compliance, emphasises the importance of academic qualifications in professionalising the sector [33].

4.1.3. Field of work of respondents
The study collected data on the field of work of respondents. *Table 3* shows the results as follows.

The findings in *Table 3* show that 76.6% of the respondents work in clearing and forwarding, 19.5% of the respondents work in shipping lines, and 3.9% of the respondents work in both shipping lines and clearing and forwarding. Clearing and forwarding provides 59 (76.6%) respondents this is because Tanzania has a significantly higher number of employees in the clearing and forwarding sector compared to the shipping line sector. According to the Tanzania Freight Forwarders Association (TAFFA), there are over 1,000 licensed clearing and forwarding companies operating within the country, representing a large workforce across various roles within these firms. This contrasts with the relatively smaller number of shipping line companies, which primarily focus on the actual transportation of goods but involve fewer direct operations compared to the extensive processes handled by clearing and forwarding firms.

4.2. Analysis of the variables under study
Variables are analysed to show their relationships, and the hypotheses are tested to show the significance level. Under this part, descriptive and inferential analyses have been shown to show the nature of the respondents and test the hypotheses. The analysis is established to explain the predictor having greater influence on the dependent variable over others using the mean and also the lowest level of respondents' opinion using the standard deviation.

This descriptive analysis provides an overview of the tendencies in respondents' perceptions of the various factors influencing empty container

Table 5
Normality test

Variables	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	Dif.	Sig.	Statistic	Dif.	Sig.
ECD_Infrastructure	0.162	77	0.44	0.964	77	0.027
ECD_Stakeholders' Perspective	0.276	77	0.000	0.865	77	0.000
ECD_Handling Equipment	0.138	77	0.001	0.944	77	0.002
Lilliefors Significance Correlation						

Source: Authors' survey data, 2024.

repositioning. These findings suggest that most respondents view the handling and repositioning processes favourably, although there is some variability, particularly in the assessment of infrastructure. The findings in *Table 4* show that the average scores for each component (infrastructure, stakeholder perspective, handling equipment, and repositioning) are reasonably high (ranging from 3.56 to 3.87). ECD Infrastructure exhibits the greatest diversity in responses (highest standard deviation), suggesting that respondents' perspectives on infrastructure were more varied.

ECD Infrastructure, ECD Handling Equipment, and Empty Container Repositioning show skewness and kurtosis values that are reasonably close to 0; that is variables are fairly close to a normal distribution. ECD Stakeholder Perspective shows more deviation from normality, with higher negative skewness and a positive kurtosis, indicating a more asymmetrical and peaked distribution. Given the standard errors of skewness (0.274) and kurtosis (0.541), most of the variables have values within an acceptable range, suggesting that their distributions are not significantly different from normal.

4.2.1. Preliminary tests
Numerous tests can be conducted to support causal relationship testing, including a normality test, a multicollinearity test, and a heteroscedasticity test. They are discussed below:

4.2.1.1. Normality test
To ascertain whether a collection of data has a normal distribution, a normality test is utilised. Many statistical analyses used in research (including ANOVA, t-tests, and regression) include the assumption that the data are normally distributed. Testing for normalcy is crucial in this

investigation of empty container repositioning and its relationships to variables like ECD Infrastructure, ECD Stakeholder Perspective, and ECD Handling Equipment.

The Kolmogorov-Smirnov and Shapiro-Wilk tests, two measures of normalcy, are displayed in the Tests of Normalcy table. The findings in *Table 5* indicate that Kolmogorov-Smirnov and Shapiro have p-values less than 0.05 for each of the three variables (ECD Infrastructure, ECD Stakeholder Perspective, and ECD Handling Equipment). This shows that the data was drawn from probability sampling.

4.2.1.2. Multicollinearity test
When two or more independent variables exhibit strong correlations, the model's information is redundant or overlapping, a phenomenon known as multicollinearity. *Table 6* illustrates the results.

The results indicate the outcome of collinearity and multicollinearity tests. The Variance Inflation Factor (VIF) describes the multicollinearity test; if the values for the variance inflation factor are less than five (5), it implies that variables do not exhibit a multicollinearity problem. The findings in Table 6 show that all variables are far from the collinearity level, as the values are less than the critical value of 5.

4.2.2. Inferential analysis
This kind of analysis is designed to describe the relationship between predictors and dependent variables, through correlation and multiple regression analysis, with the model summary test as a key indicator for the predictors' overall impact on the dependent variable (*Table 7*).

The findings in *Table 7* indicate that the independent variables (ECD Stakeholder Perspective,

Table 6
Multi-collinearity test

Coefficients								
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
1 (Constant)	.417	.352		1.182	.241		
ECD_Infrastructure	.329	.085	.344	3.889	.000	.752	1.329
ECD_Stakeholder_Perspective	.274	.101	.275	2.713	.008	.572	1.748
ECD_Handling_Equipment	.312	.096	.314	3.266	.002	.637	1.570
a. Dependent Variable: empty container_repositioning								

Source: Authors' survey data, 2024.

Table 7
R-squared and Adjusted R-squared

Model Summary				
Model	R	R Square	Adjusted R-Square	Standard Error of the Estimate
1	.755a	.570	.552	.57962
a. Predictors: (Constant), ECD_Handling_Equipment, ECD_Infrastructure, ECD_Stakeholder_Perspective				

Source: Authors' survey data.

Table 8
Analysis of variance (ANOVA)

ANOVAa						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	32.473	3	10.824	32.220	.000b
	Residual	24.525	73	.336		
	Total	56.999	76			
a. Dependent Variable: Empty container repositioning						
b. Predictors: (Constant), ECD handling equipment, ECD infrastructure, ECD stakeholders' perspective						

Source: Authors' field data (2024).

ECD Infrastructure, and ECD Handling Equipment) have a good association (R = 0.755). The R-squared = 0.570 implies that 57% of the variation in the dependent variable is explained by the independent variables included in the model. The adjusted R-square is 0.552, which is slightly lower than the R-square (0.570). This suggests that while the model explains 57% of the variance, some of the explanatory power may be due to the number of variables rather than the quality of the predictors.

Further, the adjusted R-squared shows that the model loses some of its explanatory power when accounting for the number of predictors and the sample size. In other words, the predictive power of the model is still strong, but a small portion of the variability explained by the model could be due to the number of predictors rather than the actual quality of the predictors. Suggesting that the model fits the data reasonably well. The residuals, or errors, appear to be moderately distributed around the projected values, based

Table 9
Correlation analysis

Variables		ECD_ Infrastructure	ECD_Stakeholders	ECD _Handling_ Equp
ECD_Infrastructure	Pearson Correlation	1	.475**	.262*
	Sig. (2-tailed)		.000	.021
	N	77	77	77
ECD_Stakeholders	Pearson Correlation	.475**	1	.349**
	Sig. (2-tailed)	.000		.002
	N	77	77	77
ECD Handling_Equp	Pearson Correlation	.262*	.349**	1
	Sig. (2-tailed)	.021	.002	
	N	77	77	77

Source: Authors' field data (2024).

Note: * Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

on the standard error of 0.57962. Overall, there is still space for unexplained variation or other contributing factors, but the regression model shows a good fit overall, with the predictors accounting for a sizable percentage of the outcome's variance. The model is further tested through an analysis of variance (ANOVA) test, with the results shown in *Table 8*.

The findings in *Table 8* indicate that the regression model is statistically significant ($p < 0.001$), meaning that the independent variables together significantly explain the variation in Empty Container Repositioning. The high F-value (32.220) suggests the model has strong predictive power. Therefore, the variables ECD Infrastructure, ECD Stakeholder Perspective, and ECD Handling Equipment are useful predictors in explaining the efficiency of empty container repositioning in Tanzania. As such, the results support the study's claims that infrastructure, stakeholder perspectives, and equipment handling play key roles in improving empty container logistics.

4.2.2.1. Correlation analysis

This analysis is conducted to describe the predictor that best correlates with the dependent variable. Other factors, due to the data characteristics, Spearman's correlation is best suited for this task. *Table 9* shows the results as follows.

The findings from *Table 9* show that there is no harm between variables. Variables do not correlate at a 95% confidence interval (5%) level of significance; all variables are out of collinearity level. This helps avoid **multicollinearity**, which occurs when two or more independent variables are highly linearly related.

The Spearman's rho correlation table shows the strength and direction of the association between the variables (ECD Infrastructure, ECD Stakeholder Perspective, ECD Handling Equipment, and Empty Container Repositioning) and whether these correlations are statistically significant. With p-values less than 0.001, all correlations are statistically significant and positive, indicating that the associations do not result from random chance. Empty container repositioning and ECD infrastructure had the strongest association (rho = 0.619), suggesting that infrastructure is crucial to increasing empty container repositioning efficiency. Additionally, significant correlations (rho = 0.610 and rho = 0.615) between ECD Handling Equipment and Empty Container Repositioning and ECD Stakeholder Perspective, respectively, demonstrate the significance of both equipment and stakeholder perspectives in the repositioning process. This implies that raising the ECD infrastructure, stakeholder perspective, and handling equipment standards will probably increase empty container repositioning's efficacy and efficiency.

Table 10
Multiple regression analysis

Coefficients						
Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**
		B	**Std. Error**	**Beta**		
1	(Constant)	.417	.352		1.182	.241
	ECD_Infrastructure	.329	.085	.344	3.889	.000
	ECD_Stakeholder_Perspective	.274	.101	.275	2.713	.008
	ECD_Handling_Equipment	.312	.096	.314	3.266	.002
a. Dependent Variable: Empty_Container_Repositioning						

Source: Authors' survey data, 2024.

4.2.2.2. Multiple regression

The analysis is conducted to explain the individual influence of each predictor on the dependent variable. The results are shown in *Table 10.*

The Coefficients table from the multiple regression analysis provides information on the contribution of each independent variable (predictor) to the dependent variable (outcome). All three predictors (ECD Infrastructure, ECD Stakeholder Perspective, and ECD Handling Equipment) have a statistically significant, positive relationship with Empty Container Repositioning ($p < 0.05$ for each predictor). This means that the model suggests that infrastructure has the strongest effect on improving empty container repositioning efficiency, followed by handling equipment and stakeholder perspectives. Also, all three factors are statistically significant, meaning that investment in these areas will likely improve the efficiency of empty container repositioning processes.

5. Discussion of the findings

The study found that ECD (Empty Container Depots) infrastructure has a significant positive influence on empty container repositioning ($β = 0.344$, $p < 0.001$). This finding aligns with existing literature that underscores the critical role of robust port and depot infrastructure in ensuring the efficient movement of containers [34]. The correlation analysis also revealed a strong positive relationship (Spearman's rho = 0.619), indicating that improvements in infrastructure, such as better storage facilities, transportation linkages, and depot systems, can significantly enhance the efficiency of empty container repositioning.

The correlation analysis results suggest that improving ECD infrastructure will impact forecasting and planning: Understand the relationship between container availability and import or export volumes. For instance, if higher port throughput correlates with lower container lodge times at ECDs, resources can be changed accordingly. The correlation results also affect cost efficiency, which is the relationship between transport distance, fuel cost, and container turnaround time.

The correlation results between ECD handling equipment, infrastructure and container repositioning are essential in inventory management, as they are used in discovering patterns between empty returns, maintenance cycles, and reutilization rates.

These findings are consistent with those of [15], who highlighted that seaport and inland terminal infrastructure are strongly correlated with the reduction of cargo congestion at seaports. Therefore, we accept the alternative hypothesis (Ha1) that ECD infrastructure positively influences container repositioning.

The significance of physical infrastructure is further emphasised by [35], who recommended that ports and container depots equipped with advanced facilities, such as modern storage areas and seamless transport links, are better positioned to meet the rising demand for containerised goods. In the context of Tanzania, improvements in depot infrastructure have substantially reduced congestion and enhanced the efficiency of repositioning processes [3].

Additionally, the study found that the ECD stakeholder perspective significantly influ-

ences empty container repositioning (β = 0.275, p = 0.008). This result is under stakeholder theory, which posits that effective engagement with stakeholders is vital for the smooth functioning of port operations. A moderately high positive correlation (Spearman's rho = 0.610) was observed between stakeholder perspectives and the efficiency of empty container repositioning. Previous studies, such as those conducted by [11], have highlighted the importance of stakeholder collaboration in improving logistics efficiency. In Tanzania, improved relationships between shipping lines, port authorities, and logistics providers were found to enhance coordination and decision-making, which, in turn, leads to more efficient container movements. As emphasised by [20], fostering strong stakeholder relationships reduces delays and streamlines container repositioning, benefiting the entire supply chain. The alternative hypothesis (Ha2), which posits that the ECD stakeholder perspective positively influences container repositioning, is therefore accepted. These results are consistent with previous research, including [23, 5, 14–18], which supports the view that stakeholder input in ECDs and maritime logistics aids in minimising the total costs associated with empty container movements. By leveraging stakeholder perspectives, shipping line agents can optimise the sequence for container movement, further improving the repositioning process.

Finally, the study found that ECD handling equipment plays a significant role in empty container repositioning (β = 0.314, p = 0.002), with a strong positive correlation (Spearman's rho = 0.615). This is in agreement with [26], who noted that modern, well-maintained handling equipment is essential for efficient port operations. In the Tanzanian context, the availability of advanced equipment, such as cranes, forklifts, and automated systems, has been shown to reduce turnaround times, thereby enhancing repositioning efficiency. The study [24] also supports this finding, emphasising that effective handling equipment reduces congestion and minimises delays, making the repositioning process smoother. This study further confirms that investments in state-of-the-art equipment at depots such as Fantuzzi and Kurasini positively impact the efficiency of empty container logistics. The findings of this study underscore that ECD infrastructure, stakeholder perspectives, and handling equipment are critical factors influencing empty container repositioning in Tanzania. Each of these factors plays a significant role in improving the efficiency of container logistics, and investments in these areas can result in more streamlined and cost-effective repositioning processes.

6. Conclusion and recommendation

This study aimed to determine how Empty Container Depots (ECDs) and repositioning processes contribute to improving port operation efficiency by examining three variables: ECD handling equipment, stakeholder perspectives, and ECD infrastructure. The findings indicate that all three variables significantly influence the efficiency of container repositioning. These results highlight the vital role of ECDs in supporting national customs activities and improving port operations, including key functions such as tax collection, job creation, and enhancing professionalism and expertise. Given these findings, the following recommendations are made:

Training and development: Continuous training is essential for stakeholders involved in the empty container repositioning process to remain updated on technological advancements. This can be achieved through training workshops, seminars, and online learning. Stakeholders should be regularly trained on improvements in the systems used to clear documents, such as the Single Window System for cargo clearance, which has incorporated additional modules to enhance efficiency

Maintenance of handling equipment: Handling equipment, which includes mechanical equipment used for the movement, storage, control, and protection of empty containers, should undergo regular maintenance to prevent breakdowns. This will reduce depot delays and ensure smooth operations during repositioning.

Improved road networks: The development of better road infrastructure along designated transit routes will significantly enhance the efficiency of container terminals by reducing delays experienced by trucks transporting empty containers to and from depots.

7. Implications of the findings

The practical implications of this study suggest that companies and stakeholders involved in lo-

gistics in Tanzania should prioritise infrastructure development and modernisation of equipment while fostering strong collaboration to improve container repositioning. Existing studies have explored various optimisation models and algorithms to improve repositioning strategies; however, this study contributes to policy-making by demonstrating that the integration of ECD handling equipment, stakeholder perspectives, and infrastructure can enhance container repositioning through real-time data analytics and predictive modelling, leading to better decision-making and overall performance in container logistics.

By improving the ECD infrastructure, using old or traditional ECD models like Ports overwhelmed, ECD over-capacitated, or underutilised, Manual processes and a **lack of coordination** with ports, shipping lines, and inland transport can be minimised or discouraged. Instead, ECD infrastructure can lead to digitalised or smart ECDs that increase visibility of container status (location, condition, availability), reducing idle time and repositioning costs.

Improving ECD stakeholders through regionalised & planned placement that can help the use of modern models, data-driven location selection for depots, optimising proximity to shippers, importers, and key logistics hubs and minimising "dead-haul" miles and reducing environmental impact. Integration with Logistics Network: ECD can be combined into wider logistics and intermodal networks, serving as provisional warehousing, customs clearance zones, or transshipment hubs. Sustainability and Circular Economy: By reducing unnecessary repositioning and supporting green logistics, ECD contributes to the reduction of carbon emissions.

Theoretically, this study extends both the street turn theory and stakeholder theory by suggesting the collection of qualitative data and the integration of these two theories. The combination of theories helps address the complexity of the problem by providing sufficient variables for analysis. This study integrates the two theories, tests variables related to container repositioning in Tanzania, and identifies potential variables that policymakers can use to reduce cargo congestion at ports.

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APPENDICES
Appendix 1: Questionnaire

This questionnaire is for the study titled "***The Influence of Empty Container Depots on Container Repositioning in Tanzania: Implications for Port Efficiency***"

SECTION A: Demographic Information

Answer all questions as indicated by ticking the correct answer.

Gender

Male [] Female []

Highest level of Education and training attained?

Master's Degree [] Bachelor's Degree [] Diploma [] Certificate []

Which of the following areas do you specifically work for?

Shipping line [] Clearing and forwarding []

What is your current position?

Top Management [] Middle Management [] Supervising level [] Operations []

Number of years worked in the position

Below 3 years [] 3–6 years [] 7–10 years [] above 10 years []

SECTION B. ECDs Handling Equipment

Answer all questions as indicated by ticking the correct answer.

To what extent does the ECD handling equipment influence Empty Container Repositioning in Tanzania?

5 = Strongly Agree, 4 = Agree, 3 = Neutral, 2 = Disagree, 1 = Strongly Disagree

	ASPECTS	**5**	**4**	**3**	**2**	**1**
B1	ECDs loading and unloading mechanism has improved the process of empty Container repositioning in Tanzania					
B2	ECDs automated machines have adequately influenced empty container repositioning to take place efficiently and effectively					
B3	ECDs are equipped with modern equipment, which enables efficient repositioning of empty containers in Tanzania					

SECTION C: ECD Stakeholder Perspectives

Answer all questions by ticking the correct answer.

What is the influence of the ECD stakeholders' perspectives on empty container repositioning in Tanzania?

5 = Strongly Agree, 4 = Agree, 3 = Neutral, 2 = Disagree, 1 = Strongly Disagree

	ASPECTS	**5**	**4**	**3**	**2**	**1**
C1	Logistics providers facilitate accessibility and connectivity of ECDs to the port of Dar es Salaam					
C2	The existence of Importers and Exporters increased the number of empty containers repositioned via ECDs					
C3	ECD operators positively contributed to the empty containers					

SECTION D: ECD infrastructure

Answer all questions by ticking the correct answer.

How does the ECD Infrastructure contribute to Empty Container Repositioning in Tanzania?

5 = Strongly Agree, 4 = Agree, 3 = Neutral, 2 = Disagree, 1 = Strongly Disagree

	ASPECTS	5	4	3	2	1
D1	ECDs have transport networks that ensure efficient and speedy empty container repositioning					
D2	ECDs are adequately accommodated with storage capacity that assures timely cargo clearance					
D3	ECDs have an efficient and speedy ICT system to facilitate on-time empty container repositioning					

SECTION E: Empty Container Repositioning

Answer all questions by ticking the correct answer.

To what extent do the ECDs influence Empty Container Repositioning in Tanzania?

5 = Strongly Agree, 4 = Agree, 3 = Neutral, 2 = Disagree, 1 = Strongly Disagree

	ASPECTS	5	4	3	2	1
E1	The existence of ECDs influences the elimination of the unbalanced distributions of empty containers around Dar Es Salaam Port					
E2	ECDs encourage accurately tracking the movement of empty containers to avoid overstocking and unnecessary storage expenses					
E3	ECDs have led to significant time savings and improved overall efficiency of empty containers operations in Tanzania					

Appendix 2: Survey data

S/N	ECDs -Handling Equipment (Loading and Unloading)	ECDs -Handling Equipment (Automated machine)	ECDs-Modern equipment	ECD-Stakeholders Perspectives (Logistics Providers)	ECD_Stakeholders (Existence of Importers and Exporters)	ECDs operators.	ECDs-Infrastructure (Transport Networks)	ECD Stakeholders (Accommodated with storage capacity).	ECDs- Stakeholders (Efficient and speedy ICT system)	CR- ECDs elimination of the unbalancing EC)	CR- (ECDs) encourages accurately tracking EC movement)	CR- (ECDs time savings and efficiency of EC)
1	5	5	5	5	5	5	4	5	4	4	4	4
2	1	5	5	4	5	5	5	4	5	5	5	5
3	5	4	4	4	4	4	4	4	4	5	5	5
4	2	3	3	2	3	2	3	3	3	3	3	3
5	2	3	2	4	4	2	2	4	2	3	3	4
6	2	4	3	3	2	3	3	2	4	4	2	2
7	4	4		4	4	4	4	4	4	4	4	4
8	4	4	4	4	4	4	4	2	4	4	4	4
9	2	2	2	4	4	2	1	1	1	2	3	2
10	4	4	5	4	4	4	5	4	4	5	5	5
11	3	1	3	5	3	3	5	5	5	3	3	3
12	3	3	5	4	5	5	3	3	5	5	4	5
13	5	4	4	5	4	4	4	4	3	4	4	4
14	4	5	4	4	4	4	4	4	4	4	4	4
15	3	4	3	5	4	4	4	3	3	3	3	3
16	4	4	3	5	4	4	3	3	3	4	4	4
17	3	4	4	3	4	3	4	2	3	2	4	3
18	3	3	4	4	5	5	4	5	4	5	5	5
19	4	4	3	4	4	4	2	3	3	4	4	4
20	4	4	4	4	3	5	3	3	3	2	3	3
21	5	5	5	5	5	5	5	5	5	2	2	2
22	2	1	3	1	1	3	1	5	5	2	2	2
23	5	5	5	4	4	4	3	4	3	5	5	4
24	3	3	3	4	4	4	3	3	3	3	4	3
25	3	3	3	3	3	3	3	3	3	3	3	3
26	4	4	4	2	2	1	2	2	1	2	2	3
27	4	4	4	5	4	5	5	5	4	5	5	4
28	4	5	3	4	3	5	4	4	4	4	4	4
29	3	4	4	4	4	4	4	4	4	3	4	4
30	5	5	3	5	5	5	5	5	5	5	5	5

Appendix 2 (continued)

S/N	ECDs -Handling Equipment (Loading and Unloading)	ECDs -Handling Equipment (Automated machine)	ECDs-Modern equipment	ECD-Stakeholders Perspectives (Logistics Providers)	ECD_Stakeholders (Existence of Importers and Exporters)	ECDs operators.	ECDs-Infrastructure (Transport Networks)	ECD Stakeholders (Accommodated with storage capacity).	ECDs-Stakeholders (Efficient and speedy ICT system)	CR- ECDs elimination of the unbalancing EC	CR- (ECDs) encourages accurately tracking EC movement)	CR- (ECDs time savings and efficiency of EC)
31	3	3	3	3	3	3	2	2	2	3	3	2
32	3	3	4	4	5	2	5	5	4	4	4	4
33	4	5	4	5	5	4	3	1	2	3	3	4
34	4	5	3	2	2	2	4	3	4	4	4	4
35	3	3	3	5	3	4	4	4	4	4	5	4
36	4	4	4	4	4	4	2	1	3	3	4	1
37	5	4	4	4	4	4	1	4	3	5	5	5
38	4	4	4	3	5	4	3	4	4	5	4	5
39	2	4	2	4	3	4	2	2	4	4	2	4
40	4	5	5	5	4	4	3	4	3	4	4	4
41	3	3	3	2	1	1	3	3	3	2	2	2
42	3	3	3	4	4	4	4	4	3	4	4	2
43	5	5	5	4	4	4	4	4	4	4	5	5
44	5	5	4	4	5	5	4	5	5	4	5	5
45	3	4	2	4	4	4	2	3	3	2	2	4
46	4	4	4	4	4	4	2	2	2	4	2	2
47	3	3	2	3	3	3	3	4	3	3	3	3
48	1	1	1	3	2	2	3	3	2	2	3	3
49	4	4	3	5	5	4	3	4	4	4	4	5
50	3	5	3	5	4	5	5	4	4	3	5	5
51	4	4	3	4	4	4	2	3	3	3	3	3
52	3	3	3	3	3	3	3	3	3	3	3	3
53	5	1	1	3	2	1	2	2	2	3	4	2
54	4	3	4	5	4	4	4	3	3	3	4	4
55	5	5	5	5	4	5	5	5	5	5	5	5
56	5	5	5	5	5	5	5	5	5	5	5	5
57	4	4	5	4	4	4	5	4	5	5	4	5
58	3	2	4	4	4	4	4	2	4	4	4	4
59	4	4	3	2	4	3	2	2	2	3	3	4
60	5	5	5	4	4	4	5	4	4	4	5	4
61	4	4	4	4	4	4	4	4	4	4	4	4
62	4	4	4	4	5	5	5	4	4	4	4	5
63	4	3	2	4	4	4	3	3	3	3	4	3
64	4	4	4	4	4	4	4	4	4	4	4	4
65	4	4	4	4	4	4	4	4	4	4	4	4
66	4	4	4	5	5	5	5	5	5	5	5	5
67	4	5	4	5	5	5	4		4	5	5	5
68	4	4	4	4	4	4	4	3	4	4	4	4
69	5	5	5	4	4	4	4	3	4	5	4	5
70	5	5	5	4	4	5	3	3	4	4	5	4
71	5	5	5	4	5	5	4	5	4	5	5	5
72	4	3	3	3	3	4	4	3	3	3	4	4
73	2	2	2	2	2	1	3	5	5	2	2	5
74	5	5	5	3	5	3	3	3	3	4	5	5
75	5	5	5	4	4	4	5	4	4	5	5	4
76	4	3	4	5	5	5	5	5	5	3	5	5
77	4	4	4	4	5	5	4	4	2	4	4	4

Innovators or Risk-Avoiders? The Role of Female Executives in Enterprise Innovation in China

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ABSTRACT

The author examines the relationship between female executives and enterprise innovation in Chinese A-share listed companies. **The subject** of the study is the impact of female executive representation on research and development (R&D) investment and innovation output in firms. **The purpose** of the research is to determine whether female executives inhibit innovation performance and to explore the mediating role of R&D investment while also assessing the variation of effects between state-owned and non-state-owned enterprises. **The relevance** lies in the growing international interest in understanding how gender diversity in top management affects firm-level strategic outcomes, especially in emerging markets with distinct institutional and cultural contexts. **The scientific novelty** lies in the empirical identification of the mechanism through which female executives affect innovation, using a panel dataset of 3,920 Chinese listed companies over the period 2012 to 2021. As part of the study, the author used **the methods** of two-way fixed effects, mediation analysis to assess indirect effects through R&D investment, and heterogeneity analysis to compare state- versus non-state-owned enterprises. Based on the **results**, it was found that female executives are significantly associated with reduced innovation output, primarily due to lower R&D investment. **The author concluded** that gender-based differences in risk-taking behavior influence innovation outcomes and that these effects may also be shaped by institutional settings and ownership structures.

Keywords: female executives; gender diversity; corporate leadership; enterprise innovation; R&D investment; social roles; China

Новаторы или стремящиеся избежать риск? Роль женщин-руководителей в инновационной деятельности предприятия в Китае

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АННОТАЦИЯ

Автор исследует взаимосвязь между работой женщин-руководителей и корпоративными инновациями в китайских компаниях, акции которых А-класса котируются на фондовых биржах. **Предметом** исследования является влияние представительства женщин-руководителей на инвестиции в исследования и разработки (НИОКР) и выпуск инновационной продукции в компаниях. **Цель исследования** — выяснить, сдерживают ли женщины-руководители инновационную деятельность, и изучить опосредующую роль инвестиций в НИОКР, а также оценить различия в эффекте между государственными и негосударственными предприятиями. **Актуальность** заключается в растущем международном интересе к пониманию того, как гендерное разнообразие в высшем руководстве влияет на стратегические результаты на уровне фирм, особенно на развивающихся рынках с различным институциональным и культурным контекстом. **Научная новизна** состоит

в эмпирическом выявлении механизма, с помощью которого женщины-руководители влияют на инновации, с использованием панельного набора данных из 3920 китайских компаний, зарегистрированных на бирже, за период 2012–2021 гг. В рамках исследования автор использовал **методы** двухсторонних фиксированных эффектов, опосредованного анализа для оценки косвенных эффектов от инвестиций в НИОКР и анализа неоднородности для сравнения государственных и негосударственных предприятий. **Результаты** исследования показали существенную связь между представительством женщин-руководителей и сокращением инновационного выпуска, в первую очередь из-за более низких инвестиций в НИОКР. **Автор пришел к выводу**, что гендерные различия в поведении, связанном с принятием риска, влияют на результаты инноваций и что эти эффекты также могут быть обусловлены институциональными особенностями и структурами собственности.

Ключевые слова: женщины-руководители; гендерное разнообразие; корпоративное лидерство; корпоративные инновации; инвестиции в НИОКР; социальные роли; Китай

Introduction

Over the past few decades, the impact of gender diversity among top executives on corporate decision-making and performance has emerged as a significant topic in corporate governance research. A wealth of studies has demonstrated that female executives often exhibit stronger risk aversion in decision-making processes, a characteristic that has been empirically validated in various fields. For instance, research shows that female executives tend to limit corporate risk-taking [1], which, while reducing financial risk, simultaneously enhances corporate performance [2]. Moreover, female executives are more compliance-focused on earnings management, demonstrating higher transparency and lower tendencies for accounting manipulation [3]. In the realm of corporate social responsibility, female executives generally exhibit a stronger commitment to social responsibility, driving companies to engage more deeply in socially responsible activities [4]. These findings highlight the distinct influence of female executives on multiple dimensions of managerial decision-making. However, despite extensive research on the roles of female executives in risk management, financial decisions, and social responsibility, there is still a notable gap in understanding the relationship between female executives and enterprise innovation. To explore this relationship more effectively, it is essential to situate the analysis within a context where both innovation and executive gender dynamics are undergoing rapid institutional evolution.

China provides a particularly relevant empirical setting for this study. As one of the fastest-growing economies and a leading force in global innovation output, China has witnessed substantial increases in research and development (R&D) expenditure, patent filings, and high-tech entrepreneurship in the past two decades. The Chinese government has launched multiple policy initiatives — such as the National Medium- and Long-Term Science and Technology Development Plan and the Made in China 2025 strategy — that prioritize technological self-reliance and innovation-led growth. Meanwhile, China has also promoted gender equity in leadership roles through state-level advocacy and regulatory guidance, yet female representation in senior executive positions remains relatively limited. These conditions present a valuable opportunity to examine how the behavioral tendencies of female executives, particularly their risk preferences, influence innovation in a rapidly developing institutional and economic environment. Furthermore, the coexistence of state-owned and non-state-owned enterprises within China's corporate ecosystem allows for rich heterogeneity analyses under varying governance and resource dependence conditions.

Enterprise innovation is a key driver of long-term competitiveness and sustainability for firms [5]. However, innovation is inherently risky, with uncertain returns, and often does not yield immediate economic benefits, potentially negatively impacting short-term performance [6]. Existing research suggests that female executives, given their more conservative approach to risk, may be less inclined to endorse high-uncertainty projects, particularly those that could affect short-term financial outcomes and their own professional reputation [7]. As women remain underrepresented in top management, they face greater pressures in their careers, leading them to avoid decisions that could potentially harm their professional standing [8]. Furthermore, female executives, given their heightened focus on corporate

stability and compliance, may adopt more cautious strategies when it comes to investment decisions [9], which could reduce the allocation of resources to high-risk innovation projects, thereby suppressing enterprise innovation activities.

To verify these hypotheses, this study introduces R&D investment as a mediating factor and investigates the pathways through which female executives influence enterprise innovation. I hypothesize that female executives reduce enterprise innovation by limiting R&D investment. Additionally, the study examines how this effect varies across different ownership structures, with particular attention to state-owned enterprises (SOEs) versus non-state-owned enterprises (non-SOEs). Previous studies suggest that SOEs face more intense political and social pressures, and their innovation motivations may differ from those of market-oriented firms [10]. Based on this, I propose the following research questions: (1) Do female executives suppress enterprise innovation? (2) Is R&D investment the mediating factor through which female executives negatively impact enterprise innovation? (3) Is the suppressive effect of female executives on innovation more pronounced in non-SOEs?

This study utilizes data from China's A-share listed firms from 2011 to 2021 to empirically analyze the impact of female executives on R&D investment and enterprise innovation. First, I use regression analysis to examine the direct relationship between female executives and enterprise innovation (measured by the number of patent applications). Next, I introduce R&D investment as a mediating variable to explore how female executives indirectly influence corporate innovation through their effect on R&D allocation. Finally, I divide firms into SOEs and non-SOEs to investigate the varying effects of female executives on R&D investment and innovation in different ownership structures. The results indicate that female executives significantly inhibit enterprise innovation, and this effect is primarily achieved through the suppression of R&D investment. Moreover, the suppressive effect of female executives on innovation is more pronounced in non-SOEs. These findings support the theoretical perspectives of social role theory and resource dependence theory proposed in this study.

This paper makes two key contributions to both theory and practice. First, from the perspective of social role theory, the study reveals the conservative tendencies of female executives in innovation decisions, addressing the research gap concerning the impact of female executives on enterprise innovation. Although extensive literature has examined the effects of female executives on risk-taking, corporate performance, earnings management, and CSR [1–3], there is relatively little research on how female executives indirectly reduce innovation by suppressing R&D investment. This study not only uncovers this mechanism but also shows that the suppressive effect of female executives on innovation is more significant in non-SOEs, enriching our understanding of the relationship between ownership structure and top management behavior. Second, by introducing resource dependence theory, this research elucidates how female executives play a critical role in resource allocation and investment decisions. Given that R&D investment is a major driver of innovation, the conservative investment strategies of female executives restrict R&D funding, leading to a reduction in innovation activities. This finding extends the application of resource dependence theory to the innovation domain, offering new insights into how firms balance resource allocation between short-term performance and long-term innovation.

In the sections that follow, this paper will first review the relevant literature and present the hypotheses. Next, I describe the data and methodology. Then, I report the empirical results. Finally, I conclude with a discussion of the findings, highlighting both theoretical and practical implications.

Theoretical foundations and hypothesis development
Social role theory

Social role theory posits that societal expectations and norms regarding gender lead to differences in behavior between men and women in the workplace [11]. The theory suggests that traditional gender roles often portray men as more confident, adventurous, and assertive, while women are expected to exhibit traits such as greater focus, collaboration, and an emphasis on risk management [12]. These socially constructed roles shape individual behaviors in professional environments and influence decision-making processes within organizations. Specifically, research has shown that female executives tend to exhibit higher lev-

els of risk aversion and adopt a more cautious approach when faced with high-risk decisions [11–12].

Innovation, by nature, is closely tied to high levels of uncertainty and the potential for failure, as it often involves significant financial commitments with unpredictable outcomes [13]. This inherent risk of innovation may conflict with societal expectations placed on women, which prioritize organizational stability and safety [14]. Consequently, female executives may feel a heightened sense of responsibility to protect the company from the financial and performance risks associated with innovation failure. This increased sense of responsibility could lead female leaders to adopt a more conservative stance in their decision-making, particularly when allocating resources to risky or uncertain projects [15]. Moreover, female executives may face additional scrutiny and expectations from external stakeholders, such as shareholders and investors, who may exert greater pressure on them to avoid risk in innovation-related decisions [16]. Such external pressures may reinforce their socially influenced risk-averse tendencies.

Therefore, social role theory provides a critical framework for understanding how societal expectations and norms regarding gender influence the behavior of female executives, particularly in the context of risky innovation decisions. This perspective highlights the constraints that these expectations place on female decision-makers.

Resource dependence theory

Resource dependence theory, introduced by Jeffrey Pfeffer and Gerald Salancik, posits that organizations are not fully autonomous entities but are instead reliant on the acquisition of critical resources from their external environment [17]. This dependence on external resources, such as capital, technology, raw materials, talent, and market access, is essential for the survival and development of any organization [18]. Since companies cannot fully generate all the resources they need internally, they must engage in exchange relationships with other organizations or individuals like suppliers, customers, governments, and investors. These relationships play a pivotal role in shaping organizational decisions, including strategic choices that affect the firm's direction. The theory emphasizes that access to external

resources impacts not only the firm's day-to-day operations but also its long-term competitiveness and strategic decision-making [19].

The core logic of resource dependence theory is that firms must manage their relationships with external resource providers to secure and maintain control over these vital inputs [17, 19]. A company's ability to obtain and control resources directly affects its survival and growth potential, influencing its competitive advantage and its capacity to innovate. Firms facing resource scarcity may find themselves in a vulnerable, reactive position, while those with abundant resources are more capable of making bold, strategic investments, such as in innovation or technological advancement. To mitigate dependency risks, firms typically adopt strategies such as diversifying their resource sources, thus avoiding over-reliance on a single provider, or integrating resource providers through acquisitions or vertical integration to exert greater control over essential inputs [20]. Additionally, firms may form long-term partnerships with key stakeholders, solidifying their access to critical resources through contracts, equity investments, or joint ventures [21].

Hypothesis development
Direct effect hypothesis: Female executives and enterprise innovation

Social role theory suggests that gender roles and societal expectations shape the behaviors and decision-making tendencies of individuals, particularly in professional settings [22]. According to this theory, traditional gender roles often portray men as more risk-taking, assertive, and innovation-driven, while women are expected to exhibit greater caution, cooperation, and risk aversion [23]. These socially constructed expectations can influence how female executives approach organizational decisions, particularly those involving high levels of uncertainty, such as innovation [24].

Additionally, social role theory implies that female executives may exhibit behaviors aligned with societal expectations of risk aversion and caution [25]. Innovation, by nature, involves high uncertainty and the potential for failure, as it often requires significant resource commitment without guaranteed success [26]. Given this, female executives may prioritize organizational stability and security over pursuing aggressive innovation strategies, thereby reducing corporate

innovation efforts. Empirical studies support this notion, showing that women in leadership positions tend to adopt more conservative approaches when faced with high-risk decisions, such as those related to innovation [27]. Therefore, based on social role theory and existing literature, I propose:

H1: Firms with female executives are more likely to reduce enterprise innovation.

Mediating effect hypothesis: Female executives, R&D investment and enterprise innovation

R&D investment is one of the key drivers of innovation, as it directly contributes to the generation of new products, processes, and technologies [28]. However, R&D investment also carries significant risk due to its uncertain outcomes and long-term nature [29]. Given the societal expectations that female executives should focus on stability and risk minimization [30], they may be more inclined to reduce R&D expenditures as a means of avoiding risky investments that could jeopardize the firm's financial stability. Prior studies have shown that female leaders often exhibit higher levels of risk aversion, leading to more conservative financial strategies [31]. Thus, I propose:

H2: All else being equal, female executives are more likely to reduce R&D investment.

Building on the previous hypotheses, R&D investment plays a critical mediating role in the innovation process, as firms that allocate fewer resources to R&D tend to produce fewer innovative outcomes [32]. If female executives reduce R&D expenditures due to their risk-averse behavior, this reduction in R&D investment is likely to lead to a corresponding decrease in corporate innovation output. Therefore, I posit that the reduction in R&D investment serves as a mediating mechanism through which female executives' risk aversion impacts corporate innovation. This mediating effect is consistent with the resource allocation view, which holds that decreased R&D investment limits a firm's ability to innovate [33]. Accordingly, I propose:

H3: All else being equal, female executives reduce enterprise innovation output by decreasing R&D investment, with R&D investment serving as a mediator in the relationship between female executives and enterprise innovation.

Heterogeneous effect hypothesis: State-owned enterprises vs. non-state-owned enterprises

Resource dependence theory posits that firms rely on external resources for their survival and growth, and their strategic decisions are influenced by the expectations and pressures from external resource providers, such as shareholders, investors, and banks [34]. These external parties hold significant sway in shaping a firm's decisions, especially those involving high-risk initiatives like innovation [35]. For female executives, the pressure from external resource providers can be even greater due to gender stereotypes that cast women as more risk-averse and focused on stability [21]. Stakeholders may expect female executives to prioritize risk minimization and short-term financial performance over long-term innovation strategies, intensifying their tendency toward conservative decision-making. This pressure is especially pronounced in firms that are heavily dependent on external funding and resources, such as non-state-owned enterprises (SOEs), where external stakeholders exert greater scrutiny on female leaders to mitigate innovation-related risks [36].

Innovation inherently involves substantial resource commitments and high uncertainty. In non-SOEs, which rely heavily on external capital and market support, innovation decisions are more closely monitored by external resource providers [37]. Female executives in these firms may respond to heightened external pressure by curbing innovation investments to avoid failure and preserve stakeholder confidence. This behavior aligns with the conservative decision-making tendencies traditionally associated with women in leadership roles. In contrast, SOEs often have more secure access to government-backed resources, reducing their dependence on market-driven external capital [38]. As a result, female executives in SOEs face less external pressure and are more likely to engage in innovation without the fear of external stakeholder pushback. This leads to a weaker inhibitory effect of female executives on innovation in state-owned firms. Therefore, I propose:

H4: Compared to state-owned enterprises, female executives have a stronger inhibitory effect on enterprise innovation in non-state-owned enterprises.

Methods
Sample and data

This study focuses on Chinese A-share listed companies, which constitute the largest and most actively traded segment of China's capital markets. Listed on the Shanghai and Shenzhen stock exchanges, these firms are subject to rigorous regulatory oversight from the China Securities Regulatory Commission (CSRC), including stringent requirements for information disclosure, financial auditing, and corporate governance. Spanning a broad array of industries — such as manufacturing, technology, healthcare, and services — A-share companies are widely regarded as representative of the formal and innovation-driven sector of the Chinese economy.

Compared to other types of firms, such as B-share companies (which are denominated in foreign currencies and primarily serve foreign investors) or unlisted private enterprises, A-share firms operate under greater capital market scrutiny and bear higher performance expectations from public shareholders. These firms typically face stronger innovation incentives, particularly in high-tech industries, where R&D investment is closely linked to valuation and market positioning. Accordingly, A-share companies provide an ideal context to examine how top executives — especially female leaders — shape strategic innovation decisions under institutional and market pressures.

Based on this rationale, I construct a comprehensive dataset comprising A-share listed firms from 2012 to 2021. Executive and financial data are obtained from the China Stock Market & Accounting Research (CSMAR) database, while innovation-related indicators are sourced from the China Research Data Services Platform (CNRDS) database. To ensure the quality and reliability of the data, we apply several preprocessing steps: financial firms are excluded due to their distinctive regulatory frameworks; «ST» firms flagged for financial distress by the CSRC are removed; and companies with missing core variables are eliminated. I also winsorize all continuous variables at the 1st and 99th percentiles to mitigate the influence of outliers.

Variable measurement and estimation techniques

In this study, the dependent variable, enterprise innovation (EI), is operationalized based on the framework established by Yuan and Wen. Specifically, EI is measured through the total number of invention patents, utility models, and design patents filed by the firm, with a log transformation with a "+1" applied to enhance the normality of the distribution. This comprehensive approach captures a broad spectrum of innovation activities within the firm, reflecting not only the firm's output of novel ideas but also its ability to translate these ideas into formal intellectual property. By including invention patents, utility models, and design patents, I encompass various dimensions of innovation, which collectively represent the firm's inventive capability.

Additionally, to ensure the robustness of our findings, I employ an alternative measurement of EI (EI-A) based on the total number of patents that have been ultimately authorized, again applying a log transformation with a "+1" adjustment to account for zero counts. This secondary measure serves as a verification check, as it directly reflects the successful translation of innovative efforts into protected intellectual property, thereby providing a more conservative estimate of the firm's innovative performance. The use of both the total number of filed patents and the number of authorized patents strengthens the validity of our analysis and offers a nuanced understanding of the firm's innovation dynamics.

The independent variable in this study is female executives, which serves as a critical indicator of the female executive level. Specifically, this variable is operationalized as the percentage of female executives relative to the total number of executives in the senior management team. This measure provides insight into the extent to which women are represented in leadership roles, reflecting both the organizational commitment to gender diversity and the potential influence of female executives on strategic decision-making processes.

The mediating variable in this study is R&D investment, quantified by the ratio of a firm's R&D expenditure to its total assets. This measure reflects the extent to which a company allocates its financial resources toward R&D activities relative to its overall asset base, providing insight into its commitment to innovation. This operationalization is grounded in the work of Pu and Zukafli (2024) [5], which underscores the significance of R&D investment as a critical driver of corporate

innovation outcomes. By analyzing the proportion of R&D expenditure to total assets, I can effectively assess how resource allocation decisions influence a firm's innovation capabilities and, consequently, how female executives may impact these decisions. This approach enables us to explore the potential mediating effects of R&D investment on the relationship between the presence of female executives and firm innovation outcomes.

Moreover, I include several control variables to account for factors that may influence firm innovation outcomes. Firm Size (Size) is measured by the natural logarithm of total assets, which provides a standard metric for comparing companies of different scales. Firm Age (FirmAge) is quantified as the natural logarithm of the number of years since the firm's establishment, plus one, allowing us to capture the effect of organizational experience on innovation. Return on Assets (ROA) is calculated by dividing the book value of net income by total assets, serving as an indicator of a firm's profitability and operational efficiency. Financial Leverage (Lev) is measured by the ratio of total debts to total assets, reflecting the extent to which a firm relies on borrowed funds to finance its operations. Additionally, Board Size (Board) is assessed through the natural logarithm of the total number of directors on the firm's board, as a larger board may bring diverse perspectives that influence strategic decision-making. Finally, Ownership Concentration (TOP1) is represented by the percentage of shares owned by the largest shareholder, providing insights into the governance structure and potential influence over firm decisions. Collectively, these control variables allow for a more nuanced analysis of the relationship between female executives and enterprise innovation.

To test hypothesis H1 to H4, I construct the following empirical models:

$$EI_{i,t} = \alpha_0 + \alpha_1 Female_{i,t} + \alpha_2 Size_{i,t} + \alpha_3 FirmAge_{i,t} + \alpha_4 Lev_{i,t} + \\ + \alpha_5 ROA_{i,t} + \alpha_6 Board_{i,t} + \alpha_7 TOP1_{i,t} + Year + Firm + \varepsilon, \tag{1}$$

$$RD_{i,t} = \alpha_0 + \alpha_1 Fele_{i,t} + \alpha_2 Size_{i,t} + \alpha_3 FirmAge_{i,t} + \alpha_4 Lev_{i,t} + \\ + \alpha_5 ROA_{i,t} + \alpha_6 Board_{i,t} + \alpha_7 TOP1_{i,t} + Year + Firm + \varepsilon, \tag{2}$$

$$EI_{i,t} = \alpha_0 + \alpha_1 Female_{i,t} + \alpha_2 RD_{i,t} + \alpha_3 Size_{i,t} + \alpha_4 FirmAge_{i,t} + \\ + \alpha_5 Lev_{i,t} + \alpha_6 ROA_{i,t} + \alpha_7 Board_{i,t} + \alpha_8 TOP1_{i,t} + Year + Firm + \varepsilon. \tag{3}$$

In this study, Equation (1) is used to test the direct effect and the heterogeneity effect. Building on Equation (1), Equations (2) and (3) represent the remaining two steps of the three-step mediation test, aimed at examining the mediating role of R&D investment.

The presence of a mediation effect is verified by observing the change in the coefficient and significance of α_1, which indicates whether R&D investment acts as a mediator in the relationship being tested.

Where α_0 denotes the intercept, and $\alpha_1 - \alpha_8$ are the coefficients to be estimated. This study added dummy variables that control for year and firm fixed effects (Year and Firm); ε is the error term; i denotes the cross-sectional dimension for firms; and t denotes the time series dimension.

Findings
Descriptive statistics and correlation matrix
Table 1 provides descriptive statistics for the variables used in the study, based on 26,694 observations. Enterprise Innovation (EI) has a mean of 2.649, with a standard deviation of 1.734, ranging from 0 to a maximum of 6.690, indicating variability in firms' innovation output. An alternative measurement of EI (EI-A) has a slightly lower mean of 2.476 and a standard deviation of 1.660, with a minimum of 0 and a maximum of 6.409. The variable Female, representing the percentage of female executives, has an average value of 19.326%, with significant variation across firms

Table 1
Descriptive statistics

Variable	Obs	Mean	Std. dev.	Min	Max
EI	26,694	2.649	1.734	0.000	6.690
EI-A	26,694	2.476	1.660	0.000	6.409
Female	26,694	19.326	11.408	0.000	80.000
RD	26,694	0.020	0.020	0.000	0.101
Size	26,694	22.274	1.294	19.814	26.153
FirmAge	26,694	2.922	0.319	1.609	3.497
Lev	26,694	0.422	0.203	0.050	0.893
ROA	26,694	0.041	0.063	−0.239	0.222
Board	26,694	2.123	0.197	1.609	2.708
TOP1	26,694	34.245	14.820	8.630	74.180

Source: calculated by authors.

(standard deviation of 11.408), ranging from 0 to 80%.

R&D investment (RD) has a mean of 0.020, with a relatively low standard deviation of 0.020, and values ranging from 0 to 0.101, indicating that firms on average allocate about 2% of their resources to R&D.

In terms of control variables, Firm size (Size) shows a mean logarithm of total assets of 22.274 with a standard deviation of 1.294, while firm age (FirmAge) averages 2.922, with a relatively small variation (standard deviation of 0.319). Leverage (Lev) averages 0.422, suggesting that, on average, firms finance 42.2% of their assets through debt, with a standard deviation of 0.203. Return on Assets (ROA) has a mean of 0.041, indicating a 4.1% average profitability, but also shows some variability (standard deviation of 0.063), with negative values at the minimum (−0.239) and a maximum of 0.222. Board size (Board) has a mean of 2.123 (logarithm of the number of board members), with values ranging between 1.609 and 2.708. Lastly, the shareholding of the largest shareholder (TOP1) has a mean of 34.245%, with significant dispersion (standard deviation of 14.820), ranging from 8.630% to 74.180%, reflecting varying degrees of ownership concentration. These statistics highlight significant variability across the sample firms in terms of innovation output, R&D investment, corporate governance characteristics, and financial performance.

Table 2 presents the Pearson correlation coefficients between the key variables in the study. The results indicate significant relationships across most variables at the 1% level (***). Enterprise Innovation (EI) is positively correlated with R&D intensity (RD) (0.342***) and firm size (Size) (0.294***), indicating that larger firms and those with higher R&D investments tend to have more innovation output. However, the correlation between EI and the proportion of female executives (Female) is negative (−0.144***), suggesting that firms with a higher percentage of female executives may exhibit lower levels of innovation.

Other notable correlations include a positive relationship between RD and EI (0.342***), indicating that firms with more R&D investment tend to have more innovation. The correlation between firm size and leverage (Lev) is strong (0.519***), showing that larger firms tend to have higher levels of leverage. In contrast, the negative correlation between RD and size (−0.232***) suggests that larger firms may allocate a relatively lower proportion of their resources to R&D.

Moreover, the results show a negative relationship between female executives and firm size (−0.198***), suggesting that larger firms tend to have fewer female executives in leadership positions. Additionally, the proportion of female executives is negatively correlated with leverage (−0.130***), indicating that firms with higher leverage may have fewer female executives. Finally, there are some weaker but significant correlations between variables such as ROA, board size, and ownership concentration (TOP1), although none exhibit multicollinearity issues based on their low correlation values.

Table 2
Pearson correlation

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
EI	Female	RD	Size	FirmAge	Lev	ROA	Board	TOP1
1.000								
−0.144***	1.000							
0.342***	0.030***	1.000						
0.294***	−0.198***	−0.232***	1.000					
−0.043***	0.040***	−0.129***	0.168***	1.000				
0.073***	−0.130***	−0.254***	0.519***	0.163***	1.000			
0.075***	0.024***	0.149***	−0.004	−0.081***	−0.359***	1.000		
0.045***	−0.181***	−0.122***	0.273***	0.053***	0.154***	−0.005	1.000	
−0.006	−0.062***	−0.144***	0.197***	−0.090***	0.059***	0.127***	0.027***	1.000

Source: calculated by authors.
Note: *** $p < 0.01$.

Table 3
Variance inflation factor (VIF) analysis

Variable	VIF	1/VIF
Lev	1.68	0.593834
Size	1.63	0.61521
ROA	1.25	0.802959
RD	1.13	0.88658
Board	1.11	0.90343
TOP1	1.10	0.912439
FirmAge	1.07	0.93469
Female	1.07	0.935074
Mean VIF	1.25	

Source: calculated by authors.

Table 3 shows the variance inflation factor (VIF) analysis to check for multicollinearity among the independent variables. The VIF values for all variables are well below the commonly accepted threshold of 10, indicating no severe multicollinearity concerns in the model. The mean VIF is 1.25, suggesting that multicollinearity is not an issue in this dataset.

The highest VIF is for leverage (Lev) at 1.68, followed by firm size (1.63). These values are still low, showing that the variance of each predictor is not inflated significantly due to the presence of other variables. The lowest VIF is for female executives (Female) and firm age (FirmAge) at 1.07, further supporting that multicollinearity is not problematic in this analysis. In conclusion, the Pearson correlation analysis indicates significant relationships between key variables, while the VIF analysis confirms that multicollinearity does not affect the robustness of the regression results.

Baseline results

The baseline regression results provide a comprehensive understanding of the factors influencing EI. In column (1) of *Table 4*, the key explanatory variable, Female, is negatively correlated with EI at a high significance level ($\alpha_1 = -0.022$, $p < 0.01$). This negative relationship persists across all specifications, even after including firm and year fixed effects in columns (2) and (4). Moreover, the introduction of additional control variables in columns (3) and (4) reveals the stability of this negative association, albeit with varying magnitudes. These findings suggest

Table 4
Baseline regression results

Variable	(1)	(2)	(3)	(4)
	EI	EI	EI	EI
Female	−0.022***	−0.006***	−0.015***	−0.005***
	(−10.827)	(−3.891)	(−7.316)	(−3.158)
Size			0.489***	0.486***
			(19.904)	(15.820)
FirmAge			−0.481***	−0.135
			(−6.526)	(−0.745)
Lev			−0.703***	−0.261***
			(−4.974)	(−2.706)
ROA			1.462***	0.024
			(5.239)	(0.166)
Board			−0.449***	0.114
			(−3.629)	(1.417)
TOP1			−0.011***	0.001
			(−6.340)	(0.678)
Cons	3.072***	2.778***	−4.988***	−7.861***
	(61.590)	(92.936)	(−9.499)	(−9.199)
Year FE	No	Yes	No	Yes
Firm FE	No	Yes	No	Yes
N	26694	26694	26694	26694
adj. R 2	0.021	0.762	0.121	0.772

Source: Calculated by authors.

Note: *** $p < 0.01$. The t-statistics (in brackets) are calculated from standard errors adjusted for clustering at the firm level.

a consistent pattern: firms with higher proportions of female executives tend to exhibit lower levels of EI, a result that calls for further exploration into potential underlying causes.

The negative impact of female executives on EI may be linked to several factors. First, it is possible that gender biases or structural barriers within firms prevent female leaders from fully contributing to innovation strategies [39]. Another plausible explanation is that female executives may adopt more risk-averse management styles, leading to a reduction in risk-taking behaviors [40], which are often crucial for driving EI. Prior studies have highlighted that women in leadership positions may focus more on stability and long-term sustainability rather than aggressive innovation strategies [30, 31, 40]. This conservative approach may, in turn, result in lower EI, especially in industries where bold, high-risk innovation is necessary for competitive advantage.

The control variables included in the regression models provide further insights into the determinants of EI. Size consistently shows a positive and highly significant relationship with EI, indicating that larger firms tend to innovate more, possibly due to their access to more resources and economies of scale. In contrast, Lev negatively impacts EI, suggesting that high debt levels impose financial constraints, limiting firms' ability to allocate resources to innovation. FirmAge, while significant in column (3), becomes insignificant in the fixed effects model, implying that the age-related decline in innovation may be context-dependent. Similarly, ROA has a strong positive effect on EI in the unrestricted model but loses significance when firm-specific factors are controlled. These findings largely align with previous research, such as Hadlock and Pierce (2010) [41] and Hoegl et al. (2008) [42], reinforcing the idea that financial constraints, firm size, and profitability play critical roles in shaping a firm's innovation capacity. The mixed results for other control variables, such as Board and TOP1, reflect

the nuanced and sometimes context-specific nature of these factors' influence on EI.

Robustness check

This section offers further support for the main findings by employing various alternative specifications and adjustments. Each robustness test is carefully designed to ensure the consistency and reliability of the results, addressing potential concerns related to variable selection, sample periods, and standard error clustering.

First, the dependent variable is replaced with enterprise innovation adjusted (EI-A) in column (1). This adjustment is made to assess whether alternative measures of innovation affect the core findings. The rationale behind replacing EI with EI-A is to account for any potential discrepancies in the definition or measurement of innovation, which could influence the observed relationship between female executives and enterprise innovation. The coefficient for Female remains negative and significant ($\alpha = -0.005$, $p < 0.01$), which is consistent with the baseline results. This finding suggests that regardless of the specific innovation metric used, female executives continue to exhibit a significant dampening effect on innovation, thereby reinforcing the robustness of the original conclusions.

Second, the sample period from 2020 to 2021, which corresponds to the COVID-19 pandemic, is excluded in column (2). This step is necessary because the pandemic may have introduced external shocks that could distort the normal operations and innovation strategies of firms. By removing these outliers, the analysis can focus on more stable periods to ensure that the results are not driven by extraordinary circumstances. The results remain robust, as the coefficient for Female remains significantly negative ($\alpha = -0.005$, $p < 0.01$), demonstrating that the pandemic did not materially affect the relationship between female executives and innovation. This finding highlights the resilience of the results across different time periods, confirming that the impact of female executives on innovation is stable over time.

Third, the clustering of standard errors is adjusted to the industry level in column (3). This adjustment is essential to address potential intra-industry correlations that may bias the standard error estimates. By clustering at the industry level, the model accounts for shared industry-specific factors that might influence innovation across firms in the same sector. The negative coefficient for Female ($\alpha = -0.005$, $p < 0.01$) remains significant, indicating that the results are not sensitive to the level of clustering. This confirms the robustness of the findings even when accounting for potential industry-wide effects.

Fourth, additional fixed effects, including industry, province, and city fixed effects, are incorporated in column (4). This approach controls for unobserved heterogeneity at different geographical and industry levels that may influence firm-level innovation. By accounting for these extra layers of fixed effects, the model further isolates the effect of female executives on innovation from any location-specific or industry-specific influences. The results remain consistent, with Female still exerting a significant negative effect on innovation ($\alpha = -0.004$, $p < 0.01$). This robustness check strengthens the argument that the observed relationship is not confounded by external regional or industry factors.

Fifth, firms with negative financial performance (loss-making firms) are excluded in column (5). Loss-making firms may face significant financial constraints that could hinder their ability to invest in innovation, potentially biasing the results. By removing these firms from the sample, the analysis ensures that the findings are not driven by firms in poor financial health. The coefficient for Female remains significantly negative ($\alpha = -0.005$, $p < 0.01$), further affirming the robustness of the results. This indicates that even when financially troubled firms are excluded, the negative relationship between female executives and innovation persists.

In conclusion, across all robustness checks, the main findings hold steady, demonstrating the consistency and reliability of the relationship between female executives and enterprise innovation. The negative impact of female executives on innovation remains significant in all alternative models, underscoring the robustness of the initial conclusions.

The mediating role of R&D investment

The mediation effect analysis, as presented in *Table 6*, illustrates the mediating role of R&D

Table 5
Robustness check

Variable	(1)	(2)	(3)	(4)	(5)
	EI-A	EI	EI	EI	EI
Female	−0.005***	−0.005***	−0.005***	−0.004***	−0.005***
	(−3.303)	(−2.734)	(−4.177)	(−2.682)	(−3.188)
Size	0.446***	0.471***	0.486***	0.492***	0.485***
	(15.334)	(12.710)	(11.920)	(16.871)	(14.568)
FirmAge	0.020	−0.029	−0.135	−0.033	−0.094
	(0.120)	(−0.138)	(−0.851)	(−0.189)	(−0.490)
Lev	−0.112	−0.088	−0.261**	−0.264***	−0.266**
	(−1.214)	(−0.790)	(−2.450)	(−2.927)	(−2.483)
ROA	−0.373***	0.203	0.024	−0.008	−0.118
	(−2.751)	(1.139)	(0.165)	(−0.052)	(−0.455)
Board	0.079	0.080	0.114	0.103	0.112
	(1.052)	(0.896)	(1.045)	(1.377)	(1.290)
TOP1	0.001	−0.002	0.001	0.001	0.002
	(0.368)	(−1.013)	(0.677)	(0.657)	(0.971)
Cons	−7.573***	−7.772***	−7.861***	−8.286***	−7.937***
	(−9.520)	(−7.525)	(−7.686)	(−10.108)	(−8.556)
Year FE	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes
Industry FE	No	No	No	Yes	No
Province FE	No	No	No	Yes	No
City FE	No	No	No	Yes	No
N	26 150	19 353	26 150	26 149	23 373
adj. R 2	0.791	0.791	0.772	0.775	0.777

Source: Calculated by authors.

Note: *** $p < 0.01$. The t-statistics (in bracket 1, 2, 4 and 5) are calculated from standard errors adjusted for clustering at the firm level, and the t-statistics (in bracket 3) are calculated from standard errors adjusted for clustering at the industry level.

investment (RD) in the relationship between Female and EI through a three-step regression model.

In the first step, regression model (1) reveals a significantly negative coefficient for Female (−0.00461) in relation to EI, indicating that the presence of female executives significantly inhibits innovation ($p < 0.01$). This result aligns with our main findings, suggesting that female executives may adopt more risk-averse strategies or exhibit different management styles that lead to a reduction in innovation efforts.

In the second step, model (2) examines the impact of Female on RD, showing a significantly

negative coefficient of −0.00004 ($p < 0.05$). This suggests that female executives also significantly suppress R&D investment, which is a crucial driver of innovation. Thus, female executives indirectly affect innovation by reducing R&D expenditures.

In the third step, model (3) incorporates the mediating variable, R&D investment, and the results demonstrate a significant positive effect of RD on corporate innovation, with a coefficient of 10.72179 ($p < 0.01$). This finding confirms that R&D investment substantially enhances innovation. While the negative effect of female executives remains significant, with a coefficient of −0.00423 ($p < 0.01$), the magnitude of the effect is smaller

compared to model (1). This reduction suggests that part of the negative impact of female executives on innovation is transmitted through the reduction in R&D investment, indicating a partial mediation effect.

In conclusion, the mediation effect analysis confirms that female executives not only exert a direct negative influence on innovation but also indirectly suppress innovation by reducing R&D investment. The significant positive effect of R&D as a mediator underscores its critical role in this relationship, affirming the existence of a partial mediation effect between female executives and enterprise innovation. These results are consistent with prior academic studies, such as those by Adams and Funk (2011) [43] and Amore and Garofalo (2020) [44], which highlight that female

executives tend to adopt more risk-averse strategies, potentially leading to lower innovation levels due to reduced R&D allocation.

Heterogeneity test

The heterogeneity analysis in *Table 7* compares the impact of female executives on EI across state-owned enterprises (SOEs) and non-state-owned enterprises (non-SOEs).

In column (1), which represents SOEs (SOE = 1), the coefficient for female executives is −0.003, but it is not statistically significant. This suggests that the presence of female executives does not have a significant impact on enterprise innovation within SOEs. One possible explanation is that SOEs, often benefiting from government support and a less competitive environment, may be less

Table 6
Mediating effect

Variable	(1)	(2)	(3)
	EI	RD	EI
Female	−0.00461***	−0.00004**	−0.00423***
	(−3.158)	(−2.252)	(−2.930)
RD			10.72179***
			(8.763)
Size	0.48593***	−0.00225***	0.51009***
	(15.820)	(−6.119)	(16.592)
FirmAge	−0.13520	−0.00148	−0.11930
	(−0.745)	(−0.647)	(−0.668)
Lev	−0.26070***	−0.00060	−0.25423***
	(−2.706)	(−0.526)	(−2.690)
ROA	0.02419	0.00264	−0.00409
	(0.166)	(1.286)	(−0.028)
Board	0.11376	0.00194**	0.09299
	(1.417)	(2.449)	(1.170)
TOP1	0.00124	−0.00002	0.00144
	(0.678)	(−0.768)	(0.806)
Cons	−7.86100***	0.07206***	−8.63364***
	(−9.199)	(7.035)	(−10.170)
Year FE	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
N	26150	26150	26150
adj. R 2	0.772	0.857	0.774

Source: calculated by authors.

Note: ** $p < 0.05$, *** $p < 0.01$. The t-statistics (in brackets) are calculated from standard errors adjusted for clustering at the firm level.

Table 7
Heterogeneity test

Variable	SOE = 1	SOE = 0
	(1)	(2)
	EI	EI
Female	−0.003	−0.004**
	(−1.196)	(−2.489)
Size	0.515***	0.483***
	(8.397)	(13.027)
FirmAge	0.183	−0.007
	(0.579)	(−0.029)
Lev	−0.184	−0.223**
	(−0.899)	(−2.089)
ROA	0.074	−0.177
	(0.247)	(−1.037)
Board	0.116	0.120
	(0.864)	(1.195)
TOP1	−0.005	0.002
	(−1.483)	(1.079)
Cons	−9.682***	−8.027***
	(−5.609)	(−7.631)
Year FE	Yes	Yes
Firm FE	Yes	Yes
N	9356	16 709
adj. R 2	0.826	0.735

Note: ** $p < 0.05$, *** $p < 0.01$. The t-statistics (in brackets) are calculated from standard errors adjusted for clustering at the firm level.

Source: calculated by authors.

influenced by the risk-averse behavior commonly associated with female executives, thereby diluting the impact on innovation.

In contrast, column (2) shows that for non-SOEs (SOE = 0), the coefficient for female executives is −0.004 and is statistically significant ($p < 0.05$). This indicates that female executives have a significantly negative effect on enterprise innovation in non-SOEs. Non-SOEs generally face higher competitive pressures and rely more heavily on innovation for growth and survival, making the risk-averse strategies of female executives more detrimental to innovation outcomes in these firms.

Overall, the heterogeneity analysis suggests that the negative impact of female executives on corporate innovation is more pronounced in non-SOEs, likely due to the greater reliance of these firms on innovation to maintain competi-tiveness, while SOEs appear to be more insulated from this effect.

Discussion

This study finds that the presence of female executives is associated with lower levels of R&D investment and innovation output, especially in non-state-owned enterprises. While our results are consistent with prior literature emphasizing the risk-averse behavior of female leaders [16, 3], it is important to situate these findings within the broader scholarly debate on gender and innovation.

A number of studies suggest that female executives may, under certain conditions, positively contribute to innovation outcomes. For example, Expósito et al. (2021) [27] find that female CEOs in Spanish SMEs are positively associated with innovativeness, especially when organizational cultures

support collaborative leadership. Similarly, Shropshire et al. (2021) [31] argue that although women may exhibit higher risk aversion, this can translate into more deliberate, process-driven innovation practices. These alternative perspectives suggest that the relationship between gender and innovation is not deterministic but context-dependent.

Furthermore, we acknowledge that resistance to innovation is a common behavioral tendency that can affect all employees, regardless of gender or position. Fear of change, loss aversion, and status quo bias are well-documented psychological mechanisms that influence strategic decision-making in high-uncertainty environments. Our study does not claim that women inherently resist innovation but rather posits that social role expectations may amplify risk aversion among female executives, especially in public-facing leadership roles. This interpretation is grounded in social role theory, not biological essentialism.

In addition, a more gender-sensitive interpretation must recognize that women's innovation behavior may be influenced by distinct motivational and structural factors. For instance, studies have shown that women often place greater emphasis on work–life balance, which can shape their strategic priorities in leadership roles [25]. Moreover, women frequently face structural disadvantages in accessing financial resources, market intelligence, and professional networks — factors that are critical for pursuing high-risk innovation projects [4]. These limitations may reduce their observable engagement in R&D-driven innovation, not because of individual-level aversion to innovation, but due to external constraints.

Importantly, the value of cautious decision-making should not be dismissed. Excessive risk-taking can lead to innovation failures or wasted investments, and the conservative strategies adopted by some female executives may reflect rational responses to both institutional expectations and resource constraints [45]. In fact, several studies have found that women entrepreneurs are particularly active in innovation within trade and service sectors, where innovation often takes non-technological forms such as business model redesign or customer experience improvements [27]. These findings suggest that innovation should be assessed not only in terms of R&D intensity but also across diverse industry-specific forms of value creation.

Finally, the complexity of innovation behavior necessitates consideration of multiple influencing factors beyond executive gender. These include workforce skill levels, access to government subsidies, organizational incentives, political and economic uncertainty, and regional development disparities. Although this study controls for many such variables, future research should incorporate them more explicitly to develop a deeper and more contextualized understanding of innovation dynamics.

Conclusion

Utilizing data from publicly listed Chinese firms from 2012 to 2021, this study provides new insights into the relationship between female executives and corporate innovation, with a specific focus on the mediating role of R&D investment. The findings reveal that female executives tend to have a significant negative impact on corporate innovation, both directly and indirectly, by reducing R&D investment. This suggests that the presence of female executives in top management positions may lead to more conservative investments in innovation-driven activities, such as R&D, which in turn constrains the firm's innovation capacity. These results align with prior literature, which indicates that female executives tend to be more risk-averse, often adopting strategies that prioritize stability over high-risk, high-reward initiatives. Given that R&D is widely recognized as a key driver of innovation, this study emphasizes the critical importance of maintaining sufficient R&D investment to sustain long-term innovation efforts, even when firms are led by more risk-averse executives.

Moreover, heterogeneity tests suggest that the negative effect of female executives on innovation is more pronounced in non-state-owned enterprises (non-SOEs), where competitive pressures and the need for innovation are typically higher. In contrast, state-owned enterprises (SOEs) appear to be less affected, possibly due to their relatively monopolistic market positions and reduced reliance on innovation for maintaining competitive advantage.

This study makes several theoretical contributions. First, from the perspective of leadership and innovation, it demonstrates that while female executives contribute to the diversification of

top management teams, they may adopt more conservative approaches to innovation, particularly by curtailing R&D expenditures. This finding adds nuance to the ongoing debate on gender diversity in corporate leadership and its impact on firm performance. Second, by exploring R&D investment as a mediating factor, the study highlights the intricate dynamics between leadership decisions and innovation strategies, offering a more detailed understanding of how leadership characteristics influence corporate innovation.

Our findings have practical implications for corporate leaders and policymakers alike. For firms, particularly those led by female executives, it may be critical to cultivate a balanced approach that encourages risk-taking in innovation while maintaining prudent management practices. For policymakers, fostering an environment that supports R&D investment, especially in non-SOEs, could help mitigate the conservative tendencies of female-led firms and stimulate greater innovation. Additionally, initiatives that encourage female executives to pursue innovation-oriented strategies could further enhance their contribution to corporate growth and competitiveness.

However, this study has certain limitations. First, the sample is restricted to publicly listed Chinese firms, which limits the generalizability of our findings to other institutional or cultural contexts. While our results provide useful insights into the behavioral and structural mechanisms through which female executives may influence corporate innovation, these patterns may be shaped by characteristics specific to the Chinese market. These include the governance structure of Chinese listed firms, state influence on executive appointments, and cultural norms regarding gender roles and managerial behavior. As such, the theoretical implications of our study should be interpreted within the bounds of this national context. Future research could address this limitation by conducting comparative studies across different countries, ownership systems, and cultural settings to assess whether the observed gender-innovation dynamics hold in varied environments. Moreover, future work may examine additional moderating variables — such as internal corporate governance structures, financial constraints, or regional development differences — to further unpack the complexity of this relationship.

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ORIGINAL PAPER

Time-Varying Co-Movements Between Green Bonds, CO₂ Emissions, the Investor Sentiment, and Financial Stress

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ABSTRACT

Green bonds are attracting growing interest as sustainable financial instruments that support the transition to a low-carbon economy by financing environmentally responsible projects. Understanding how these instruments interact with CO_2 emissions and investor sentiment is essential to assess their stability and long-term potential. **The aim** of this study is to explore the dynamic relationships between green bonds and a selection of financial and environmental variables, including US conventional bonds, the WilderHill Clean Energy equity index, and CO_2 emission allowances. Additionally, the study evaluates the impact of investor sentiment and financial stress on green bond performance. **The methods** used include a quantile regression model, which assesses whether the Standard and Poor's (S&P) Green Bond Index can be explained by the aforementioned variables — namely CO_2 emissions, clean energy stocks, investor sentiment (proxied by Google Trends), and financial stress [measured by the Office of Financial Research (OFR) Index]. The analysis covers the period from July 6, 2011, to September 15, 2023. To account for time-varying relationships, a Bayesian time-varying vector autoregressive (BTC–VAR) model is also applied. **The results** show a negative unidirectional effect from CO_2 emissions to the green bond index and a positive unidirectional effect from the clean energy index. However, green bonds appear weakly correlated with the other considered assets. Investor sentiment does not show a significant influence, while financial stress plays a more important role, indicating that green bonds may be perceived as safer assets during periods of uncertainty. **The key conclusion** is that green bonds exhibit selective sensitivity to specific financial and environmental factors. Their relative stability during episodes of financial stress reinforces their position as both sustainable and resilient investment tools. These findings provide useful insights for investors, policymakers, and researchers interested in the evolving dynamics of green finance.

Keywords: green bonds; CO_2 emissions; clean energy; investor sentiment; financial stress; ecology; time-varying VAR; quantile regression

ОРИГИНАЛЬНАЯ СТАТЬЯ

Изменения во времени соотношения между «зелеными» облигациями, выбросами CO₂, настроениями инвесторов и финансовым стрессом

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АННОТАЦИЯ

«Зеленые» облигации привлекают все больший интерес как устойчивые финансовые инструменты, которые поддерживают переход к экономике с низким уровнем выбросов углерода путем финансирования

экологически ответственных проектов. Понимание того, как эти инструменты взаимодействуют с выбросами CO_2 и настроениями инвесторов, имеет важное значение для оценки их стабильности и долгосрочного потенциала. **Целью** данного исследования является изучение динамических взаимосвязей между «зелеными» облигациями и рядом финансовых и экологических переменных, включая обычные облигации США, индекс акций WilderHill Clean Energy и квоты на выбросы CO_2. Кроме того, в исследовании оценивается влияние настроений инвесторов и финансового стресса на эффективность «зеленых» облигаций. **Используемые методы** включают модель квантильной регрессии, которая оценивает, можно ли объяснить индекс «зеленых» облигаций Standard and Poor's (S&P) вышеупомянутыми переменными, а именно выбросами CO_2, акциями чистой энергии, настроениями инвесторов (по данным Google Trends) и финансовым стрессом [(измеренным индексом Управления финансовых исследований (OFR)]. Анализ охватывает период 06.07.2011–15.09.2023 гг. Для учета изменяющихся во времени взаимосвязей также применяется байесовская векторная авторегрессия с изменяющимися во времени параметрами (BTC–VAR). **Результаты** показывают отрицательное однонаправленное влияние выбросов CO_2 на индекс «зеленых» облигаций и положительное однонаправленное влияние индекса чистой энергии. Однако «зеленые» облигации, по-видимому, слабо коррелируют с другими рассматриваемыми активами. Настроения инвесторов не оказывают существенного влияния, в то время как финансовый стресс играет более важную роль, что указывает на то, что «зеленые» облигации могут восприниматься как более безопасные активы в периоды неопределенности. **Основной вывод** заключается в том, что «зеленые» облигации демонстрируют избирательную чувствительность к определенным финансовым и экологическим факторам. Их относительная стабильность во время эпизодов финансового стресса укрепляет их позицию как устойчивых и надежных инвестиционных инструментов. Эти результаты дают полезную информацию инвесторам, политикам и исследователям, интересующимся развивающейся динамикой «зеленых» финансов.
Ключевые слова: «зеленые» облигации; выбросы CO_2; чистая энергия; настроения инвесторов; финансовый стресс; экология; векторная авторегрессия с изменяющимися во времени параметрами; квантильная регрессия

1. Introduction

Climate risk can notably serve as a transmission channel for policy action by influencing public and political opinion, according to R. Willis et al. [1]. As the impact of climate change becomes more severe and apparent, it often yields an increased public awareness and concern about the issue. This growing awareness, coupled with the tangible effects of climate change, can create pressure on policymakers to act and implement appropriate policies to address the challenges posed by climate change.

When the consequences of climate change, such as extreme weather events, rising sea levels, or disruptions in ecosystems, become more pronounced, people are more likely to claim that their governments take steps to mitigate and adapt to these risks. They expect policymakers to develop and implement policies that reduce uncertainty and effectively address climate risks, as claimed by C. Wamsler and J. Bristow [2].

To effectively handle climate change, policies need to be designed to reduce uncertainty by providing clear goals, guidelines, and regulations. This can include setting emissions reduction targets, imple-

menting renewable energy incentives, promoting sustainable practices, and encouraging adaptation measures [the United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol]. Through implementing these policies, governments can help mitigate climate risk and provide a framework for businesses, organizations, and individuals to make informed decisions and push towards a more sustainable future.

Additionally, policies aimed at reducing climate risk often involve promoting research and development of clean technologies, investing in infrastructure that can withstand climate impacts, and facilitating international cooperation to tackle global climate challenges. These measures can help mitigate the risks associated with climate change and enhance societal resilience.

In recent years, both governmental bodies and non-governmental organizations have increasingly acknowledged the danger posed by the release of excessive quantities of greenhouse gases. This has prompted them to initiate significant actions aimed at reducing the impact of these emissions on the environment and the well-being of humanity. Even-

tually, a new approach urging investors to claim environmental difficulties and work to diminish them — known as "the Green finance" — emerged in the financial sector.

It focuses basically on allocating capital towards projects, businesses, and technologies aiming to foster a more sustainable and resilient global financial system.

While there has been some research at the intersection of finance and ecology, the body of literature remains relatively small compared to other interdisciplinary fields. Y. Wang and Q. Zhi [3] asserted that fostering financial support for solar energy is a key avenue for achieving environmental sustainability. Similarly, W. Li and Z. Jia [4] emphasized that environmental finance, or sustainable finance, represents an impactful strategy in mitigating environmental degradation. The consensus is on the fact that sustainable finance, also referred to as green finance, stimulates investments in novel technologies, particularly those related to renewable energy, as highlighted by A. Jones [5]. Notably, previous research has overlooked the correlation between green bonds and other asset classes and considered a proxy for green finance as well as carbon dioxide (CO_2) emissions.

Under these circumstances, green bonds were issued by the European Investment Bank in 2007 and were defined as "a hybrid financial instrument that combines environmental benefits and conventional fixed income instruments to channel funds to environmentally friendly projects," according to S. Hyun et al. [6]. Basically, "Green Bonds are any type of bond instrument where the proceeds or equivalent amount will be exclusively applied to finance or refinance, in part or in full, new and/or existing eligible Green Projects that are aligned with the four core components of the Green Bond Principles" (ICMA, 2021).[1] Green bonds have evolved into a desirable financial investment product that can help maintain the transition to a low-carbon economy.

Recent studies have explored the interaction between green bond issuance, investor response, and environmental policy frameworks. Flammer [7] investigates corporate green bonds' role in signaling environmental commitment, while Tang and Zhang

[8] show that green bond announcements can lead to positive abnormal stock returns. Wang et al. [9] further demonstrate how climate policies influence green bond development and carbon emissions reduction. Mezghani et al. [10] examine the impact of green bonds on extreme spillover effects and hedging across stocks and commodities, highlighting the role of green bonds in mitigating risk and enhancing portfolio diversification during extreme market conditions. These findings reinforce the relevance of studying green bond dynamics under varying environmental and financial conditions.

Behavioral finance theories assume that investors, in their decision-making processes, can be swayed by information and psychological biases, as evidenced by investor sentiment (T. Yao et al. [11]). The impact of investor sentiment extends to influencing the interconnections within green finance markets through two theoretical channels.

The first channel involves limited information. Due to incomplete information, investors are prone to either underreact or overreact in green finance markets (Z. Chen et al. [12]). This tendency contributes to the biased pricing of green assets and the emergence of systemic risk within green finance markets, amplifying the potential for market inefficiencies.

The second channel is linked to the real economy. Concerns surrounding climate change have the potential to influence consumer spending and alter business investment strategies in the real economy. These shifts can, in turn, have a cascading effect on the valuation of green assets, thereby facilitating the transmission of information among green finance markets. Notably, the interplay between investor sentiment and the broader economic landscape creates a dynamic relationship that shapes the functioning and interconnectedness of green finance markets.

In this respect, several empirical studies have attempted to investigate the relationship between green bonds and a few environmental and financial assets, as well as the impact that investors' behavior has on the green bond market. X. [13] and V. Baulkaran [14] reported the interest that investors have in green bonds and discovered that Chinese stock market investors react favorably to news of green bond issuance. [15], who highlighted the strong correlation between investor responses and green bond market performance, equally reinforced this topic. Several researchers have pointed out that people's motivations for making investments fre-

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[1] ICMA stands for International Capital Market Association. See: International Capital Market Association. Green Bond Principles — Voluntary Process Guidelines for Issuing Green Bonds. June 2021. URL: https://www.icmagroup.org/assets/documents/Sustainable-finance/2021-updates/Green-Bond-Principles-June-2021–140621.pdf

quently extend beyond monetary gains and include other aspects such as the impact on society and the environment. X. Zhou and Y. Cui [16] demonstrated that corporate performance and social responsibility to environmental issues have a favorable influence on the growth of the green bond market. Likewise, the analysis performed by O. Zerbib [17] revealed a considerable impact of investors' pro-environmental inclinations on the growth of this market, which was considered as one of the markets with the highest efficiency for reducing future emissions (J. Jin et al. [18]). Furthermore, through inciting investors to participate more effectively, M. Voica et al. [19] clarified how a suitable legal and institutional framework may help countries build up their green bond markets. This reinforces the link between green finance and behavioral finance and highlights the significance of considering not only financial factors but also the behavioral factors that influence individual decision-making when promoting sustainable and environmentally friendly economic activities.

According to [15], there is a correlation between investors' attention, measured using the Google Search Volume Index, and the performance of the green bond market, measured by five green bond market indexes, over the period from 2014 to 2019. The researchers discovered that investors' attention has a significant impact on the return and volatility of the green bond market. Additionally, they found that this relationship varies over time, with stronger effects observed in the short-run compared to the long-run.

A. Elsayed et al. [20] examined the relationship and dynamic interconnectedness between green bonds and financial markets. They accordingly incorporated multiple uncertainty indices. These indices cover financial uncertainty, financial stress, and economic uncertainty. They demonstrated the correlation between the green bonds and the financial stress.

The central objective of this study is not only to examine the causal relationships between green bonds and other related assets — including US conventional bonds, the WilderHill clean energy (WCE) equity index and CO_2 emission allowances price — but also to analyze the effects of investor sentiment and financial stress, as measured through the Google Trends Index and the OFR Financial Stress Index, respectively. The Quantile regression model and Bayesian time-varying vector autoregressive (BTVAR) model have been used to address the connections between multiple time series variables.

Exploring the relationship between green bonds and other eco-friendly market indices holds paramount importance for both portfolio managers and policymakers. Gaining a deeper and better insight into this relationship has the potential to encourage increased investments in cleaner production and foster the development of innovative green financial instruments. In recent years, a substantial body of literature has delved into the interconnections between green bonds and diverse markets, shedding light on the intricate dynamics at play in the realm of sustainable finance.

This research primarily contributes to clarifying how connections between green bonds and several financial instruments evolve throughout quantiles in order to enable investors and policymakers to make more effective choices. Hence, the basic target of this research is to explore the robustness of green bonds in relation to CO_2 emissions, investor sentiment, and financial stress. Furthermore, it implements the Bayesian TVC–VAR to investigate potential shifts and fluctuations in the causal connections across the parameters in discussion. It also highlights the effect of investor sentiment and financial stress on the green bond market.

This study makes three contributions to existing literature. Firstly, compared to prior studies, which mostly emphasize the role of financial development instead of highlighting the effect of green finance on environmental variables, this study presents a pioneering examination of green finance, CO_2 emissions, investor sentiment and financial stress.

Secondly, this study uses the quantile approach that captures the heterogeneous and asymmetric relationship between green finance and CO_2 emissions, investor sentiment and financial stress.

Thirdly, this work corresponds to one of the first studies that use the Bayesian time-varying vector autoregressive (BTC–VAR) model in order to examine the relationship between green finance bonds, CO_2 emissions, investor sentiment and financial stress.

2. Data and methodology
2.1. Data

This research used data covering daily S&P green bond Index, CO_2 Emission index, US Bonds and WCE index prices over a period extending from June the 6th, 2011 to September the 15th, 2023. Data were extracted from the Thomson Reuters DataStream.

Data related to the study of the impact of the investor sentiment and financial stress on the

green bonds were collected from Google Trends (Google Trends) and the Office Financial Research (OFR Financial Stress Index | Office of Financial Research) from June 6th, 2011, to September the 15th, 2023.

2.1.1. Google trends index and financial stress index

The Google Trends Index, also known as Google Trends, refers to a free online tool provided by Google that allows users to explore the popularity and search interest for specific keywords or topics over time. It provides insights into the relative search volume of specific terms and helps users understand trends in search behavior.

The Google Trends Index aggregates and normalizes search data from Google Search, providing a numerical representation of search interest over a selected time period.

The OFR Financial Stress Index (FSI) stands for an indicator developed by the Office of Financial Research (OFR), which is part of the U.S. Department of Treasury. It is designed to measure the level of stress in the financial system through incorporating various market-based indicators and economic data. It takes into consideration factors such as asset price movements, market volatility, credit spreads, and funding conditions so as to assess the overall financial stress experienced in the economy. By monitoring these indicators, the FSI aims to provide early warnings of potential financial instability.

The OFR Financial Stress Index serves as a tool for market participants to monitor the overall health and stability of the financial system. It can help identify periods of growing financial stress and inform policy decisions, aiming at the mitigation of potential risks or imbalances in the financial markets.

Figure 1 illustrates each of the factors' time-trials. We notice that the trends of the green and traditional Treasury bond indices are similar during all the time periods, except for the first trimester of 2018. The WilderHill clean energy index and the CO_2 emission allowance price have a relatively similar motion, distinguished by a substantially stable trend until 2018, when they climbed a rising trend. Moreover, all the mentioned variables crashed during the first quarter of 2020. This sudden bearish peak arose from the COVID-19 crisis and its precarious financial effects on the market, which are reflected by a significant unexpected peak of the OFR Financial stress index during the same period of time.

The Google Trends Index reveals severe bullish peaks during all the presented periods of time. It seems to be excessively random and chaotic to accurately reflect the market sentiment and to evaluate it effectively. The "OFR Financial Stress Index", however, seems more reliable and informative, as its trend accurately captures market sentiment without becoming chaotic, therefore enabling a clear interpretation of the outcomes.

Table 1 depicts some prevalent statistics for all the variables and the descriptive analysis of the data. All daily averages of variables, with the exception of the FSI, are positive, as determined by statistics. The measurement of US Treasury bonds reveals the greatest average. Considering that they have the largest standard deviations among the different stocks, the US Treasury bond index is the second-most risky, closely followed by the WilderHill clean energy index. With regard to the positive and significant values of the skewness, all of the examined time series are skewed to the right.

The graphs demonstrate that the frequency distributions of CO_2 Emissions Index Price are higher than those of other variables, such as the S&P Green Bond Index, the US Treasury Bond Index, and the WCE Index. A distribution is referred to as leptokurtic if it features thick tails, which are indicated by an excess of kurtosis. When the skewness is positive and different from zero for the various variables, the distribution is said to be skewed to the right. For these reasons, in view of the low positive skewness, each graph displays a small divergence to the right.

2.2. Methodology

We adopted the VAR model to examine the causal relationship between the green bonds and the three other parameters as well as the effects of investor sentiment and financial stress on the green bond market. Moreover, the quantile regression method is invested to analyze the predictive ability of the various parameters. In addition, in order to explore the dynamic correlations among the variables, we apply the Bayesian time-varying VAR that allows the coefficients to change over time.

2.2.1. Quantile regression

In a traditional quantile regression, the influence of the independent variable is investigated to examine the impacts of the dependent variables' conditional distribution on the dependent variable itself.
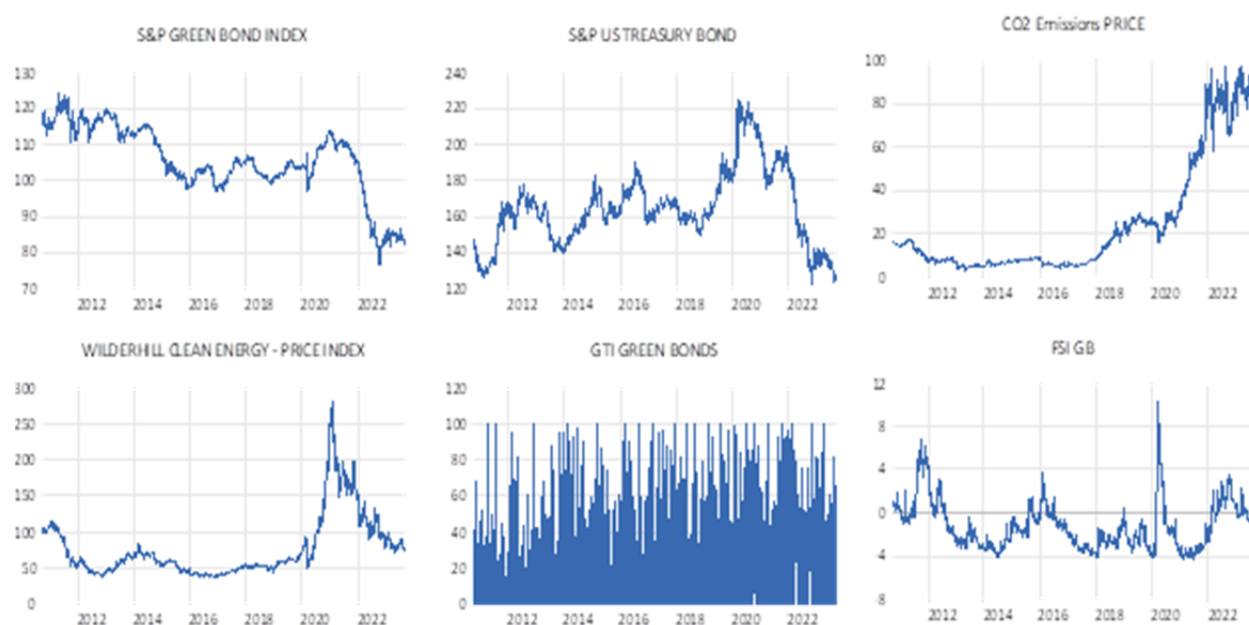
Fig. 1. **Time-paths of the considered variables**

Source: The Thomson Reuters DataStream.

Table 1
Descriptive statistics

Measures	SP_GB	USBOND	WCEI	CO2	GTI	OFR_FSI
Mean	105.3629	164.5726	76.54208	24.23333	19.04885	−1.195171
Maximum	124.3048	224.4338	281.4400	97.58000	100.0000	10.26600
Minimum	76.26968	122.1600	36.53000	2.680000	0.000000	−4.364000
Std. Dev.	9.815400	20.76409	42.91041	26.70824	23.06387	2.226883
Skewness	−0.742488	0.527290	1.968251	1.465266	1.148842	1.285019
Kurtosis	3.298509	3.249986	6.983676	3.714539	3.857872	5.142189

Source: Authors' calculation.
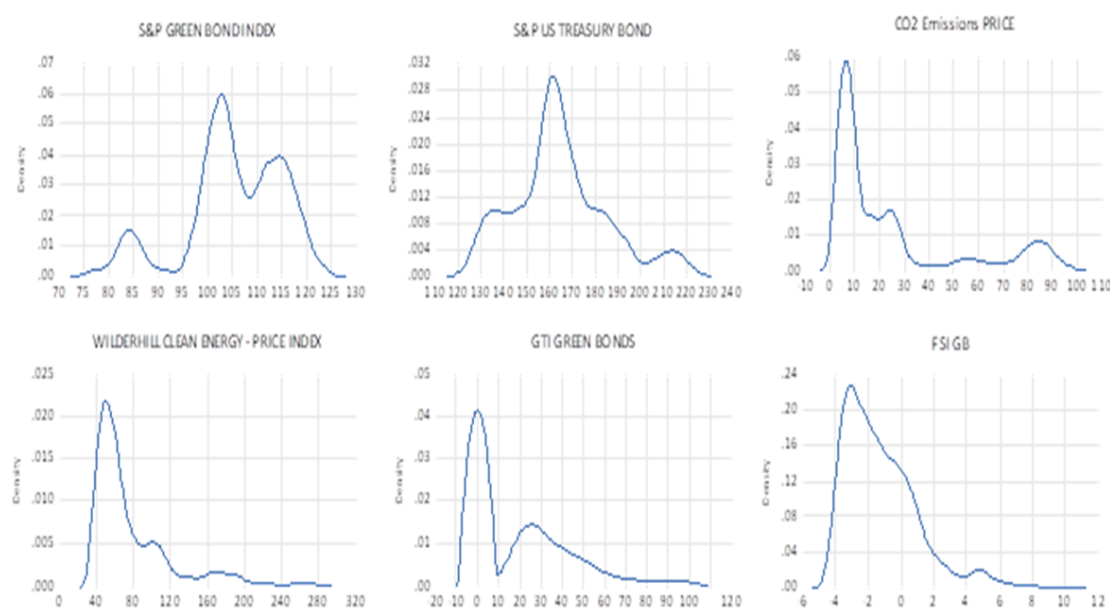
Fig. 2. **The distributive properties of the variables**

Source: Created by the authors.

2.2.2. The Bayesian time-varying VAR (BTVC–VAR)

Bayesian time-varying vector autoregressive (BTC–VAR) models correspond to a statistical framework that is used to analyze multivariate time series data. They extend the traditional Vector Autoregressive (VAR) models by allowing the parameters to vary over time in a Bayesian setting.

In a BTVAR model, the relationships between multiple variables are captured by lagged values of the variables themselves. However, unlike traditional VAR models, where the parameters are assumed to be constant over time, BTC–VAR models introduce time-varying coefficients. This allows for the modeling of changing dynamics and relationships among the variables over different time periods.

The Bayesian approach in BTC–VAR models incorporates prior information about the coefficients and uses Bayesian inference techniques to estimate the parameters. This provides a flexible and robust framework for capturing time-varying patterns and uncertainties in data.

The Bayesian time-varying vector autoregressive models offer outstanding applications in various fields, including economics, finance, and econometrics, where understanding the dynamic relationships between variables and capturing their time-varying nature is crucial for an accurate analysis and forecasting.

The parameter estimates of a Bayesian time-varying vector autoregressive (BTC–VAR) model are presumed to fluctuate throughout intervals of time and are regarded as random variables selected from a given distribution. Furthermore, the Bayesian approach to the model allows the quantification and incorporation of uncertainty in the coefficient estimations. The model incorporates the assumption that there is a linear relationship between each of the different variables and that every parameter in the system is dependent on both their historical values and those of the other variables. The main features of the time-varying VAR coefficient refer to the Bayesian approach, dynamic modeling, Markovian structure, and flexibility.

S. Ahmed and M. Mortaza [21] applied B. Hansen's [22] threshold model to explore the threshold effects on the bivariate inflation-growth correlation. On the other hand, A. Chowdury and R. Ham [23] investigated a bivariate threshold autoregressive (BTVAR) model. They derived the BTVAR model through further elaborating B. Hansen's [22] threshold model,

substituting the dependent and independent variables with vectors of bivariate endogenous variables.

The Bayesian TVC–VAR model can be expressed as

$$y_t = c_t + \sum_{i=1}^{p} A_{it} y_{t-i} + \sum_{j=1}^{q} B_{jt} x_{t-J} + e_t,$$

where y_t denotes the vector of endogenous variables;

X_t indicates the vector of exogenous variables;
C_t represents the vector of constant terms;
A_{it} and B_{jt} stand for the matrices of parameters;
P and q correspond to the number of lags.

3. Results and discussion
3.1. ADF unit root test

In order to analyze the variables' integration order, we applied augmented Dickey-Fuller (ADF) unit root test. The ADF evaluates the stationarity under the alternative hypothesis while assuming the null hypothesis and assessing the existence of unit roots. In both intercept and trend instances, the test was run at the level as well as the first difference.

*Table 3* displays an overview of the ADF unit root test's conclusions.

Table 3 demonstrates that except for the GTI, which is stationary at level, all variables are stationary in the first difference $I(1)$. As a matter of fact, the optimum lag to work with is $d = 1$.

3.2. Quantile regression model

Table 4 and *Figs. 3, 4 and 5* unveil the quantile regression models' results.

The results corroborate that β_1, β_2 and β_3 coefficients are significant for the three models. Thus, S&P Green Bond index is largely affected by the explanatory variables (CO_2 EI, WCEI and USBI) over time. Likewise, the positive coefficients disclose that a rise in the dependent variables' (S&P GBI) conditional quantile is related to an increase in the independent variable. Moreover, the significant δ_2 reflects the impact of FSI on the dependent variable. However, δ_1 is not significant, which implies that the GTI does not have an impact on the dependent variable. As a result, we can assume that the investor sentiment does not affect the green bond market. Yet, green investors tend to be sensitive to risky and stressful financial environment.

In fact, the negative coefficient δ_2 reflects a reverse relationship between the OFR financial stress index and the S&P green bond index. Particularly,

Table 2
Quantile regression models

QR model	Equation	Notation
Price	$QP_{GB,t} = \beta_0 + \beta_1(\tau) P_{1,t} + \beta_{1.0}(\tau) P_{1,t-1} + \beta_2(\tau)P_{2,t} + \beta_{2.0}(\tau) P_{2,t-1} + \beta_3(\tau)P_{3,t} + \beta_{3.0}(\tau)P_{3,t-1} + \mathcal{E}_t$	(1.0)
Investor sentiment	$QP_{GB,t} = \beta_0 + \beta_1(\tau)P_{1,t} + \beta_{1.1}(\tau)P_{1,t-1} + \beta_2(\tau)P_{2,t} + \beta_{2.1}(\tau)P_{2,t-1} + \beta_3(\tau)P_{3,t} + \beta_{3.1}(\tau)P_{3,t-1} + \delta_1(\tau)GTI_t + \delta_{1.1}(\tau) GTI_{t-1} + \mathcal{E}_t$	(1.1)
Financial stress	$QP_{GB,t} = \beta_0 + \beta_1(\tau)P_{1,t} + \beta_{1.2}(\tau)P_{1,t-1} + \beta_2(\tau)P_{2,t} + \beta_{2.2}(\tau) P_{2,t-1} + \beta_3(\tau)P_{3,t} + \beta_{3.2}(\tau)P_{3,t-1} + \delta_2(\tau)FSI_t + \delta_{2.2}(\tau)FSI_{t-1} + \mathcal{E}_t$	(1.2)

Source: Developed by the authors.

where:

$P_{GB,t}$ is the price of S&P Green Bond Index,
$P_{1,t}$ is the price of CO_2 Emission Index WCE Index,
$P_{2,t}$ is the price of WCE Index,
$P_{3,t}$ is the price of UST Bonds Index and

GTI_t is the google trends index
FSI_t is the OFR financial stress index
τ is the quantile coefficient
$\mathcal{E}_t$ is the white noise at time t, $\mathcal{E}_t \sim \mathbb{N}(0,1)$

Table 3
Unit root test results

Variable	Level		First difference		Conclusion
	Intercept	Intercept and trend	Intercept	Intercept and trend	
SPGB	0.9026	0.7747	0.0001	0.0000	I(1)
CO2EI	0.9483	0.6467	0.0000	0.0000	I(1)
USBTI	0.4746	0.8868	0.0001	0.0000	I(1)
WCEI	0.3984	0.5559	0.0000	0.0000	I(1)
FSI	0.0337	0.1327	0.0001	0.0000	I(0)
GTI	0.0000	0.0000	0.0000	0.0000	I(0)

Source: Authors' calculation.

the decrease in the independent variable is associated with an increase in the conditional quantile of the dependent variable. Additionally, the results indicate a negative relationship between the OFR financial stress index and prices in the quantiles of the price distribution. This would suggest that high levels of financial stress are associated with low prices, and vice versa. In accordance with our results, A. Tsagkanos et al. [24] found sound evidence about the causal connection between green bonds and financial stress.

3.3. Bayesian time-varying vector autoregressive (BTC–VAR)

Figs. 6, 7 and 8 foreground the empirical results of the generalized impulse response functions conditioned on the initial state. The impulse responses are evaluated from June the 6th 2011 to September the 15th 2023.

The Bayesian time-varying vector autoregressive (BTC–VAR*)* relying on the VAR model, is basically undertaken to establish the direction and intensity of the relationship between the multiple factors. We can, therefore, detect (price model) a unidirectional relation between the CO_2 emission index, the WCE index, and the S&P green bond index. In particular, the S&P green bond index results from the WCE index and the CO_2 emission index. These analyses are the byproduct of a p-value for the CO_2 emission index, the WCE index being less than 5%, and a p-value for S&P green bond index, being greater than 5%. The results for the investor sentiment model are nearly identical to those obtained for the price model, confirming that there is no correlation or cause-and-effect link between the Google Trends index, reflecting investor sentiment and green bonds. Conversely, financial stress model enacts a one-way causal relationship between investor sentiment and

Table 4

Quantile regression models' results

Quantile estimated			0.1	0.25	0.5	0.75	0.9
Price	β_1	Coefficient	−0.265919	−0.316009	−0.382785	−0.393565	−0.248491
		t-Stat	−27.62621	−34.73561	−97.13579	−80.58878	−7.502641
		Prob	0.0000	0.0000	0.0000	0.0000	0.0000
	β_2	Coefficient	0.094794	0.122053	0.173293	0.156419	0.068103
		t-Stat	22.71782	20.33995	37.79350	25.94855	4.654177
		Prob	0.0000	0.0000	0.0000	0.0000	0.0000
	β_3	Coefficient	0.054486	−0.008794	−0.063881	−0.050856	−0.084877
		t-Stat	6.827608	−0.877826	−17.35557	−9.858895	−4.318385
		Prob	0.0000	0.3801	0.0000	0.0000	0.0000
Investor sentiment	β_1	Coefficient	−0.269059	−0.315790	−0.371838	−0.379668	−0.302397
		t-Stat	−28.85390	−31.83710	−91.06599	−64.59437	−4.280244
		Prob	0.0000	0.0000	0.0000	0.0000	0.0000
	β_2	Coefficient	0.094498	0.124933	0.173144	0.158026	0.104642
		t-Stat	18.22665	18.17301	37.25314	26.77436	3.235499
		Prob	0.0000	0.0000	0.0000	0.0000	0.0012
	β_3	Coefficient	0.056202	−0.007789	−0.051872	−0.036083	−0.054284
		t-Stat	6.418509	−0.700073	−12.68903	−5.655350	−1.979815
		Prob	0.0000	0.4839	0.0000	0.0000	0.0478
	δ_1	Coefficient	−0.041291	−0.027000	−0.049865	−0.084267	−0.099267
		t-Stat	−4.715703	−3.417428	−7.695369	−10.55924	−5.138084
		Prob	0.0000	0.0006	0.0000	0.0000	0.0000
Financial stress	β_1	Coefficient	−0.180840	−0.254527	−0.397125	−0.415001	−0.334763
		t-Stat	−20.14647	−20.97903	−71.87070	−78.86707	−0.434230
		Prob	0.0000	0.0000	0.0000	0.0000	0.6642
	β_2	Coefficient	0.051512	0.089019	0.183621	0.175619	0.101859
		t-Stat	14.74505	12.92019	37.91039	27.40639	0.340841
		Prob	0.0000	0.0000	0.0000	0.0000	0.7332
	β_3	Coefficient	0.143594	0.054364	−0.068436	−0.051167	−0.031571
		t-Stat	18.65303	4.102865	−11.98628	−8.224422	−0.121686
		Prob	0.0000	0.0000	0.0000	0.0000	0.9032
	δ_2	Coefficient	−0.991332	−0.614027	0.373884	0.684301	0.9032
		t-Stat	−11.68967	−7.237133	3.418207	13.52946	1.297509
		Prob	0.0000	0.0000	0.0006	0.0000	0.1946

Source: Authors' calculation.

green bonds, with the OFR financial stress index contributing to the S&P green bond index. This essentially illustrates the impact of financial stress on the green bond market and how sensitive green investors are to financial news, whether it involves positive or negative published information. Furthermore, this exemplifies pessimistic biases, which are marked by a propensity to overestimate the chance of unfavorable outcomes while underestimating the likelihood of favorable outcomes.

A financial stress index is a measure of the overall level of financial stress in the economy, such as increased uncertainty, increased volatility, and decreased liquidity. Hence, the negative correlation between the financial stress index and the S&P Green Bond Index is suggestive that the dependent variable is overvalued. These results can be attributed to psychological biases within the field of behavioral finance. Notably, the overconfidence bias contributes to inflated assessments of one's abilities.

Quantile Process Estimates
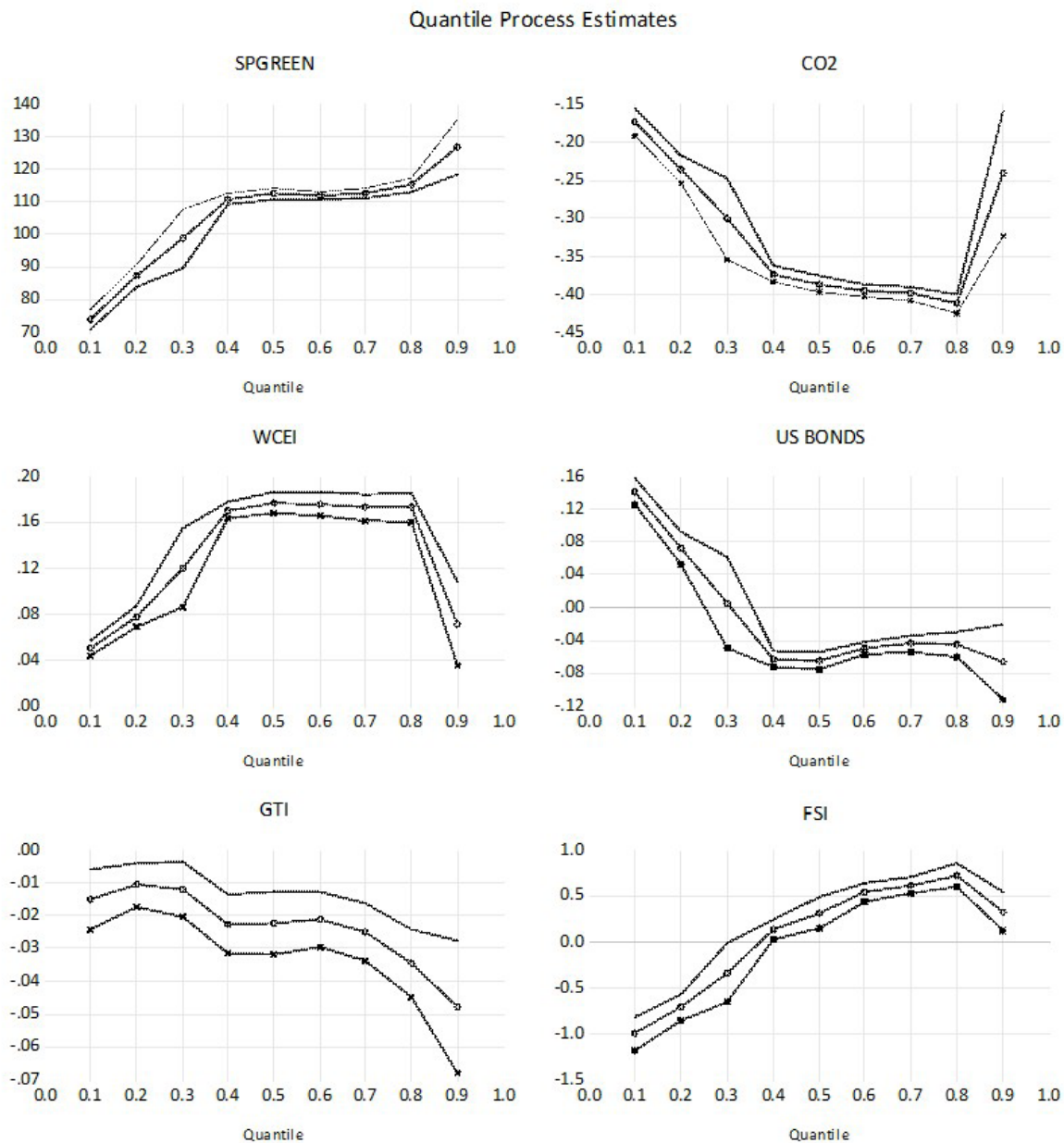
Fig. 3. **Quantile process estimates of the price model**

Source: Created by the authors.

The comparison between clinical and statistical prediction methods underscores the prevalence of subjective judgment over objective analysis. Additionally, confirmation bias plays a role as individuals selectively process information to align with pre-existing beliefs.

Evidence from studies corroborates that psychological biases can result in systemic inefficiencies as well as cognitive biases that may influence investors' decision-making. Our instance is concerned, green investors have a propensity to overestimate their own capabilities and judgements when it comes to the stability of green bonds. This refers to the fact that they frequently assume that one would have forecasted or anticipated the outcome after a positive occurrence has actually happened (overconfidence bias). Consequently, they interpret data in a way that supports existing assumptions or expectations on the connection between green bonds and low financial stress (confirmation bias). Indeed, this leads individuals to base their decisions on widely accessible favorable information on green bonds

Quantile Process Estimates
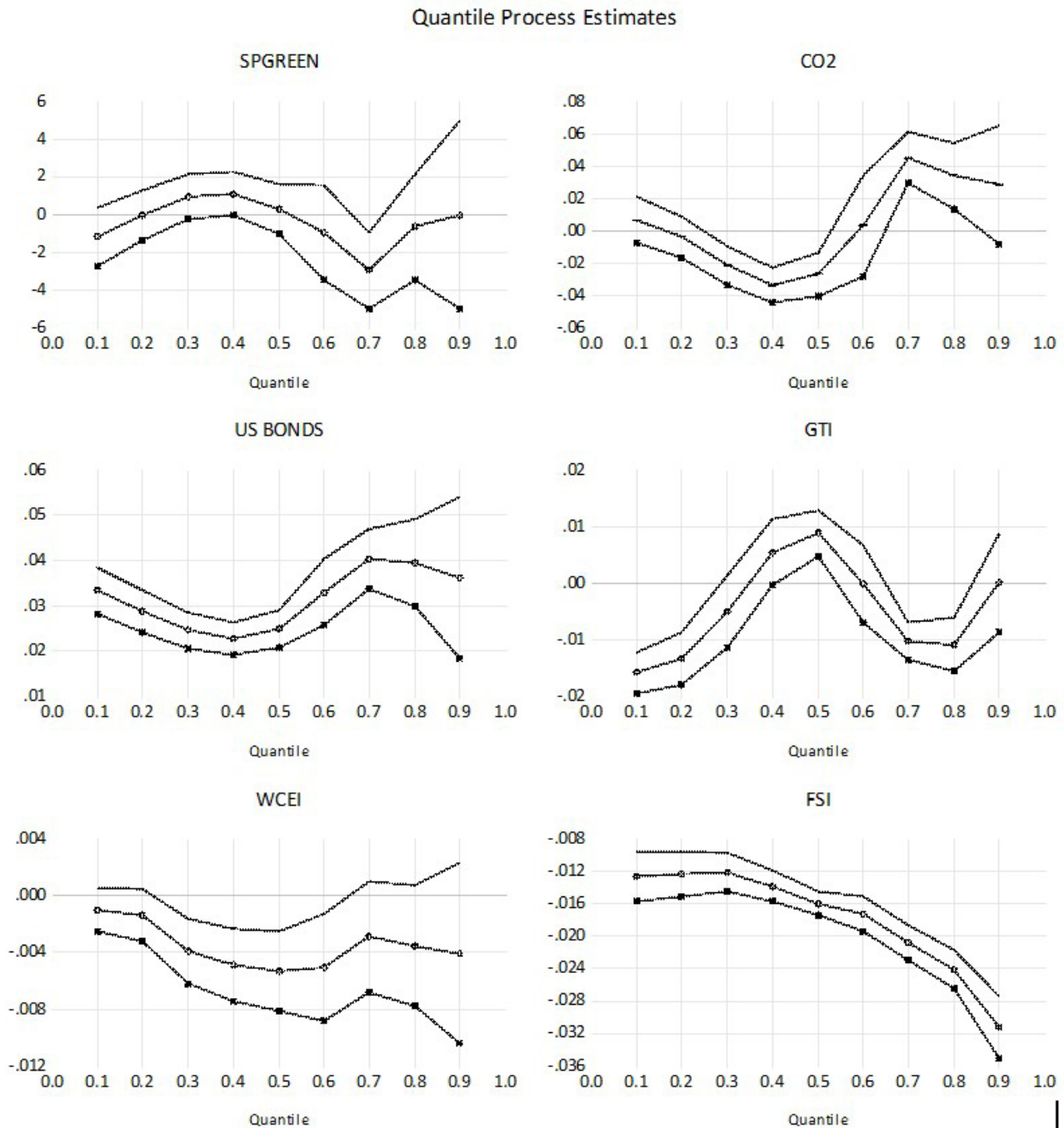
Fig. 4. **Quantile process estimates of the investor sentiment model**

Source: Created by the authors.

rather than considering all pertinent data (heuristic availability). They equally tend to think that future events will be better than comparable ones in the past (optimism bias).

4. Conclusion

The ultimate objective of the present research resides primarily in assessing the causal connections between green bonds and other related assets (including US conventional bonds, the WilderHill clean energy (equity) index, and the price of CO_2

emission allowances), along with analyzing the effects of investor sentiment and financial stress.

Our research goes in good agreement with prior literature results, establishing a unidirectional causal relationship between financial stress and green bonds as well as other financial and environmental assets. We anticipate that the price-shifting mechanisms of green bonds will be heavily influenced by investor behavior regarding green bonds. To build up an empirical framework, we examined time series data from green bonds, treasury, clean energy as

Quantile Process Estimates
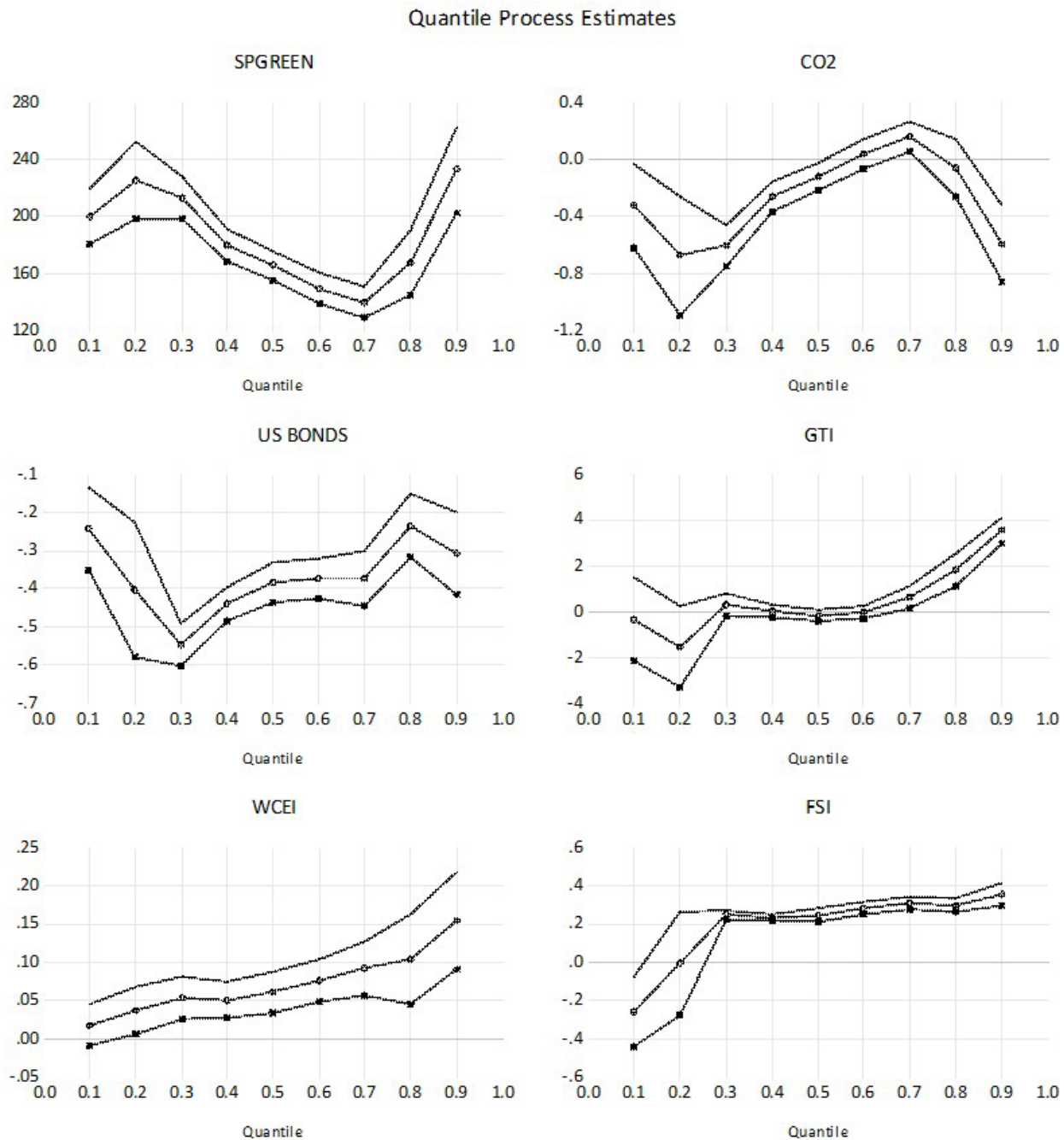
Fig. 5. **Quantile process estimates of the financial stress model**

Source: Created by the authors.

well as CO_2 emission assets and investor sentiment measurements. Furthermore, we applied quantile autoregressive models to examine the prediction of green bonds. Moreover, we deployed The Bayesian Time-Varying Vector Autoregressive (BTC–VAR) to analyze the relation between green bonds and the different variables.

Our findings demonstrated that green bonds' statistical properties are distinct from those of other financial and environmental assets, leading us to use quantile regressions to account for the factors of

these fluctuations. Additionally, the negative unidirectional causal relationship between the S&P green bond index and the CO_2 Emission index was interpreted in terms of the divergence of objectives of each asset. However, the positive unidirectional causal relationship between the S&P green bond index and the Wilderhill Clean Energy index was outlined by resemblance and uniformity purposes. Besides, the investor sentiment measured by Google Trend Index was insignificant and didn't reflect accurately the impact of investor sentiment on green bonds

SPGB Equation Coefficients
Posterior Medians

Fig. 6. **TVC VAR estimates of the price model**
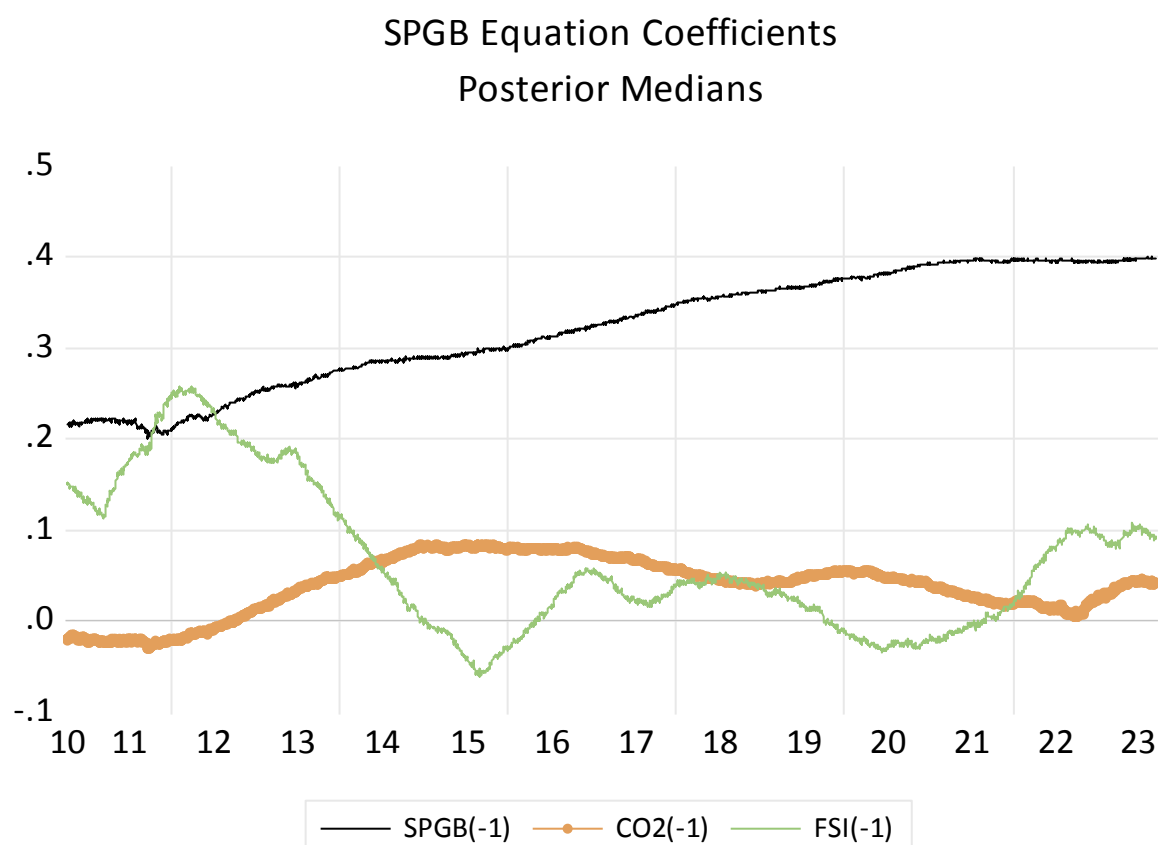
Source: Created by the authors.

GTI Equation Coefficients
Posterior Medians
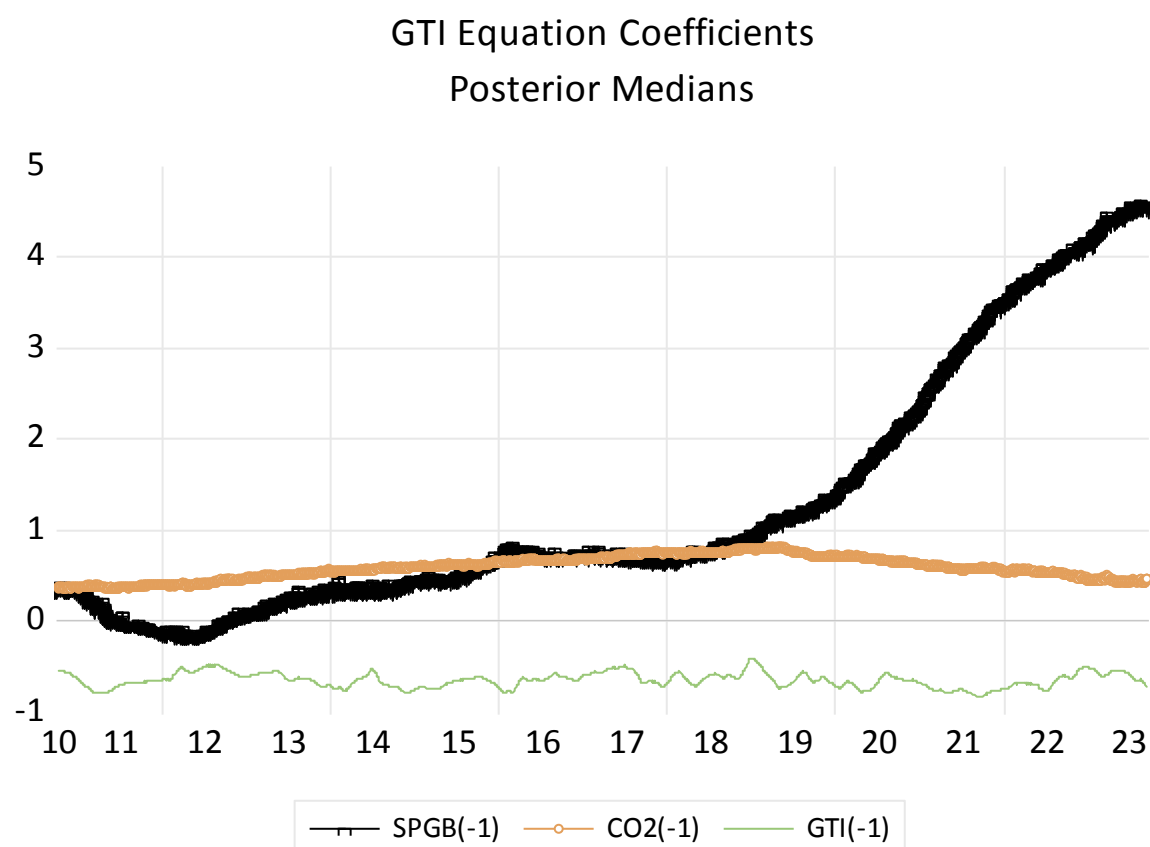
Fig. 7. **TVC VAR estimates of the investor sentiment model**

Source: Created by the authors.

FSI Equation Coefficients
Posterior Medians
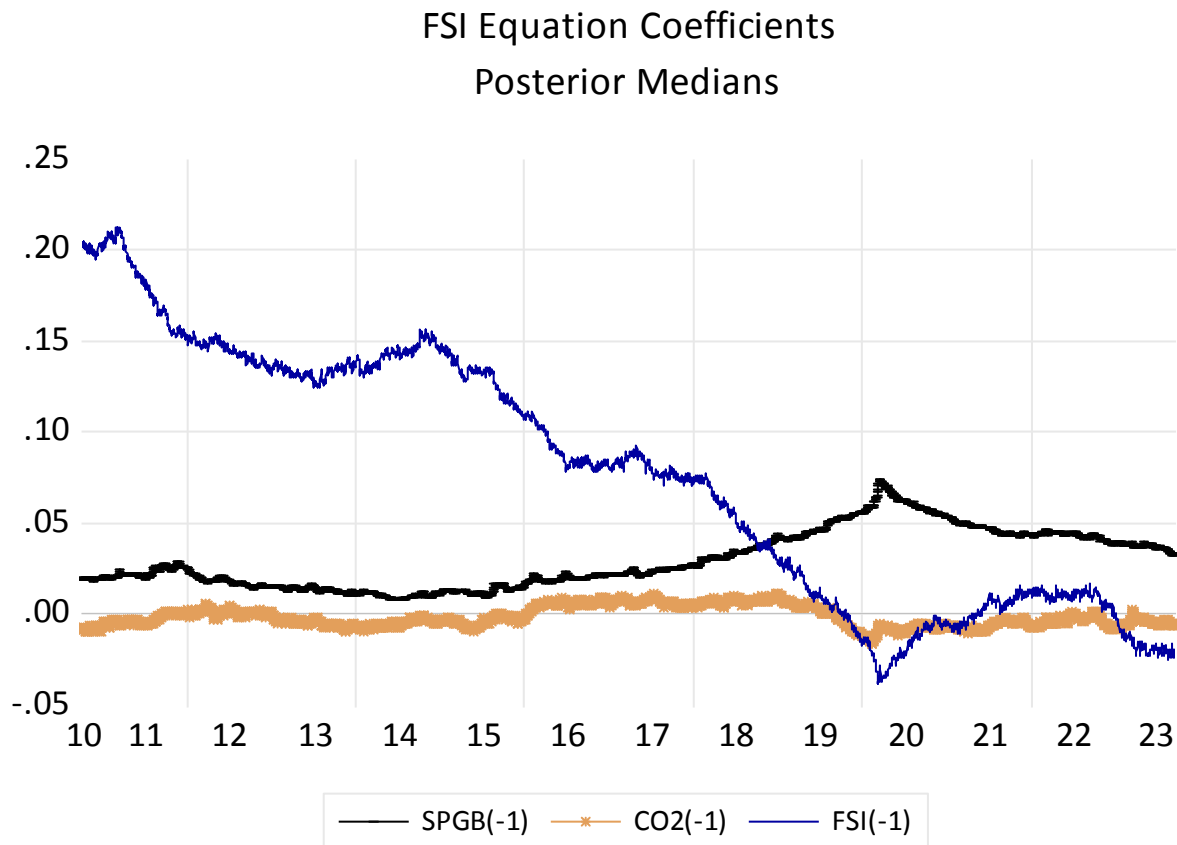
Fig. 8. **TVC VAR estimates of the financial stress model**

Source: Created by the authors.

market. However, the financial stress (measured by the OFR Financial Stress Index) has a significant reversed impact on green bonds, leading us to infer that green investors are sensitive to financial news and that psychological biases might have a noticeable impact on green bond markets.

In fact, based on our findings, we deduce that investor sentiment has no significant influence on the price of green bonds since the investor sentiment index's coefficient was negligible and had no impact on the initial model. Green investors, however, have a propensity to be sensitive to stressful and risky financial environments. This was explicitly corroborated through the financial stress index's negative correlation with the S&P Green Bond Index, indicating an overestimation of the dependent variable's price. Moreover, the over estimation of the S&P Green Bond Index was accounted for in terms of four main psychological biases, namely overconfidence bias, confirmation bias, availability heuristic, and optimism bias.

Despite the fact that green investor sentiment has relatively no impact on the green bond market and that investors tend to overvalue green bonds, investing in such a nascent market without a clear

and transparent legal framework is still perceived as a risky investment. Therefore, ethical investors are still highly exposed to greenwashing risk.

The central target of this investigation resides in analyzing the causal relationships between green bonds and various financial and environmental variables (CO_2 emission allowances price). The period of analysis spans from June, 2011, to July 10, 2021.

The basic motivation underlying this research is to surmount the limitations of existing studies that have not thoroughly examined the relationship between the green bond market and other financial and environmental variables. Through conducting this analysis, the study aims to gain a better and deeper insight into the causal dynamics between green bonds and the selected variables, providing enlightening details upon the interactions between the green bond market and the broader financial and environmental landscape.

The results of the study would notably have significant implications for both investors and policymakers. For policymakers, particularly those focusing on achieving goals related to a low-carbon economy, the study highlights the weight of considering not only the green bond market but also the predictive

power of traditional bonds as well as the price of CO_2 emission allowances.

Policymakers need to consider the dynamic causality between these variables, which may vary over different periods. This implies that the relationships and causal dynamics between green bonds and CO_2 emission allowances price can alter over time. Policymakers need to be aware of these changing relationships when formulating and implementing policies related to the green bond market.

Furthermore, the study suggests that policymakers should not overlook the predictive power of traditional bonds and the CO_2 emission allowances price when designing policies for the green bond market. These variables can provide valuable information and better insights that can largely help inform policy decisions and promote the effectiveness of measures aimed at fostering a low-carbon economy.

For investors, the findings suggest that understanding the interactions between green bonds, traditional bonds, and the CO_2 emission allowances price is crucial for making informed investment decisions. Recognizing the predictive power and the relationships among these variables can help investors identify potential investment opportunities, manage risks, and align their portfolios with the goals of sustainability and climate change mitigation. Overall, the study emphasizes the need for policymakers and investors to consider the dynamic variability and predictive power of various financial and environmental variables when addressing the green bond market. This comprehensive approach can contribute to more effective policymaking, appropriate investment strategies, and the advancement of a low-carbon economy.

However, this study is subject to certain limitations. It focuses on a specific set of variables — green bonds, CO_2 emissions, investor sentiment, and financial stress — while other potentially influential factors such as monetary policy shifts, geopolitical events, or technological innovation in clean energy were not included. Future research could expand the scope by incorporating a broader range of variables and applying alternative modeling techniques to further enhance the robustness and generalizability of the findings.

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The Impact of Basic Macroeconomic Variables and Market Risks on Borsa Istanbul Indices: A Comparative Sectoral Analysis

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ABSTRACT

The aim of this study is to empirically investigate the impact of various macroeconomic variables on the Borsa Istanbul Benchmark and Sectoral Indices. The impetus for this inquiry stems from the significant fluctuations in macroeconomic variables within the Turkish economy, particularly during the early 2020s. We utilized the Autoregressive Distributed Lag (ARDL) **methodology** to examine the dataset covering the period from 2013 to 2024. **The results** indicate that, in the long term, the Borsa İstanbul (BIST) general indices are negatively affected by interest rates and credit default swaps (CDS) premiums, while exchange rates positively influence them. Notably, there is no discernible impact from US interest rates, inflation, or gold prices; however, the influence of the volatility index (VIX) is observed to be significant only in the short term. When examining sectoral effects, the negative impacts of interest rates and CDS premiums, as well as the positive influence of exchange rates, are consistent across sectors, with particularly pronounced effects in the banking and real estate sectors. Conversely, the effects of US interest rates, inflation, gold prices, and the VIX index mirror those observed in the general indices. An interesting finding is that while the VIX fear index only negatively affects bank and construction company stocks in the long term, companies in almost all sectors are affected by global risks in the short term. **The key conclusion** of the research is that exchange rates and domestic risk indicators — such as interest rates and CDS premiums — are the most influential long-term drivers of Turkey's stock market and sectoral performance, whereas global factors like US monetary policy and the VIX primarily affect short-term dynamics and investor sentiment.

Keywords: macroeconomic variables; stock returns; volatility index (VIX); inflation rate; interest rate; exchange rate; CDS premiums; gold prices; Turkey

Влияние основных макроэкономических переменных и рыночных рисков на индексы Стамбульской фондовой биржи: сравнительный отраслевой анализ

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АННОТАЦИЯ

Целью данного исследования является эмпирическое изучение влияния различных макроэкономических переменных на индекс Стамбульской фондовой биржи и отраслевые индексы. Поводом для этого исследования послужили значительные колебания макроэкономических переменных в экономике Турции, особенно в начале 2020-х гг. Мы использовали **методологию** авторегрессии с распределенным лагом

(ARDL) для изучения набора данных, охватывающего период 2013–2024 гг. **Результаты** показывают, что в долгосрочной перспективе общие индексы Стамбульской фондовой биржи (BIST) испытывают отрицательное влияние процентных ставок и премий по кредитным дефолтным свопам (CDS), в то время как валютные курсы оказывают на них положительное влияние. Следует отметить отсутствие заметного влияния процентных ставок США, инфляции или цен на золото; однако влияние индекса волатильности (VIX) наблюдается только в краткосрочной перспективе.

При изучении секторальных эффектов негативное влияние процентных ставок и премий CDS, а также позитивное влияние обменных курсов согласуются между секторами с особенно выраженными эффектами в банковском секторе и секторе недвижимости. Напротив, влияние процентных ставок США, инфляции, цен на золото и индекса VIX отражает то, что наблюдается в общих индексах. Интересным результатом является то, что в то время как индекс волатильности VIX отрицательно влияет только на акции банков и строительных компаний в долгосрочной перспективе, компании почти во всех секторах подвержены влиянию глобальных рисков в краткосрочной перспективе. **Основной вывод** исследования заключается в том, что обменные курсы и внутренние индикаторы риска, такие как процентные ставки и премии CDS, являются наиболее влиятельными долгосрочными драйверами фондового рынка Турции и секторальных показателей, тогда как глобальные факторы, такие как денежно-кредитная политика США и индекс VIX, в первую очередь влияют на краткосрочную динамику и настроения инвесторов.

Ключевые слова: макроэкономические переменные; доходность акций; индекс волатильности (VIX); уровень инфляции; процентная ставка; обменный курс; премии CDS; цены на золото; Турция

Introduction

The effect of macroeconomic indicators on stock market indices is a significant topic, particularly regarding inflation, which is closely monitored by investors. In high-inflation countries, alternative investments such as exchange rates and commodities may divert attention from stocks. Contractionary monetary policies to combat inflation can also affect investor preferences by raising interest rates and altering bond yields. Inflation impacts the stock market by affecting investor sentiment and corporate profits. High inflation reduces consumers' purchasing power, leading to decreased spending and potentially lower stock prices, especially in consumer sectors. Conversely, households may increase stock demand to protect their wealth against inflation, potentially driving prices up. After years of stable inflation, the recent resurgence has drawn attention from households, investors, and policymakers due to its impact on economic activity and the stock market. Since the 1980s, when U.S. inflation peaked at 13.55% from oil crisis shocks, the Federal Reserve has maintained an inflation rate near the 2% target. However, inflation concerns have reemerged due to COVID-19 economic policies, the Russia-Ukraine conflict, and NATO sanctions on Russia. In response, the Federal Reserve raised interest rates in mid-March 2022, leading to policy uncertainty and a signifi- cant stock market sell-off as investors anticipated higher discount rates and a potential economic slowdown [1].

The relationship between low- and high-risk assets has been studied since the 1960s [2]. A key finding is that investment decisions depend on the balance between risk and return. Rising interest rates make the bond market more attractive than the stock market, leading to declining stock prices [3]. Higher rates also reduce borrowing, reducing cash flow and investor demand for stocks. Additionally, rate hikes may increase the risk premium for stock investors, boosting demand for bonds and further depressing stock prices. This study aims to provide empirical evidence on whether ignorance of monetary policy interest rates affects stock market returns [4].

In financial markets, information is vital. Stock prices should reflect relevant macroeconomic variables and risks, as forecast errors and unexpected factors can negatively impact them. Deviations in macroeconomic variables can significantly affect stock returns, with research showing that "surprises" have a statistically significant negative impact. Studies on central bank transparency emphasize the influence of information from monetary authorities on market behavior [5]. Greater transparency can reduce volatility, enhance investor responsiveness, and improve financial stability [6]. Central banks

aim to narrow the information gap with economic participants to achieve their inflation targets [7]. Therefore, confidence in macroeconomic indicators is essential for stock market returns.

This study examines the effects of key macroeconomic variables and market risks on Borsa Istanbul indices by sector. Key macroeconomic variables include the inflation rate, exchange rate, bond yields, and gold prices, while the volatility index (VIX) and credit default swaps (CDS) assess market risks. This study is significant for two reasons. First, while many studies have analyzed the relationship between stock returns and macroeconomic indicators, none have conducted a sectoral analysis specific to Turkey. This research investigates sectoral differences in the impact of these indicators on the stock market. Second, it is the first study in Turkey to explore the effects of the volatility index (VIX) and credit default swaps (CDS) on stock returns.

Literature review

Many studies have examined the relationship between macroeconomic indicators and stock returns, but the literature shows contradictory findings. The relationship between inflation and stock market returns has been widely studied, with many indicating a negative correlation [8, 9, 10]. A study in the USA found that stock returns are inversely related to inflation, a finding supported by subsequent research across various markets [11, 12]. Generally, stock returns decline as inflation rises due to increased costs eroding corporate profits and higher interest rates reducing the present value of future earnings. While there have been significant studies on the relationship between stock returns and inflation, the majority focus on the aggregate market, and most follow the development of individual sector sentiment. Some sectors may offer a potentially positive relationship and therefore provide protection against inflation risk. Some studies suggest a positive relationship between inflation and stock returns, particularly if companies can adjust prices in response to inflation [13]. This indicates that stocks may serve as a hedge against inflation under certain conditions, allowing returns to rise with increasing prices. Conversely, some research shows no significant relationship between inflation and stock returns [14, 15]. Explanations for a negative relationship include the money illusion effect, where investors sell stocks believing they won't keep pace with inflation, and

the proxy effect, which suggests a negative correlation between stock returns and inflation through real output [16, 17].

The economic literature lacks consensus on the causal relationship between exchange rates and stock prices. Two main perspectives exist: the flow-oriented approach, which suggests a positive relationship [18], and the stock-oriented approach, which proposes a negative link [19]. The flow-oriented approach suggests that exchange rates are influenced by a country's external balance, while the stock-oriented view, supported by models like the portfolio balance model and the monetary model, argues for a negative relationship. Several studies support a negative relationship between exchange rates and stock returns. Fluctuations in exchange rates significantly impact company valuations and stock market returns in both developed and emerging markets [20, 21]. This relationship is often linked to multinational corporations: an appreciating domestic currency reduces the value of foreign earnings, leading to lower stock prices, while depreciation can enhance foreign earnings and potentially increase stock returns. This underscores the need for effective exchange rate risk management for companies in international trade and investors with global portfolios. Some studies indicate a positive relationship between exchange rates and stock returns. One study highlighted this connection, especially in countries with significant imports, while another study confirmed a significant correlation between exchange rate fluctuations and stock market returns [22, 23]. This relationship is often seen in economies where stronger domestic currency lowers import costs, reduces inflation, and boosts consumer spending, benefiting stock markets. For example, companies reliant on imports may see increased profitability and stock prices when the local currency strengthens. Additionally, industries like transportation and manufacturing, sensitive to input costs, can gain from favorable exchange rate movements, enhancing stock returns.

Many studies suggest a negative relationship between interest rates and stock returns, largely due to rising interest rates increasing borrowing costs, consumer spending, and business investments, which can lower corporate profits and stock prices. This inverse relationship is well-documented, though some studies suggest a positive correlation, albeit rarely [24–26]. Overall, most research supports the negative link between interest rates and stock market returns.

Investing in gold protects financial assets against inflation and serves as a crucial hedge in asset allocation [27]. Since gold prices are denominated in U.S. dollars, a dollar depreciation usually increases gold's nominal price, preserving its real value. The minimal correlation between gold and stock market prices indicates low systemic risk for gold. Thus, diversifying with both gold and stocks significantly reduces overall investment risk compared to investing solely in stocks, highlighting gold's role as «risk insurance» in portfolios [28]. Research on the relationship between gold prices and the stock market has yielded inconsistent results. Some studies suggest no correlation between gold prices and economic growth or stock market returns, as gold primarily serves as a store of value [29, 30]. A study examined the US, UK, and German markets and found that under normal conditions the relationship between gold prices and the stock market was very weak [31]. In contrast, other studies indicate a negative correlation, suggesting that investors convert funds into gold for protection during stock market declines. In a study conducted in 1983, a negative beta coefficient for gold in the US market was found [32], and in 2009, a study similarly identified a negative correlation between ASEAN stock market returns and international gold market returns [33]. Additional studies also support this negative relationship between gold prices and stock returns. However, some studies suggest a positive correlation between gold spot returns and stock market returns [34, 35].

A study conducted in 2021 provided empirical insights into how sustainability (ESG) and broad-based indices are affected by risk indicators such as VIX, CDS, and foreign exchange rates (FX) volatility index. Results showed that companies in Germany ESG-X, France ESG-X, and SRI-KEHATI are less affected by shocks than those in broad-based indices. In contrast, BIST Sustainability is more impacted than BIST All. Causality tests indicated that VIX has a greater influence on broad-based and ESG indices than other risk indicators [36]. Overall, stock returns are influenced by macroeconomic variables like inflation, exchange rates, interest rates, and gold prices, with no consensus on the nature of these relationships.

Data and methodology
Data

The estimated empirical model is presented in equation (1).

$$lnep = lnir^{tur} + lnir^{us} + lncds + lner + lninf + lngold + lnvix. \quad (1)$$

The study examined the influence of macroeconomic factors on the Turkish stock market by employing the indices established by Borsa İstanbul (BIST) as indicators of stock prices. Initially, general indices of BIST were employed to assess the collective impact on all stocks traded on the exchange. These indices encompass XUTUM, which consists of shares from 543 companies that are listed on the main market, star market, sub-market, and pre-market. The XU 100 represents the stock prices of the top 100 companies listed on the BIST. XU 030 represents the stock prices of the 30 largest companies listed on BIST.

In the second stage, sectoral indices established by BIST were employed to ascertain the sectoral impacts of macroeconomic variables. The analyzed indices encompass: XGIDA; Food, beverage, and tobacco sectors, XINSA; Construction and public works, XKMYA: Chemicals, pharmaceuticals, petroleum and other, XUTEK; Technology in the information and defence sectors, XHOLD; Holdings and investment, XTCRT; Retail and wholesale trade sectors, XGMYO; Real estate investment trusts, XBANK: Banks.

lnep represents the logarithm of one of the aforementioned indices based on the market being analyzed and serves as the dependent variable. *lnir^{tur}* is the natural logarithm of the Turkish 5-year bond yield and *lnir^{us}* is the natural logarithm of US 5-year bond yield. *lncds* signifies the natural logarithm of Turkey 5-year credit default swap (CDS) value. *lner* stands for the natural logarithm of the nominal exchange rate ($/TL). *lninf* represents the natural logarithm of the inflation rate in Turkey, *lngold* denotes the natural logarithm of gold prices (in $/ounce), and *lnvix* signifies the natural logarithm of the volatility index (VIX). The VIX index provides a measure of the constant, 30-day expected volatility of the US stock market.

The study utilizes data from various sources covering the period from January 2013 to June 2024. Specifically, the *lnir^{tur}*, lner, and lninf data are sourced from the CBRT database, while the index data for lnep are obtained from the BIST database.[1]

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[1] URL: BIST Database. URL: https://www.borsaistanbul.com (accessed on 20.07.2024).

Additionally, data for the *lnir^us* variable are retrieved from the St. Louis FED database,[2] and data's on lncds, lngold, and lnvix are sourced from Investing.[3]

Methodology

The study utilizes the Autoregressive Distributed Lag (ARDL) methodology developed by Pesaran and Shin (1999) and Pesaran et al. (2001) to perform both long-term and short-term estimations [37, 38]. ARDL methodology can produce efficient estimates even in situations with small and limited samples [39].

$$
\begin{aligned}
\Delta \ln ep_t = {} & \alpha_0 + \sum_{i=1}^{m}\alpha_1\Delta\ln ep_{t-i} + \sum_{i=0}^{m}\alpha_2\Delta\ln ir_{t-i}^{tur} + \sum_{i=0}^{m}\alpha_3\Delta\ln ir_{t-i}^{us} + \\
& + \sum_{i=0}^{m}\alpha_4\Delta\ln cds_{t-i} + \sum_{i=0}^{m}\alpha_5\Delta\ln er_{t-i} + \sum_{i=0}^{m}\alpha_6\Delta\ln\inf_{t-i} + \\
& + \sum_{i=0}^{m}\alpha_7\Delta\ln gold_{t-i} + \sum_{i=0}^{m}\alpha_8\Delta\ln vix_{t-i} + \alpha_9\ln ep_{t-1} + \alpha_{10}\ln ir_{t-1}^{tr} + \\
& + \alpha_{11}\ln ir_{t-1}^{us} + \alpha_{12}\ln cds_{t-1} + \alpha_{13}\ln er_{t-1} + \alpha_{14}\ln\inf_{t-1} + \alpha_{15}\ln gold_{t-1} + \\
& + \alpha_{16}\ln vix_{t-1} + \varepsilon_t
\end{aligned}
\tag{2}
$$

To investigate the cointegration relationship among the variables, the model outlined in equation (1) of the study is transformed into the unrestricted error correction model (UECM) form, as illustrated in equation (2). In this equation, α_0 is the constant term, and $\alpha_1, \dots, \alpha_8$ represent the short-term coefficients derived from the lagged value of dependent, and current and lagged values of the independent variable. On the other hand, $\alpha_9, \dots, \alpha_{16}$ correspond to the long-term coefficients, and ε_t signifies the error term. The parameter *m* denotes the optimum lag length. The bound test is utilized to investigate the cointegration relationship by evaluating the joint significance of the first lags of the dependent and independent variables after estimating model (2) using the Ordinary Least Squares (OLS) method. Hypothesis testing is based on critical values from tables established by Narayan (2005) [40].

$$
\begin{aligned}
\ln ep_t = {} & \beta_0 + \sum_{i=1}^{q_1}\beta_1\ln ep_{t-i} + \sum_{i=0}^{q_2}\beta_2\ln ir_{t-i}^{tur} + \sum_{i=0}^{q_3}\beta_3\ln ir_{t-i}^{us} + \\
& + \sum_{i=0}^{q_4}\beta_4\ln cds_{t-i} + \sum_{i=0}^{q_5}\beta_5\ln er_{t-i} + \sum_{i=0}^{q_6}\beta_6\ln\inf_{t-i} + \sum_{i=0}^{q_7}\beta_7\ln gold_{t-i} + \\
& + \sum_{i=0}^{q_8}\beta_8\ln vix_{t-i} + e_t.
\end{aligned}
\tag{3}
$$

After establishing the cointegration relationship in equation (2), the model of the study is adjusted to equation (3) to calculate the long-term coefficients. The constant term is denoted as β_0, and the error term is represented by e_t in equation (3). The optimum lag length (q_i) is determined based on the Akaike Information Criteria. The long-term coefficients are computed by dividing the coefficients of the independent variables estimated using the OLS method in the ARDL model ($q_i, \dots$) by the difference in the lagged dependent variable coefficient.

$$
\begin{aligned}
\Delta \ln ep_t = {} & \sigma_0 + \sum_{i=1}^{p_1}\sigma_1\Delta\ln ep_{t-i} + \sum_{i=0}^{p_2}\sigma_2\Delta\ln ir_{t-i}^{tur} + \sum_{i=0}^{p_3}\sigma_3\Delta\ln ir_{t-i}^{us} + \\
& + \sum_{i=0}^{p_4}\sigma_4\Delta\ln cds_{t-i} + \sum_{i=0}^{p_5}\sigma_5\Delta\ln er_{t-i} + \sum_{i=0}^{p_6}\sigma_6\Delta\ln\inf_{t-i} + \\
& + \sum_{i=0}^{p_7}\sigma_7\Delta\ln gold_{t-i} + \sum_{i=0}^{p_8}\sigma_8\Delta\ln vix_{t-i} + \sigma_9 ECT_{t-1} + u_t.
\end{aligned}
\tag{4}
$$

[2] Louis FED Database. URL: https://fred.stlouisfed.org/ (accessed on 20.07.2024).
[3] Investing, URL: https://tr.investing.com/ (accessed on 20.07.2024).

In the final stage, the error correction model (ECM) specified in equation (4) is estimated using the OLS technique to derive findings related to short-term dynamics. In equation (4), σ_0 represents the constant term and u_t denotes the error term. The operator Δ denotes the first difference, and p_i indicates the lag lengths (according to equation (3) $(q_i - 1)$). σ_9 is the coefficient of the error term. The presence of the σ_9 term within the range of 0 to -1 serves as evidence for the existence of a cointegration relationship. Moreover, the proximity of this value to 0 indicates a slower rate at which the impact of a short-term shock, leading to a deviation from the long-term equilibrium, diminishes.

In order to ensure the robustness of the long-term coefficients, they were re-estimated using the Fully Modified Ordinary Least Squares (FMOLS) method introduced by Phillips and Hansen (1990) and the Dynamic Ordinary Least Squares (DOLS) method developed by Stock and Watson (1993) [41, 42]. FMOLS provides efficient and consistent results by integrating a semi-parametric correction to address endogeneity and serial correlation in the stochastic error terms inherent in the Ordinary Least Squares (OLS) method. In contrast, the DOLS approach addresses these issues by incorporating the levels and differences of the independent variables, as well as their leads, in the model. The determination of the optimal lag length and lead values is based on information criteria.

Findings and results

In the ARDL approach, the stationarity of the series is crucial. We conducted the ADF test using models with a constant and a constant plus trend. The results indicate that the lninf variable is stationary at its level, while all other variables are stationary at their first difference, suggesting no stationarity issues in subsequent estimations.

The estimations of the BIST general indices

After the unit root tests, model (2) predicted the XUTUM, XU 100, and XU 030 indices, while model (3) estimated the long-term coefficients. *Table 1* shows the bound test results, long-term coefficients, and diagnostic tests for the estimations. The F test results in *Table 1* show that the statistics exceed the upper critical value (4.23) for the XUTUM, XU 100, and XU 030 models, indicating a cointegration relationship. The Jarque-Bera Normality Test confirms that the null hypothesis of normal distribution is not rejected in any model. The Breusch-Godfrey Serial Correlation LM test and the Breusch-Pagan-Godfrey heteroskedasticity test also do not reject their respective null hypotheses of no serial correlation and equal variance. The Ramsey RESET test supports the null hypothesis of correct model specification. Stability tests (CUSUM and CUSUMSQ) reject the null hypothesis of an out-of-control process. Overall, these diagnostic tests indicate that the estimations are statistically reliable.

The long-term coefficients reveal that lnir^{tur} exerts a statistically significant negative impact on lnbisttum, lnbist100, and lnbist30. Specifically, a 1% increase in lnir^{tur} leads to decreases of -1.07%, -0.96%, and -0.88% in lnbisttum, lnbist100, and lnbist30, respectively. lnir^{us} demonstrates a statistically significant positive effect solely on lnbist30 at a significance level of 10%. Shocks in lncds exhibit a statistically significant negative influence on lnbisttum, lnbist100, and lnbist30, with a 1% increase in lncds resulting in decreases of -1.54%, -1.32%, and -1.24% in lnbisttum, lnbist100, and lnbist30, respectively. Shocks in lner show a statistically significant positive impact on lnbisttum, lnbist100, and lnbist30, with a 1% increase in lner leading to increases of 4.29%, 4.05%, and 3.74% in lnbisttum, lnbist100, and lnbist30, respectively. lngold does not significantly affect lnbisttum but has a statistically significant positive effect on lnbist100 and lnbist30 at the 5% significance level. A 1% increase in lngold results in a 0.92% increase in lnbist100 and a 0.84% increase in lnbist30. lninf and lnvix do not exhibit statistically significant effects in the long term.

In the ARDL estimation for the XUTUM, XU 100, and XU 030 models, the error correction model specified in equation (4) is estimated. The coefficient estimates are detailed in *Table 2*. Notably, the error correction terms fall within the range of 0 to -1. This observation suggests that short-term shocks gravitate towards equilibrium in the long run, implying the presence of a cointegration relationship. In terms of the short-term coefficients, it is observed that shocks in lnvix exhibit a statistically significant and negative impact on lnbisttum, lnbist100, and lnbist30. Additionally, lnir^{us} demonstrates a statistically significant and positive

Table 1

The bound test, long-term coefficients, and diagnostic tests

Variables	XUTUM (5,0,1,0,2,2,0,6)	XU 100 (1,0,1,0,0,0,0,6)	XU 030 (1,0,0,0,0,0,0,6)
	Coefficient	Coefficient	Coefficient
$lnir^{tur}$	−1.070*	−0.964*	−0.884*
$lnir^{us}$	0.082	0.111	0.202***
lncds	−1.547*	−1.329*	−1.240*
lner	4.293*	4.050*	3.740*
lninf	0.018	−0.037	−0.036
lngold	0.800	0.921**	0.844**
lnvix	0.315	0.053	−0.057
F Test I(0): 3.07 / I(1): 4.23	12.298	13.537	5.615
R^2	0.99	0.98	0.99
	Stat.[Prob.]	Stat.[Prob.]	Stat.[Prob.]
$\chi^2_{J-B\ test}$	2.928 [0.231]	1.151 [0.562]	2.610 [0.271]
$\chi^2_{B-G\ LM\ test}$	1.246 [0.291]	0.588 [0.556]	0.533 [0.588]
$\chi^2_{B-G-D\ test}$	1.111 [0.343]	1.280 [0.217]	1.325 [0.193]
$\chi^2_{RESET\ test}$	0.209 [0.648]	0.013 [0.907]	0.030 [0.861]
CUSUM	Stable	Stable	Stable
CUSUMSQ	Stable	Stable	Stable

Source: Compiled by the author based on the estimations.

Note: *, **, *** denote statistical significance at the 1%, 5%, and 10% levels, respectively.

influence in all three models. Notably, the dummy variable representing the COVID-19 pandemic does not show a statistically significant negative effect in any of the three models.

The estimations of the BIST sectoral indices

In the initial phase, Equation (2) was individually estimated for each index utilizing BIST sectoral stock indices to estimation sectoral trends. Subsequently, Equation (3) was calculated to derive the long-term coefficients. The bound test, long-term coefficients, and diagnostic tests are detailed in *Table 3*.

The bound test reveals that F-statistic values for all sectors exceed the upper bound of 4.23, indicating a cointegration relationship among the variables. Additionally, diagnostic tests including the Jarque-Bera Normality test, the Breusch-Godfrey Serial Correlation LM test, the Breusch-Pagan-Godfrey heteroskedasticity test, the Ramsey RESET test, as well as the CUSUM and CUSUM SQ tests conducted on the estimates indicate the absence of any statistical problems with the estimates.

Upon examining the long-term coefficients, it is evident that $lnir^{tur}$ exerts a negative and statistically significant influence on the dependent variables across all sectors. Notably, $lnir^{tur}$ demonstrates the most pronounced impact on the XBANK, XGMYO, and XINSA models, while its effect is weakest on the XTCRT, and XGIDA models. In contrast, $lnir^{us}$ exhibits a statistically significant negative effect solely on XUTEK and XGMYO models, with a positive impact on the XBANK model. The coefficients associated with $lnir^{us}$ in the remaining models are deemed statistically insignificant. Similarly, lncds is found to

Table 2
Error correction model regression

XUTUM		XU 100		XU 030	
Variable	**Coefficient**	**Variable**	**Coefficient**	**Variable**	**Coefficient**
D(lnbisttum(−1))	−0.000	D($\mathbf{lnir^{us}}$)	0.243*	D(lnvix)	−0.159*
D(lnbisttum(−2))	−0.038	D(lnvix)	−0.141*	D(lnvix(−1))	−0.092***
D(lnbisttum(−3))	−0.038	D(lnvix(−1))	−0.093***	D(lnvix(−2))	−0.029
D(lnbisttum(−4))	−0.207*	D(lnvix(−2))	−0.040	D(lnvix(−3))	−0.010
D($\mathbf{lnir^{us}}$)	0.243*	D(lnvix(−3))	−0.026	D(lnvix(−4))	0.061
D(lner)	2.184*	D(lnvix(−4))	0.047	D(lnvix(−5))	−0.083***
D(lner(−1))	−0.759**	D(lnvix(−5))	−0.093**	COVID-19	−0.023***
D(lninf)	−0.016	COVID-19	−0.021	ect(−1)*	−0.428*
D(lninf(−1))	0.016	ect(−1)*	−0.389*		
D(lnvix)	−0.105**				
D(lnvix(−1))	−0.141*				
D(lnvix(−2))	−0.062				
D(lnvix(−3))	−0.078				
D(lnvix(−4))	−0.031				
D(lnvix(−5))	−0.151*				
COVID-19	−0.002				
ect(−1)*	−0.362*				
R^2	0.63	R^2	0.59	R^2	0.60
F-stat	11.430 (0.000)	F-stat	19.749 (0.000)	F-stat	23.523 (0.000)

Note: *, **, *** denote statistical significance at the 1%, 5%, and 10% levels, respetively.

Source: Compiled by the author based on the estimations.

have a statistically significant negative impact on the dependent variables in all sectors, with coefficient magnitudes being relatively consistent except in the XINSA model. lner's coefficient is statistically significant and positive across all models, with the most substantial impact observed on XBANK, and the least impact on XINSA, and XKMYA. Analysis of lninf's coefficients reveals a statistically significant negative impact solely on XGIDA and while showing a positive effect on XKMYA. However, the coefficients of lninf in the other models are statistically insignificant. Notably, lngold's coefficients have no statistical significance in the XHOLD, XTCRT, XGMYO, and XBANK models. Conversely, a positive impact is observed in the XGIDA and XINSA models, while a negative impact is noted in the XKMYA and XUTEK models. Lastly, the coefficients of lnvix indicate a negative impact on XBANK and XINSA, with the remaining coefficients being statistically insignificant.

The error correction regression specified in Equation (4) has been estimated. The results are displayed in *Table 4*. The coefficient for the error correction term is consistently negative and statistically significant across all models. This indicates that disturbances leading to deviations from the long-run equilibrium have a tendency to be corrected, implying the presence of a cointegration relationship.

The analysis of the short-term coefficients reveals noteworthy findings. $lnir^{us}$ exhibits statistically significant positive coefficients in the XGIDA, XKMYA, XHOLD, and XGMYO models, while displaying statistically significant negative coefficients in the XTCRT models. lninf demonstrates statistically significant positive coefficients in certain lagged values within the XGIDA, XTCRT, and XBANK models. lnvix showcases statistically significant negative coefficients in various lagged values across nearly all models. Furthermore, the inclusion of a dummy variable to signify the impact of the COVID-19 pandemic reveals statistically significant negative coefficients in the XINSA, XGMYO, and XBANK models, and statistically significant positive coefficients in the XTCRT model.

Table 3

The bound test, long-term coefficients, and diagnostic tests

Variables	XGIDA, (1,6,1,0,1,5,0,6)	XINSA (2,2,0,1,0,0,6,0)	XKMYA (5,0,1,0,5,1,4,6)	XUTEK (1,0,1,0,0,0,0,0)	XHOLD (5,0,1,0,6,1,0,6)	XTCRT (1,6,5,0,6,2,0,6)	XGMYO (1,6,1,0,1,1,0,5)	XBANK (1,0,0,5,4,6,0,5)
	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.	Coef.
$lnir^{tur}$	−0.363*	−0.700*	−0.659*	−0.544*	−0.360*	−0.194*	−0.924*	−1.230*
$lnir^{us}$	−0.033	−0.065	−0.000	−0.457*	0.056	−0.005	−0.294**	0.305**
lncds	−0.709*	−0.132	−0.423**	−0.929*	−0.536*	−0.547*	−0.659*	−0.877*
lner	2.198*	1.604*	1.777*	2.123*	1.926*	1.929*	2.105*	3.303*
lninf	−0.131*	0.000	0.099***	−0.007	0.024	0.001	0.018	−0.054
lngold	0.977*	1.300*	−0.947**	−1.923*	0.048	0.171	0.332	0.743
lnvix	0.123	−0.220**	0.099	−0.206	0.100	0.101	0.154	−0.535**
F Test I(0): 3.07 I(1): 4.23	7.888	6.705	5.615	6.755	10.069	7.426	6.543	10.014
R^2	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.98
	Stat. [Prob.]	Stat. [Prob.]	Stat. [Prob.]	Stat. [Prob.]	Stat. [Prob.]	Stat. [Prob.]	Stat. [Prob.]	Stat. [Prob.]
$\chi^2_{J-B\ test}$	0.957 [0.619]	5.335 [0.069]	0.707 [0.701]	1.552 [0.460]	1.605 [0.448]	1.447 [0.484]	4.437 [0.108]	0.329 [0.848]
$\chi^2_{B-G\ LM\ test}$	0.829 [0.439]	0.709 [0.494]	0.163 [0.849]	0.102 [0.902]	0.711 [0.493]	0.338 [0.713]	1.184 [0.309]	0.390 [0.678]
$\chi^2_{B-G-D\ test}$	1.039 [0.426]	2.674 [0.000]	1.050 [0.412]	0.995 [0.453]	1.087 [0.368]	1.323 [0.143]	1.442 [0.105]	0.705 [0.859]
$\chi^2_{RESET\ test}$	2.042 [0.156]	0.084 [0.772]	1.296 [0.197]	0.000 [0.984]	0.468 [0.640]	0.753 [0.452]	0.618 [0.433]	0.170 [0.681]
CUSUM	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable
CUSUMSQ	Stable	Stable	Stable	Stable	Stable	Stable	Stable	Stable

Source: Compiled by the author based on the estimations.

Note: *, **, *** denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Robustness check

The long-term coefficients of the model, initially estimated with the ARDL approach, have been re-estimated using FMOLS and DOLS methodologies. *Table 5* shows the long-term coefficients for both the general and sectoral BIST indices. The results for $lnir^{tur}$, lncds and lner from FMOLS and DOLS closely match previous findings, with their influence on the overall indices increasing in the order of XU 030, XU 100, and XUTUM. As before, the XBANK index shows the most significant effect for all three variables. The coefficients for lninf and lngold resemble previous findings, while lnvix remains statistically insignificant on any index over the long term. $lnir^{us}$, which exhibited statistically significant coefficients for XU 030 and certain sectoral indices in the ARDL approach, demonstrates significant effects in these estimations. Additionally, it is observed to have significant impacts on the remaining overall indices and several other sectoral indices.

Table 4

Error correction model regression

XGIDA		XINSA		XKMYA		XUTEK	
Variable	Coef.	Variable	Coef.	Variable	Coef.	Variable	Coef.
$D(lnir^{tur})$	−0.147*	D(lnbistinsa(−1))	−0.139**	D(lnbistkmya(−1))	0.007	$D(lnir^{tur})$	−0.010
$D(lnir^{tur}(-1))$	−0.098**	$D(lnir^{tur})$	0.005	D(lnbistkmya(−2))	0.018	COVID-19	−0.013
$D(lnir^{tur}(-2))$	−0.136*	$D(lnir^{tur}(-1))$	0.105**	D(lnbistkmya(−3))	−0.029	ect(−1)*	−0.209*
$D(lnir^{tur}(-3))$	−0.104**	D(lncds)	−0.143*	D(lnbistkmya(−4))	−0.194*		
$D(lnir^{tur}(-4))$	0.137*	D(lngold)	0.045	$D(lnir^{us})$	0.137*		
$D(lnir^{tur}(-5))$	0.112*	D(lngold(−1))	−0.335***	D(lner)	0.845*		
$D(lnir^{us})$	0.075***	D(lngold(−2))	−0.253	D(lner(−1))	−0.631*		
D(lner)	1.147*	D(lngold(−3))	−0.693*	D(lner(−2))	0.133		
D(lninf)	−0.023*	D(lngold(−4))	−0.070	D(lner(−3))	−0.326**		
D(lninf(−1))	0.038*	D(lngold(−5))	−0.424**	D(lner(−4))	0.437*		
D(lninf(−2))	0.024*	COVID-19	−0.039*	D(lninf)	0.004		
D(lninf(−3))	0.020*	ect(−1)*	−0.299*	D(lngold)	−0.225		
D(lninf(−4))	0.015*			D(lngold(−1))	0.042		
D(lnvix)	−0.048**			D(lngold(−2))	−0.257		
D(lnvix(−1))	−0.071*			D(lngold(−3))	−0.382**		
D(lnvix(−2))	−0.013			D(lnvix)	−0.068*		
D(lnvix(−3))	−0.015			D(lnvix(−1))	−0.057**		
D(lnvix(−4))	−0.024			D(lnvix(−2))	−0.009		
D(lnvix(−5))	−0.074*			D(lnvix(−3))	−0.045		
covid-19	0.002			D(lnvix(−4))	−0.004		
ect(−1)*	−0.313*			D(lnvix(−5))	−0.080*		
				COVID-19	0.002		
				ect(−1)*	−0.247*		

XHOLD		XTCRT		XGMYO		XBANK	
Variable	Coef.	Variable	Coef.	Variable	Coef.	Variable	Coef.
D(lnbisthold(−1))	0.103	$D(lnir^{tur})$	−0.049	$D(lnir^{tur})$	−0.189*	D(lncds)	−0.759*
D(lnbisthold(−2))	−0.037	$D(lnir^{tur}(-1))$	−0.006	$D(lnir^{tur}(-1))$	0.027	D(lncds(−1))	−0.075
D(lnbisthold(−3))	−0.098	$D(lnir^{tur}(-2))$	−0.032	$D(lnir^{tur}(-2))$	−0.072	D(lncds(−2))	−0.002
D(lnbisthold(−4))	−0.180*	$D(lnir^{tur}(-3))$	0.035	$D(lnir^{tur}(-3))$	0.009	D(lncds(−3))	0.194***
$D(lnir^{us})$	0.110*	$D(lnir^{tur}(-4))$	0.156*	$D(lnir^{tur}(-4))$	0.144*	D(lncds(−4))	0.327*
D(lner)	1.045*	$D(lnir^{tur}(-5))$	0.137*	$D(lnir^{tur}(-5))$	0.117**	D(lner)	2.041*
D(lner(−1))	−0.401*	$D(lnir^{us})$	0.042	$D(lnir^{us})$	0.084***	D(lner(−1))	−1.286**
D(lner(−2))	−0.373**	$D(lnir^{us}(-1))$	−0.079***	D(lner)	0.766*	D(lner(−2))	−0.615
D(lner(−3))	−0.285***	$D(lnir^{us}(-2))$	−0.111**	D(lninf)	−0.014**	D(lner(−3))	−1.932*
D(lner(−4))	0.236	$D(lnir^{us}(-3))$	−0.048	D(lnvix)	−0.058**	D(lninf)	−0.032***
D(lner(−5))	−0.310**	$D(lnir^{us}(-4))$	−0.126*	D(lnvix(−1))	−0.042	D(lninf(−1))	0.048**
D(lninf)	−0.014**	D(lner)	0.663*	D(lnvix(−2))	−0.014	D(lninf(−2))	0.052**
D(lnvix)	−0.051**	D(lner(−1))	−0.477**	D(lnvix(−3))	−0.000	D(lninf(−3))	0.074*
D(lnvix(−1))	−0.055**	D(lner(−2))	−0.192	D(lnvix(−4))	0.065*	D(lninf(−4))	0.050*
D(lnvix(−2))	−0.023	D(lner(−3))	−0.259	COVID-19	−0.043*	D(lninf(−5))	0.020
D(lnvix(−3))	−0.043***	D(lner(−4))	−0.054	ect(−1)*	−0.230*	D(lnvix)	−0.092
D(lnvix(−4))	−0.000	D(lner(−5))	−0.460*			D(lnvix(−1))	0.267*
D(lnvix(−5))	−0.079*	D(lninf)	−0.004			D(lnvix(−2))	0.340*

Table 4 (continued)

COVID-19	0.004	D(lninf(−1))	0.010***			D(lnvix(−3))	0.292*
ect(−1)*	−0.419*	D(lnvix)	−0.019			D(lnvix(−4))	0.285*
		D(lnvix(−1))	−0.019			COVID-19	−0.061*
		D(lnvix(−2))	0.012			ect(−1)*	−0.594*
		D(lnvix(−3))	−0.012				
		D(lnvix(−4))	−0.023				
		D(lnvix(−5))	−0.075*				
		COVID-19	0.029*				
		ect(−1)*	−0.443*				

Source: Compiled by the author based on the estimations.

Note: *, **, *** denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Limitations of the study

This study has several limitations that should be acknowledged. First, the analysis is limited to the Turkish stock market and may not be generalizable to other emerging or developed markets with different macroeconomic structures. Second, the use of annual or monthly macroeconomic data may not fully capture high-frequency fluctuations or sudden market reactions. Third, while the ARDL approach effectively models both short- and long-term relationships, it assumes linear interactions and may not account for potential nonlinearities or structural breaks in the data. Fourth, external shocks such as geopolitical developments or pandemic-related disruptions were not explicitly modeled, despite their possible influence on investor behavior and market performance. Lastly, the study focuses primarily on selected macroeconomic indicators; including additional financial or firm-level variables could provide a more comprehensive understanding of sectoral dynamics in future research.

Discussion and conclusion

This study conducts an econometric analysis of macroeconomic variables' impacts on Turkey's stock markets, aiming to identify factors influencing sectoral fluctuations. Initially, it will examine overall market effects using the XU 030, XU 100, and XUTUM indices as benchmarks. XU 030 and XU 100 represent larger, established companies, while XUTUM includes nearly all BIST-listed companies. The study examines long-term effects, finding that local interest rates and CDS premiums negatively impact stock markets, with CDS premiums being more influential. This impact is less pronounced in indices with larger institutional firms, which can leverage diverse financing options and maintain better cash flow. Exchange rates positively affect stock prices, particularly benefiting export-heavy companies and those with foreign exchange assets, while negatively impacting import-dependent sectors. The influence of US monetary policy is minor, showing a positive association only with XU 030. In emerging markets like Turkey, US interest rates can significantly affect local stock indices, especially those including large companies. Long-term effects of Turkish inflation and the global fear index on stock markets are not evident. Contrary to expectations, gold prices positively impact stock prices for XU 030 and XU 100. In Turkey, as expectations grew that foreign exchange assets, including gold, would yield returns below inflation due to exchange rate controls, economic units shifted to stock investments during a prolonged period of low interest rates and monetary expansion. In the short term, the positive effects of US monetary policy are evident across all stock prices, while increases in the VIX correlate with declines in stock markets. Long-term impacts of other factors can also be observed in the short term.

The analysis of sectoral impacts on stock prices reveals that the exchange rate is the most influential long-term variable, positively affecting all sectors. Rising Turkish interest rates and increased risk premiums negatively impact stock prices, especially in banking. While US interest rates generally have little effect, contractionary US monetary policy decreases technology stock prices and increases bank stock prices. Inflation has no long-term effect except for negatively impacting food companies. In the short term, inflation positively affects stocks in food, trade, and banking, but negatively impacts chemical, real estate, and holding companies. The VIX fear index negatively impacts bank and construction stocks long-term, while short-term effects are felt across nearly all sectors. These effects are linked to investor sentiment and market liquidity, changing with market conditions. High VIX levels particularly harm the banking sector, which relies on financial confi-

Table 5

FMOLS and DOLS regression

Variables	XUTUM DOLS Coef.	XUTUM FMOLS Coef.	XU 100 DOLS Coef.	XU 100 FMOLS Coef.	XU 030 DOLS Coef.	XU 030 FMOLS Coef.	XGIDA DOLS Coef.	XGIDA FMOLS Coef.
$lnir^{tur}$	−0.887*	−0.842*	−0.868*	−0.836*	−0.790*	−0.778*	−0.308*	−0.267*
$lnir^{us}$	0.277*	0.242**	0.347*	0.312*	0.374*	0.344*	−0.009	−0.020
lncds	−1.351*	−1.213*	−1.270*	−1.165*	−1.208*	−1.150*	−0.645*	−0.592*
lner	3.930*	3.935*	3.707*	3.733*	3.482*	3.534*	1.944*	1.980*
lninf	0.061	−0.004	0.053	−0.011	0.032	−0.030	0.030	−0.010
lngold	0.711**	0.927*	0.738**	0.924*	0.615**	0.761*	0.379	0.415***
lnvix	0.096	−0.076	0.065	−0.089	0.030	−0.098	0.038	−0.012

Variables	XINSA DOLS Coef.	XINSA FMOLS Coef.	XKMYA DOLS Coef.	XKMYA FMOLS Coef.	XUTEK DOLS Coef.	XUTEK FMOLS Coef.	XHOLD DOLS Coef.	XHOLD FMOLS Coef.
$lnir^{tur}$	−0.497*	−0.490*	−0.484*	−0.491*	−0.322**	−0.239**	−0.370*	−0.358*
$lnir^{us}$	0.134	0.103	0.161**	0.160**	−0.171	−0.1022	0.125*	0.113*
lncds	−0.269**	−0.243*	−0.402*	−0.315*	−0.901*	−0.827*	−0.466*	−0.449*
lner	1.627*	1.653*	1.583*	1.519*	1.575*	1.335*	1.722*	1.728*
lninf	0.081**	0.033***	0.028	0.010*	0.042	0.011	−0.002	−0.017**
lngold	0.684**	0.806*	−0.257	−0.032	−1.426*	−0.951*	0.250	0.293**
lnvix	−0.065	−0.101	0.044	−0.064	−0.079	−0.031	−0.037	−0.073**

Variables	XTCRT DOLS Coef.	XTCRT FMOLS Coef.	XGMYO DOLS Coef.	XGMYO FMOLS Coef.	XBANK DOLS Coef.	XBANK FMOLS Coef.		
$lnir^{tur}$	−0.172*	−0.166*	−0.681*	−0.596*	−1.406*	−1.417*		
$lnir^{us}$	−0.067	−0.063	−0.169***	−0.142	0.534*	0.529*		
lncds	−0.574*	−0.579*	−0.676*	−0.569*	−0.846*	−0.794*		
lner	1.898*	1.898*	2.248*	2.128*	2.073*	2.113*		
lninf	−0.012	−0.043*	0.079**	0.030	0.060	−0.020		
lngold	−0.073	0.028	−0.597***	−0.303	0.933***	1.146*		
lnvix	−0.016	−0.038	−0.014	−0.042	0.007	−0.101		

Source: Compiled by the author based on the estimations.

Note: *, **, *** denote statistical significance at the 1%, 5%, and 10% levels, respectively.

dence, and the construction sector, which depends on financing and economic stability. As global risks rise, investors often shift to safer assets, creating selling pressure that can lower stock prices across sectors.

Implications

The empirical investigation of the impact of various macroeconomic variables on the Borsa Istanbul Benchmark and Sectoral Indices can have several practical implications.

Investment strategy formulation. Investors may adjust their portfolios based on the anticipated changes in macroeconomic conditions, optimizing their sectoral investments to minimize risk and maximize returns.

Risk management. Knowing the relationship between macroeconomic factors and stock market indices allows both individual and institutional investors to effectively manage their risk exposure.

Monetary policy impact assessment. The findings can help policymakers understand how changes in monetary policy could impact different sectors of the stock market.

Global comparison and adaptation. The study's findings may help explain why Borsa Istanbul might react differently to other international markets under similar macroeconomic conditions.

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Examining the Relationship Between Tax Revenue and Economic Growth in Indonesia Through the Endogenous Growth Model

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ABSTRACT

The aim of this study is to analyze the causal relationship between tax revenues and economic growth in Indonesia using an endogenous growth economic model. The causality analysis employed a multivariate setup using a vector autoregression approach, with the Toda–Yamamoto **method** serving as the causality test. Using time series data from 1983 to 2021, the research **findings** indicate that the control variables — capital, labor, foreign direct investment, government spending, inflation, and exchange rates — reflect innovation mechanisms and technological progress or total factor productivity in the endogenous growth model, which captures the relationship between tax revenues and economic growth in Indonesia. **The results** of the causality test using the Toda–Yamamoto method show that tax revenues and economic growth influence each other; tax revenues help boost economic growth, and at the same time, higher economic growth leads to more tax revenues. The authors **concluded** that, in addition to tax revenue causing or encouraging economic growth through financing economic activities, increased economic growth and activity will also raise the amount of tax revenue, both from the tax base and from nominal tax revenue determined by economic growth.

Keywords: tax revenues; economic growth; endogenous; causality; Toda–Yamamoto; Indonesia

Изучение взаимосвязи между налоговыми поступлениями и экономическим ростом в Индонезии с помощью модели эндогенного роста

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АННОТАЦИЯ

Целью данного исследования является анализ причинно-следственной связи между налоговыми поступлениями и экономическим ростом в Индонезии с использованием экономической модели эндогенного роста. Для анализа причинно-следственной связи применялась многомерная модель с применением подхода векторной авторегрессии, а в качестве теста — метод Тода–Ямамото. **Результаты исследования** временных рядов с 1983 по 2021 г. показывают, что контрольные переменные — капитал, труд, прямые иностранные инвестиции, государственные расходы, инфляция и обменные курсы — отражают инновационные механизмы и технический прогресс или общую производительность факторов производства в модели эндогенного роста, которая отражает взаи-

мосвязь между налоговыми поступлениями и экономическим ростом в Индонезии. Результаты теста причинно-следственной связи с использованием метода Тоды–Ямамото показывают, что налоговые поступления и экономический рост влияют друг на друга; налоговые поступления способствуют стимулированию экономического роста и в то же время более высокий экономический рост приводит к увеличению налоговых поступлений. Авторы пришли к **выводу**, что в дополнение к налоговым поступлениям, вызывающим или стимулирующим экономический рост посредством финансирования экономической деятельности, возросший экономический рост и активность также увеличат объем налоговых поступлений, как из налоговой базы, так и из номинальных налоговых поступлений, определяемых экономическим ростом.
Ключевые слова: налоговые поступления; экономический рост; эндогенность; причинно-следственная связь; Тода–Ямамото; Индонезия

1. Introduction

Government intervention in fiscal policy can improve the economy because government spending and taxes have a multiplier effect that stimulates household consumption [1]. Taxation is a fiscal policy instrument that collects state revenue and regulates the economy [2, 3]. Taxes have a significant role for the state, particularly in spurring economic development, because the largest source of state revenue comes from the tax sector [4]. Moreover, tax is a component of economic policy that is indispensable in maintaining, strengthening, and increasing a country's economic growth and competitiveness in a globalized world.

Economic growth is one of the most significant indicators of a country's economy [5]. Indonesia is included in the Wonderlanders Asia group because of its relatively high economic growth [6]. During the last two decades (2002–2021), the average economic growth per year was 4.91% Yo Y.[1] If 2020 is excluded (when economic growth was negative due to the COVID-19 pandemic), Indonesia's average economic growth has been 5.28% Yo Y. Indonesia's relatively high economic growth has often been achieved through fiscal policy, especially from tax revenues. Over the past 20 years, namely the 2002–2021 period, tax revenues in Indonesia have continued to increase, with an average revenue of 899 trillion rupiah over these two decades.[2] Indonesia's GDP for the last two decades has continued to increase yearly, with an average of 8.539 trillion rupiah from the 2002–2021 period.[3]

Viewed from a macroeconomic perspective, a country's revenue increase will increase state spending. With an increase in government spending, GDP also increases. GDP will increase more than public spending if the increase in government spending is allocated to the domestic sector, which can cause a multiplier effect, sparking the country's economic growth and development. The economy's development will increase state revenue sources, especially tax revenues. During the 2002–2021 period, the percentage of tax revenue to GDP in Indonesia remained small, only about 8–13%.

Syadullah and Wibowo [7] conducted an empirical analysis of the factors affecting tax revenues in ASEAN countries during 2003–2012, revealing that the trend of the percentage of taxes to GDP in Indonesia continued to decline by 0.03% per year. The Organisation for Economic Co-operation and Development (OECD) remarked that the percentage of taxes to GDP in Indonesia is still below the average of countries in the Asia-Pacific region, which on average reached 20%. The percentage of tax to GDP in Indonesia in 2021 is only 9.12%, which is the lowest among the G20 and ASEAN countries.

The relationship between taxation and GDP as a proxy for economic growth has long been of great interest to policymakers, academics, and researchers in economics and taxation. Theoretically, two views consider the relationship and influence of tax revenues on economic growth. The first opinion is that taxes harm economic growth. First put forward by Keynes [1], the theory arguing for a negative influence of tax claims that taxes (T) are a government function that reduces household consumption (C). The theory maintains that the larger the T, the smaller the C, and the smaller the effect on economic growth (Y). Thus, the higher the tax revenue, the lower the economic

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[1] The World Bank. World Bank national accounts data, and OECD National Accounts data files, Indonesia 2000–2021.
[2] BPS. Statistik Indonesia, Realization of Indonesian state revenue 2000–2021. Statistical Yearbook of Indonesia 2000–2021.
[3] BPS. Statistik Indonesia, Indonesia's GDP by expenditure 2000–2021. Statistical Yearbook of Indonesia 2000–2021.

growth [1]. Taxation harms economic growth due to distortions in choices and the impact of pressure factors attached to taxes [8–10]. Several empirical studies in the 2020s found results supporting Keynes's opinion that tax revenue has a negative relationship and influence on economic growth, including Adhikari et al. [11], Chen et al. [12], Guo and Shi [13], Kim and Park [14], Maganya [15], and Mtui and Ndanshau [16].

The second opinion is that taxes have a positive effect on economic growth, a view first put forward by Peacock and Wiseman [17]. According to the authors, government expenditure is needed to encourage economic growth. To fuel growth, the government requires significant amounts of revenue, including taxes, to fund these expenditures [18]. This opinion is based on the theory of the existence of tax tolerance at a certain level in society, namely the condition that the public understands that the amount of tax the government collects is a source for government spending [17]. The tax tolerance level prevents the government from arbitrarily increasing tax collection. This second view of taxation is supported by scholars such as John F. Due and Steven A.Y. Lin, who claim that taxation has an indirect positive effect through tax-financed government spending [19, 20]. Recent research in the 2020s by theorists following Peacock and Wiseman concurs that tax revenue has a positive relationship and influence on economic growth. These studies include papers by Gurdal et al. [21], Ho et al. [22], Neog and Gaur [23, 24], Phuong et al. [25], Özker [26], and Sihaloho [27]. Empirical cross-country research on the relationship between taxation and economic growth is frequently inapplicable in Indonesia. For example, studies such as Acosta Ormaechea et al. [28] cannot be directly applied in Indonesia because the results are not in accordance with the factual conditions and experiences faced in Indonesia.

The neoclassical economic growth model provides a theoretical basis for the relationship between tax revenues and economic growth [29, 30]. The theory proposes a production function $Y = AF(K, L)$ that incorporates technological progress into the economic growth model. After deducting the contribution of input factor growth from total output growth, we can obtain total factor productivity (TFP), namely, the contribution of technological progress (A) to output, so that A = TFP.

Following the endogenous growth model pioneered by Romer [31], the mechanism of innovation and technological progress (A = TFP) is not constant but varies from time to time. Increasing TFP can encourage the transformation of economic growth to high-quality and efficient types of growth, thereby achieving sustainable economic development by relying on TFP [32]. The assumption that A is expanding allows factors such as foreign direct investment, investment in research and development, government spending, and tax revenues to influence TFP [14, 21, 33–36].

The endogenous growth model can be divided into two types: the basic model and the extensive model. The extensive model defines factors other than production factors (capital and labor) as factors that influence output or economic growth, such as financial, political, policy, and institutional factors [34, 37–39]. This study allows innovation and technology (A) to develop over time following the endogenous growth theory. Empirical studies on economic growth demonstrate that many variables can affect A or TFP. This study analyzes the relationship between tax revenues and economic growth based on an endogenous growth model. The model allows the nature and flow of the causal relationship between the two macroeconomic variables, tax revenues and economic growth, to be seen clearly, both theoretically and empirically.

In this paper, control variables in the form of capital (K), labor (L), foreign direct investment (FDI), government spending (GOV), inflation (INF), and the exchange rate of the rupiah against the US dollar (KURS) are used to illustrate the causal relationship between tax revenues and economic growth. In addition to being an illustration of the variables that affect A or TFP, the function of the control variable, which is endogenous, is to link tax revenue and economic growth so that only constants become exogenous variables.

Causality analysis in this study uses a vector autoregression (VAR) approach. The VAR is needed to model structural equations by treating all variables in the system as endogenous [40]. This study uses the Toda–Yamamoto causality test, which overcomes weakness in the Granger causality test by avoiding the spurious regression of nonstationary data at level [41].

Based on research and empirical evidence in various countries, an analysis of the exact effect of taxation on economic growth is vital for policymakers or the government. However, the nature of the causal relationship between these two macroeconomic variables has an equally important meaning. A causal flow of tax revenues to economic growth indicates that the government can use taxation as a tool of fiscal policy to influence economic activity.

The author is interested in researching the relationship between tax revenue and economic growth in Indonesia, aiming to: (1) Estimate and analyze the causal relationship between tax revenues and economic growth in Indonesia from the perspective of an endogenous growth model. The research assesses whether tax revenue follows economic growth, that is, economic growth causes an increase in tax revenue, which will ultimately increase overall state revenue, or the opposite — tax revenues are a determinant of economic growth. This relationship is indicated by the causality of tax revenue (financial sector) toward economic growth (real sector). (2) This work considers and assesses the role of the tax revenue variable in boosting the rate of economic growth in Indonesia by examining indicators of the real and financial sectors affecting *A* or TFP in the form of capital, labor, foreign direct investment, government spending, inflation, and exchange rates.

2. Materials and methods
2.1. Materials

In this study, researchers used secondary data with time series data types, which were obtained from the World Bank, the Indonesia Ministry of Finance (Directorate General of Taxes), Bank Indonesia, Statistics Indonesia, and other data sources. The data used in this study include tax revenue, economic growth, foreign capital, total workforce, government spending, inflation, and exchange rates from 1983–2021 (annual). The selection of research data began in 1983 because it was in this year that Indonesia's tax reform began. Consequently, empirical analysis of the relationship between taxation and the economy must start from this year of reform.

2.2. Methods

In this study, the analytical model used to answer the research objectives is a VAR model with a Toda–Yamamoto causality test to analyze the causal relationship between tax revenues and economic growth. Toda and Yamamoto [41] developed their causality test to overcome the weakness of the Granger causality test by avoiding spurious regression data that is not stationary at levels. According to Toda and Yamamoto, the Granger causality test can be applied to nonstationary data. It will obtain valid estimation results if the maximal order is at the level of integration (*dmax*) used in the analysis model. We can overcome spurious causality by using an augmented VAR model with the optimal lag order plus the maximum integration order in the variables. This technique can also ensure that statistical and causality tests have a standard asymptotic distribution.

The Solow and Swan [29, 30] growth model illustrates that a country's economic output is the result of two types of input, namely capital and labor, with the following production function:

$$Y_t = f\left(K_t, L_t\right), \qquad (1)$$

where Y = output, K = capital, and L = labor, the production function is a constant return to scale, meaning that the same percentage increase in all factors of production also causes an increase in production with the same percentage. Furthermore, by incorporating technology into the production function, the production function becomes:

$$Y_t = f\left(K_t, L_t, A_t\right), \qquad (2)$$

A is a new variable in the form of technological progress, which causes capital and labor efficiency. Capital efficiency includes the use of technology in the form of tools and machines in the production process. Meanwhile, labor efficiency refers to increasing labor productivity in the form of improving the workforce's education, skills, and health. The production function in Solow and Swan's [29, 30] model is based on the following Cobb–Douglas production function:

$$Y_t = A_t K_t^{\alpha} L_t^{\beta}. \qquad (3)$$

The equation above shows the Cobb–Douglas function, where Y represents the total production in an economy. A represents total factor productivity (TFP), K is capital, L is labor, and the parameters α and β are the elasticity of capital and labor output, respectively. These values are constants determined by the available technology. The Cobb–Douglas production function can be described as economic output in the form of economic growth and GDP [42]. Economic growth arises from capital accumulation, population or labor growth, and technological change as exogenous.

This study adopts an endogenous growth model by allowing technological variables, *A* or TFP, to develop over time. Empirical studies on economic growth have revealed that many variables can affect *A* or TFP. The production function equation used in this research model adopts previous research conducted by Fosu and Magnus [43], Ghazo et al. [44], Gurdal et al. [21], Mtui and Ndanshau [16], and Takumah and Iyke [36], by replacing and adding new variables, the equation becomes as follows:

Table 1

Stationarity test results from ADF and PP tests

Variable	ADF test		PP test	
	Level	First difference	Level	First difference
Y	1.0000[d]	0.0029*	1.0000[d]	0.0031*
K	0.3492[d]	0.0006*	0.5562[d]	0.0006*
L	0.4905[d]	0.0021*	0.0190**	0.0006*
TAX	0.9985[d]	0.0000*	0.9994[d]	0.0000*
FDI	0.5780[d]	0.0000*	0.6780[d]	0.0000*
GOV	0.2676[d]	0.0000*	0.2676[d]	0.0000*
INF	0.0004*	0.0000*	0.0004*	0.0001*
KURS	0.8181[d]	0.0000*	0.8608[d]	0.0000*

Source: Developed by the authors.

Note: * significant at 1% degree of confidence; ** significant at 5% confidence level; [d] not significant

$$A_t = f\left(TAX_t, FDI_t, GOV_t, INF_t, KURS_t\right) =$$
$$= TAX_t^{\delta_1} \, FDI_t^{\delta_2} \, GOV_t^{\delta_3} \, INF_t^{\delta_4} \, KURS_t^{\delta_5}. \quad (4)$$

By substituting equation (4) into equation (3), the following equation model is obtained:

$$Y_t = \mu K_t^{\alpha} \, L_t^{\beta} TAX_t^{\delta_1} FDI_t^{\delta_2} GOV_t^{\delta_3} INF_t^{\delta_4} KURS_t^{\delta_5}. \quad (5)$$

By changing $\mu = \gamma$, then the equation (5) becomes:

$$Y_t = \gamma + \alpha K_t + \beta L_t + \delta_1 TAX_t + \delta_2 FDI_t +$$
$$+ \delta_3 GOV_t + \delta_4 INF_t + \delta_5 + \varepsilon_t, \quad (6)$$

where ε_t denotes the unobserved determinant of the total output and Y_t is white noise.

The VAR approach is needed to model structural equations by treating all variables in the system as endogenous variables. These endogenous variables are described as a function of all endogenous variables' past (*lag*) values. Theoretically, economic growth (*Y*), capital (*K*), labor (*L*), tax revenues (TAX), foreign direct investment (FDI), government spending (GOV), inflation (INF), and the rupiah exchange rate against the U.S. dollar (KURS) are interrelated variables. Therefore, the eight variables are endogenous and can then be analyzed using the VAR method, leaving only constants as exogenous variables.

Following Yamada [45], the estimation of the VAR analysis model using the Toda–Yamamoto causality test begins with testing the stationarity of the data or variables whose purpose is to determine the order of integration to obtain the *dmax* value. Next, the optimum lag (*m*) to be used is determined for a

multivariate causality test (because several variables are used in the study).

3. Results and discussion
3.1. Results

To estimate and analyze the quality relationship between tax revenues and economic growth, control variables are used that affect *A* or TFP, the steps conducted include the following.

3.1.1. Stationarity testing with the ADF and PP tests

The results of differencing at the first difference level indicated that all variables are stationary using either the ADF or PP stationarity tests. All variables estimated in this study were stationary at the first difference or integrated at the integration degree of one, *I*(1), or *dmax* = 1 (*Table 1*).

3.1.2. Optimum lag length test with FPE and AIC

In particular, this study uses FPE and AIC criteria in determining the length of the optimal lag as well as the information shown in *Table 2*. An optimal lag of 3 not only fulfills the FPE and AIC criteria but also the LR and HQ; thus, the optimal lag length used in this study is 3, or *m* = 3.

3.1.3. Johansen cointegration test

Cointegration test results show a long-term balance among the variables in this study (*Table 3*). The Toda–Yamamoto causality test can be used to see long-term relationships between variables and is

Table 2
Optimal lag length test results

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−1953.089	NA	2.86e+37	108.9494	109.3013	109.0722
1	−1669.819	424.9055	1.60e+32	96.76773	99.93477*	97.87311
2	−1597.421	76.42048	1.76e+32	96.30116	102.2833	98.38910
3	−1450.820	89.58958*	1.25e+31*	91.71221*	100.5095	94.78271*

Source: Developed by the authors.

Table 3
Johansen cointegration test results

Unrestricted Cointegration Rank Test (Trace)				
Hypothesized	Eigenvalue	Trace	0.05	Prob.**
No. of CE(s)		Statistic	Critical Value	
None *	0.861876	209.2675	159.5297	0.0000
At most 1 *	0.620632	136.0222	125.6154	0.0099
At most 2 *	0.609259	100.1599	95.75366	0.0240
At most 3	0.473569	65.39067	69.81889	0.1072
At most 4	0.440402	41.65019	47.85613	0.1688
At most 5	0.338604	20.17037	29.79707	0.4114
At most 6	0.117494	4.874492	15.49471	0.8220
At most 7	0.006731	0.249882	3.841466	0.6172

Source: Developed by the authors.

Note: * Denotes rejection of the hypothesis at the 0.05 level. **MacKinnon–Haug–Michelis (1999) p-values.

still able to produce valid and reliable estimates on data that has integration, no integration, cointegration, or even no cointegration at all, if the maximal order of integration (*dmax*) and optimal *lag* (m) are added to the model [46–49].

3.1.4. Toda–Yamamoto causality test with modified Wald test (mWald test)

Testing with the Toda–Yamamoto method aims to examine the relationship between the variables analyzed in the study (*Table 4*). The question posed in this research regards the causal relationship between the development of tax revenue and economic growth in Indonesia. Specifically, this study examines whether the development of tax revenue follows economic growth so that economic growth causes an increase or change in tax revenue as well as other control variables. This study also examines the converse, asking whether tax revenues and control variables representing *A* or TFP in the endogenous growth model are determinants of economic growth.

3.2. Discussion

Endogenous growth theory is one of the economic theories used to look at the relationship and influence of tax revenues on the economic development of a country, both in terms of the factors that drive economic growth and in realizing sustainable economic development. Robust evidence from this study demonstrates that the variable tax revenue is one factor that influences A or TFP. Several previous researchers who justified the variable tax revenue as a critical factor affecting economic growth as seen from endogenous growth models were Arvin et al. [50], Bhattacharyya and Gupta [51], Curtis et al. [52], Fu and Le Riche [53], and Todtenhaupt and Voget [54].

The results of the causality test using the Toda-Yamamoto method show that tax revenues determine and cause changes and increase economic growth, with a chi-squared value of 78.96730 and a very real probability of $\alpha = 0.0000$. The growth of economic activity requires many funds to expand; this can be done if the sources of state revenue are fulfilled or are in large numbers, and through tax revenues, as

Table 4
mWald test causality test results

Variable	Chi-Squared	Probability	Conclusion
K → Y	5.141001	0.1618[d]	There is no causality
L → Y	37.78705	0.0000[*]	Have causality
TAX → Y	78.96730	0.0000[*]	Have causality
FDI → Y	12.49263	0.0059[*]	Have causality
GOV → Y	9.652102	0.0218[**]	Have causality
INF → Y	74.44929	0.0000[*]	Have causality
KURS → Y	6.864010	0.0764[***]	Has causality at α = 10%
Y → K	17.69821	0.0005[*]	Have causality
L → K	15.13820	0.0017[*]	Have causality
TAX → K	16.81594	0.0008[*]	Have causality
FDI → K	20.70149	0.0001[*]	Have causality
GOV → K	16.52883	0.0009[*]	Have causality
INF → K	15.23952	0.0016[*]	Have causality
KURS → K	18.68051	0.0003[*]	Have causality
Y → L	8.791405	0.0322[**]	Have causality
K → L	10.42271	0.0153[*]	Have causality
TAX → L	3.143121	0.3701[d]	There is no causality
FDI → L	6.730624	0.0810[***]	Has causality at α = 10%
GOV → L	5.135627	0.1621[d]	There is no causality
INF → L	6.408598	0.0933[***]	Has causality at α = 10%
KURS → L	2.426588	0.4887[d]	There is no causality
Y → TAX	7.291364	0.063[2****]	Has causality at α = 10%
K → TAX	32.81029	0.0000[*]	Have causality
L → TAX	16.57753	0.0009[*]	Have causality
FDI → TAX	13.86143	0.0031[*]	Have causality
GOV → TAX	20.51545	0.0001[*]	Have causality
INF → TAX	8.992576	0.0294[**]	Have causality
KURS → TAX	21.59716	0.0001[*]	Have causality
Y → FDI	0.632820	0.8889[d]	There is no causality
K → FDI	0.942870	0.8151[d]	There is no causality
L → FDI	1.357898	0.7154[d]	There is no causality
TAX → FDI	3.913526	0.2710[d]	There is no causality
GOV → FDI	1.329687	0.7221[d]	There is no causality
INF → FDI	1.928040	0.5875[d]	There is no causality
KURS → FDI	7.227704	0.0650[***]	Has causality at α = 10%
Y → GOV	0.413011	0.9375[d]	There is no causality
K → GOV	2.139001	0.5441[d]	There is no causality
L → GOV	2.110619	0.5498[d]	There is no causality
TAX → GOV	1.787212	0.6177[d]	There is no causality
FDI → GOV	3.582055	0.3103[d]	There is no causality
INF → GOV	0.953870	0.8124[d]	There is no causality
KURS → GOV	1.895864	0.5943[d]	There is no causality

Variable	Chi-Squared	Probability	Conclusion
Y → INF	21.34223	0.0001*	Have causality
K → INF	10.27779	0.0163*	Have causality
L → INF	13.80633	0.0032*	Have causality
TAX → INF	21.50674	0.0001*	Have causality
FDI → INF	1.496107	0.6832[d]	There is no causality
GOV → INF	4.618413	0.2020[d]	There is no causality
KURS → INF	1.967998	0.5791[d]	There is no causality
Y → KURS	174.2510	0.0000*	Have causality
K → KURS	46.01384	0.0000*	Have causality
L → KURS	156.0532	0.0000*	Have causality
TAX → KURS	178.9649	0.0000*	Have causality
FDI → KURS	32.08240	0.0000*	Have causality
GOV → KURS	53.31360	0.0000*	Have causality
INF → KURS	170.3759	0.0000*	Have causality

Source: Developed by the authors.

Note: * significant at 1% degree of confidence; ** significant at 5% confidence level; *** significant at 10% confidence level; [d] not significant.

the most potential and largest source of state revenue, will be able to meet the needs of the government to encourage economic growth. Similar results that tax revenue has a causal relationship and a positive influence on economic growth were also obtained by Chen et al. [12] in Vanuatu, Ho et al. [22] in 29 developing countries, Neog and Gaur [23] in India, and Takumah and Iyke [36] in Ghana, who examined the relationship between tax revenue and economic growth by modeling the endogenous growth model in assessing the relationship and effect of taxation on economic growth.

Furthermore, with a chi-squared value of 7.291364 and a real probability of $\alpha = 0.0632$, economic growth causes an increase in tax revenue, which will ultimately result in an increase in overall state revenue. These findings indicate that there is a bidirectional causality relationship between tax revenues and economic growth. This means that besides tax revenue causing or encouraging economic growth through financing economic activity, increased economic growth and economic activity will also increase the amount of tax revenue, both from the tax base and nominal tax revenue. Previous empirical studies that yielded the same findings, namely that there was a two-way relationship or mutual influence between tax revenues and economic growth, were research conducted by Maganya [15] in Tanzania and Vatavu et al. [55] in some Central and Eastern European countries and the richest European countries. Gurdal et al. [21] found

two conflicting pieces of evidence in analyzing the relationship between tax revenue and economic growth in G7 countries. The study uses two different causal panel approaches to make comparisons. According to the causality test results based on the time level, there is no causal relationship between economic growth and tax revenues. On the other hand, the results of causality in the frequency domain indicate that there is mutual causality between economic growth and tax revenues. Combining tax revenues and economic growth will reduce long-term dependence on debt and aid from other countries [56–58]. This good combination can be realized by ensuring good governance for the people by promoting government openness and accountability [59].

The results of this study also prove that the control variables used in this study represent innovation, mechanisms, and technological progress, symbolized by A or TFP in the endogenous growth model, to capture the relationship between tax revenue and economic growth in Indonesia. Endogenous growth theory implies that policies that adhere to openness, competition, change, and innovation will encourage economic growth [60].

The size of the effect of tax revenue in driving the rate of economic growth depends on the structure of the model and the value of the parameters in the model. Endogenous growth theory provides a model that can assess the relationship and influence of taxation on economic growth. When economic growth

is endogenous, taxation has an influence and can also influence the factors that determine the level of economic growth [61].

4. Conclusion and recommendations

The endogenous growth theory provides a model that can assess the relationship and influence of taxation on economic growth. Based on the analysis of the VAR model with Toda Yamamoto's causality test, there is a bidirectional causality phenomenon between tax revenues and economic growth in Indonesia. Tax revenue acts as an engine that will boost economic growth through the availability of funds from tax revenue collection to facilitate economic activity and expansion. The size of the effect of tax revenues in driving economic growth depends on the structure of the model and the parameter values in the model. The results of this study confirm that taxes are an important instrument for the government and must be used to boost economic growth. Likewise, economic growth will increase the amount of tax revenue, both from the tax base and nominal tax revenue.

Indonesia is one of the countries that fall into the category of countries that often experience budget deficits. Policymakers or the government can implement policies that increase the scope of tax revenue to increase state revenue from the taxation sector.

Increasing the scope of tax revenue will be realized if the government or policymakers can ensure that the government has good legitimacy, accountability, and responsiveness to the community through promoting government openness and accountability. This policy certainly requires the role and contribution of the government, economic actors, and society. An efficient, effective, safe, fair, transparent, and legally clear tax system will become a source of state revenue, which, apart from boosting economic growth, is also to get out of dependence on debt or foreign aid and natural resources.

5. Limitations and future research

This study it is not free from limitations. This research only analyzes the relationship between tax revenues and economic growth by using quantitative variables originating from the financial sector and the real sector. The author suggests further research involving qualitative variables such as certainty and accountability of law enforcement, political stability and security, regulatory quality, fraud and corruption control, market sentiment, and other variables that could be considered so that the role and contribution of tax revenues in driving economic growth and creating sustainable economic development can be further optimized.

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