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CONTACT INFORMATION
Financial University
Leningradsky prospekt, 53,
office 5.6
125167, Moscow,
Russian Federation
Telephone: +7 (499) 553-10-74
(internal 10-88)
Website: https://rbes.fa.ru/jour

AUTHOR INQUIRIES
Inquiries relating to the submission of articles can be sent by electronic mail to ambotchkarev@fa.ru.

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A Systematic Review on Exploring the Influence of Industry 4.0 Technologies to Enhance Supply Chain Visibility and Operational Efficiency

T. Khan[a], Md M.H. Emon[b], Md A. Rahman[c]
[a,b] Bangladesh University of Professionals (BUP), Dhaka, Bangladesh;
[c] Infrastructure University Kuala Lumpur (IUKL), Kajang, Malaysia

ABSTRACT

This systematic review investigates the implications of Industry 4.0 technologies on supply chain visibility and operational efficiency. The primary **aim** is to discern the impact of technological integration on contemporary supply chain dynamics. **Methods:** A comprehensive search strategy identified 65 pertinent studies published between 2015 and 2023. The review adheres to systematic methodologies, employing the Critical Appraisal Skills Programme framework for quality assessment. Data synthesis incorporates qualitative and quantitative analyses to distill key themes and patterns. **Results:** The review unveils the pivotal role of information visibility in fortifying supply chain outcomes, emphasizing the need for a dual investment strategy encompassing technological solutions and a collaborative organizational culture. Regional variations in supply chain practices, insights from humanitarian supply chains, and the influence of environmental factors on agility broaden the understanding of Industry 4.0 implications. Organizations are urged to adopt a context-specific, adaptive approach, recognizing the significance of intangible assets and tailoring strategies to local contexts for optimal supply chain performance. This systematic review **contributes** a nuanced understanding of Industry 4.0's transformative potential in supply chain management, emphasizing the interplay between technology, organizational culture, and regional contexts.
Keywords: Industry 4.0; supply chain management; supply chain visibility; operational efficiency; information visibility; collaboration; agility; sustainability; artificial intelligence; internet of things; systematic review

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ОРИГИНАЛЬНАЯ СТАТЬЯ

Систематический обзор по изучению влияния технологий Индустрии 4.0 на повышение прозрачности цепочки поставок и операционной эффективности

Т. Хан[a], Мд М.Х. Эмон[b], Мд А. Рахман[c]
[a, b] Бангладешский университет специалистов (BUP), Дакка, Бангладеш;
[c] Университет инфраструктуры Куала-Лумпур (IUKL), Каджанг, Малайзия

АННОТАЦИЯ

В данном систематическом обзоре исследуется влияние технологий Индустрии 4.0 на прозрачность цепочки поставок и операционную эффективность. Основная **цель** — выявить влияние технологической интеграции на современную динамику цепей поставок. **Методы:** с помощью комплексной стратегии поиска было выявлено

65 соответствующих исследований, опубликованных в период с 2015 по 2023 г. В обзоре использовалась систематическая методология, а для оценки качества применялась программа развития навыков проведения критической оценки. Синтез данных включает качественный и количественный подходы для выявления ключевых тем и закономерностей. **Результаты:** в обзоре раскрывается ключевая роль информационной прозрачности в улучшении результатов работы цепочки поставок, подчеркивается необходимость двойной инвестиционной стратегии, включающей технологические решения и организационную культуру, основанную на сотрудничестве. Анализ региональных различий в практике цепочек поставок, опыта гуманитарных цепочек поставок и влияния экологических факторов на гибкость расширяют понимание последствий Индустрии 4.0. Организациям настоятельно **рекомендуется** применять адаптивный подход с учетом конкретных условий, принимая во внимание важность нематериальных активов и адаптируя стратегии к местным контекстам для оптимального функционирования цепочки поставок. Данный систематический обзор способствует детальному пониманию преобразующего потенциала Индустрии 4.0 в управлении цепочкой поставок, подчеркивая взаимодействие между технологиями, организационной культурой и региональными контекстами.
Ключевые слова: Индустрия 4.0; управление цепочкой поставок; прозрачность цепочки поставок; операционная эффективность; прозрачность информации; сотрудничество; гибкость; устойчивость; искусственный интеллект; интернет вещей; систематический обзор

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Introduction

Industry 4.0 has brought about a significant change in manufacturing and supply chain methods, introducing a new age defined by linked, intelligent, and automated systems [1]. Industry 4.0, often known as the fourth industrial revolution, signifies the integration of technological progress that has fundamentally changed conventional business structures and operating procedures [2]. This revolution expands upon the groundwork established by previous movements, integrating cyber-physical systems, the Internet of Things (IoT), Artificial Intelligence (AI), big data analytics, and automation into a unified and revolutionary structure [3]. The term "Industry 4.0" was coined in Germany as a component of a government endeavour to promote the digitization of industry [4]. The concept draws upon the chronological development of industrial revolutions — the initial one distinguished by the utilization of water and steam power for mechanization, the second one characterized by the widespread production facilitated by electric power, and the third one propelled by automation and computerization [5]. Industry 4.0 signifies the merging of physical and digital technologies, resulting in the development of intelligent systems that can make decisions in a decentralized manner and communicate in real-time [6].

Although there is an increasing amount of literature on Industry 4.0 and its influence on supply chain management, there is a requirement for a methodical examination that combines and assesses the current understanding. While individual studies may give insights into certain issues, a holistic knowledge of how Industry 4.0 technologies together contribute to supply chain visibility and operational efficiency (OE) is absent [7]. This systematic review seeks to address this deficiency by thoroughly examining and consolidating the existing literature, thus enhancing our comprehension of the present research landscape. It will uncover patterns, discern trends, and provide valuable perspectives for future studies and industry implementations.

Industry 4.0 is fundamentally based on a set of essential components that work together to provide its revolutionary capacity [2, 8]. Cyber-physical systems serve as the foundation, merging physical operations with digital connection to provide independent decision-making [9, 10]. The Internet of Things (IoT) enables the linking of devices, enabling smooth data interchange and live monitoring throughout the whole production and supply chain [11]. AI facilitates the use of sophisticated machine learning algorithms, empowering systems to scrutinize data, provide well-informed judgements, and adjust to ever-changing surroundings [12]. Big data analytics utilizes extensive databases to derive significant insights, which guide strategic decision-making. Automation, which integrates robots and autonomous systems, improves efficiency and adaptability in manufacturing and supply chain processes [13].

The ramifications of Industry 4.0 extend well beyond the physical production area, exerting a substantial influence on the management of supply chains [14, 15]. The conventional linear supply chain model, which is defined by distinct and sequential phases, has transformed into a dynamic, networked, and data-centric supply network [16]. The incorporation of Industry 4.0 technology offers unparalleled insight into the complete supply chain ecosystem, encompassing the procurement of raw materials to the delivery of the final product to the end-user [17].

Industry 4.0 significantly improves supply chain visibility, which is a crucial aspect of supply chain management. Historically, supply chain visibility denoted the capacity to monitor the progression of merchandise across many phases [18]. Nevertheless, in the era of Industry 4.0, it assumes a more expansive connotation. Organizations may obtain valuable information about inventory levels, manufacturing progress, and logistical operations through real-time monitoring, which is made possible by IoT devices and sensors [19]. The utilization of real-time data enables organizations to forecast and take proactive measures to mitigate future interruptions, optimize the management of inventories, and improve overall operational resilience [20].

The incorporation of Industry 4.0 technology profoundly transforms the methods by which operational efficiency is attained within the supply chain. Utilizing data-driven solutions improves operational processes, resulting in shorter lead times, decreased bottlenecks, and improved resource utilization [21]. AI systems utilize past and current data to predict patterns in demand, allowing organizations to optimize their production schedules and inventory levels. AI and robotics-driven automation optimize repetitive tasks, allowing human resources to dedicate their efforts to intricate decision-making processes [22]. This cohesive strategy establishes a versatile and efficient network of suppliers, resulting in a supply chain structure that can easily adjust to dynamic market requirements [23].

Industry 4.0 offers unique prospects for improving supply chain operations, but it also brings about obstacles that organizations need to overcome. Factors such as worries about cybersecurity, protection of data privacy, and the necessity of a competent staff to handle this sophisticated technology necessitate thoughtful deliberation [24]. Furthermore, the adoption of Industry 4.0 technologies requires a change in the culture of organizations, ensuring that all stakeholders are in sync with the revolutionary nature of these innovations [25].

In addition to its growing significance in business, I4T is also becoming more widely discussed in academic circles. This has influenced a variety of fields, including business research, which has taken an interest in the topic and is now researching I4T from a more comprehensive standpoint [26]. In this connection, supply chain management (SCM) has been identified as one of the domains that stands to gain the most from I4T applications [27]. It is necessary to investigate how AI might benefit the dynamic aspects of SCM such as supply chain visibility (SCV) and OE, as evident from the emerging interest from practitioners and researchers in this area [28]. This need has come up in a number of investigations. The current study fills this gap by examining the research aims and conducting a systematic review. This, we hope, will encourage more study on this fascinating and significant subject.

Aim of the paper

The main aim of this work is to provide a thorough and analytical systematic evaluation of the current literature that examines the effects of Industry 4.0 technologies on supply chain visibility and operational efficiency. In this regard, the article focuses on a thorough analysis of a wide range of studies that focus on the relationship between Industry 4.0 and supply chain management. Keeping this in mind, the primary objective of the research is to comprehensively analyze relevant research studies on Industry 4.0 technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), big data analytics, and automation, specifically in the context of supply chain operations. In addition, the article aims to thoroughly assess the methodological quality of the chosen studies by examining their research designs, data collection techniques, and analytical procedures to assure the credibility and accuracy of the information provided. An essential task is to identify and analyze recurring patterns, emerging trends, and common themes in the chosen literature. This will provide valuable insights into the impact of various Industry

4.0 technologies on supply chain visibility and operational efficiency. The article seeks to draw comprehensive conclusions on the impact of Industry 4.0 on supply chain dynamics by conducting analytical research and interpretation. It examines how these technologies affect visibility, simplify processes, and improve overall efficiency. Furthermore, it is essential to identify gaps and limits in the current body of literature in order to direct future research and provide valuable insights to academics, practitioners, and policymakers on unanswered problems and challenges in the field. Thereby, the research aims to examine the practical implications of the findings for industry practitioners and decision-makers. It provides actionable advice on how to successfully use Industry 4.0 technologies to improve supply chain visibility and operational efficiency. Having said that, the present study aims to enhance scholarly knowledge by summarizing important insights, theoretical frameworks, and methodological advancements from the literature review. It provides a comprehensive and current understanding of the research on Industry 4.0 in the context of supply chain management. Altogether, the article intends to serve as a helpful resource for academics, industry experts, and policymakers who are interested in the convergence of Industry 4.0 technologies and supply chain operations. It aspires to stimulate additional study in this dynamic and expanding sector.

Literature review

Search strategy

The search strategy aimed to systematically identify and retrieve relevant studies published between 2015 and 2023 that explored the intersection of Industry 4.0 technologies with supply chain visibility and operational efficiency. This search was conducted in major academic databases, including PubMed, IEEE Xplore, ScienceDirect, and SpringerLink. The search utilized a combination of keywords and Boolean operators to refine and target the query effectively [29]. The primary search terms included "Industry 4.0", "supply chain visibility", "operational efficiency", "Internet of Things (IoT)", "Artificial Intelligence (AI)", "big data analytics", and "automation". The search was restricted to English-language publications, and the publication date range was set from 2015, to the knowledge cutoff date in 2023. The search strategy was an it-

Table 1

Inclusion and exclusion criteria

Criteria	Inclusion Criteria	Exclusion Criteria
Publication period	Studies published between 2015, and 2023	Studies published before 2015 or after the knowledge cutoff date in 2023
Type of document	Peer-reviewed journal articles and conference proceedings	Non-peer-reviewed documents, books, theses, and dissertations
Type of study	Studies focusing on the integration of Industry 4.0 technologies in supply chain management	Studies unrelated to Industry 4.0 or lacking a clear focus on supply chain management
Language	Studies published in the English language	Studies published in languages other than English
Population	No specific population criteria	Studies with a primary focus on populations unrelated to supply chain management or Industry 4.0 technologies
Research topic	Studies examining the impact of Industry 4.0 on both supply chain visibility and operational efficiency	Studies not directly related to Industry 4.0 technologies, supply chain visibility, or operational efficiency

Source: Developed by the authors.

erative process, allowing for adjustments based on initial search results and additional keywords identified during the process [30].

Inclusion and exclusion criteria

To maintain the relevance and rigor of the systematic review, explicit inclusion and exclusion criteria were established (*Table 1*). Inclusion criteria encompassed studies published in peer-reviewed journals or conference proceedings, focusing on the integration of Industry 4.0 technologies (specifically IoT, AI, big data analytics, and automation) in supply chain management. Studies were required to examine the impact of Industry 4.0 on both supply chain visibility and operational efficiency. Exclusion criteria included studies not published in English, those not directly related to Industry 4.0 technologies or supply chain management, and studies lacking a clear focus on supply chain visibility or operational efficiency.

Methodological quality assessment

To ensure the reliability and validity of the synthesized findings, a methodological quality assessment was conducted for each selected study. The Critical Appraisal Skills Programme (CASP) framework for systematic reviews was adapted for this purpose [31]. The assessment criteria included study design, data collection methods, data analysis, and the overall contribution to the research area. Two independent reviewers assessed each study, and any discrepancies were resolved through discussion and consensus. The methodological quality assessment aimed to identify biases and limitations within each study, allowing for the weighting of evidence during data synthesis [32]. Studies with robust methodologies and transparent reporting were given greater weight in the analysis.

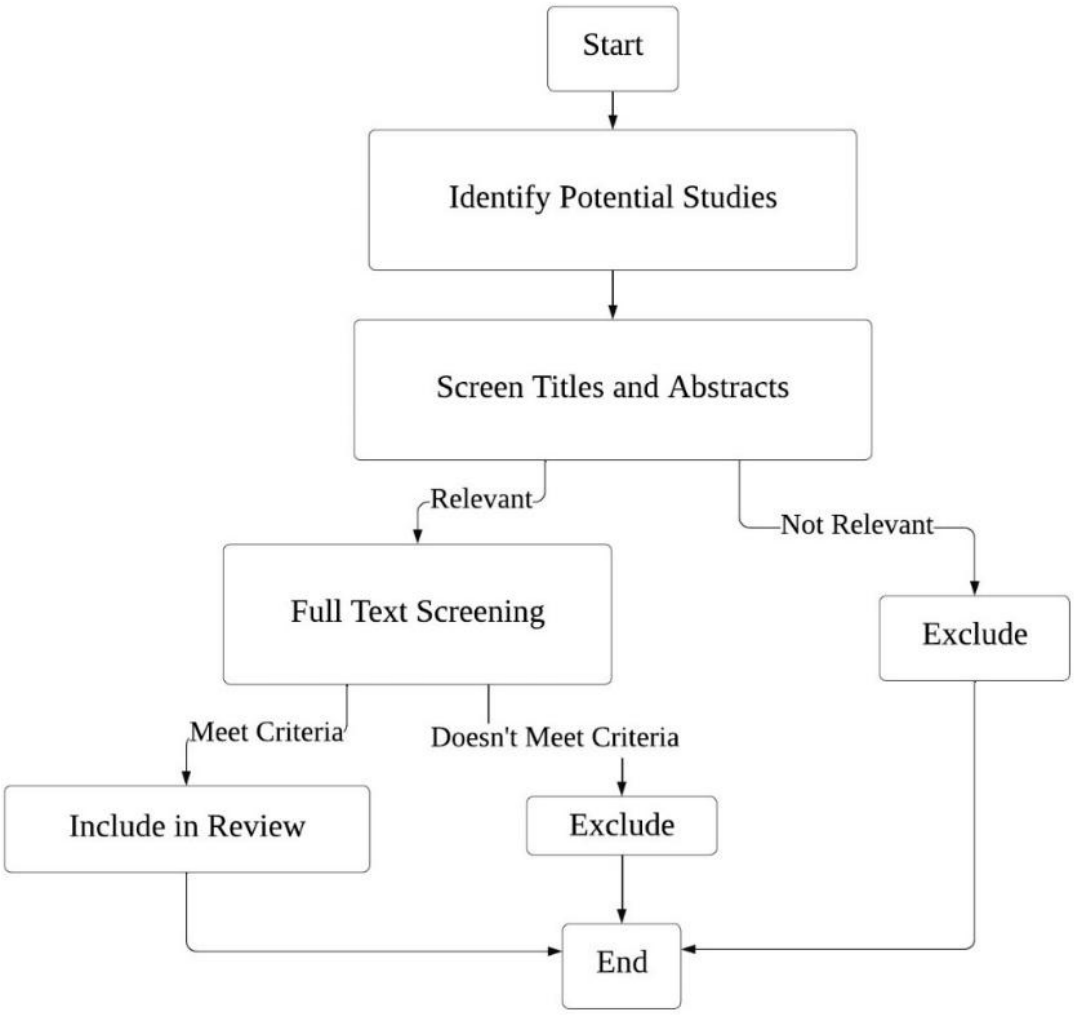

Fig. **Search strategy, outlining the subsequent identification and screening of appropriate sources**

Source: Developed by the authors.

Selection of studies

The systematic review commenced with an exhaustive database search, spanning prominent academic repositories such as PubMed, IEEE Xplore, ScienceDirect, and SpringerLink (see *Figure* below). This initial search identified a total of 152 records related to Industry 4.0 technologies and their implications for supply chain visibility and operational efficiency. Subsequently, the removal of duplicates was undertaken to streamline the dataset, resulting in the elimination of 76 redundant records. Following this de-duplication process [33], the remaining records underwent a meticulous title and abstract screening to assess their alignment with the systematic review's research objectives.

The next step involved a comprehensive evaluation of the full texts of these retained studies, applying predefined inclusion and exclusion criteria. This critical assessment led to the exclusion based on quality issues identified during the checklist evaluation. After this thorough evaluation, 65 studies remained eligible for inclusion in the qualitative and, where applicable, quantitative synthesis. The systematic review process adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [34], and a PRISMA flowchart was employed to document the transparent selection process, illustrating the progression from the identification of relevant records to the final inclusion of studies in the synthesis.

Data extraction and analysis

Once the final set of studies was selected, a systematic data extraction process was implemented [35]. A standardized data extraction form was developed, including key elements such as study characteristics, research objectives, Industry 4.0 technologies investigated, supply chain visibility outcomes, operational efficiency outcomes, and key findings. Data extraction was performed independently by two reviewers to enhance reliability. The extracted data were then synthesized to identify common themes, trends, and patterns related to the impact of Industry 4.0 technologies on supply chain visibility and operational efficiency. This synthesis involved both qualitative and, where appropriate, quantitative analysis. The findings were organized and presented in a structured manner, facilitating the exploration of relationships and variations across the selected studies (*Table 2*). This systematic approach aims to provide a robust foundation for the subsequent presentation and discussion of the systematic review results [36].

Table 2
Characteristics of the studies included in the review

Sl.	Authors/ Year	Methodology	Country / Continent	Findings
1	[37]	Quantitative	Malaysia	Addressing knowledge gaps and fostering technological collaboration between multinational and local firms improves energy efficiency for businesses. Initiatives include converting waste into energy, empowering local companies to generate renewable energy within their supply chain networks
2	[38]	Quantitative (Survey)	India	Supply chain visibility (SCV) significantly influences social and environmental performance under the moderation effect of product complexity in India
3	[39]	Quantitative (Survey)	India	Reducing behavioral uncertainty amplifies the direct influence of trust and cooperation on bolstering supply chain resilience in India. Positive interaction effects strengthen the dynamics of trust, cooperation, and supply chain visibility

Table 2 *(continued)*

Sl.	Authors/ Year	Methodology	Country / Continent	Findings
4	[40]	Quantitative (PLS-SEM)	24 countries	The synergy between tangible and intangible resources fosters collaboration among disaster relief partners, enhancing supply chain agility across 24 countries. Artificial intelligence-driven big data analytics and intergroup leadership shape humanitarian supply chain dynamics
5	[41]	Quantitative (Survey)	India	Crisis leadership enhances the impact of digital technologies, improving information visibility and collaboration within emergency supply chain relief efforts in India
6	[42]	Quantitative (PLS-SEM)	India	The integration of open innovation and relational view offers a theoretical framework for understanding the interplay among information sharing, supply chain visibility, swift-trust, commitment, and collaboration in humanitarian supply chains in India
7	[43]	Quantitative (Survey)	India	Effective information sharing and supply chain connectivity resources positively impact supply chain visibility in India. Top management commitment amplifies synergy, enhancing supply chain agility, adaptability, and alignment
8	[44]	Quantitative (Survey)	205 International Non-Government Organizations	Big Data Predictive Analytics (BDPA) significantly impacts visibility and coordination in humanitarian supply chains for 205 international non-government organizations. Swift trust serves as a mediating factor, challenging its essential role in enhancing actor coordination
9	[45]	Quantitative (PLS-SEM)	India	Coercive pressures, mediated by top management belief and participation, significantly influence resource selection, impacting supply chain connectivity and information sharing in India. Normative and mimetic pressures show no significant influence on top management participation
10	[46]	Quantitative (PLS-SEM)	China	Social control effectively diminishes opportunistic behaviors among supply chain members in China. Information sharing with customers curtails opportunistic behaviors, while sharing with suppliers enhances overall supply chain performance
11	[47]	Quantitative (Survey)	France	External and internal managerial processes contribute to enhanced agility in France. Limited impact observed from supply chain visibility processes, emphasizing the role of unexplored higher-level processes and routines

Table 2 *(continued)*

Sl.	Authors/ Year	Methodology	Country / Continent	Findings
12	[48]	Quantitative (PLS-SEM)	India	Data analytics capability enhances supply chain resilience in India. Big data access, improved data processing capabilities, and human skills contribute to a competitive advantage through effective coordination, domain knowledge, and data science
13	[49]	Systematic Literature Review (SLR)	-	Supply chain visibility (SCV) attributes contribute to benefits surpassing operational efficiency through information accessibility, quality, and usefulness. A process-oriented perspective underscores the correlation between SCV effectiveness and enhanced business performance
14	[50]	Quantitative (Survey)	International participants	Higher supply chain visibility requires a strong organizational information processing capability. Positive association between supply chain visibility and responsiveness is evident with high internal integration
15	[51]	Quantitative (Survey)	Taiwan	Supply chain visibility plays a pivotal role in bolstering reconfigurability and performance in Taiwan. Emphasizes the critical contribution of visibility for learning, coordinating, and integrating
16	[52]	Quantitative (Structured Equation Modeling)	Taiwan	Supply chain complexity (SCC) serves as an external catalyst for supply chain resilience (SCRES) in Taiwan. Supply chain (SC) flexibility, shaped by SC velocity and visibility, emerges as the sole contributor to SC agility
17	[53]	Quantitative (Hierarchical Regression)	Germany	Supply chain agility and adaptability have a positive impact on cost and operational performance in Germany. Product complexity enhances the effects of adaptability
18	[54]	Hypotheses Testing and Moderation Analysis	UK	Environmental dynamism significantly influences three key business divergence capabilities (BDCs) in the UK. Velocity dimension positively impacts supply chain agility (SCAG), moderated by supply chain organizational learning and data-driven culture
19	[55]	Quantitative (SEM)	Europe, Aisa, Americas	Heightened supply chain risk correlates positively with supplier and customer integration in Europe, Asia, and the Americas. Integrations positively influence agility performance, acting as mediators between supply chain risk, internal integration, and agility performance

Table 2 *(continued)*

Sl.	Authors/ Year	Methodology	Country / Continent	Findings
20	[56]	Non-experimental Survey	-	Higher levels of firm supply chain agility (FSCA) positively correlate with increased effectiveness in meeting customer requirements in an international context. The relationship between FSCA and costs is stronger in dynamic and complex settings
21	[57]	Quantitative (PLS)	Germany	Supply- and demand-side competence impact supply chain agility in Germany. Process compliance moderates the relationship between competence and agility
22	[58]	Structural Equation Modeling (SEM)	China	Locally Grown Agri-food Supply Chain (LGA-SC) practices positively associate with Governance Integrity (GI), Supply Chain Resilience (SCR), Strategic Collaborative Performance Advantage (SCPA), and Strategic Financial Performance (SFP) in China. GI and SCR mediate the relationship between LGA-SC practices and SCPA
23	[59]	Secondary Data Analysis (Documentary Research)	-	Successful relationship integration with key partners is crucial for overcoming control dissipation in supply chains. Prioritizing relationship integration in agility and flexibility programs enhances overall supply chain performance
24	[60]	Quantitative (SEM)	China	Supply chain integration and external learning contribute positively to supply chain agility in China. Supply chain agility fully mediates the impact of integration and external learning on overall performance
25	[61]	Multidisciplinary Literature Review	-	Agility and resilience share common dimensions, such as flexibility, speed or acceleration, and environmental scanning. They also have distinct characteristics, highlighting the need for both in supply chain operations
26	[62]	Systematic Literature Review (SLR)	-	Enhancing supply chain traceability is essential for superior visibility, a critical precursor for effectively coordinating modern supply chains and gaining a competitive edge
27	[63]	Quantitative (Survey)	UK	Enhanced connectivity and information sharing lead to improved visibility, subsequently bolstering supply chain resilience and robustness in the UK. Supply base scale moderates this relationship
28	[64]	Mixed-Methods Survey and Case Studies	United States	Positive correlation identified between the implementation of Industry 4.0 technologies and supply chain efficiency in the United States

Table 2 *(continued)*

Sl.	Authors/ Year	Methodology	Country / Continent	Findings
29	[65]	Qualitative Interviews and Simulation	China	Impact of AI-driven automation in Chinese manufacturing: Increased production speed and reduced errors
30	[66]	Quantitative Analysis of IoT Data	Brazil	Integration of IoT devices in Brazilian supply chains enhances real-time monitoring, reducing lead times and minimizing stockouts
31	[67]	Comparative Case Study	South Korea	Adoption of Industry 4.0 in South Korean manufacturing results in improved production flexibility and adaptability to market changes
32	[68]	Experimental Design and Analytics	Germany	Big data analytics in German logistics significantly reduces operational costs through predictive maintenance
33	[69]	Cross-sectional Survey	Japan	Level of Industry 4.0 adoption among Japanese companies positively associated with overall supply chain visibility
34	[70]	Longitudinal Analysis	Mexico	Evolution of Industry 4.0 technologies in the Mexican automotive sector enhances production efficiency and reduces downtime
35	[71]	Case-Control Study and AI Simulation	Singapore	AI simulations analyze the impact of automation on the supply chain in Singapore, identifying a significant reduction in lead times
36	[72]	Ethnographic Observations	Italy	Ethnographic studies in Italian manufacturing plants illustrate the transformative impact of automation on worker roles and production processes
37	[73]	System Dynamics Modeling	Bangladesh	System dynamics modeling assesses the long-term effects of Industry 4.0 adoption in Bangladesh, highlighting increased operational resilience
38	[74]	Cross-Functional Collaborative Research	China	Collaborative impact of IoT and AI in the Chinese electronics supply chain results in improved demand forecasting accuracy and reduced stockouts
39	[75]	Survey and Comparative Analysis	South Korea	Surveyed South Korean manufacturing firms, finding a positive relationship between Industry 4.0 adoption and improvements in supply chain visibility and operational efficiency
40	[76]	Longitudinal Case Studies	Portugal	Longitudinal case studies in Portuguese logistics companies indicate that the integration of Industry 4.0 technologies enhances overall supply chain visibility

Table 2 *(continued)*

Sl.	Authors/ Year	Methodology	Country / Continent	Findings
41	[77]	Agent-Based Modeling and Simulation	United States	Agent-based modeling simulates the impact of automation on the U.S. retail supply chain, demonstrating increased efficiency and reduced lead times
42	[78]	Comparative Analysis of Automation	Vietnam	Compared automation levels in Vietnamese manufacturing plants, showing a positive correlation between higher automation and improved operational efficiency
43	[79]	Experimental Design and Surveys	Taiwan	Adoption of AI-driven robotics in Taiwanese semiconductor manufacturing leads to enhanced production efficiency and reduced defect rates
44	[80]	Qualitative Case Studies	Brazil	Exploration of the implementation of IoT in Brazilian agribusiness reveals improved traceability and real-time monitoring of supply chain activities
45	[81]	Longitudinal Observations and Analytics	India	Longitudinally observed the integration of Industry 4.0 technologies in the Indian pharmaceutical supply chain, showcasing reduced lead times and improved regulatory compliance
46	[82]	Cross-National Comparative Analysis	South Korea, Germany	Cross-national analysis comparing Industry 4.0 adoption in South Korean and German automotive industries. Highlights differences in approaches and commonalities in efficiency gains
47	[83]	Simulation Modeling and Interviews	China	Simulation modeling and interviews assess the impact of AI on production scheduling in Chinese manufacturing, showcasing optimized scheduling and resource allocation
48	[84]	Mixed-Methods Approach	Mexico	Mixed-methods approach studies the implementation of Industry 4.0 in the Mexican aerospace sector, revealing improved supply chain visibility and streamlined processes
49	[85]	Comparative Analysis of Robotics	India	Comparative analysis of robotic automation in the Indian textile industry demonstrates a substantial reduction in production time and increased product quality
50	[86]	Network Analysis and Surveys	Japan	Network analysis evaluates the collaborative impact of Industry 4.0 technologies on Japanese manufacturing networks, revealing increased connectivity and knowledge-sharing

Table 2 *(continued)*

Sl.	Authors/ Year	Methodology	Country / Continent	Findings
51	[87]	Case-Control Study and Analytics	Portugal	Case-control study and analytics investigate the adoption of big data analytics in Portuguese logistics companies, indicating improved decision-making and resource optimization
52	[88]	Longitudinal Observations and Surveys	China	Longitudinal observations and surveys assess the evolution of Industry 4.0 in Chinese electronics manufacturing, showcasing increased production flexibility and adaptability
53	[89]	Comparative Case Studies and Interviews	South Korea	Comparative case studies and interviews explore the implementation of IoT in South Korean logistics companies, highlighting improved asset tracking and reduced transit times
54	[90]	Mixed-Methods Research	Brazil	Mixed-methods research assesses the impact of Industry 4.0 on Brazilian automotive supply chains, revealing enhanced agility and responsiveness to market fluctuations
55	[91]	Longitudinal Analysis and Surveys	South Korea	Longitudinal analysis of Industry 4.0 adoption in South Korean semiconductor manufacturing shows a positive impact on production efficiency and reduced error rates
56	[92]	Qualitative Interviews and Analytics	Brazil	Qualitative interviews and analytics explore the implementation of big data analytics in Brazilian retail supply chains, indicating improved demand forecasting accuracy and inventory management
57	[93]	Case-Control Study and Simulation	Singapore	Case-control study and simulations investigate the effects of AI-driven automation on the efficiency of Singaporean pharmaceutical supply chains, showing decreased lead times and increased capacity utilization
58	[94]	Comparative Analysis of Robotics	Germany	Comparative analysis of robotic automation in German automotive manufacturing demonstrates a reduction in production costs and enhanced worker safety
59	[95]	Mixed-Methods Research	Portugal	Mixed-methods research studies the adoption of IoT in Portuguese maritime logistics, showcasing improved tracking and monitoring of maritime assets and shipments
60	[96]	Cross-Sectional Surveys and Analytics	China	Cross-sectional surveys and analytics in Chinese electronics manufacturing assess the impact of IoT on production efficiency, highlighting improved quality control and reduced downtime

Sl.	Authors/ Year	Methodology	Country / Continent	Findings
	[97]	Agent-Based Modeling and Interviews	India	Agent-based modeling and interviews simulate the effects of AI-driven automation on the Indian textile industry, demonstrating increased production output and decreased defect rates
	[98]	Longitudinal Observations and Analytics	South Korea	Longitudinal observations and analytics examine the effects of big data analytics in South Korean logistics companies, indicating enhanced decision-making capabilities and improved supply chain visibility
	[99]	Comparative Case Studies	China	Comparative case studies evaluate the implementation of automation in Chinese manufacturing, revealing increased production efficiency and reduced lead times
	[100]	Network Analysis and Surveys	Portugal	Network analysis and surveys assess the collaborative impact of Industry 4.0 technologies on Portuguese logistics networks, revealing increased connectivity and information exchange
	[101]	Mixed-Methods Research	United States	Mixed-methods research studies the integration of AI and robotics in the U.S. aerospace sector, showcasing improved efficiency and reduced operational costs

Source: Developed by the authors.

Results

The synthesis of findings from the reviewed studies provides comprehensive insights into various aspects of supply chain management, with a particular focus on factors influencing agility, resilience, and performance. The studies encompass diverse methodologies, geographic locations, and industrial contexts, contributing to a nuanced understanding of the complex interplay between different variables. The key results can be categorized into several themes, each shedding light on crucial elements within the realm of supply chain dynamics.

Influence of information visibility and sharing

A recurring theme across multiple studies is the pivotal role of information visibility and sharing in shaping supply chain outcomes. Enhanced visibility is consistently associated with improved performance metrics, including agility, adaptability, and responsiveness. For instance, study [44] highlights the positive impact of effective information sharing and connectivity resources on supply chain visibility, further amplified by top management commitment. Similarly, research [50] stresses the importance of organizational information processing capability in translating higher supply chain visibility into improved responsiveness. This emphasizes the need for a refined understanding of supply chain integration beyond mere visibility, considering internal integration as a critical factor.

Technology adoption and Industry 4.0

A significant portion of the reviewed studies delves into the transformative effects of technology adoption, particularly within the context of Industry 4.0. The integration of technologies such as big data analytics, artificial intelligence (AI), and the Internet of Things (IoT) emerges as a common thread. Notably, studies [65, 66] showcase how AI-driven automation and IoT integration contribute to increased production speed, reduced errors, and real-time monitoring, ultimately enhancing supply chain efficiency. Furthermore, the studies conducted in various

countries, including China, India, and South Korea, provide a global perspective on the widespread adoption of Industry 4.0 technologies and their positive implications for supply chain visibility and performance.

Supply chain resilience and adaptability

The resilience of supply chains is a critical factor, especially in the face of uncertainties and disruptions. Studies [40] and [53] contribute valuable insights into the relationship between supply chain resilience and different organizational capabilities. Study [40] emphasizes the synergy between tangible and intangible resources, highlighting the role of artificial intelligence-driven big data analytics and intergroup leadership in shaping humanitarian supply chain dynamics. In contrast, study [53] explores the positive impact of supply chain agility and adaptability on cost and operational performance. This underscores the interconnected nature of resilience, adaptability, and agility in ensuring supply chain robustness.

Global variances and cross-national comparisons

The geographical diversity of the studies enables a nuanced understanding of how supply chain dynamics vary across regions. Study [55] presents findings from Europe, Asia, and the Americas, indicating that the relationship between supply chain risk and agility performance is influenced by factors such as supplier and customer integration. Study [82] conducts a cross-national analysis comparing Industry 4.0 adoption in South Korean and German automotive industries, revealing differences in approaches and commonalities in efficiency gains. This global perspective emphasizes the need for context-specific strategies in addressing supply chain challenges and leveraging opportunities.

Humanitarian supply chains

Several studies focus specifically on humanitarian supply chains, recognizing their unique challenges and the need for specialized approaches. Study [41] highlights the role of crisis leadership in enhancing the impact of digital technologies in emergency supply chain relief efforts. Study [44] delves into the significance of big data predictive analytics (BDPA) in humanitarian supply chains, challenging the notion that swift trust is essential for enhancing actor coordination. The findings underscore the complexity of humanitarian supply chain management and the multifaceted factors that contribute to its effectiveness.

Environmental influences and sustainable practices

Study [54] contributes to the understanding of how environmental dynamism influences key business dimensions, with volume and velocity showing significance in relation to competitive pressures. The study emphasizes the need for supply chain organizational learning and a data-driven culture to moderate the impact of environmental dynamism on supply chain agility. This aligns with the growing emphasis on sustainable practices and the recognition that supply chain strategies must be responsive to environmental considerations.

Role of external and internal factors

Study [47] highlights the contributions of both external and internal managerial processes to enhanced agility. The study suggests that while supply chain visibility processes, such as those utilizing Enterprise Resource Planning and tracking tools, have a limited impact, unexplored higher-level processes and routines play a crucial role in explaining agility. This distinction between external and internal factors underscores the complexity of achieving agility and the need for a holistic approach that considers both dimensions.

The synthesis of results from the reviewed studies offers a rich tapestry of insights into contemporary supply chain management. The findings contribute to advancing theoretical frameworks, refining practical strategies, and guiding future research directions in this dynamic field. The multifaceted nature of supply chain dynamics, influenced by factors ranging from information visibility to technology adoption and global variances, underscores the need for a holistic and adaptable approach to supply chain management.

Discussion

A state-of-the-art summary of empirical research on I4T and SCV is provided by this comprehensive literature review and the conceptual structure that goes with it.

To present an all-encompassing overview of SCV, this paper compiles previously published

research. Thereby, the study specifically helps in the following ways. First, a large number of variables connected to SCV and I4T were found. Next, in order to enable a thorough understanding of the essential components of supply chain visibility, the authors also combined the main traits and findings from past research to present a synopsis of how these parameters are connected to I4T, SCV and OE. Therefore, by combining various viewpoints and SCV-related elements, this study advances the prevailing knowledge on SCV.

The discussion part presents important insights obtained from the thorough synthesis of data, revealing the complex relationships among the identified themes and their significant implications for using Industry 4.0 technology in supply chain management. The studies consistently highlight the crucial importance of making information visible and sharing it to improve supply chain outcomes. This emphasizes the need for a comprehensive approach that goes beyond just integrating technology and includes organizational processes and managerial dedication. The findings support the idea of investing in both modern technical solutions and building a collaborative culture that promotes knowledge exchange. Furthermore, the widespread impact of Industry 4.0 technologies on the way supply chains operate is becoming a powerful driver for change. This requires organizations to strategically align their aims and consider the specific details of their context in order to achieve the best possible results. Nevertheless, the subtle differences in the impacts of particular technologies in various situations emphasize the insufficiency of a one-size-fits-all strategy, prompting organizations to customize their implementation tactics according to their own circumstances. The discussion on supply chain resilience and adaptation reveals the interconnectedness of these concepts, emphasizing the significance of a holistic strategy that considers both tangible and intangible resources. In addition to strengthening real infrastructure, organizations must allocate resources to intangible assets such as leadership and teamwork in order to successfully traverse risks. The combination of agility, flexibility, and improved cost and operational performance strengthens the strategic benefit of flexible supply chain structures, impacting decision-making, resource allocation, and risk mitigation measures. International comparisons demonstrate the wide range of techniques in supply chain management, highlighting the importance of tailored solutions influenced by legislative frameworks, cultural subtleties, and market forces. It is crucial to use geographically sensitive techniques in order to match plans with the unique problems and possibilities present in various locations. By including research that specifically examines humanitarian supply chains, we get insight into the distinct difficulties that arise in these situations. Understanding the significance of crisis leadership, the use of big data predictive analytics, and the utilization of adaptive technology offer significant insights for improving disaster relief operations. These findings enhance our understanding of supply chain management in humanitarian settings and highlight the flexibility and versatility of particular solutions in different situations. Furthermore, the analysis of environmental factors highlights the increasing significance of using sustainable methods in supply chain management. The results emphasize the need for organizational learning and a culture that relies on data to mitigate the influence of environmental changes on the ability of the supply chain to adapt quickly. This places sustainability as a top priority in strategic decision-making. Brusset's analysis of the impacts of external and internal elements leads to a reassessment of conventional methods to supply chain management. Although visibility procedures are important, the study indicates that unknown higher-level processes and routines are essential for attaining agility. Organizations face the task of exploring their own capabilities more thoroughly, promoting a culture of ongoing development and innovation. The consequences go beyond just investing in technology, highlighting the importance of organizational procedures and routines in attaining agility. To summarize, the comprehensive discussion combines various research findings to provide a detailed understanding of the intricate relationship between information visibility, technology adoption, resilience, global differences, humanitarian concerns, environmental impacts, and the influence of external and internal factors. These deep discoveries have a significant influence on the strategic decision-making process, organizational practices, and the future direction of supply chain management in the era of Industry 4.0. The complex nature of supply chain dynamics necessitates a comprehensive and flexible strategy that takes into account the interdependence of different components, enabling the implementation of agile, resilient, and sustainable supply chain practices.

Conclusion

This systematic review has meticulously explored the intersection of Industry 4.0 technologies with supply chain visibility and operational efficiency, offering a comprehensive synthesis of findings from a diverse range of studies. The extensive analysis has revealed a nuanced landscape where information visibility, collaborative culture, and the strategic adoption of technological solutions converge to reshape contemporary supply chain management. The synthesized evidence underscores the transformative potential of Industry 4.0 technologies but equally emphasizes the need for organizations to navigate this landscape with a context-specific, adaptive approach. The centrality of information visibility emerges as a key takeaway, with studies consistently highlighting its pivotal role in bolstering supply chain outcomes. From increased collaboration and adaptability to enhanced agility and cost performance, the visibility of information acts as a linchpin for achieving optimal results. However, the discussion has also illuminated the multifaceted nature of this influence, urging organizations to go beyond technological investments and cultivate a collaborative culture that encourages information sharing. The strategic integration of Industry 4.0 technologies in supply chain management extends beyond mere technological adoption. The findings advocate for a dual investment strategy, encompassing both advanced technological solutions and the cultivation of organizational processes conducive to innovation and collaboration. The recognition of intangible assets, such as leadership and organizational culture, as critical elements in fortifying supply chain resilience and adaptability underscores the need for a holistic organizational approach. Global variances in supply chain practices have been a focal point, emphasizing the diversity in approaches across different regions. The findings urge organizations to tailor their strategies based on local contexts, considering regulatory environments, cultural nuances, and market dynamics. Such a geographically sensitive approach becomes imperative for organizations to navigate the specific challenges and opportunities inherent in diverse regions.

The exploratory and comprehensive literature research, which led to the creation of the proposed framework, could significantly aid decision-making within organizations. This framework offers an in-depth analysis of how Industry 4.0 can enhance supply chain visibility and operational efficiency. It explores the interaction between key technological advancements that are crucial for establishing interconnected and seamless supply chains. Additionally, it demonstrates how the capabilities enabled by Industry 4.0 technologies can improve both supply chain visibility and operational efficiency. As a result, it provides a practical framework for incorporating cutting-edge technological advancements throughout the supply chain, facilitating the integration and achievement of enhanced performance in these areas.

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ABOUT THE AUTHORS / ИНФОРМАЦИЯ ОБ АВТОРАХ

Tahsina Khan — Deputy Director for Research, Bangladesh University of Professionals (BUP), Dhaka, Bangladesh
Тахсина Хан — заместитель директора по исследованиям, Бангладешский университет профессионалов (BUP), Дакка, Бангладеш
https://orcid.org/0000-0001-8032-3376
tahsina171@gmail.com

Md Mehedi Hasan Emon — Master of Business Administration, Independent Researcher, Bangladesh University of Professionals (BUP), Dhaka, Bangladesh
Мд Мехеди Хасан Эмон — магистр делового администрирования, независимый исследователь Бангладешский университет профессионалов (BUP), Дакка, Бангладеш
https://orcid.org/0000-0002-6224-9552
Corresponding Author
emonmd.mhasan@gmail.com

Md Adnan Rahman — Postdoctoral Researcher, Infrastructure University Kuala Lumpur (IUKL), Kajang, Malaysia
Мд Аднан Рахман — постдокторант, научный сотрудник, Университет инфраструктуры Куала-Лумпур (IUKL), Каджанг, Малайзия
https://orcid.org/0000-0003-3378-0958
dr.adnan1628@gmail.com

Authors' declared contributions:
Tahsina Khan — conceptualization, methodology development, research design, final editing and review of the manuscript.
Md Mehedi Hasan Emon — conducted the literature review and analytics; responsible for writing the first draft of the manuscript; contributed to refining the research methodology.
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Understanding the Republic of Malawi's Trade Dynamics: A Bayesian Gravity Model Approach

B.B. Sambiri, N.C. Mutai, S. Kumari
Berlin School of Business and Innovation, Berlin, Germany

ABSTRACT

International trade enables countries to expand their markets, access more products, improve resource allocation, and boost economic growth by leveraging comparative advantage and specialization. The aim of this article is to analyze the primary factors that influence Malawi's international trade flows. The study is relevant because it examines Malawi's trade patterns with its main partners, which include surrounding nations and traditional trade allies. The novelty is that, through the analysis, the research offers valuable insights into the primary factors that influence Malawi's international commerce. Panel data is gathered from various sources, including the International Monetary Fund (IMF) and World Bank, covering the period from 2000 to 2023 for 11 countries that are trading partners with Malawi. We employ the Bayesian Mindsponge gravity methodology. The results show that the economic size (characterized by the gross domestic product) of the origin and destination countries, bilateral agreements, and the population size of the destination country have a beneficial impact on Malawi's exports. In conclusion, Malawi's export performance is significantly enhanced by the economic size of both Malawi and its trading partners, the existence of bilateral agreements, and the population size of the destination countries, underscoring the importance of strategic economic partnerships and targeted trade policies in boosting Malawi's international trade. We recommend Malawi authorities focus on strengthening bilateral agreements and targeting trade relationships with larger and more populous economies to boost international trade.

Keywords: Bayesian Mindsponge theory; bilateral trade flows; gravity model of trade; Malawi; Africa; international trade; trade dynamics

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ОРИГИНАЛЬНАЯ СТАТЬЯ

Понимание динамики торговли Республики Малави: подход с использованием байесовской гравитационной модели

Б.Б. Самбири, Н.Ч. Мутай, С. Кумари
Берлинская школа бизнеса и инноваций, Берлин, Германия

АННОТАЦИЯ

Международная торговля позволяет странам расширять свои рынки, получать доступ к большему количеству продуктов, улучшать распределение ресурсов и стимулировать экономический рост за счет использования сравнительных преимуществ и специализации. **Целью** данной статьи является анализ основных факторов, влияющих на международные торговые потоки Малави. **Актуальность** исследования заключается в том, что в нем рассматриваются модели торговли Малави с ее основными партнерами, в том числе соседними странами и традиционными торговыми союзниками. **Новизна** исследования в том, что проведенный ана-

лиз позволил получить ценные сведения об основных факторах, влияющих на международную торговлю Малави. Панельные данные собраны из различных источников, включая Международный валютный фонд (МВФ) и Всемирный банк, и охватывают период с 2000 по 2023 г. для 11 стран, которые являются торговыми партнерами Малави. Авторы используют **методологию** байесовой гравитации Mindsponge. Результаты показывают, что экономический размер (характеризуемый валовым внутренним продуктом) стран происхождения и назначения, двусторонние соглашения и численность населения страны назначения оказывают благоприятное влияние на экспорт Малави. Автоы делают **вывод**, что экспортные показатели Малави значительно улучшаются за счет экономического размера как Малави, так и ее торговых партнеров, наличия двусторонних соглашений и численности населения стран назначения, что подчеркивает важность стратегических экономических партнерств и целенаправленной торговой политики для стимулирования международной торговли Малави. Авторы **рекомендуют** властям Малави сосредоточиться на укреплении двусторонних соглашений и налаживании торговых отношений с более крупными и густонаселенными экономиками для стимулирования международной торговли.

Ключевые слова: байесовская теория mindsponge; двусторонние торговые потоки; гравитационная модель торговли; Малави; Африка; международная торговля; динамика торговли

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Introduction

International trade plays a vital role in the economic progress of countries, especially developing nations such as Malawi. Gaining insight into the determinants of trade flows can assist policymakers in formulating efficient approaches to strengthen economic growth and facilitate integration into the global market [1, 2].

Malawi, a country located entirely inside the borders of other countries in Southeastern Africa, encounters distinctive difficulties in its patterns of commerce [3]. Malawi's primary export is tobacco, representing 55% of its overall exports. Others include uranium, sugar, tea, and coffee. The European Union (EU) is Malawi's primary export partner, accounting for 50% of its total exports. Additional countries in this category are Zambia, Zimbabwe, South Africa, and the United States [4].

Like other countries, Malawi's trade flows are influenced by various factors, such as geographic boundaries, infrastructure quality, and regional trade agreements. The country has a small economy that is primarily agriculture-dependent. Examining these factors offers insights into the forces that influence Malawi's trade patterns. In the context of the study, we consider Malawi as the country of origin. The destination countries would be Malawi's various trade partners (for this study we consider 11 countries), which include countries in the Southern African Development Community (SADC) region, as well as other significant trading partners globally. The gravity model analyzes the trade flows between Malawi (the origin) and its partner countries (the destinations) to identify the factors influencing the trade relationships. The model draws inspiration from Newton's law of gravity in physics and states that the amount of trade between two countries is directly related to their economic sizes (often measured by gross domestic product (GDP) and inversely related to the distance between them [5–7].

Throughout the years, the gravity model has been widely utilized and improved to consider numerous aspects that impact trade. The variables considered include geographical, economic, political, and social factors, such as proximity, linguistic similarities, historical connections, bilateral treaties, and commercial regulations [5, 8]. One area of improvement is in the use of Bayesian estimation to incorporate prior information. The new Bayesian Mindsponge Theory (BMT) has fewer applications in this area. We borrowed the estimation procedure from BMT to estimate a Bayesian gravity model following [9, 10]. This enhances the existing body of knowledge by providing a comprehensive analysis of the elements that impact trade flows, emphasizing the significance of economic scale, distance, and other crucial drivers.

Malawi's exports and imports with its major trading partners

Figs. 1 and *2* demonstrate that a wide variety of imports and exports are involved in Malawi's trading connections with other nations. Malawi's main exports to China are agricultural goods such as tea and tobacco. In exchange, Malawi receives significant supplies of textiles, machinery, and electronics from China. Malawi recently received products from China valued at about $ 333 million. Malawi

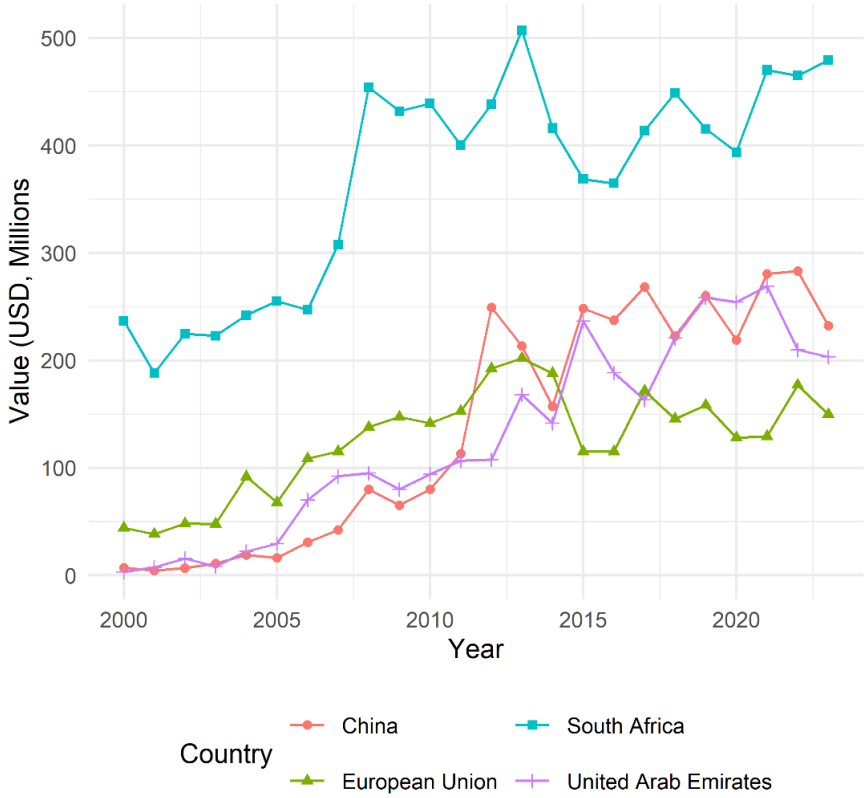

Fig. 1. **Malawi's imports with its major trading partners**

Source: Authors' computations.

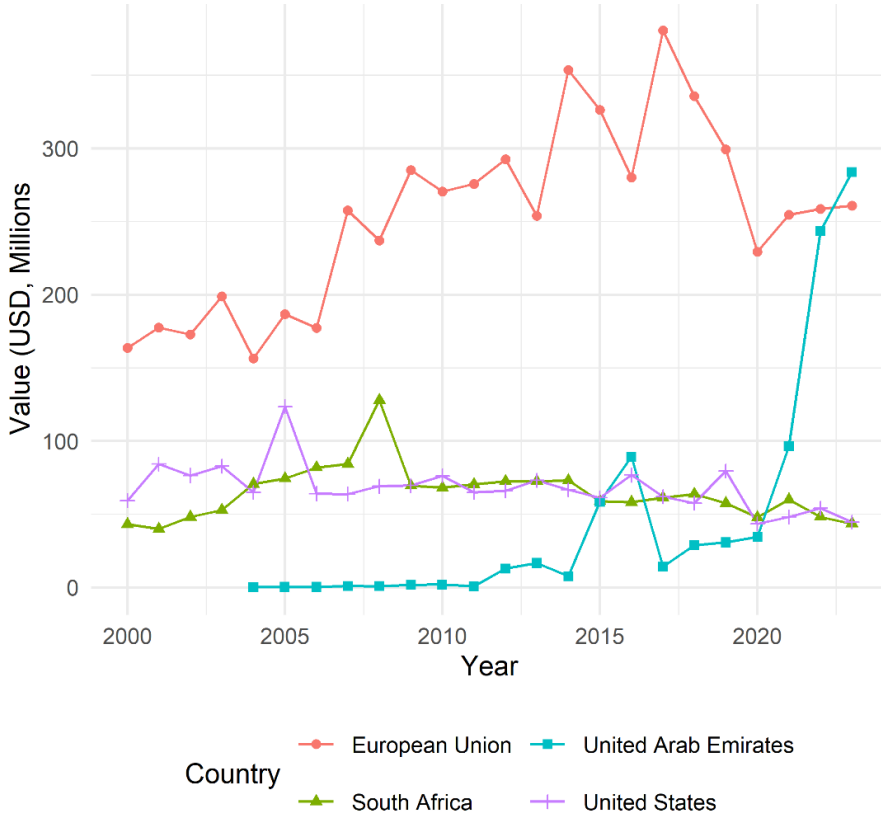

Fig. 2. **Malawi's imports with its major trading partners**

Source: Authors' computations.

and Eswatini have very little trade when compared to other partners. While manufactured items are imported from Eswatini, Malawi's exports to that country are mostly agricultural products, but the trade amounts are not very large.

The EU is an important market for Malawi's agricultural exports, especially tobacco, tea, and sugar. Malawi, on the other hand, imports automobiles, machines, and medications from the EU. Furthermore, the European Union provides Malawi with significant development assistance and backs a range of economic initiatives. India is another country to which Malawi sends beans, pulses, and other agricultural goods. Pharmaceuticals, machinery, and refined petroleum are among India's top exports to Malawi; the value of trade with Malawi last year was approximately $ 132 million. Malawi exports a range of manufactured commodities as well as agricultural products to Mozambique. Trade within the Southern African Development Community (SADC) is facilitated by Malawi receiving energy products and agricultural inputs from Mozambique.

South Africa is another important trading partner for Malawi. It's biggest import partner, South Africa, is a market for its tobacco, tea, and other agricultural exports. With $ 442 million in imports, South Africa provides Malawi with refined petroleum, food products, and manufactured goods. For Malawian tobacco and tea, the United Arab Emirates (UAE) is a significant market. The UAE is Malawi's supplier of petroleum products and other items, and trade between the two countries has increased significantly in recent years. Tobacco, tea, and other agricultural products are imported by the UK from Malawi. Malawi buys automobiles, machinery, and pharmaceuticals from the UK in exchange. Malawi exports agricultural goods, especially tobacco, to the United States. Malawi receives consumer products, automobiles, and machinery from the US. Strong regional trade links are demonstrated by the fact that Malawi exports consumer goods and agricultural products to Zambia, and Zambia supplies Malawi with food products, chemicals, and fertilizers. Finally, Malawi exports certain manufactured items and agricultural products to Zimbabwe. Zimbabwe promotes substantial bilateral trade with Malawi by exporting agricultural items and machinery. In general, Malawi imports manufactured goods and raw materials from its trading partners and exports agricultural products, which mostly dominate its trade.

Literature review

Theoretical review

The gravity model of trade, inspired by Newton's law of gravity, is a powerful tool for analyzing trade flows between countries. The model posits that bilateral trade between two countries is directly proportional to their economic sizes (usually measured by GDP) and inversely proportional to the geographic distance between them. This theoretical framework has been extensively used and validated in empirical trade research. In the context of Malawi, a low-income country heavily dependent on agriculture and primary commodities, understanding trade dynamics through the gravity model can provide crucial insights into the factors influencing its international trade flows.

The gravity model was first introduced to economics by Tinbergen [7]. Tinbergen's work demonstrated that trade between two countries could be predicted based on their economic sizes and the distance between them, like the gravitational force in physics. Over time, the model has been refined to include various other factors such as population size, trade agreements, common languages, colonial history, and infrastructure quality. The basic gravity model can be expressed as:

$$T_{ij} = A\frac{X_i Y_j}{D_{ij}},$$

where T_{ij} represents the trade flow between country i and j, Y_i and Y_j are the economic masses of countries i and j, D_{ij} is the distance between them and A is a constant of proportionality. The model makes assumptions such as: (a) Economic Mass: Larger economies have a greater capacity to produce and consume goods, leading to higher trade volumes. (b) Distance: Greater distances increase transportation costs and reduce trade flows. (c) Additional Factors: Other variables, such as common borders, language, and historical ties, also play significant roles. Over the years, numerous extensions to the basic gravity model have been proposed, for example, [11] introduced the multi-resistance model, accounts for the fact that trade resistance depends not only on bilateral distance but also on the relative distance to all trading partners. Others include the incorporation of factor proportions and endowment as per the Heckscher-

Ohlin model. This helps to explain how different resources influence trade patterns. Further, trade policies, tariffs, and non-tariff barriers significantly impact trade flows and can be incorporated into the model to improve its explanatory power.

Empirical review

Several empirical studies have investigated the factors that influence bilateral trade among origin and destination countries. Tinbergen utilized the gravity model to examine the trade patterns among 42 nations [7]. The findings indicate that the distance elasticity of trade flow is approximately –0.89, and the GDP of both the exporting and importing countries has a favorable impact on trade flows, as anticipated. Eichengreen and Irwin [12] utilized the gravity model within a dynamic framework to examine the influence of history on trade. Countries that have a historical record of engaging in trade with each other, whether due to political, policy, or other grounds, are inclined to maintain their commercial relationships. Consistent with their hypothesis and reasoning, the authors discovered that previous bilateral commerce encourages current trade between partners, even when accounting for the factors considered in the standard gravity model. They argue that neglecting historical considerations leads to an exaggeration of the influence of trading blocs.

Further, the study [13] examined the variables that influence the amount of commerce between 14 nations in the Asia-Pacific area. The study suggested that market size, physical distance, political stability, cultural similarity, membership in the Association of Southeast Asian Nations (ASEAN), and being a newly industrialized country are important factors that influence bilateral trade relationships in the Pacific basin. Similarly, the study [14] demonstrated that the conventional variables play a significant role in determining bilateral trade among the 18 Asia-Pacific economies they examined.

Yu and Zietlow [15] found that the distance between trading partners is a substantial barrier to commerce among the economies in the Asia-Pacific region. Additionally, they stated that the establishment of the Asia-Pacific Economic Cooperation (APEC) has bolstered economic interdependence in regional commerce. In contrast, a study [16] discovered that the elasticity of trade to distance decreases when an additional barrier to trade is considered. This suggests that distance is no longer a significant factor in bilateral commerce. Using a panel data set that included 130 nations from 1962 to 1996, the authors demonstrated that the phenomenon known as the "death of distance" was found to mostly affect trade between wealthy nations. However, Anderson and Van Wincoop [17] demonstrated that national borders have a significant impact on reducing bilateral trade levels by reasonable and meaningful amounts.

Cheng and Wall [18] conducted a comparative analysis of several specifications of the gravity model of trade. The researchers also analyzed the influence of regional integration on trade volumes by studying five regional trading blocs: the European trading bloc, the North American trading bloc, Mercosur, the Australian-New Zealand Closer Economic Relations, and the Israel-USA Free Trade Agreement. The authors utilized many specifications, including the pooled cross-section model and fixed effects model. The researchers discovered that the impact of the European trade bloc on trade volume is quite small. The fixed effect model indicates that the trading bloc had a statistically significant impact of 8.2%.

Kimura and Lee [19] analyzed the determinants that impact the trade of services between ten Organization for Economic Co-operation and Development (OECD) nations and other economies in comparison to the trade of goods. Empirical evidence suggests that the gravity equation exhibits higher performance when used to international trade in services as opposed to trade in products. Moreover, it has often been noted that the distance between locations has a more substantial influence in the trade of services as compared to the trade of goods. Similarly, the conclusions reported by [13, 20] observe that membership in a regional trade agreement significantly influences commerce. The study undertaken by Ceglowski [21] revealed that economic size, geographical proximity, and linguistic links are significant determinants of services trade between countries. When applying the gravity model to the Gulf Cooperation Council (GCC) countries, Boughanmi [22] discovered that the trade between these countries is twice as high as what would be expected based on the basic gravity model.

In Africa, Boughanmi [23] used the gravity model to compare the trade-creating effect of the

main African Regional Trading Agreements (RTAs). The research found an overall positive impact of African RTAs is estimated to be approximately 27–32% after accounting for publication bias. The origin of upward bias is not solely restricted to the selection of publications, as the impacts of RTA tend to be greatly overstated when zero flows and MRT are not adequately controlled for.

Osabuohien et al. [24] investigated the operations of regional trade agreements within the Economic Community of West African States (ECOWAS), with a specific emphasis on the bilateral trade obstacles that impact trade movements across member nations. The research highlights trade barrier indicators that are not frequently examined, such as the multilateral resistance term, trade complementarity, and economic integration agreements. They utilize an enhanced gravity model to determine that trade complementarity has a substantial positive impact on bilateral commerce within the region. In addition, the reluctance to commerce between many countries and the agreements for economic integration, such as the West African Economic and Monetary Union (WAEMU), are important factors in improving trade between the ECOWAS member countries.

Mwangi [25] investigated the factors that influence agricultural imports in Sub-Saharan Africa (SSA) by using an enhanced gravity model on a dataset that includes information from 37 SSA nations between 1995 and 2018. The findings indicate that factors such as GDP, arable land endowment, membership in regional trade agreements, cultural proximity (measured by the sharing of a common language), inflation, and governance quality have a positive and significant impact on agricultural imports.

Ali-Ismaiel et al. [26] demonstrate that a mere 1% increase in export pricing results in a substantial 3.97% surge in the volume of Egyptian rice shipments to partner nations. According to economic theory, increased transportation costs have a negative impact on trade volumes for both exports and imports. The varying distance between capitals has a detrimental impact on Egyptian exports.

In Malawi, there are few studies in this area. Simwaka [27] investigated Malawi's trade relationships with its major trading partners by employing an econometric gravity model. This model assesses bilateral trade as a function of factors such as the economic size of the countries involved, geographical distance, and exchange rate volatility. Key findings from the study reveal that Malawi's bilateral trade is positively influenced by the economic size of its trading partners, specifically the GDP of the importing country, and by shared membership in regional integration agreements. In contrast, transportation costs, as indicated by the distance between trading partners, negatively impact Malawi's trade. Additionally, exchange rate volatility is found to depress bilateral trade, while regional economic groupings have an insignificant effect on trade flows.

Despite extensive research on the factors influencing bilateral trade and the impact of RTAs, research gaps remain, particularly in the context of Malawi. Previous studies, such as [27], have explored various determinants of trade flows, including economic size, geographical distance, and historical trade relations. However, there is no recent study on Malawi's international trade flows utilizing the gravity model. Addressing this research gap would significantly enhance our understanding of trade dynamics in Malawi and inform the formulation of more effective trade policies and strategies.

Research methodology

Data

We obtained the data from diverse sources. The trade data is obtained from the International Monetary Fund (IMF) trade statistics section. The World Bank's World Trade Indicators database provides the data for GDP, per capita GDP, and population figures. The data is from 2000 to 2023 for Malawi and its trading partners: China, Eswatini, European Union, India, Mozambique, South Africa, United Arab Emirates, United Kingdom, United States, Zambia, Zimbabwe. This results in panel data of 23 years and across 11 countries. Descriptive statistics are used to present a comprehensive analysis of Malawi's trade patterns.

Method

Model specification

The basic gravity model may be supplemented with many auxiliary variables to account for a wide range of trade-influencing circumstances. Cultural considerations, geographical factors, historical factors, and other factors are examples of these. Cultural factors determine whether countries have comparable ethnic groupings and

share language, culture, and habits. Geographic variables explain whether countries have shared boundaries, are landlocked, or are island states. The historical nature of the connection between countries demonstrates whether one colonized the other or whether they share a common colonizer. When all conceivable variables impacting commerce between nations are considered, the remaining unexplained portion is the effect of artificial trade barriers.

The article employs a Bayesian formulation for the gravity model. In this model, we consider Malawi's exports as the dependent variable. The model is formulated as follows:

$$\ln(Y_{ij}) \sim \text{normal}(\mu, \sigma),$$
$$\mu_i = \alpha + \beta_1 \ln(\text{GDP}_i) + \beta_2 \ln(\text{GDP}_j) + \beta_3 \text{PoP}_i + $$
$$+ \beta_4 \text{PoP}_j + \beta_5 B i_{ij},$$
$$\alpha \sim \text{normal}(M_\alpha, S_\alpha),$$
$$\beta_i \sim \text{normal}(M_\beta, S_\beta).$$

In this model, the probability around the mean μ is determined by the shape of the normal distribution, where the width of the distribution is specified by the standard deviation σ. The variables are defined as: $\ln(Y_{ij})$ is the exports between country *i* and *j*, $\ln(\text{GDP}_i)$ = log of GDP of country *i*, $\ln(\text{GDP}_j$ = log of GDP of country *j*, PoP_i = population of country i, PoP_j = population of country *j* and B_i is whether country i and j have bilateral agreements. β_i = regression coefficients. Incorporating GDP and population in the same equation can provide valuable insights into economic relationships, but it is crucial to recognize and address the endogeneity problem to obtain meaningful and accurate results.

Estimation and validation

This study employed a framework that synergizes the reasoning strengths of the BMT with the inferential advantages of Bayesian analysis [9]. The Bayesian approach treats all properties, including unknown parameters, probabilistically, facilitating accurate predictions through simple models [28]. The application of the Markov chain Monte Carlo technique permits the fitting of complex models, such as polynomial and nonlinear regression structures [29]. In comparison to the frequentist approach, Bayesian inference provides several benefits, such as the utilization of credible intervals and the determination of parameter probabilities instead of binary decision-making based on p-values [30]. To accommodate the exploratory nature of this study, models were constructed with uninformative priors or flat prior distributions, offering minimal prior information for model estimations [31]. To assess the models' goodness-of-fit with the data, Pareto-smoothed importance sampling leave-one-out (PSIS-LOO) diagnostics were employed, as outlined in equation (1) below and previous literature [31, 32]:

$$\text{LOO} = -2\text{LPPDloo} = -2s\sum i = $$
$$= 1\text{nlog}\int p(yi \mid \theta)\text{ppost}(-i)(\theta)\text{d}\theta. \qquad (1)$$

The posterior distribution derived from the data minus the data point *i* is ppost(−*i*)(θ). The R loo package employs the PSIS technique for leave-one-out cross-validation. This technique integrates k-Pareto values to identify influential observations. However, precisely computing leave-one-out cross-validation becomes challenging when dealing with observations that possess k-Pareto values exceeding 0.7 — which are generally considered significant. A widely accepted criterion for assessing the goodness-of-fit of a model involves k values below 0.5.

Results

Model results

In this analysis, we explore the posterior summaries of parameters from a Bayesian econometric model examining exports. The Bayesian framework provides a comprehensive view of parameter estimates, including credible intervals, which offer insights into the uncertainty surrounding these estimates.

Table 1 presents the model fit summary. The Bayesian results provided include the posterior summaries for several parameters related to an econometric model of exports. The breakdown the key statistics for each parameter: a_Exports: Mean: 0.02, with a credible interval from −1.90 to 1.22. This suggests the effect is centered around zero, indicating no strong effect. n_eff and Rhat: High n_eff and Rhat close to 1 indicate good convergence and reliable estimates. b_GDP_Origin_Exports: Mean: 0.15, with a credible interval from −1.22 to 1.80. This suggests a slight positive effect, but with considerable uncertainty. n_eff and Rhat: High n_eff and Rhat close to 1 indicate good convergence. b_GDP_Destination_Exports:

Table 1
Model fit summary

	mean	se_ mean	sd	2.50%	25%	50%	75%	97.50%	n_eff	Rhat
a_Exports	0.02	0.82	1.16	−1.90	−0.24	0.37	0.63	1.22	2.00	40131.75
b_GDP_Origin_ Exports	0.15	0.79	1.11	−1.22	−0.59	0.01	0.75	1.80	2.00	26183.37
b_GDP_ Destination_ Exports	0.87	0.72	1.01	−0.44	0.04	0.96	1.79	1.97	2.00	30166.63
b_Bilateral_ Exports	0.16	0.77	1.09	−1.71	−0.04	0.67	0.87	1.00	2.00	27142.35
b_Population_d_ Exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	1.88
b_Population_o_ Exports	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	25.25

Source: Developed by the authors.

Mean: 0.87, with a credible interval from −0.44 to 1.97. This indicates a stronger positive effect of the GDP of the destination country on exports. n_eff and Rhat: High n_eff and Rhat close to 1 indicate good convergence. b_Bilateral_Exports: Mean: 0.16, with a credible interval from −1.71 to 1.00. This suggests a modest positive effect, with substantial uncertainty. n_eff and Rhat: High n_eff and Rhat close to 1 indicate good convergence. b_Population_d_Exports and b_Population_o_Exports: Mean: 0.00, with essentially no variation (sd = 0.00). This suggests these parameters were either not identified or have no effect in the model. n_eff and Rhat: Low effective sample sizes and Rhat values indicate potential issues with these parameters.

The parameters generally have means close to zero, indicating that the model does not find strong evidence for large effects. The credible intervals are wide for most parameters, reflecting considerable uncertainty. High n_eff and Rhat values near 1 for most parameters indicate good convergence of the MCMC sampler, suggesting the estimates are reliable. The zero variance in population-related parameters suggests potential issues with model specification or identification. Overall, the results indicate that while GDP of the destination country (b_GDP_Destination_Exports) has a somewhat stronger and more positive effect on exports, other parameters show weak or negligible effects with considerable uncertainty. The model appears to have converged well for most parameters, except those related to population.

In a gravity model of trade, the expected signs for the variables GDP_origin, GDP_destination, Bilateral agreements, Population_o, and Population_destination are as follows: (a). GDP_origin (Gross Domestic Product of the exporting country): Positive. A higher GDP in the origin country indicates a larger economic capacity to produce goods for export, thus leading to higher trade flows. (b). GDP_destination (Gross Domestic Product of the importing country): Positive. A higher GDP in the destination country suggests greater economic capacity to consume imports, leading to higher trade flows. (c). Bilateral agreements: Positive. The presence of bilateral trade agreements typically reduces trade barriers, facilitating higher trade volumes between the countries involved. (e) Population_o (Population of the exporting country): Ambiguous, but often positive. A larger population can imply a larger market and more production capacity, potentially leading to more exports. However, if the domestic market is large enough to absorb most of the production, it could result in less export activity. (f) Population_destination (Population of the importing country): Positive.

Table 2
Expected and realised signs for the various dependent variables

Variable	Expected Sign	Actual sign
GDP_origin	+ve	+ve
GDP_destination	+ve	+ve
Bilateral agreements	+ve	+ve
Population_o	Ambiguous, but often positive	Ambiguous
Population_destination	Positive	Ambiguous

Source: Developed by the authors.

A larger population in the destination country indicates a larger market size and greater demand for imports. From *Table 2*, it is clear that, as expected for Malawi, all the variables behave as expected, except for the population of the destination country.

Discussion

This study investigates the trade dynamics of Malawi by utilizing a gravity model of trade. This research offers insights into the primary factors that influence Malawi's international commerce by examining its trade patterns with important partners, including surrounding nations and historic trade allies. We have developed a Bayesian Mindsponge gravity model that is fully implemented in R software. The results suggest that the economic sizes, measured by the GDP of the origin and destination nations, bilateral agreements, and the population size of the destination country, have a beneficial impact on Malawi's exports, which are the products originating from Malawi.

There are few studies on Malawi's international trade using the gravity model. Our results concur with those of Simwaka [27]. They established that the extent of Malawi's commerce is influenced by the economic size (GDP) of the importing country and its membership in the same regional economic organization. However, the expense of transportation has been observed to have a detrimental impact on Malawi's trade. This suggests that Malawi has the potential to improve its economic performance by increasing its commerce with neighboring countries.

Other studies on globalization and economic growth in Malawi include report by Thindwa [33]. The study examined the impact of the China-Malawi connection on the economic growth of Malawi. The volume of exports from Malawi to China was relatively small in comparison to the volume of exports from China to Malawi. This results in trade deficits for Malawi, which consequently has ramifications for both its development and society.

A study [34], examined the possible consequences of the African Continental Free Trade Area (AfCFTA) on Least Developed Countries (LDCs), specifically highlighting the case of Malawi. Results showed that implementing the AfCFTA in Malawi is expected to result in a steady and progressive decrease in trade-tax revenues. Malawi is classified as a Least Developed Country (LDC) that heavily relies on international trade levies, which account for over one-third of its total revenue. To achieve this objective, it is necessary to formulate policies and implement measures that will guarantee the AfCFTA's inclusivity and benefit for all member nations.

In relation to South Africa, Macheso [35] revealed that the commercial connections between Malawi and South Africa, albeit unequal, yet demonstrate significant reciprocity for both countries and their interests. The study found that despite being lopsided, the formal trade between the two nations has experienced significant expansion and continues to do so, albeit with some fluctuations. Additionally, it has been discovered that there have been observed alterations in trade patterns and Foreign Direct Investment (FDI) between the two trading partners. Ultimately, the analysis revealed that the trade connections between Malawi and South Africa, despite being unequal, still demonstrate significant reciprocity for both countries and their respective interests.

Conclusion and recommendations

The gravity model of trade has allowed for a thorough analysis of Malawi's trade dynamics in this study. Using this model, we have verified that the economic size and distance between Malawi's trading partners have a considerable impact on the country's trade flows. The results highlight how proximity and economic size influence trade connections. Greater trade activity between Malawi and larger economies and those located closer to the country are common. Additionally, by lowering barriers and promoting economic cooperation, regional trade agreements — particularly those within the Southern African Development Community (SADC) —have been essential in facilitating commerce.

Based on the findings of this study, we suggest the following to improve Malawi's trade performance and inclusion into the global economy considering the knowledge gained from this study: (a). Strengthen trade agreements with regions: Malawi should keep up its active participation in and bolstering of regional trade accords, especially those that are part of the SADC. Improving collaboration and increasing integration with surrounding nations can aid in lowering trade obstacles, decreasing transaction expenses, and expanding market accessibility. (b) Expand the list of trade partners: diversifying trade partners beyond conventional and regional friends helps reduce risks connected with economic downturns in particular regions, even though proximity and economic size are still significant factors. Finding new markets to explore and building trade relationships with developing nations may open new economic prospects. (c) Support export competitiveness: measures like incentives for value addition, quality enhancement, and adherence to international standards can enhance Malawi's export competitiveness and help the nation establish a larger presence in international markets.

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ABOUT THE AUTHORS / ИНФОРМАЦИЯ ОБ АВТОРАХ

Benjamin Bensam Sambiri — PhD, Professor, Berlin School of Business and Innovation, Berlin, Germany
Бенджамин Бенсам Самбири — PhD, профессор, Берлинская школа бизнеса и инноваций, Берлин, Германия
https://orcid.org/0009-0006-6662-0183
Corresponding author
benjamin.sambiri@berlinsbi.com

Noah Cheruiyot Mutai — PhD, Professor, Berlin School of Business and Innovation, Berlin, Germany
Ной Черуйот Мутай — PhD, профессор Берлинской школы бизнеса и инноваций, Берлин, Германия
https://orcid.org/0000-0001-9677-223X
noah.mutai@berlinsbi.com

Sushma Kumari — PhD, Professor, Berlin School of Business and Innovation, Berlin, Germany
Сушма Кумари — PhD, профессор Берлинской школы бизнеса и инноваций, Берлин, Германия
https://orcid.org/0009-0009-1663-8651
sushma.kumari@berlinsbi.com

Authors' declared contribution:
B.B. Sambiri — Conceptualization, literature review, data collection, curation and analysis, initial draft of manuscript.
N.C. Mutai — Data curation, review, analysis and editing.
S. Kumari — Review, editing and preparation of a list of sources.

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The Impact of Information and Communication Technologies on International Trade: A Case of Sub-Saharan Africa

E. Bessan Ayédoun, C.O.S. Ayédoun
University of Abomey-Calavi, Cotonou, Benin

ABSTRACT

The aim of this research is to analyze the effect of information and communication technologies (ICT) on the bilateral trade flows of the countries of Sub-Saharan Africa (SSA). We use **the method** of generalized least squares (GLS) panel to correct for correlation and heteroskedasticity problems. We have employed the gravity model extended to ICT to examine the effects of key ICT indicators on bilateral exports and imports. The sample includes 44 African countries of the subcontinent, including 43 countries as partners (importers/exporters) and one reporter country (exporter/importer) and covers the period 2010 to 2019. **The results** show that access to mobile telephony and the internet, as well as the development of e-commerce, have a great potential for improving intra-African bilateral trade and that the effect of ICT is not unequivocal according to the category of flow considered. However, it emerges from these results that the development of ICT as it is today has not yet succeeded in overturning the argument of physical distance as a barrier to trade in sub-Saharan Africa. **The key conclusion** is that the establishment of better-quality ICT services and infrastructure is more critical to intra-African trade. African policymakers should accommodate sufficient support to establish the ICT infrastructure and expand ICT penetration by reducing the costs of communication, transactionы and access to ICT.

Keywords: ICT; information and communication technologies; international trade; innovation; bilateral trade; gravity model; general least square; Sub-Saharan Africa; SSA

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ОРИГИНАЛЬНАЯ СТАТЬЯ

Влияние информационно-коммуникационных технологий на международную торговлю: исследование в странах Африки к югу от Сахары

Э. Бессан Айедун, К.О.С. Айедун
Университет Абоме-Калави, Котону, Бенин

АННОТАЦИЯ

Целью данного исследования является анализ влияния информационно-коммуникационных технологий (ИКТ) на двусторонние торговые потоки стран Африки к югу от Сахары (SSA). Авторы используют **метод** обобщенных наименьших квадратов (GLS) для коррекции проблем корреляции и гетероскедастичности. Также авторы использовали гравитационную модель, расширенную для ИКТ, для изучения влияния клю-

чевых показателей ИКТ на двусторонний экспорт и импорт. Выборка исследования включает 44 африканские страны субконтинента, в том числе 43 страны в качестве партнеров (импортеров/экспортеров) и одну страну-респондента (экспортера/импортера), и охватывает период с 2010 по 2019 г. **Результаты** показывают, что доступ к мобильной связи и интернету, а также развитие электронной коммерции имеют большой потенциал для улучшения внутриафриканской двусторонней торговли. Кроме того, влияние ИКТ не является однозначным и зависит от категории рассматриваемого потока. Однако из результатов исследования следует, что развитие ИКТ в его нынешнем виде еще не смогло преодолеть аргумент о физической удаленности как барьере для торговли в странах Африки к югу от Сахары. **Основной вывод** заключается в том, что создание более качественных услуг и инфраструктуры ИКТ имеет важное значение для внутриафриканской торговли. Африканские политики должны обеспечить достаточную поддержку для создания инфраструктуры ИКТ и распространения ИКТ за счет снижения затрат на связь, транзакции и доступ к ИКТ.

Ключевые слова: ИКТ; информационно-коммуникационные технологии; международная торговля; инновации; двусторонняя торговля; гравитационная модель; обобщенный метод наименьших квадратов; Африка к югу от Сахары; SSA

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Introduction

Technological changes play a key role in the process of economic development, although, within the traditional economic and theoretical framework for analyzing economic growth, technological change was an unexplained residue (Solow, 1957).[1] Technological advancement can take place through various channels that involve the transformation of ideas and the adoption of new technologies, thus making economic activities efficient both in the credit market and in the real market when using a technology. State-of-the-art communication relies on the continuous and ubiquitous availability of information [1–2]. Information and communication technologies (ICT)[2] in general and the Internet have contributed significantly to the globalization of the world economy [3–7]. Indeed, in an increasingly globalized environment, the business landscape has profoundly changed and been reshaped by innovations based on information and communication technologies (ICT), which give companies access to larger markets, allowing them to expand their customer base, increase their scale, and increase their profits [8–10]. It also forces companies to face world-class competitors, exposes them to new ideas and expertise, and encourages them to keep abreast of market trends [11]. These remarkable changes are contributing to accelerated productivity growth and an increase in international trade [2].

The relationship between ICT and commerce has long fueled debate in economic literature. Three main analyses can be deduced. First, the development of ICTs has overturned the argument of physical distance as a barrier to trade [12–13, 9]. Thus, the debate on the "death of distance" has been current, showing that proximity can no longer be a requirement or a necessary condition for face-to-face interaction between business partners because innovations in ICT such as telephone, email and virtual conferencing have become substitutes for face-to-face interactions [14–13]. These innovations enabled by ICTs have helped poor and developing countries with considerable geographic distances and cultural and political barriers with their trading partners to strengthen their trade links by compensating for the lack of strong historical trade links [15]. Second, the mechanisms by which ICTs can affect the flow of international trade [16, 8] make markets more competitive and efficient by improving information flows and lowering transaction costs, such as fixed market entry costs, communication and information costs, and negotiation and coordination costs associated with trade [17]. Third, with respect to communication costs, telecommunications create a way to maintain fast, cheaper, and ef-

[1] Solow R. M. Technical change and the aggregate production function. The review of Economics and Statistics, 1957;39(3): 312–320. URL: https://doi.org/10.2307/1926047

[2] ICT is a term that includes any communication device or application like radio, television, mobile phones, computers, network hardware and software, etc., as well as the various services and applications related to them such as videoconferencing and distance education URL: https://www.techtarget.com/searchcio/definition/ICT-information-and-communications-technology-or-technologies.

ficient communication with business partners to maintain the competitiveness of businesses [18, 4, 10]. All these explanations indicate that there would be a positive impact of ICT on trade between countries.

Historically, the performance of sub-Saharan Africa has steadily deteriorated. The integration of these countries in world trade is extremely weak. The market share of sub-Saharan Africa in 1999 (1.4%) was lower than that of Malaysia alone (1.6%) and much lower than that of Mexico (2.5%). The share of its merchandise exports in world trade (in current dollars) decreased from 4.1% in 1980 to 2% in 1990 and 1.4% in 1999, according to the World Bank Indicator (2001). Comparatively, we can highlight the dynamism of Asian countries: the value of Asian exports increased by 142.7% between 1990 and 1999. The South American continent recorded an increase of 54.1% over this same period, approaching the growth rate of world trade (59.9%). As a result, sub-Saharan Africa's weight in world trade remains the lowest of all regions (2.1% in 2010). On the other hand, the share of intraregional trade in sub-Saharan Africa's total trade did not exceed 16% in 2019, a level well below that of developing countries, Asia (around 45%) and Latin America (nearly 20%), despite the proliferation of free trade areas and the establishment of two monetary and customs unions.

In this context, the development of information and communication technologies (ICT) was an effective means of improving the level of sub-Saharan trade. ICTs, especially high-speed internet and the mobile industry, now play a leading role in economic development by contributing to the emergence and diffusion of innovations in commerce, agriculture, financial services, or transport, and the modernization of public administrations, in particular fiscal administrations, the digitization of the economy is revolutionizing economic exchanges and stimulating growth, employment and poverty reduction [19–20, 6–7]. According to data from the International Telecommunications Union (ITU), sub-Saharan Africa (SSA) lags in terms of Internet penetration among the population, a delay that is particularly noticeable vis-à-vis East Asia and North Africa. If Asia, South America, and North Africa were quickly connected by submarine fiber optic cables (CSM) to the countries of the North, SSA remained relatively isolated until 2010. Since then, the digital infrastructure has expanded rapidly, facilitating access, and reducing the cost of high-speed internet and mobile telephony. Currently, almost all coastal countries, including African ones, are connected directly to the global internet through CSMs.

In such a context, can the argument of the death of distance still be applicable? Faced with the growth in ICT development observed in recent decades, what are the impacts on the dynamics of trade and bilateral trade? How can the progress observed through access and use relating to ICTs help to better diversify countries' exports? Is there a way for this development to change the import structure, which heavily contributes to the trade imbalance in finished goods? Our work will attempt to address all these questions. This study aims to analyze the impact of ICT on bilateral SSA exports and imports for the period 2010–2019 using an augmented gravity model on panel data. More specifically, the study aims to (i) determine the effect of distance on trade in the context of the growth of ICTs, and (ii) identify the flow of trade and the channel through which we observe a dynamic due to ICTs.

The paper revisits the literature on the interaction of ICT and trade and assesses the associated benefits for the economies of sub-Saharan Africa. Specifically, it explains how the different components of ICT and trade costs hamper trade performance, and how the removal of these barriers could boost both exports and imports of various products within the subcontinent. This could help prioritize different policy options in the context of limited government budgets. Also, the paper incorporates indicators of trade facilitation by distinguishing between cost elements of trade in countries at each end of the bilateral trade relationship, suggesting that exporters and importers may not benefit equally from the trade. Trade facilitation occurring at a given end.

The article enriches the literature in many important ways, particularly in the context of sub-Saharan Africa. First, as the measurement of ICT development steadily improves, more recent data can be expected to provide more relevant and accurate information than previous ones. These improvements could offer relatively new and better insight into how the ICT environment affects business performance. Second, by developing a unified framework that combines all disaggregated trade facilitation measures and the detailed struc-

ture of trade products, the document will reveal which ICT indicators are most relevant to trade flows and which measures need to be implemented to make the required improvements.

The empirical approach is based on a gravity model that links ICT indicators to bilateral trade flows. We retain three main indicators: access to mobile phones, the number of internet users and e-business, which considers three sub-indicators (availability of the latest technologies, absorption of technology by companies and business scope) obtained from the Global competitiveness report (GCR) of the World Economic Forum (WEF). Resistance to multilateral trade is controlled through various sets of country- and time-fixed effects. Additional controls include traditional severity variables, such as gross domestic product (GDP), distance, fares, languages, and border. With data on 43 sub-Saharan African countries trading with South Africa, various model specifications combining disaggregated measures of trade and ICT are estimated using generalized feasible least squares. This approach is particularly effective when dealing with autocorrelation and heteroscedasticity issues.

The results suggest that ICTs do indeed promote trade in sub-Saharan Africa and that bilateral imports are more sensitive to improving internet access than bilateral exports, which, on the other hand, are more sensitive to the development of mobile telephony. Distance continues to be a barrier to trade despite recent efforts in both ICT and the business environment. Indeed, the weak development of ICT remains imperative to be improved to hope for significant positive effects.

The remainder of the document proceeds as follows. Section 2 presents the literature review. Section 3 outlines the research methodology, explaining the variables we use in our analysis, detailing our data sources; this is followed by a detailed discussion of our econometric estimation approach. In section 4, we present the results of this research, and in Section 5 — the conclusion.

Literature review

International trade theory and gravity model

The idea that trade is a vital factor in the economic growth of a country is not new and dates to the literature of Adam Smith (1723–1790) in his book entitled "An Inquiry into the Nature and Causes of the Wealth of Nations".[3] In the literature, Adam Smith has often pointed out that trade between countries would improve economic productivity by expanding the size of markets and increasing the scale of economies, thereby increasing economic performance. In 1821, Ricardo introduced the theory of comparative advantage, which explained why it is advantageous for two countries to trade, even though one of them may be able to produce both goods and services at a better price than the other. According to his theory, a country can reap welfare gains by specializing in the production of a good or service in which it has the lowest opportunity cost compared to the others. Since then, extensive studies of developing and least developed countries have long focused on how international trade can best contribute to a country's overall economic growth and why countries participate in the economy and world trade (see Paul Krugman, 1982)[4] in the presence of non-complementarity of economies and highly differentiated products.

Following a specification reminiscent of Newton's theory of gravity, gravity models relate bilateral trade to the mass of these two countries (generally measured as the size of the countries concerned) and to the distance between them. This standard formulation of the model, which is consistent with standard models of international trade, is generally extended to include other factors generally perceived to affect bilateral trade relations. Indeed, the concept of distance does not only concern geographical distance (i.e., transport costs) but also other factors affecting the transaction made. In addition to or instead of the distance variable, some other variables can also be used, such as a dummy variable for each of the variables having a common language, a common border, being in the same territory and the same free trade arrangement [22]. There are several reasons, however, for including distance as an

[3] Smith A. An Inquiry into the Nature and Causes of the Wealth of Nations: By Adam Smith. 1793. Vol. 1. William Porter.

[4] Krugman P. Trade in differentiated products and the political economy of trade liberalization. In Import competition and response. 1982:197–222. University of Chicago Press. URL: http://www.nber.org/chapters/c6005

explanatory variable. Batra (2004)[5] cited by [23] has some of these reasons as follows:

- Distance is an approximation of costs.
- Distance is an indicator of the elapsed time during the expedition. For perishable goods, the probability of surviving intact is a decreasing function of transit time.
- Synchronization cost: when factories combine several inputs, the timing of these must be synchronized to avoid the emergence of bottlenecks. Synchronization costs increase with distance.
- Transaction costs: Distance can be correlated with the costs of finding business opportunities and building trust between potential business partners.
- Cultural distance: It is possible that greater geographic distance correlates with greater cultural differences. Cultural differences can hamper trade in several ways, such as inhibiting communication, conflict in negotiating styles, etc.
- To study the magnitude of trade flows between countries, the trade gravity model is considered an effective analytical tool.

ICT development: what effects on bilateral trade flows?

During the 1990s, information and communications technologies became a subject of increasing interest to governments and industry [5]. After fundamental research by [24] and [25], several studies have analyzed the impact of ICTs on international trade. Recently, many researchers have studied the influence of information technologies on international trade [8, 11, 16, 26–27].

It is widely recognized that trade is a crucial factor in economic growth. For developing and least developed countries, income from the export of their goods and services to the Global North is seen as a vital source of foreign exchange that alleviates pressure on the balance of payments and creates investment opportunities and employment [5–7]. The study [25] further examines the role of Internet adoption in two-way merchandise trade flows. The authors find that a 10-percentage point increase in Internet adoption leads to a 0.2 percentage point increase in merchandise trade. Likewise, study [28], applying the framework of the panel gravity model, examines the impact of ICT on bilateral trade between 64 countries for the years 1985 to 2005 and obtains a positive and significant impact of ICT on international exchanges. Indeed, a 10% increase in Internet use leads to a 2% increase in bilateral trade. In the same vein, [29] studies how the use of different means of telecommunications affects US imports of differentiated goods from 1975 to 2000. Using a fixed-effect model approach, the study finds that adoptions of landlines, mobile phones and Internet connections among exporting countries have a significant impact on U.S. imports of differentiated products, indicating that a 10% increase in the rate of Internet adoption by exporters is increasing by 1% of total merchandise exports to the United States. [14] uses the Business Internet Use Index to estimate the effect of the Internet on total goods exports in 2011 for 40 countries (OECD countries plus Brazil, China, India, Indonesia, Russia and South Africa). It finds that the use of the Internet by business circles in exporting and importing countries has a positive link with export flows between these countries. While [14] indicates that a doubling of Internet use would increase a country's service exports by 2–4% among 151 countries from 1990 to 2006, [31] find that subscriptions to Internet and Internet hosts are positively and significantly related to business performance in 40 emerging market economies in 1995–2010.

In the related literature, a few recent studies use panel data gravity models to estimate the impact of ICT on trade. A panel data study estimates the impact of Internet users on the two-way trade of 200 countries from 1990 to 2006 in a panel gravity model [4]. Internet use has a positive and statistically significant impact on international trade, and its effect on exports is stronger than that on imports. Study [3] also uses Internet users per 100 people to examine the impact of ICT on trade in services for 151 countries from 1990 to 2006 and finds that an increase in the number of Internet users promotes trade and total services, as well as the export and import of services.

Furthermore, using a panel gravity model, [32] uses different indicators as indicators of ICT and research their impacts on bilateral trade between Malaysia and its 36 trading partners from 1980

[5] Batra A. India's Global Trade Potential: The Gravity Model Approach. ICRIER Working Paper. 2002. No. 151, New Delhi: Indian Council for Research on International Economic Relations. URL: http://www.icrier.org/pdf/wp151.pdf

to 2008. The results favor positive and significant impacts of ICT on bilateral trade. In another study, [25] examines the impact of the Internet on two-way merchandise trade between 56 countries from 1995 to 1999 by first using a theoretical model, then using both a cross-section and a panel data severity model. They find that the Internet stimulates two-way trade between countries. However, instead of using one or more indicators at a time of telecommunication infrastructure development, some studies have developed aggregate composite indices or sub-indexes of ICT to limit multicollinearity problems. Among them we have: [9] using a panel data gravity model, examines the effects of four ICT indices on Turkish bilateral exports and imports for the period 2000–2014. The sample includes 35 countries which import Turkish products and 34 countries which export products to Turkey. The results indicate that ICTs have positive and significant impacts on Turkish import and export volumes. In addition, ICTs have a quantitatively larger effect on imports than on exports. A study [33] analyzes the impact of the ICT development index on trade within the European Union (EU) and between the EU and its main trading partners for the period 1995–2007. The results indicate that ICTs have a significant impact on inter- and extra-European trade. In another study, [31] estimates the effect of ICT on exports and imports in 40 emerging markets from 1995 to 2010. Their results show that Internet subscriptions and Internet hosts have significant positive effects on consumers, exports and imports.

In contrast, for a similar ICT development index also used in [34], applying a dynamic panel data model to examine the effects of ICT on exports and imports and total trade of five service items by using panel data for 19 Middle East and North Africa (MENA) countries from 2005 to 2019. The results suggest that the development of ICT has a negative and statistically significant effect on exports of information technology services, and a positive and statistically significant effect on imports and total trade in financial services. The author [35] uses a panel gravity model to assess the role of Internet adoption on commerce in 34 OECD countries over the period 1990–2010. He finds that the Internet has less impact on international trade. Subsequently, using cross-sectional data on total exports of goods in 2001 for 26 developed and 72 developing countries. The study [11] finds that greater Internet penetration favors trade flows from developing countries to developed countries, but no significant effect is seen when trade flows from developed to developing countries. According to the study [36], the specific case of Malaysia is that the effects of financial and ICT developments on growth depend on economic leadership. They conclude that Malaysia should foster competent economic leadership, financial development and a comprehensive ICT infrastructure network to stimulate long-term economic growth. To test whether internet use affects exports, [11] used national data to assess whether internet availability increased trade and, in this regard, compared developed countries and countries in development. They found that higher internet penetration in developing countries correlates with increased exports to industrialized countries, but not to trade among developing countries or to exports from industrialized countries.

ICT and bilateral trade: What mechanisms of action?

Previous studies have shown that ICTs have trade-creating or trade-enhancing effects. Indeed, thanks to exchanges organized with several buyers and sellers on the Internet and through powerful search engines allowing sellers and buyers to find themselves at low cost, ICTs have the potential for fixed entry costs, such as those of research, advertising and establishing a distribution network in a market [4, 15, 27].

Regarding communication costs, telecommunications create a means of maintaining fast and efficient communication with business partners to maintain the competitiveness of enterprises [18, 36]. In addition, cheaper and faster communication can stimulate business transactions and expand the reach of international trade [7, 17]. In summary, in the case of information costs, ICTs provide an inexpensive channel for the collection, processing and dissemination of information. It also leads to improved well-being by reducing information asymmetries, as all members of a given exchange share the same information [32, 25]. In addition, information acquisition and transmission times are reduced, and planning is more efficient and accurate thanks to advances in ICT [31, 18, 27, 7].

Research Methodology

Model and definition of variables

This study uses an augmented version of the gravity model as a standard analytical tool for the prediction of bilateral trade flows. Gravity models are commonly used to predict bilateral trade flows in international trade. Using gravity models, the researchers mainly examined the effects of economic size and distance to analyze bilateral trade flows between countries [37, 25, 11]. Based on Newtown's law of universal gravity, the basic shape of the gravity model can be expressed as follows:

$$T_{ij} = A\frac{(Y_i \times Y_j)^a}{D_{ij}^{\gamma}}, \tag{1}$$

where T_{ij} is the volume of bilateral trade between country *i* and country *j*; *A* is a constant; Y_i and Y_j are the economic sizes of country *i* and *j*; D_{ij}^{γ} is the distance between countries.

The study [37] was the first to propose a gravity equation for bilateral trade as an empirical specification, of course taking clues from Newton's universal law of gravity. In the international trade gravity model, bilateral trade flows between countries are proportional to the size of the markets (economic masses) of the exporting and importing economies and are inversely related to the distance between these countries. In addition, GDP is used as a proxy for the size of the economy and should have a positive coefficient. The distance between the countries is expected to have a negative impact on bilateral trade due to transportation costs. The original version of the gravity model in the study [37] is defined in log-logarithmic form so that the parameters are the elasticities of trade flows with respect to the explanatory variables. The variables in our model are like those in the studies by [9, 8, 16]. Based on this, we specify our model in the equation (2) as an extended version of the original gravity equation.

$$\begin{aligned}\ln Y_{ijt} = {} & \alpha_0 + \alpha_1 \ln\left(100 + Tariff_{jt}\right) + \alpha_2 \ln\left(PIB_{it} \times PIB_{jt}\right) + \alpha_3 \ln\left(POP_{it} \times POP_{jt}\right) + \\ & + \alpha_4 \ln\left(MOB_{it} \times MOB_{jt}\right) + \alpha_5 \ln\left(I_{it} \times I_{jt}\right) + \alpha_6 \ln\left(RE_{it} \times RE_{jt}\right) + \\ & + \alpha_7 \ln\left(HI_{it} \times HI_{jt}\right) + \alpha_8 \ln\left(EB_{it} \times EB_{jt}\right) + \alpha_9 \ln Dis\tan ce_{ij} + \alpha_{10} Frontiere_{ij} + \\ & + \alpha_{11} ComLang\_off_{ij} + \alpha_{12} Comlang\_eth_{ij} + \alpha_{13} ACR_{ij} + \alpha_{14} SADC_j + \\ & + \alpha_{15} CEMAC_j + \alpha_{16} CEDEAO_j + \alpha_{17} COMESA_j + \alpha_{18} UEMOA_j + \beta_i + \gamma_t + \varepsilon_{ijt},\end{aligned} \tag{2}$$

where *i* and *j* denote South Africa and the 43 sub-Saharan African trading partner countries, respectively, while *t* is the period and αk the elasticities. Moreover, β_i and γ_t are individual (country) and time effects, and ε_{ijt} is an error term that is assumed to be normally distributed with a zero mean.

$\mathbf{Ln}\boldsymbol{Y_{ijt}}$ denotes the volume of exports (respectively imports) from country *i* to country *j* during period *t*.

$\mathbf{Ln}\left(100 + \boldsymbol{Tariff_{jt}}\right)$ is the tariff applied in bilateral trade. The linearization form forces us to adjust the tariff to 100.

$\mathbf{Ln}\left(\boldsymbol{PIB_{it}} \times \boldsymbol{PIB_{jt}}\right)$ is the mass of GDP which measures the real GDP of country *i* and country *j* during period *t*. It is expected to have positive effects on exports and imports.

$\mathbf{Ln}(\boldsymbol{POP_{it}} \times \boldsymbol{POP_{jt}})$ is the mass of the population, which is used as an indicator of the size of the country and measures the populations of country i and country j during period t. The impact of the population on exports is not clear a priori (see [31]). A growing population can increase domestic production and exports by increasing the supply of labor. However, by creating domestic demand, it can also reduce exports. Likewise, its impact on imports is not certain either. On the one hand, increased domestic demand may increase demand for imports. On the other hand, the country may decide to produce locally instead of importing, which will lead to a decrease in the volume of imports.

Ln($MOB_{it} \times MOB_{jt}$) measures the subscription to mobile telephony (per 100 inhabitants) of country *i* and country *j* during period *t* and is expected to have positive impacts on exports and imports.

Ln($I_{it} \times I_{jt}$) denotes the number of internet users (in % of the population) of country *i* and country *j* during period *t* and should have positive impacts on exports and imports.

Ln$\left(RE_{it} \times RE_{jt}\right)$ measures the score of the regulatory environment of country *i* and country *j* during period t and should have a mixed effect on trade flows.

Ln$\left(HI_{it} \times HI_{jt}\right)$ refers to the score for the quality of physical infrastructure (port, road, airport, train, etc.) that can facilitate the mobility of goods and people. It should have a positive effect on trade flows.

Table 1
Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max	Observation
Exports	568.3265	1035.135	0.223258	5047.832	430
Imports	243.5986	633.4155	0.001804	5431.64	430
distcap	3671.998	1934.631	256.25	7199.892	430
Front	0.1395349	0.3469074	0	1	430
Comlang_off	0.4651163	0.4993626	0	1	430
Comlang_ethn	0.3953488	0.489495	0	1	430
ACR	0.2325581	0.4229549	0	1	430
Tariff_ij	6.7268	6.706122	0	27.9984	430
PIB_j	2.65e+10	6.58e+10	1.97e+08	4.77e+11	430
PIB_i	4.10e+11	1.77e+10	3.75e+11	4.30e+11	430
POP_j	1.99e+07	3.18e+07	87441	2.01e+08	430
POP_i	5.49e+07	2368468	5.12e+07	5.86e+07	430
AcMOB_j	74.4699	36.46467	5.843835	198.1522	430
AcMOB_i	142.5664	19.49184	98.35023	165.5999	430
UseINT_j	16.72608	14.98243	0.58	75	430
UseINT_i	48.71565	12.47821	24	68.2	430
EBusiness_j	3.085969	1.711987	0.01	5.666667	430
EBusiness_i	5.263333	0.1561375	5.033333	5.433333	430
Hard_infrastructures_j	2.605136	1.484449	0.01	4.975	430
Hard_infrastructures_i	4.735	0.1158932	4.575	4.925	430
Regulatory_environment_j	2.637151	1.472564	0.01	5.675	430
Regulatory_environment_i	3.233256	0.5926668	0.01	3.6	430
SADC	0.3255814	0.4691375	0	1	430
CEMAC	0.1395349	0.3469074	0	1	430
CEDEAO	0.3488372	0.4771575	0	1	430
COMESA	0.3488372	0.4771575	0	1	430
UEMOA	0.1860465	0.3895975	0	1	430

Source: Authors' calculation.

$\mathbf{Ln}(EB_{it} \times EB_{jt})$ refers to the extent of the market thanks to new technologies in terms of availability and absorption capacity. It should have a positive effect on trade.

$Distance_{ij}$ is the weighted distance from country i to country j which is calculated using the population weights of these countries [14].

The binary variables from equation (2) are included in the gravity model to capture trade costs, such as transport costs and information costs [38]. Among them, common borders are used to reflect shipping costs, which are higher for landlocked and island countries and lower for neighboring countries. In addition, binary variables such as common official language and ethnicity indicate the cultural proximity between countries and the capture of information costs that go hand in hand with sharing a common language.

Estimation methods

Standard gravity models typically use cross-sectional data to estimate trade effects for a period, such as a year, or on average data. However, panel data models can provide additional information, capture relevant relationships over time, and avoid the risk of choosing an unrepresentative year [23]. In addition, panels allow monitoring unobservable individual effects between trading partners. Therefore, to study the impact of gravitational factors on the bilateral trade of SSA countries, we will use a panel gravity model. Panel data models have three basic approaches: they are pooled and estimated by ordinary least squares (OLS), or they are assumed to be driven by a fixed-effects model (FEM). The third approach concerns random effects models (REM). Each approach has its own advantages and disadvantages. As pointed out in [23], the REM would be more suitable for estimating trade flows between a random sample of trading partners belonging to a larger population. On the other hand, the FEM would be a better choice than the REM if one is interested in the estimation of trade flows between a predetermined selection of countries. Since our sample contains trade between SSA countries, the REM specification might be the most appropriate. However, the result of the Hausman specification test will validate our choice. Thus, we first estimate the effect of ICT (Internet users and mobile phone subscriptions) on the trade flow of SSA countries. Then the effect of electronic commerce on bilateral trade. In cases of multi-collinearity problems between the variables, we will estimate the data by generalized least squares. This estimator fits linear models of panel data. This estimator allows estimation in the presence of AR(1) autocorrelation within panels and cross-sectional correlation and heteroskedasticity between panels.

Data and data sources

Tables 1 and 2 show descriptive statistics for the variables selected from 43 sub-Saharan African trading partner countries in their trade with South Africa.

We chose South Africa for the following three reasons: (i) South Africa is the 3rd importing country (6.12% of trade share) and the 2nd exporting country (6.83% of trade share) in sub-Saharan Africa in 2019 (see *Table 3*); (ii) The preponderance of this country in intra-African trade shows that most of the subcontinent's trade takes place with it, thus making our results generalizable; (iii) South Africa has one of the largest information and communications technology (ICT) markets in Africa. As an increasingly important contributor to South Africa's GDP, the country's ICT and electronics sector is both sophisticated and developing. The South African ICT products and services industry is entering the growing African market. South African companies and local subsidiaries of international companies have supplied most of the new fixed and wireless telecommunications networks established on the continent in recent years. It is considered a regional hub and a supply base for neighboring countries.[6] In addition to avoiding zero exchanges between countries, the South Africa buffer allows us to have a balanced panel where 43 out of the 48 African countries have their data updated.

We use 5 data sources. We use cross-country trade (export and import) data from the IMF's Trade Statistics Directorate (DOTS, 2021). ICT is derived from the International Telecommunication Union (ITU, 2021) and the World Development Indicators (WDI, 2021). The gravity data comes from CEPII's gravity dataset (2021). The data on trade facilitation come from the Global Competitiveness Report (GCR) of the World Economic Forum from 2010 to 2019. Note that in 2018 and 2019,

[6] International Trade Administration of USA. 2021.

Table 2
Correlation test between the main variables

	Exports	**distcap**	**ACR**	**Tariff~j**	**AcMOB_j**	**UseINT_j**	**EBusin~j**
Exports	1.0000						
distcap	−0.6497	1.0000					
ACR	0.7584	−0.7367	1.0000				
Tariff_ij	−0.3528	0.2214	−0.3244	1.0000			
AcMOB_j	0.2465	0.0941	0.0629	−0.0736	1.0000		
UseINT_j	0.1257	0.0693	0.0705	−0.0715	0.7480	1.0000	
EBusiness_j	0.2734	−0.0707	0.2301	−0.0718	0.4265	0.3604	1.0000
	Exports	**distcap**	**ACR**	**Tariff~j**	**AcMOB_i**	**UseINT_i**	**EBusin~i**
Exports	1.0000						
distcap	−0.6497	1.0000					
ACR	0.7584	−0.7367	1.0000				
Tariff_ij	−0.3528	0.2214	−0.3244	1.0000			
AcMOB_i	−0.0063	0.0000	0.0000	−0.0177	1.0000		
UseINT_i	−0.0098	0.0000	−0.0000	−0.0157	0.9625	1.0000	
EBusiness_i	0.0181	−0.0000	−0.0000	0.0173	−0.6538	−0.7430	1.0000
	Exports	**distcap**	**Tariff~j**	**PIB_j**	**POP_j**	**PIB_i**	**POP_i**
Exports	1.0000						
distcap	−0.6497	1.0000					
Tariff_ij	−0.3528	0.2214	1.0000				
PIB_j	0.0367	0.0194	0.1301	1.0000			
POP_j	−0.0018	−0.0169	0.1337	0.8583	1.0000		
PIB_i	−0.0122	0.0000	−0.0148	0.0458	0.0609	1.0000	
POP_i	−0.0174	−0.0000	−0.0160	0.0455	0.0605	0.9681	1.0000
	Exports	**distcap**	**Tariff~j**	**Hard_i~j**	**Hard_i~i**	**Regula~J**	**Regula~i**
Exports	1.0000						
distcap	−0.6497	1.0000					
Tariff_ij	−0.3528	0.2214	1.0000				
Hard_infra~j	0.3074	−0.0413	−0.1080	1.0000			
Hard_infra~i	−0.0018	0.0000	0.0058	0.0015	1.0000		
Regulatory~J	0.2975	−0.0857	−0.1193	0.9383	0.0021	1.0000	
Regulatory~i	0.0808	−0.1784	0.1323	0.2409	0.4280	0.2380	1.0000

Source: Authors' calculations.

Table 3
Main trading partners of Sub-Saharan Africa in 2019

Importer	Trade (US$ Mil)	Partner share(%)	Exporter	Trade (US$ Mil)	Partner share(%)
China	25.987	10.77	China	45.548	17.98
India	18.494	7.66	South Africa	17.303	6.83
South Africa	14.765	6.12	India	17.087	6.74
United States	12.460	5.16	United States	16.407	6.47
Netherlands	11.338	4.7	Germany	12.397	4.89

Source: World Integrated Trade Solution (WITS), 2021.

the method of calculating the GCR changed. In order not to lose information and since the year-to-year variations between scores are between 0.1 and 0.9, we use the top-adjustment method for the past two years. The same method is used for other types of data. *Table 4* summarizes the definitions of the variables, the expected signs and their sources.

Results

The results are consigned in *Tables 5 and 6*. We use a sample of 43 African countries[7] of the subcontinent as partners (importers/exporters) and a rapporteur country (exporter/importer). There is a relatively high level of collinearity between aggregate severity indicators on the one hand and between the constituent elements of each aggregate indicator on the other. To correct for these problems, the estimator used is generalized least squares (GLS). Five separate regressions are therefore considered for the ICT indicators and for the constituent elements of regional trade agreements, considering the bilateral flows of exports and imports from the countries of sub-Saharan Africa to South Africa.

We regress two models: one model considers the bilateral exports of country *i* to countries *j* of sub-Saharan Africa, and the second model considers the bilateral imports of country *i* to countries *j* of sub-Saharan Africa. For each of these models, we regress five (5) equations. The first (I) regresses a standard gravity model, the second (II), third (III) and fourth (IV) regress all roles in addition to trade facilitation indicators, a standard indicator of ICT, as well as follows: mobile phone access, the number of internet users as a percentage of the population and the feasibility of electronic commerce. Finally, the fifth (V) equation, in addition to the three ICT indicators, integrates the effect of the trade potential of five different regional trade agreements.

Confirmation of the gravity model and effects of ICT

First, the results obtained are consistent with the literature and therefore correspond to the predictions. Indeed, distance has a significant negative impact on bilateral trade, whatever the model or even the equation. The estimated distance coefficient is significantly greater than unity in absolute value for the import model, which broadly corresponds to what is found in the literature (see, for example, [39–41]). The effect of distance is stronger for imports than for exports. In quantitative terms, these results show that a 1% increase in the distance between two countries leads to a drop in import trade of around 1.30%, 1.25%, 1.20%, depending on whether the ICT integrated into the equation of the mobile phone, the internet and e-commerce respectively. We can see that the development of ICT has not yet canceled the argument of physical distance as an obstacle in sub-Saharan Africa. However, this effect is weaker for the export model where 0.79%, 0.72% and 0.70% reduction in export trade occurs when the distance increases by 1 point.

[7] Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Comoros, Congo (Brazzaville), Côte d'Ivoire, Djibouti, Eritrea, Ethiopia, Gabon, Ghana, Guinea, Guinea Bissau, Equatorial Guinea, Kenya, Liberia, South Africa, Madagascar, Malawi, Mali, Mauritius, Mozambique, Namibia, Niger, Nigeria, Uganda, Central African Republic, Democratic Republic of Congo, Rwanda, Senegal, Seychelles, Sierra Leone, Sudan, Tanzania, Chad, Togo, Zambia, Zimbabwe.

Table 4
Summary of variables and data sources

Variables Definitions	Expected signs		Data sources
Exports$_{ijt}$ / Imports$_{ijt}$	**Total Exports / Imports from country *i* to country *j* (constant 2010 US $)**		**DOTS (2021)**
	Macroeconomic variables		
PIB	Gross domestic product, GDP (constant 2010 US $)	+	World Development Indicator (WDI 2021) de la Banque mondiale
POP	Total population: used as an indicator of the size of the country	+/–	
Tariff	AHS tariffs on all products applied to bilateral trade	-	World Integrated Trade Statistics (2021)
	ICT indicators		
MOB	Mobile phone use subscription for 100 people	+	(WDI, 2021)
INT	Internet users (% of the population)	+	(WDI, 2021)
E-business	E-business is the simple average of 3 scores from the GCR related to (i) the availability of the latest technologies, (ii) the company's ability to absorb these technologies and (iii) the extent of marketing. If the score is close to 7, e-business is developed, close to 1, the opposite is true.	+	Global competitiveness Report of World Economic Forum (2010–2020)
	Gravity indicators		
ACR	Regional trade agreements: binary dummy variable which is the unit if there is an RTA. To measure the isolated effect, we integrate the variables UEMOA, COMESA, ECOWAS, SADC, CEMAC	+	*CEPII Gravity Dataset* (2021)
DistanceCap	Weighted distance between country *i* and country *j*, in km	-	GeoDist / CEPII Gravity Dataset (2021)
Frontière	A binary variable which is the unit if country *i* and country *j* share a common border	+	GeoDist / CEPII Gravity Dataset (2021)
ComLangue	Language is a binary variable which is the unit if a language is spoken by at least 9% of the population of country *i* and country *j*	+	GeoDist / CEPII Gravity Dataset (2021)
ComLangue_ Ethnie	Ethnicity: is a binary variable which takes the value 1 if country *i* and country *j* have been jointly an ethnic group	+	GeoDist / CEPII Gravity Dataset (2021)
	Trade facilitation indicators		
Hard infrastructures	Physical infrastructures measure the quality of 4 infrastructures: port, roads, rails and the airport for each country, obtained by averaging the scores from the GCR: The infrastructures are efficient and of quality if the score is close to 7, no developed so close to 1	+	Global competitiveness Report of World Economic Forum (2010–2020)
Regulatory custom and environment	The regulatory and customs environment of each country is designed from 4 scores from the GCR by simple average: These are (i) irregular payment and corruption in public contracts, (ii) favoritism in government decisions (iii) transparency in the government's political strategy and (iv) public confidence in politics. When the value is close to 7, the regulatory environment facilitates trade and when the value is close to 1, the environment is harmful to trade	+	Global competitiveness Report of World Economic Forum (2010–2020)

Source: Developed by the authors. 2021.

This effect is more reduced when all three indicators are included in the model evaluated at 0.39%. This indicates potential for reducing the negative effects of distance on trade through ICT. Even if this result calls into question the argument of the death of distance, efforts to develop ICT in the subcontinent remain palpable.

We can see that the development of ICT has not yet canceled the argument of physical distance as an obstacle in sub-Saharan Africa. Efforts still need to be made to ensure that innovations in ICT such as telephone, e-mail, virtual conferencing, and e-commerce become substitutes for face-to-face interactions.

The results also clearly show that there is a positive relationship between the level of trade between the two countries and the GDP of the destination country. For example, a 1% increase in the GDP of this country leads to an increase in bilateral imports of 0.70%. This result certainly captures a market effect. On the other hand, the effect of the GDP of the country of origin and of the population is not significant or of negative sign, thus justifying that the growth of the population can be a factor of the increase of the local production [31]. We also see that countries that have a common border and a common ethnic language exchange much more often. These results are in line with expectations. Indeed, the

Table 5

Results of estimates of the bilateral export model

	(I)	(II)	(III)	(IV)	(V)
Lndistcap	−0.5610*** (0.1407433)	−0.798647*** (0.1352459)	−0.7257643*** (0.1390125)	−0.7040709*** (0.1421988)	-0.3964434*** (0.1223383)
Frontière	1.1730*** (0.294226)	0.3728759 (0.2820369)	0.7752345*** (0.2842011)	0.7447372** (.2933616)	1.146108*** (0.2514546)
Comlang_off	−0.0506729 (0.2299639)	−0.0834302 (0.2110199)	−0.3218896 (0.2152224)	−0.3707367* (.2232609)	0.0677923 (0.1683062)
Comlang_ethno	0.8996356*** (0.2232961)	0.754611*** (0.2021973)	0.9080373*** (0.2071288)	1.012312*** (0.217234)	0.7631496*** (0.1611441)
ACR	1.230533*** (0.2329186)	1.261777*** (0.2093181)	1.21504*** (0.2160477)	1.198424*** (0.2200654)	
LnTariff_ij	−0.049054*** (0.9345523)	−0.069773*** (0.8995497)	−0.0619256*** (0.9209979)	−0.0506766*** (0.9150219)	-0.0298042*** (0.7603003)
LnPIB_j	0.9320*** (0.0618627)	0.5176934*** (0.0692418)	0.5550767*** (0.079316)	0.7860919*** (0.0627901)	0.7096722*** (0.0697269)
LnPIB_i	0.2791 (4.813084)	4.054432 (10.01064)	4.848237 (6.462661)	2.624387 (5.970609)	2.470516 (7.798894)
LnPOP_j	−0.0209 (0.0545457)	0.322564*** (0.0665759)	0.3191021*** (0.087754)	0.0195821 (0.0527069)	0.2228287*** (0.0701991)
LnPOP_i	-0.37794 (4.893608)	-8.017621 (6.806545)	-14.67828** (6.436782)	-4.029027 (7.952703)	-7.022141 (10.16699)

Source: Developed by the authors. 2021.

Table 6
Estimation results of the bilateral import model

	(I)	(II)	(III)	(IV)	(V)
Lndistcap	−0.971312*** (0.2382021)	−1.302272*** (0.2467367)	−1.256784*** (0.2455797)	−1.201979*** (.2500201)	−1.496473*** (0.2518688)
Frontière	0.8051213 (0.497965)	0.1294338 (0.5231651)	0.203754 (0.5020702)	0.2246873 (0.5158013)	0.0639651 (0.517692)
Comlang_off	−0.096919 (0.3892042)	0.0633322 (0.390003)	−0.4244762 (0.3802122)	−0.4385729 (0.3925471)	−0.3112493 (0.346507)
Comlang_ethno	0.4437684 (0.3779192)	0.207196 (0.3754704)	0.5212219 (0.365914)	0.6029333 (0.3819505)	0.148088 (0.3317619)
ACR	1.739049*** (0.3942049)	1.261777*** (0.2093181)	1.726053 *** (0.3816702)	1.691473*** (0.3869287)	–
LnTariff_ij	−0.052957*** (1.58169)	−0.075470*** (1.641099)	−0.07322294 (1.627036)	−0.0583490*** (1.608832)	−0.0431923*** (1.565298)
LnPIB_j	1.824059*** (0.1047)	1.401406*** (0.1263217)	1.322135*** (0.1401197)	1.64618*** (0.1104004)	1.418939*** (.143553)
LnPIB_i	0.2481098 (8.145941)	8.297634 (18.26297)	6.36659 (11.41695)	1.510278 (10.49779)	4.987033 (16.05628)
LnPOP_j	−0.509491*** (0.0923162)	−0.1514398 (0.1214582)	0.0041959 (0.1550264)	−0.4367476*** (0.0926715)	−0.0109374 (0.1445251)
LnPOP_i	−1.517199 (8.282224)	−8.39674 (12.41756)	−17.56755 (11.37123)	1.457168 (13.98279)	−9.836023 (20.93169)
LnAccèsMoB_j	–	0.8930549*** (0.2505896)	–	–	0.2865185 (0.2769561)
LnAccèsMob_i	–	−1.410388 (2.722507)	–	–	−2.106342 (4.282573)
LnInt_j	–	–	0.0433146*** (.0122731)	–	0.5567015*** (0.162843)

Table 6 *(continued)*

	(I)	(II)	(III)	(IV)	(V)
LnInt_i	–	–	0.0116516 (0.0406839)	–	0.7439181 (3.218176)
LnEbusiness_j	–	–	–	-0.157937 (0.5002699)	0.1413419 (0.4386264)
LnEbusiness_i	–	–	–	9.312746 (11.51685)	7.935119 (16.66207)
LnHardInf_j	–	2.382778*** (0.6254909)	2.143392*** (0.6240286)	2.29509*** (0.7159076)	1.570523** (.6555663)
LnHardInf_i	–	–5.42876 (4.822226)	–3.637092 (4.741971)	–9.153412 (7.930405)	–9.858413 (9.923911)
LnRegulatory_j	–	–2.400874*** (0.6401913)	–2.11787*** (0.6207366)	–2.003449*** (0.6526718)	–1.906345*** (0.5963375)
LnRegulatory_i	–	0.2930428** (0.1136779)	0.2437417) ** (0.1109466)	0.1815044 (0.1115877)	0.2701699*** (0.1011773)
SADC	–	–	–	–	2.363435*** (0.2891487)
CEMAC	–	–	–	–	–0.8699883** (0.3712042)
CEDAO	–	–	–	–	1.823215*** (0.3952677)
COMESA	–	–	–	–	0.1583708 (0.2708639)
UEMOA	–	–	–	–	–1.567904*** (0.3225982)
Constante	20.31872 (83.96116)	–43.51144 (287.2637)	162.2328 (274.071)	–60.32446 98.6636	49.50743 (385.7266)
Observations	430	430	430	430	430
Wald chi2	1089.83 (10) (0.0000)	1225.50 (16) (0.0000)	1224.39 (16) (0.0000)	1180.29 (16) (0.0000)	1777.33 (24) (0.0000)

NB: *, **, *** significance at 10%, 5%, 1%. () are the standard errors

Source : Authors, 2021

results show that countries with a common ethnic language trade 76% more than others, especially for exports. Likewise, when two countries share a border, their trade improves, especially for the flow of exports.

The tariff is negative and significantly associated with trade in both models. This means that for African countries, the tariff continues to be a constraint on trade as well as non-tariff barriers which appear to be the main challenge for African countries [39].

Effect of ICT development

Second, the results indicate that access to and development of ICTs has great potential for improving bilateral intra-African imports. For example, a one-point improvement in mobile and internet access could lead to an improvement in bilateral exports by 0.95% and 0.029% respectively. Likewise, for bilateral imports, where the points of improvement increase this trade flow by 0.89% and 0.043% respectively, due to the improvement of one point of access to the mobile phone and to the Internet. These two results agree with most of the work on the subject, that of [35] who found that the Internet has a less clear impact on international trade than access to mobile phones. In addition, it should be noted that the effect of ICT is not unequivocal depending on the category of flow considered. We observe that the impact of the Internet is more pronounced on the imports of country i from countries j; while for exports from country i to country j, it is rather the effect of mobile access that is more pronounced (see *Table 3 and 4*). In other words, bilateral imports are more sensitive to improved internet access than bilateral exports, which are more sensitive to the development of mobile telephony.

However, an improvement in e-commerce has an insignificant effect in both models, unlike found in the work [40]. This result can be understood given the relatively recent development of e-commerce in the countries of sub-Saharan Africa [20]. In addition, the constraints as identified in the literature may justify its negative effect on trade. Because for a developed e-commerce, you need internet access that is neither characterized by low Internet penetration, particularly broadband, nor poor coverage of the mobile telephone network, and nor high telecommunications pricing.

Table 7

List of countries by Regional Trade Agreements

SADC	CEMAC	ECOWAS	COMESA	WAEMU
Angola	Cameroon	Benin	Burundi	Benign
Botswana	Central African	Burkina Faso	Comoros	Burkina Faso
Democratic	Republic Republic	Cape Verde	Djibouti	Côte d'Ivoire
Republic of the	of the Congo	Côte d'Ivoire	Egypt	Guinea Bissau
Congo	Gabon	Gambia	Eritrea	Mali
Lesotho,	Equatorial Guinea	Ghana	Ethiopia	Niger
Madagascar	Chad	Guinea	Mauritius	Senegal
Malawi		Guinea Bissau	Kenya	Togo
Mauritius Island		Liberia	Libya,	
Mozambique,		Mali	Madagascar	
Namibia		Niger	Malawi	
Seychelles		Nigeria	Uganda	
South Africa		Sierra Leone	Democratic	
Eswatini		Senegal	Republic of Congo	
Tanzania		Togo	Rwanda	
Zambia			Seychelles	
Zimbabwe			Sudan	
			Eswatini	
			Tunisia	
			Zambia	
			Zimbabwe	

Source: Compiled by the authors.

Effects of trade facilitation

Third, the results clearly indicate that trade facilitation in the subcontinent has great potential for improving trade. For example, a one-point improvement in physical infrastructure could result in an increase ranging from 1.08% to 1.36% for export flows and between 1.57% and 2.38% for import flows. On the other hand, a similar improvement in the regulatory environment generates a persistent negative impact for the country of destination while for the country of origin the effect is positive and encourages bilateral trade by around 0.25% on average. This result matches that of [40] and [39]. Indeed, these authors show that the regulatory environment of the importer has a significant and positive effect on trade while the regulatory environment of the exporter has a significant and negative effect. The negative effect recorded may come from the low level of the regulatory framework in Africa, whose average score is around 2.63 while it is 3.2 in the country of origin of South Africa.

The effect of regional trade agreements (RTA)

In both models, belonging to the same RCA contributes to improving trade and this effect is robust in all equations at 1% significance. However, this effect is more pronounced in the import model than in the export model. This is understandable as the sub-Saharan region has the most RTAs which have between 5- and 20-members economies with a composition tending to overlap (see *Table 7*). This overlap will tend to boost trade between countries. However, taken individually, some RTAs appear to be more effective than others. Indeed, in the export model, the CEMAC agreement is significant and negatively linked to trade while UEMOA and ECOWAS have non-significant positive effects, the effect becomes significant for ECOWAS in the import model. In contrast, the RTAs of Southern and South Africa (SADC, COMESA) have significant positive effects in both models. These results call for three main comments: (i) the improvement in trade can be linked to the size of the RTA, the larger the number of countries the greater the potential for trade. For example, COMESA has 20 members countries while CEMAC has only 6; (ii) the geographical area of integration or even seems to have a significant impact, we note that the RTAs of West and Central Africa are less dynamic than those of southern Africa; (iii) trade facilitation rules are not really applied. For example, in ECOWAS or UEMOA, several provisions are made with well-structured regulatory frameworks, but they are hardly applied, particularly in the case of TEC-UEMOA and TEC-ECOWAS.

As a result, interregional trade remains relatively low between African RTAs. According to data from the United Nations Conference on Trade and Development (UNCTAD), between 2015 and 2017, the share of intra-continental trade represented 15% of trade, compared to 49% in America, 61% in Asia and 67% in Europe. Intra-RTA trade represents between 2% and 11% of total exports, except in the case of SADC, where it represents 19% of exports. Increasing intraregional trade in sub-Saharan Africa faces obstacles such as poor infrastructure and high export and import costs, which prevent African economies from taking full advantage of their proximity to markets. However, the entry into force of the African Continental Free Trade Area (AfCFTA) Agreement should help increase trade in this area of Africa.

Conclusion

The gap between the subcontinent and the outside world with respect to any element of the business environment is strongly indicative of the potentially significant impact of further improving the ICT environment.

The results suggest that the development of telecommunications infrastructure has positive and significant effects on the import and export volumes of intra-African trade. However, their weak development, especially internet access (an important prerequisite for the development of e-commerce), suggests that the physical distance argument is still relevant as a barrier to trade. As a result, technological innovations must be more pronounced to be able to help developing countries to move away from geographical distances. Also, the improvement of physical infrastructure and the regulatory environment must be stimulated to increase trade links by compensating for the lack of solid historical trade links, and thus make markets more competitive and efficient by improving information flows and lowering transaction costs. Likewise, the tariffs are still too high

on regional imports and should be considerably reduced or even eliminated.

The policy implications of this study are threefold: (i) invest massively in ICT development to reduce the impact of distance on trade, with a particular focus on high-speed internet; (ii) provide sufficient support for the development of ICT infrastructure through regional agreements, regulatory and environmental frameworks, and the reduction of tariffs; (iii) expand ICT/internet penetration by reducing communication, transaction and access costs. In the perspective of broader results, this study could be extended to all African countries in bilateral trade.

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ABOUT THE AUTHORS / ИНФОРМАЦИЯ ОБ АВТОРАХ

Eudoxie Bessan Ayedoun — PhD in Economics, specializes in international trade, member of Public Economics Laboratory, University of Abomey-Calavi (LEP/UAC), Cotonou, Benin
Эвдокси Бессан Айедун — доктор экономических наук в области международной торговли, член лаборатории государственной экономики, Университет Абоме-Калави, Котону, Бенин
https://orcid.org/0000-0001-5479-254X
Corresponding Author
eudoxiebessan@gmail.com

Christian Olatundé Sinda Ayedoun — Economist-Statistician, Researcher and Food security officer at World Food Program (WFP), Cotonou, Benin
Кристиан Олатунде Синда Айедун — экономист-статистик, исследователь и специалист по продовольственной безопасности Всемирной продовольственной программы (ВПП), Котону, Бенин
https://orcid.org/0009-0008-1505-1851
ayedounchristian2015@gmail.com

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Assessing the Impact of Digital Supply Chain Management on the Sustainability of Construction Projects

S. Aziz[a], P. Kumar[b], A.B. Khan[c]
[a] Asia e University, Selangor, Malaysia;
[b] Shaheed Zulifqar Ali Bhutto Institute of Science and Technology, Karachi, Pakistan;
[c] Muhammad Ali Jinnah University, Karachi, Pakistan

ABSTRACT

Purpose: The implementation of digital supply chain management (DSCM) has brought about a paradigm shift in the construction industry, which is known for its complex and dynamic nature. This study examines the advantages of implementing a digital supply chain into building projects, focusing on efficient procurement, real-time tracking, and its effects on the sustainability of the project. **Methodology:** A stratified sampling approach is used in the research methodology to collect quantitative data from construction project managers and supply chain specialists using surveys and questionnaires. The study's main objective is to measure how improved stakeholder coordination, real-time tracking, and streamlined procurement procedures affect sustainability and efficiency.
Findings: The results of this study highlight the significant advantages of DSCM in raising the effectiveness of building projects. The results include shortened lead times, improved supply chain visibility, streamlined procurement procedures, and optimal resource allocations.
Originality and conclusions: This paper is focused on the potential difficulties and roadblocks to a successful DSCM implementation. The study provides insightful information for decision-makers and practitioners in the construction sector. To successfully apply DSCM, organizations need to make investments in technology and training, improve teamwork, and create risk-reduction plans.
Keywords: digital supply chain; DSCM; construction industry; project management; real-time data access; sustainability; IT management

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ОРИГИНАЛЬНАЯ СТАТЬЯ

Оценка влияния цифрового управления цепочками поставок на устойчивость строительных проектов

Ш. Азиз[a], П. Кумар[b], А.Б. Хан[c]
[a] Университет Asia e (AEU), Селангор, Малайзия;
[b] Институт науки и технологий им. Шахида Зулифкара Али Бхутто, Карачи, Пакистан;
[c] Университет Мухаммеда Али Джинны, Карачи, Пакистан

АННОТАЦИЯ

Цель: внедрение цифрового управления цепочками поставок (DSCM) привело к смене парадигмы в строительной отрасли, которая известна своей сложной и динамичной природой. В данном исследовании рассматриваются преимущества внедрения цифровых цепочек поставок в строительные проекты с акцентом на

эффективные закупки, отслеживание в режиме реального времени и их влияние на устойчивость проектов.
Методология: в исследовании используются стратифицированные выборки для получения количественных данных от менеджеров строительных проектов и специалистов по цепочкам поставок с использованием опросов и анкет. Основная цель исследования — оценить, как улучшенная координация заинтересованных сторон, отслеживание в реальном времени и оптимизированные процедуры закупок влияют на устойчивость и эффективность проектов.
Результаты: полученные данные подтверждают значительные преимущества DSCM в повышении эффективности строительных проектов. Результаты включают сокращение сроков выполнения заказов, улучшение прозрачности цепочек поставок, оптимизированные процедуры закупок и оптимальное распределение ресурсов.
Оригинальность и выводы: в исследовании основное внимание уделяется потенциальным трудностям и препятствиям на пути к успешной реализации DSCM. Исследование содержит полезную информацию для лиц, принимающих решения, и специалистов — практиков в строительном секторе. Для успешного применения DSCM организациям необходимо инвестировать в технологии и обучение, улучшать командную работу и создавать планы по снижению рисков.
Ключевые слова: цифровые цепочки поставок; DSCM; строительная отрасль; управление проектами; доступ к данным в реальном времени; устойчивое развитие; управление ИТ

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Introduction

Modern society is based on construction, which shapes our infrastructure and built environment. The construction sector is essential to a country's economic progress because it creates jobs, builds infrastructure, and advances national prosperity. Nonetheless, the business is characterized by complicated supply chains, complicated procedures, and wide ranges of project scopes. Construction project management efficiency is critical since it directly affects project costs, schedules, and overall success. Construction efficiency may result in considerable cost savings, shortened project timelines, and improved sustainability. Completing a project on time not only benefits the finances but also minimizes disturbances across the entire supply chain and optimizes the return on investment [1]. Moreover, the environmental concerns in developing the sustainable building structure have raised the concern, and it compels the project manager to focus on waste reduction and effective resource management. In this regard, the construction sector has seen a significant shift towards the implementation of digital supply chain management (DSCM). Throughout the project supply chain, DSCM optimizes the movement of resources, sharing information, and materials by utilizing cutting-edge technologies. Connecting different stakeholders, from contractors and customers to suppliers, DSCM improves coordination, visibility, and communication [2]. DSCM has a broad and profound effect on the efficiency of construction projects. Firstly, it streamlines the procurement process: DSCM helps construction businesses cut lead times, negotiate better prices, and source supplies more effectively. By ensuring that goods arrive when needed, this minimizes idle time on building sites and lowers project costs. Secondly, the DSCM helps the real-time tracking and data analytics give project managers insightful information [3]. Better decision-making results from this, making it possible to optimize resources, foresee possible bottlenecks, and resolve problems quickly. Last but not least, DSCM promotes improved coordination amongst diverse stakeholders by cultivating an environment of transparency and accountability [4]. This in turn, reduces the conflict, accelerates problem-solving, and improves the overall efficiency of the construction project. The importance of sustainability in construction projects is undeniable, which has broad societal, economic, and environmental implications. The construction sector may attain these crucial efficiency targets through the use of DSCM, which can improve real-time tracking, coordination/collaboration, and procurement. This will ultimately support the industry's expansion and sustainability.

Figure 1 illustrates the construction project workflow, which follows a systematic progression from planning through execution, monitoring and tracking, to evaluation. The planning stage involves defining the project's needs and scope, finding a qualified team, and creating a rough timeline. During the execution phase, the

team is being aligned, deploying resources efficiently, coordinating activities, and ensuring that construction progresses according to plan. The monitoring and tracking phase involves real-time oversight, issue identification, and quality control to maintain adherence to schedule and standards.

Continuous evaluation of project performance allows for the identification of successes and areas for improvement. The lessons learned contribute to refining future projects, enhancing overall project management practices, and ensuring client satisfaction through feedback. By following this structured workflow, construction projects can navigate challenges, optimize resource utilization, and deliver successful outcomes while maintaining quality and client expectations.

Regular evaluation and continuous improvement are integral to the success of the construction process. The efficiency and coordination of building projects can be improved by integrating a DSCM with the conventional project workflow. The digital tools like Building information modeling (BIM) offer the improved communications and real-time data access. Highly sophisticated project management software makes it easier to allocate, purchase, and schedule resources efficiently, allowing project managers to act quickly and decisively. Furthermore, the implementation of digital supply chain technologies improves inventory management by guaranteeing timely procurement and delivery of materials, which reduces delays and expedites construction schedules. Through the utilization of digital innovations in the supply chain, construction projects can attain a smooth progression from planning to execution and assessment, thereby augmenting project success and sustainability.

The implementation of DSCM technologies has been vital in the development of various high profile smart city projects in the United Arab Emirates (UAE). The South of UAE project, a major urban development, integrated DSCM to simplify procurement and logistics for its large-scale construction projects. By utilizing real-time tracking systems and advanced analytics, the project management team could monitor the various activities such as raw material deliveries, optimize inventory levels, and reduce lead times. As a result, the project has achieved a 20% reduction in procurement costs and a 15% reduction in lead times. The management not only cut costs but also helped maintain the determined project schedule, contributing to the overall success of South Dubai as a smart city initiative.

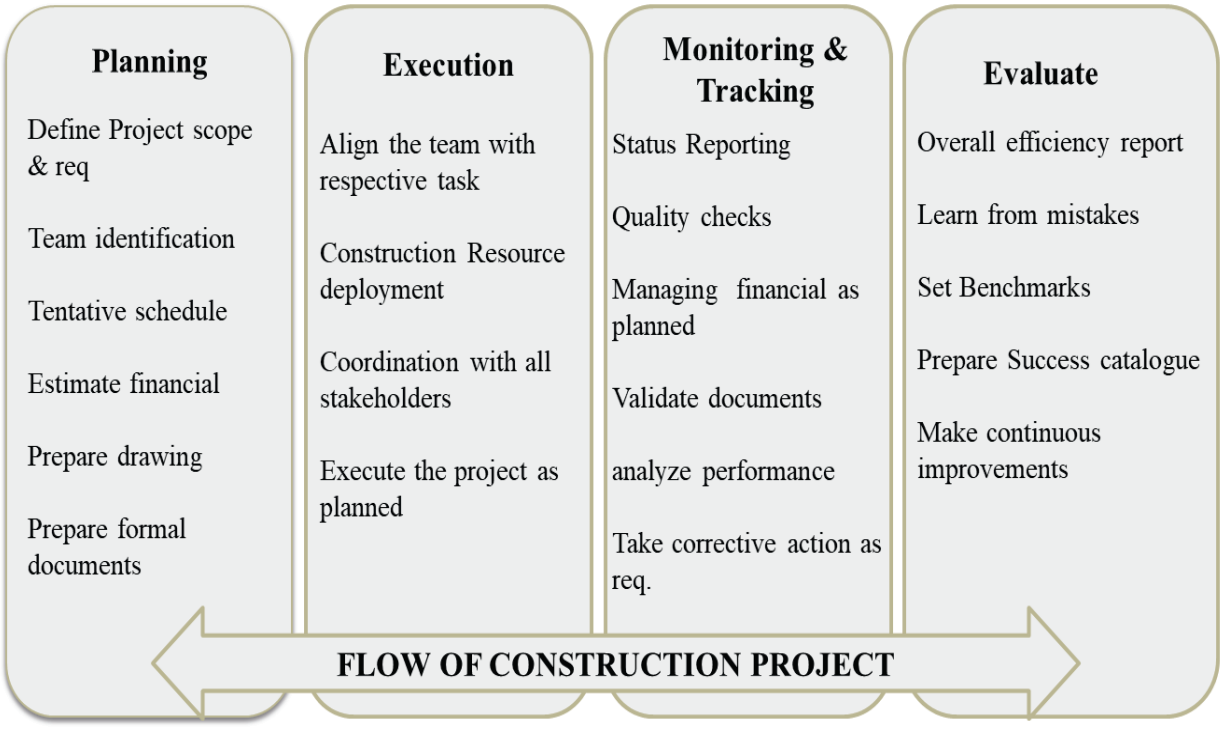

Fig. 1. **Workflow of construction project**

Source: Developed by the authors.

Research objective

The objective of the study is to investigate the digital tools that enhance efficiency, sustainability and resilience for the flow of material, product and information throughout the stakeholders of a construction project.

Research questions

- How can digital tools, such as the Internet of Things (IoT), artificial intelligence (AI) and block chain, be used to track, monitor, and manage the movement of construction materials and products in real-time?
- What are the key challenges and opportunities in implementing digital supply chain solutions in the construction industry?
- How can AI and predictive analytics be used to predict and optimize construction material demand and supply?
- How can digital tools enhance coordination among various stakeholders in the construction supply chain?

Literature review

The construction industry is a vital sector in the global economy, with its direct and indirect effects on employment, infrastructure development, and economic growth. According to the World Economic Forum, over 7% of the global workforce is directly employed in the construction industry, which contributes significantly to job creation and makes up around 13% of the global GDP. Further highlighting its significance in the global context, it acts as a catalyst for economic development by enabling the construction of necessary housing, commercial, and infrastructure structures [1]. Its importance goes beyond mere infrastructure development, encompassing diverse aspects that contribute to the welfare and prosperity of nations worldwide. Recognizing the significance of the construction industry in global development involves identifying its environmental, social and economic impact [5]. While this industry remains integral to the global economy, it faces several challenges and barriers that can be effectively addressed with the adoption of DSCM practices. The integration of digital technologies and processes to optimize the flow of materials, information, and finances along the supply chain in the construction industry, DSCM utilizing the various technologies, including the Internet of Things (IoT), big data analytics, cloud computing, and mobile applications, to streamline supply chain activities, enhance collaboration, and facilitate real-time decision-making [6]. Effective procurement directly impacts cost management, material quality and services, which account for a significant portion of project expenses [7]. Effective procurement strategies can aid in cost optimization by negotiating terms with suppliers, ensuring competitive pricing, and minimizing cost overruns [8]. The success of the project depends upon the availability of material and equipment, while delays in procurement can lead to delays in completing the project and increased costs. Effective procurement ensures the availability of all necessary resources when required, thereby ensuring the meeting of all project deadlines. Procurement strategies can mitigate risks associated with price fluctuations, reliability of suppliers, and market uncertainties. Diversifying suppliers' portfolios and developing contingency plans are vital components of project risk management within the construction industry. Digital supply chain (DSC) provides real-time information and procurement data, allowing management to make better decisions. Digital tools enable cost analysis, demand forecasting, and supplier performance evaluation. It automates the procurement process, reducing manual tasks and chances of errors [9]. It simplifies the entire procurement process, from requisition to payment, improving cost efficiency and reducing administrative overhead. DSC identifies the potential risks through data analysis. It facilitates the proactive monitoring of supplier performance, market trends, and potential disruptions, contributing to a more sustainable procurement process [10]. Real-time tracking of all activities in construction projects is critical for meeting the project timeline. It helps the decision-makers to track progress, identify potential delays, and take proactive measures to keep projects on schedule. Tracking of resources, materials, and equipment usage enables cost control [11]. It helps in avoiding cost overruns, enhancing resource allocation, and minimizing the risk of budget exhaustion. Real-time tracking helps managers to implement quality assurance by monitoring that the right materials and equipment are used as per specifications [12]. This avoids the need for repetition and ensures the construction's long-term durability. Real-time tracking can also enable safety on construction sites. Safety measures are being monitored; potential hazards are detected at an early stage, and proactive risk mitigation is

underway. DSC combines the IoT sensors and hardware, which allows the real-time tracking of equipment, material and human resources [13]. Initially, this data is collected and transferred to a central platform for analysis and decision-making; it also provides cloud-based platforms for stakeholders to access real-time tracking information from any specific activity. This enhances coordination and decision-making, irrespective of physical availability, and employs data analytics to develop insights from real-time tracking. These insights help in improving resource allocation, forecasting potential issues, and enhancing project decision-making. Real-time data tracking ensures that project managers are aware of progress in real time regardless of geographical location. They can identify blockages and take corrective actions, thereby ensuring timely completion of the project. The construction industry is a complex and multidimensional sector that relies on smooth coordination among various participants, including investors, architects, contractors, suppliers, and subcontractors. The success of the project depends upon effective communication and collaboration among these parties, quality assurance, and timely delivery [14]. The introduction of DSCM technologies enables transformative capabilities that enhance stakeholder communication in construction projects. Effective coordination ensures that all project activities align to meet the project timeline. Any kind of miscommunication among stakeholders can result in project delays, which have financial implications and can impact the overall efficiency. The participation of all stakeholders in coordination is central to maintaining construction quality. It ensures that all parties are lined up in following project specifications, safety standards, and quality control measures, reducing the probability of rework and errors. Construction projects are recognized for their complexity, involving multiple stakeholders, intricate logistics, and the chances for disruptions at various levels. Lack of communication and coordination among project members often leads to delays, rework, and increased costs. Traditional supply chain management struggles to keep balance with the dynamic nature of construction, resulting in ineffective resource allocation and inadequate visibility into the progress of the project. These challenges need to be addressed for the growth of the industry and to meet the concern for sustainable, cost-effective, and timely project delivery. Various authors in the field have recognized DSCM as a promising solution to the construction industry's persistent challenges. A study [15] suggests a more connected and data-driven approach to supply chain coordination by leveraging technologies such as the IoT and sophisticated project management software. For example, BIM serves as a central repository for project data, encouraging cooperation between various stakeholders and reducing errors by providing a single platform. Real-time monitoring is made possible by the integration of IoT devices, which also makes proactive decision-making possible and offers priceless insights into the dynamics of projects. The previous research [16] suggested digital supply chain solutions place a strong emphasis on improved stakeholder coordination and communication. These technologies facilitate real-time data sharing and dismantle silos, thereby enhancing the coherence and intelligence of the construction ecosystem. This leads to better decision-making, less rework, and eventually a more efficient building process.

We found a substantial gap in identifying the contribution of DSC and application in the construction industry. In terms of resource management, DSCM technologies enabled better forecasting and utilization of construction materials, leading to a 10% reduction in material waste. This not only contributed to cost savings but also supported environmental sustainability goals by reducing the project's ecological footprint (5). This research is focused on how DSCM defines conceptualization within the construction industry, especially streamlining the flow of material, information and resources throughout the project lifecycle. In the construction industry, every project is unique, and that became the real challenge for the supply chain specialists to handle the specific project, whereas this research implies addressing these issues, which enables the managers to smoothen their process in the construction projects.

Methodology

This section explains the research framework, hypothesis, data, and methodology of our study.

Research design

This study applies quantitative research methodology to gather and analyze numerical data. A structured survey is designed to collect responses from a diverse group of participants within the construction industry. To ensure diversity in the sample, a stratified sampling approach is em-

ployed. The industry professionals are stratified into distinct groups based on project size, geographical location, and technology adoption level.

Research framework

This is shown in *Fig. 2*.

Hypothesis development

H1: Integration of DSC positively enhances the efficiency of procurement within construction projects.

H2: Integration of DSC positively improves the real-time tracking in construction projects.

H3: The adoption of DSC results in positive effects on collaboration and coordination among all stakeholders in the construction supply chain.

H4: Digitalized procurement practices make a beneficial contribution to the efficiency and sustainability of construction projects.

H5: Real-time tracking positively enhances the efficiency and sustainability of construction projects.

H6: The collaboration and coordination among all stakeholders positively influence the efficiency and sustainability of construction projects.

Data collection

The questionnaires were distributed to supply chain professionals and decision makers in construction industries to gather data on the integration of DSC tools and their impact on the productivity of the construction industry.

Data analysis

The quantitative data collected by the survey was analyzed using statistical software Smart PLS 4. Descriptive statistics was employed to summarize the characteristics of the sample.

Pilot test

A small-scale data collection effort has been made prior to the main data collection from respondents to ensure the pilot test. The pilot test is conducted to ensure that the questionnaire is fully intelligible to respondents and to identify any possible issues that may arise. It also helps to assess the reliability and validity of the questionnaire.

Validity and reliability

Content Validity: The survey questionnaire will be pre-tested to ensure content validity and adjusted accordingly.

Reliability: Reliability of the data will be assessed through test-retest reliability for survey instruments.

Ethical considerations

Informed consent was obtained from survey participants. Respondents' privacy and anonymity was preserved.

Results

This study's first subsection describes the survey respondents' demographics who were involved in determining how DSCM affected construction projects' efficiency. The general qualities and reliability

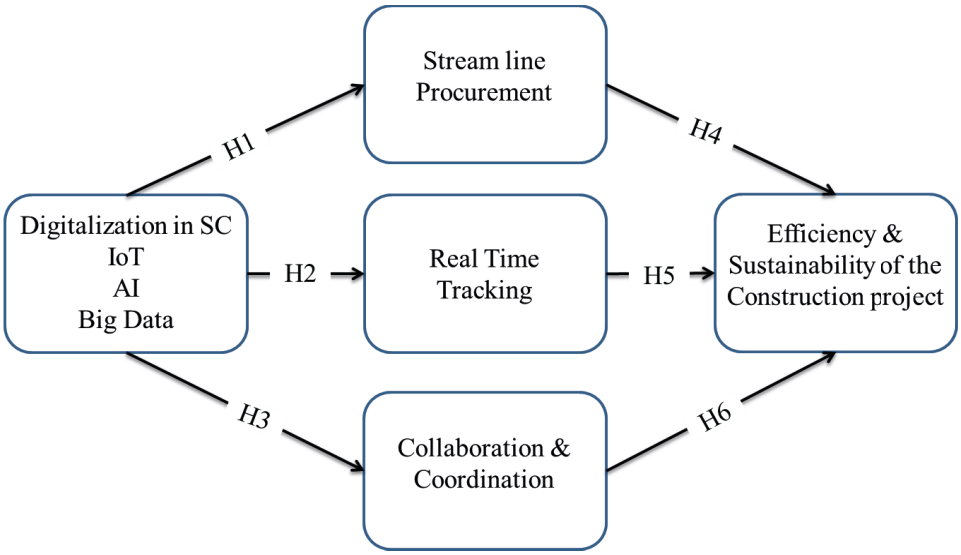

Fig. 2. **Conceptual framework of the study**

Source: Developed by the authors.

of the respondents are then assessed, and the internal consistency of the measurement instruments used is scrutinized. After that, the study presents and discusses the quantitative analysis findings obtained by using partial least square structural modeling, which shows the implications for construction project efficiency in relation to digital supply chain management.

Survey respondents' demographics

The research paper explores the demographic characteristics of a sample group, focusing on job role, years of experience, company size, geographical location, type of construction projects and the technology adoption level (*Table 1*). Out of a total of 180 questionnaires distributed, 136 were successfully returned; the turnout was 76%.

Measurement model and assessment

This is shown in *Fig. 3*. The researchers employed partial least square structural modeling (PLS 4.0-SEM) to analyze the data. Two types of validity assessments, namely convergent validity and discriminant validity, were utilized to evaluate the measurement model. *Fig. 3* illustrates the research model for this investigation, focusing on the role of the digital supply chain on the efficiency of construction projects.

Convergent validity

Table 2 provides information about a measurement model, including the number of items, factor loadings, composite reliability (CR), and average variance extracted (AVE) for different factors. According to [17], the factor loading must be greater than 0.7 for construct valid-

Table 1
Demographic characteristics of sample group

Factor	Description	Frequency	Percent, %	Cumulative percent, %
Job Role/Position	Project Managers	35	26	26
	Site Supervisors	17	13	38
	Architects	22	16	54
	Engineers	24	18	72
	Construction Workers	38	28	100
Years of Experience in Construction Industry	0 to 5 years	66	49	49
	5 to 10 years	49	36	85
	10 to 15 years	21	15	100
Company Size (Number of Employees)	Small Size Firms 0–50	64	47	47
	Medium Size Firms 50–100	41	30	77
	Large Size Corporation 100+	31	23	100
Geographical Location	Rural	74	54	54
	Urban	62	46	100
Type of Construction Projects	Residential	51	38	38
	Commercial	44	32	70
	Industrial	22	16	86
	Infrastructure (roads, bridges, etc.)	19	14	100
Technology Adoption Level	Early Adopters of Technology	37	27	27
	Moderate Technology Adopters	46	34	61
	Traditional/Non-tech Adopters	53	39	100

Source: Compiled by the authors.

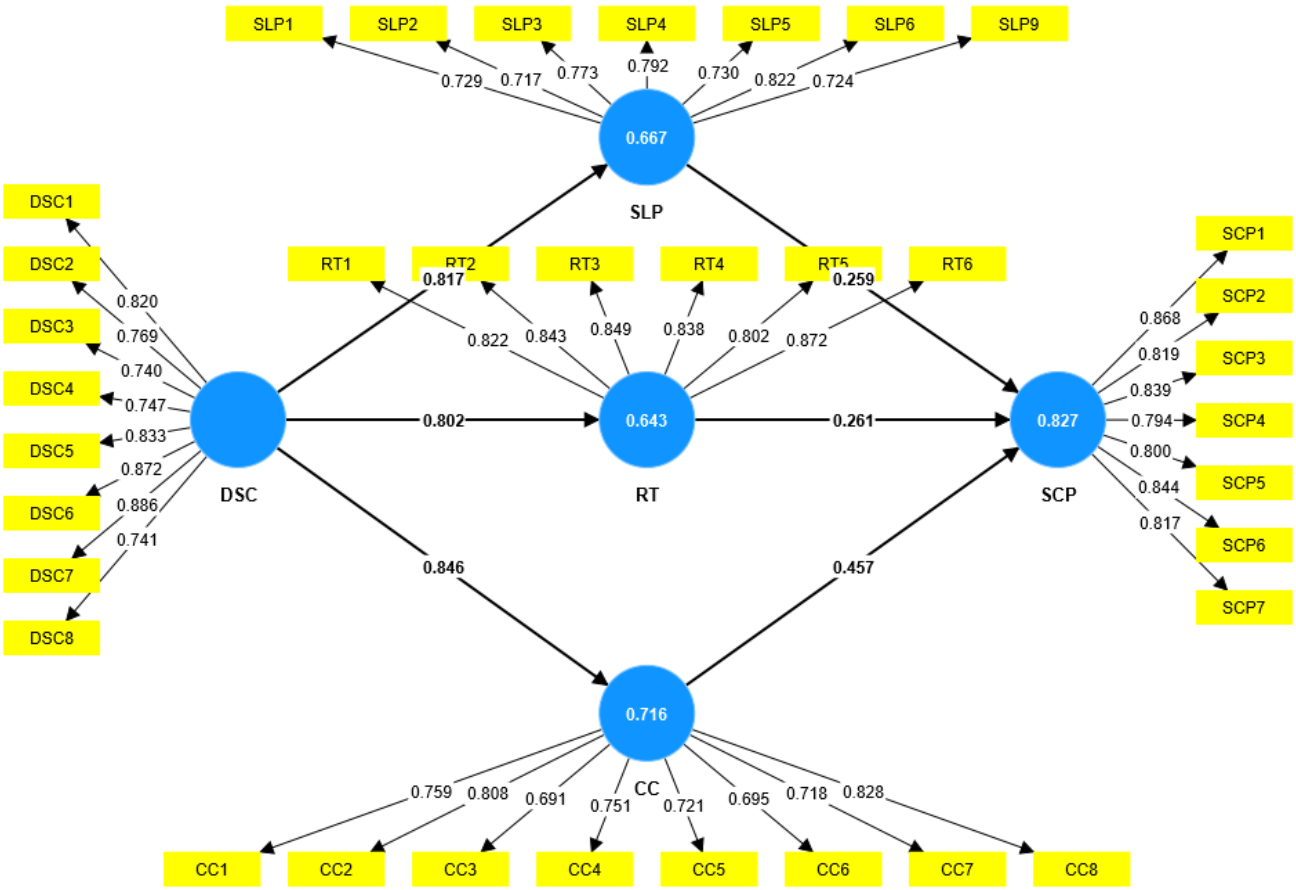

Fig. 3. **PLS path model**

Source: PLS 4.0 SME.

ity, composite reliability should be 0.8, and average variance should be higher than 0.5 for acceptable reliability and convergence of the construct, so the table depicts that all the values are in an acceptable range.

Discriminant validity

Table 3 presents the hetero-trait mono-trait (HTMT) ratios for the correlation between constructs in the study, providing insights into discriminant validity. The table shows the correlation coefficients between different constructs. The HTMT ratios between different constructs provide insights into the hetero-trait correlations, assessing the strength of correlations between different constructs. The values generally suggest that the constructs are distinct from each other, indicating good discriminant validity. Researchers often use these ratios to ensure that the measures are more strongly correlated with their own constructs than with other constructs in the model, supporting the idea that each construct is measuring a unique aspect of the phenomenon under study.

Results of hypothesis

This is shown in *Table 4*. We provide the results of the hypothesis testing in the study assessing the impact of DSCM on the efficiency of construction projects reveal strong and statistically significant relationships. Firstly, DSC demonstrates a remarkably positive impact on streamline procurement (SLP), as evidenced by the high standardized beta coefficient of 0.856 and an extremely low p-value ($p < 0.001$). This implies that the adoption of digital supply chain practices significantly contributes to improved streamline procurement within construction projects. Additionally, DSC positively influences real-time tracking (RT) and coordination and collaboration (CC) with standardized beta coefficients of 0.458 and 0.391, respectively. Both relationships are statistically significant ($p < 0.002$ and $p < 0.001$), highlighting the integral role of digital strategies in enhancing resource utilization and overall construction competence. Furthermore, the study finds that streamline procurement (SLP), real-time tracking (RT), and coordination and collaboration (CC) collectively contribute to sus-

Table 2
Results of measurement model assessment

Construct	Total no of Items	Item	Factor Loading	Composite reliability (CR)	Average Variance (AVE)	Cronbach's alpha
Digital Supply Chain	8	DSC 1	0.77	0.921	0.645	0.92
		DSC 2	0.76			
		DSC 3	0.81			
		DSC 4	0.82			
		DSC 5	0.76			
		DSC 6	0.87			
		DSC 7	0.76			
		DSC 8	0.71			
Streamline Procurement	9	SLP1	0.77	0.877	0.572	0.875
		SLP2	0.76			
		SLP3	0.78			
		SLP4	0.75			
		SLP5	0.82			
		SLP6	0.83			
		SLP7	0.71			
		SLP8	0.84			
		SLP9	0.73			
Real Time	6	RT1	0.79	0.916	0.702	0.915
		RT2	0.61			
		RT3	0.77			
		RT4	0.78			
		RT5	0.76			
		RT6	0.77			
Coordination and Collaboration	8	CC 1	0.81	0.89	0.559	0.887
		CC 2	0.82			
		CC 3	0.81			
		CC 4	0.84			
		CC 5	0.87			
		CC 6	0.81			
		CC 7	0.82			
		CC 8	0.82			
Sustainability in Construction Project	7	SCP1	0.76	0.924	0.683	0.922
		SCP2	0.85			
		SCP3	0.72			
		SCP4	0.81			
		SCP5	0.94			
		SCP6	0.779			
		SCP7	0.821			

Source: PLS 4.0 SME.

Table 3
Hetero trait – Mono trait (HTMT)

	CC	DSC	RT	SCP	SLP
CC					
DSC	0.934				
RT	0.912	0.873			
SCP	0.956	0.891	0.915		
SLP	0.855	0.909	0.878	0.899	

Source: Developed by the authors.

Table 4
Hypothesis testing

Hypothesis	Path	Std Beta	SE	T values	P values	F Square	Decision
H1	DSC → SLP	0.856	0.033	24.752	0.000	0.203	Supported
H2	DSC→ RT	0.458	0.051	15.646	0.002	0.262	Supported
H3	DSC→ CC	0.391	0.045	18.628	0.000	0.292	Supported
H4	SLP→ SCP	0.601	0.080	3.258	0.001	0.123	Supported
H5	RT→SCP	0.722	0.108	2.413	0.016	0.273	Supported
H6	CC → SCP	0.263	0.099	4.642	0.005	0.108	Supported

Source: PLS 4.0 SME.

tainability in construction projects (SCP). The relationships between Streamline procurement → Sustainability in construction projects, real-time tracking → sustainability in construction projects, and coordination and collaboration → sustainability in construction projects are supported with standardized beta coefficients of 0.601, 0.722, and 0.263, respectively. These relationships are statistically significant ($p < 0.001$, $p = 0.016$, and $p = 0.005$), emphasizing that efficient scheduling, optimized resource use, and enhanced construction competence play vital roles in improving overall sustainability in the construction industry. The study underscores the significance of embracing digital supply chain management for achieving efficiency and effectiveness in construction project management.

Discussion

The results of this study reveal a significant positive impact of DSCM on the efficiency of construction projects. The integration of digital tools such as IoT devices, real-time tracking, and data analytics into supply chain processes has evidently aligned the flow of materials and information. This is consistent with the literature indicating that the adoption of digital technology in construction can lead to improved project efficiency and resource utilization [6]. The adoption of DSCM has aligned procurement processes in the construction industry, as supported by a notable reduction in lead times and improved supplier coordination. The comparison between projects with and without DSC solutions highlights that smooth procurement through automated workflows and digital documentation significantly speed up the procurement of materials. This stands in sharp contrast to conventional methods of procurement, where manual processes often result in delays due to paperwork, approvals, and communication gaps [18]. Consequently, the study emphasizes the crucial aspect of DSCM in streamlining procurement, minimizing administrative efforts, and fostering a more agile construction supply chain. There is a noticeable difference in real-time visibility between projects using DSCM tools and those using traditional tracking techniques. Projects integrating digital tools for tracking solutions show enhanced control over the movement of materials, fostering proactive decision-making. Project managers may respond quickly to unanticipated events such as congestion

or supplier delays when they use real-time tracking, which also lowers the risk of stockouts and delays. This enhanced visibility is a clear advantage over traditional projects, where interruptions may only be identified retrospectively during project reviews [19]. The study highlights the impact of DSCM on real time tracking and its substantial positive influence on project efficiency. When construction projects using digital supply chain management are compared to those using traditional communication channels, it is evident how much better coordination and collaboration are facilitated by digital solutions. By enabling smooth communication and data sharing between project stakeholders, DSCM platforms dismantle organizational silos and foster a more collaborative workplace. In contrast, traditional projects usually face challenges associated with distorted communication, leading to misunderstandings, delays, and increased chances of errors [20]. The research highlights the significance of DSCM in developing a connected construction ecosystem where all participants are synchronized in real time, facilitating improved project coordination and collaboration [21]. An important benefit noted is the improved coordination and visibility across the construction supply chain. Project managers can keep an eye on the flow of materials, spot possible bottlenecks, and take proactive measures to handle supply chain interruptions because of real-time tracking. Digital platforms help stakeholders communicate and coordinate better, which makes the construction ecosystem more responsive and agile [22]. The information gathered for this study provides support to the idea that DSCM adoption boosts operational effectiveness and lowers costs in building projects. Digital supply chain technologies

Table 5
Cost savings after DSCM

Type of Cost	Description	Cost	Remarks
Initial Setup Costs	Technology Costs: Software, hardware, integration, and customization of DSCM systems	1,500,000–2,000,000	A medium-sized construction firm investing in DSCM for procurement efficiency
Training Costs	Training personnel (project managers, procurement teams) to use DSCM tools	2000–5000 per employee	Training costs for a team of 20 employees range from 40,000 to 100,000
Ongoing Operational Costs	Maintenance Costs: Subscription fees, software updates, system maintenance (cloud-based or on-premises)	100,000–200,000 Annually	Cloud-based DSCM system maintenance for a year
Cost Savings Post-Implementation	Reduced Procurement Costs: Automation and improved supplier management reduce procurement inefficiencies	5–15% reduction in procurement costs	Estimated savings of 50,0000–150,0000 on procurement for a mid-sized project
Decreased Lead Times	Real-time tracking reduces material delays, improving project timelines	20–30% reduction in lead times	Savings of 500,000–1000,000 by avoiding project delays on a mid-sized project.
Resource Optimization:	Better labor and material utilization minimize waste and inefficiency	5–10% savings in labor and material costs	1000,000+ savings through optimal resource allocation in a large construction project
Profitability Improvements	Increased Overall Profitability: Cost reductions and efficiency gains lead to higher profit margins	10–20% increase in project profitability	Estimated profitability increase of 2000,000+ for a large construction project

Source: Developed by the authors.

help to reduce idle time, minimize delays, and optimize inventory management, all of which lead to a more economical project execution. This is consistent with the research findings of [23] that highlight how digital technologies can reduce costs in the construction supply chain management process.

Cost savings after implementation of DSCM

Implementing DSCM can dramatically cut expenses while increasing efficiency. Initial setup expenditures range from 1.5 to 2 million, with training costs ranging from 40,000 to 100,000 per team. Annual operating expenditures range from 100,000 to 200,000. Following implementation, DSCM can result in a 5–15% reduction in procurement costs, a 20–30% drop in lead times, a 5–10% savings in resource expenses, and a 10–20% gain in total profitability (*Table 5*).

Implication for practice and future research

The findings of this research highlight significant implications for experts in the construction industry. First and foremost, the adoption of DSCM begins as a strategic imperative for enhancing the overall project efficiency. Reluctant adopters of digital tools run the risk of falling behind their competitors and project performance. To ensure a smooth transition, construction organizations must invest in training programs for their employees, ensuring that the entire workforce is equipped with the necessary skills to absorb advanced digital technologies. Moreover, industry professionals and stakeholders are encouraged to explore collaboration platforms combined with DSCM for smooth coordination and data sharing, ultimately promoting a more collaborative and efficient project environment. Developing mechanisms for continuous monitoring of DSC processes and adapting strategies based on real-time data insights is vital for navigating the complex nature of construction projects. The study provides opportunities for more investigation in a number of important areas. First, strategic planning requires an understanding of the long-term effects of DSCM on the results of construction projects and the resilience of the sector as a whole. In order to gain insight into the universal applicability of DSCM solutions, researchers should also look into how well they scale across projects of different sizes and complexity. There is potential to improve efficiency, security, and transparency in construction supply chains by investigating the integration of new technologies such as block chain with DSCM. Furthermore, it is imperative to investigate the ways in which DSCM impacts sustainable practices in the construction sector. Understanding the role of DSCM in promoting environmentally friendly supply chain practices will help steer the industry towards more responsible and eco-friendly approaches as sustainability becomes a central focus. In summary, the implications for practice underscore the importance of embracing DSCM, investing in training, and utilizing collaboration platforms, while future research should focus on the long-term impact, scalability, integration of emerging technologies, and sustainability aspects of DSCM in construction projects.

Conclusions

This research illustrates the transformative role of DSCM in revolutionizing the efficiency of the construction industry. The evidence from the statistical results underscores the role of DSCM in smoothening procurement processes, enhancing real-time tracking, and raising improved coordination and collaboration among all stakeholders. The implications of DSCM for practice are clear, urging construction industry decision makers to embrace DSCM as a tactical imperative for uplifting project performance and competitiveness. The results not only recommend the adoption of DSCM but also emphasize the necessity of investing in workforce training, the implication of collaboration platforms, and the development of a continuous monitoring system. These measures are pivotal for taking full advantage of the benefits derived from DSCM and making certain a smooth transition to a digital supply chain in the construction industry that is more responsive in the long run. The study prepares the ground for more research in this crucial aspect. Researchers should look into the long-term effects of DSCM on project outcomes and industry resilience, as this is an interesting topic. Digital supply chain solutions for the construction industry will continue to evolve as a result of research into the integration of emerging technologies like block chain and an understanding of how scalable DSCM is across projects of different sizes. Furthermore, investigating the impact of DSCM on sustainable practices is consistent with the in-

dustry's growing commitment to ecologically conscious approaches. In summary, this study explains the benefits of DSCM in the construction industry today and anticipates that digitalization will be crucial in forming a more productive, cooperative, and sustainable sector of the market. Stakeholders can confidently navigate the changing construction project landscape by taking into account the insights gained from this study. They can also seize the opportunities that DSCM offers for the benefit of individual projects, organizations, and the industry as a whole.

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ABOUT THE AUTHORS / ИНФОРМАЦИЯ ОБ АВТОРАХ

Shahid Aziz — PhD student in Management Science, Asia e University, Selangor, Malaysia
Шахид Азиз — аспирант в области управленческих наук, Университет Asia e (AEU), Селангор, Малайзия
https://orcid.org/0000-0002-8110-3655
engrshahidaziz@gmail.com

Prince Kumar — PhD student in Management Science, Shaheed Zulifqar Ali Bhutto Institute of Science and Technology, Karachi, Pakistan
Принц Кумар — аспирант в области управленческих наук, Институт науки и технологий им. Шахида Зулифкара Али Бхутто, Карачи, Пакистан
https://orcid.org/0000-0001-8737-2007
Corresponding author
prince.rajput06@gmail.com

Anwar Baz Khan — PhD student, Muhammad Ali Jinnah University, Karachi, Pakistan
Анвар Баз Хан — аспирант, Университет Мухаммеда Али Джинны, Карачи, Пакистан
https://orcid.org/0000-0002-4109-4619
anwerbaz@gmail.com

Authors' declared contribution:
Shahid Aziz — conceptualization of the research, development of methodology, and supervision of the study. Led the writing of the original draft and was responsible for project administration.
Prince Kumar — data collection, formal analysis, and visualization. Contributed to reviewing and editing the manuscript, as well as handling the software (PLS SME) tools used in the analysis.
Anwer Baz Khan — literature review, validation of results, and investigation of theoretical framework. Reviewed the final manuscript and provided critical revisions to improve the research quality.

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Dynamic Programming Principle for Optimal Control of Uncertain Random Differential Equations and its Application to Optimal Portfolio Selection

J. Chirima[a], F.R. Matenda[b], E. Chikodza[c], M. Sibanda[d]
[a] University of Malawi, Zomba, Malawi;
[b,d] University of KwaZulu-Natal, Durban, South Africa;
[c] University of Botswana, Gaborone, Botswana

ABSTRACT

This study **aimed** to examine an uncertain stochastic optimal control problem premised on an uncertain stochastic process. The proposed approach is used to solve an optimal portfolio selection problem. This paper's research is **relevant** because it outlines the procedure for solving optimal control problems in uncertain random environments. We implement Bellman's principle of optimality **method** in dynamic programming to derive the principle of optimality. Then the resulting Hamilton-Jacobi-Bellman equation (the equation of optimality in uncertain stochastic optimal control) is used to solve a proposed portfolio selection problem. The **results** of this study show that the dynamic programming principle for optimal control of uncertain stochastic differential equations can be applied in optimal portfolio selection. Also, the study results indicate that the optimal fraction of investment is independent of wealth. The main **conclusion** of this study is that, in Itô-Liu financial markets, the dynamic programming principle for optimal control of uncertain stochastic differential equations can be applied in solving the optimal portfolio selection problem.
Keywords: randomness; uncertainty; uncertain random differential equations; dynamic programming; optimal control; portfolio selection; equation of optimality; Itô-Liu financial markets

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ОРИГИНАЛЬНАЯ СТАТЬЯ

Принцип динамического программирования для оптимального управления неопределенными случайными дифференциальными уравнениями и его применение к оптимальному выбору портфеля

Дж. Чирима[a], Ф.Р. Матенда[b], Э. Чикодза[c], М. Сибанда[d]
[a] Университет Малави, Зомба, Малави;
[b,d] Университет Квазулу-Натал, Дурбан, Южная Африка;
[c] Университет Ботсваны, Габороне, Ботсвана

АННОТАЦИЯ

Целью данного исследования было изучение поведения финансовых рынков как неопределенной стохастической задачи оптимального управления, основанной на неопределенном стохастическом процессе. Предлагаемый подход используется для решения задачи оптимального выбора портфеля. Исследование,

проведенное в данной работе, является актуальным, поскольку оно описывает процедуру решения задач оптимального управления в неопределенных случайных средах. Авторы реализуют **метод** принципа оптимальности Беллмана в динамическом программировании для вывода принципа оптимальности. Затем полученное уравнение Гамильтона–Якоби–Беллмана (уравнение оптимальности в неопределенном стохастическом оптимальном управлении) используется для решения предложенной задачи выбора портфеля. **Результаты** данного исследования показывают, что принцип динамического программирования для оптимального управления неопределенными стохастическими дифференциальными уравнениями может быть применен при оптимальном выборе портфеля. Кроме того, результаты исследования указывают на то, что оптимальная доля инвестиций не зависит от состояния. Основной **вывод** данного исследования заключается в том, что на финансовых рынках Ито-Лю принцип динамического программирования для оптимального управления неопределенными стохастическими дифференциальными уравнениями может быть применен при решении задачи оптимального выбора портфеля.

Ключевые слова: случайность; неопределенность; неопределенные случайные дифференциальные уравнения; динамическое программирование; оптимальное управление; выбор портфеля; уравнение оптимальности; финансовые рынки Ито-Лю

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Introduction

Generic uncertainty experienced in natural and physical processes manifests in different forms [1]. In this modern world, the primary forms of generic uncertainty are fuzziness, randomness, uncertainty, and the interaction effects between any of these three [1, 2]. Randomness describes the state of a system that is entirely unknown due to a lack of information [3]. Similarly, [4] propounded that randomness is an objective indeterminacy. Randomness is modelled by probability theory, which is defined as a branch of pure mathematics that deals with dynamic random phenomena [5, 6]. Conceptually, probability theory is implemented when the sample size is big enough to approximate the probability distribution from existing frequency [6]. Probability theory is the bedrock of stochastic finance theory. Fuzziness is the vagueness surrounding the description of the meaning of events, phenomena, and statements themselves [3]. Fuzzy set theory models fuzziness [7]. The application of fuzzy theory in finance theory led to the emergence of fuzzy finance theory.

In practice, some knowledge or information is typically shown by human semantic terms like ''stock price is about $ 28'' [2, 5, 8]. About $ 28 might mean any number close to $ 28, which is imprecise. Existing literature has indicated that these ''unknown constants'' and ''unsharp concepts'' behave neither like fuzziness nor randomness [2]. This phenomenon is called uncertainty or Liu's uncertainty [5, 8], and [4] postulated that uncertainty is subjective indeterminacy. The lack of precise or sufficient knowledge about realities identifies uncertainty. It should be noted that uncertainty is different from randomness and fuzziness.

To model uncertainty, [8] introduced uncertainty theory. Uncertainty theory is an axiomatic branch of mathematics that analyzes uncertain phenomena. Uncertainty theory is applied when the sample size is missing or too small to approximate the probability distribution. Domain specialists are asked to examine their belief degrees of every event happening. People typically overvalue odd events. Hence, belief degrees can have a greater variance than the real frequency. In this instance, implementing probability theory results in counter-intuitive results. Uncertainty theory is the foundation of uncertain finance theory. For more information concerning Liu's uncertainty, the reader is referred to other authors [5, 8].

In probability theory, stochastic processes (e.g., a Brownian motion introduced by Robert Brown in 1827) were designed to analyze the random phenomena dynamics that change with time. Numerous differential equations are powered by a Brownian motion in probability theory. These differential equations are called stochastic differential equations. In uncertainty theory, uncertain processes (e.g., a canonical Liu process [9]) were introduced to analyze the uncertain phenomena and dynamics that change with time. Numerous differential equations are powered by a canonical Liu process in uncertainty theory. These differential equations are called uncertain differential equations.

Randomness and uncertainty often appear simultaneously in a dynamic system [4]. This indicates that

more than probability theory or uncertainty theory is needed to deal with systems that exhibit randomness and uncertainty [4, 6]. Chance theory [10] was introduced to deal with sophisticated systems exhibiting uncertainty and randomness. Chance theory is a mathematical methodology comprising uncertainty theory and probability theory [4]. It is defined as a branch of pure mathematics concerned with the analysis of uncertain random phenomena [4, 6].

To analyze the uncertain random phenomena dynamics that change with time in chance theory, [11] introduced an uncertain random process. A myriad of differential equations are powered by an uncertain random process in chance theory. These differential equations are known as uncertain random differential equations and are powered by both a canonical Liu process and a Brownian motion. Uncertain random differential equations describe complex mathematical systems that exhibit randomness and uncertainty [2]. When randomness and uncertainty concurrently appear in dynamical systems, chance theory is an efficient framework to deal with such scenarios.

Since the 1950s, the optimal control theory has been a vital division of modern control theory [4]. These authors [4] further articulated that analyzing optimal control problems is a topic of interest to many researchers, and the analysis has practical connotations. Optimal control problems are usually categorized into two, i.e., optimal control problems associated with adequate information and optimal control problems associated with inadequate information [4]. The parameters of the systems are known, and the dynamics of the systems are described by deterministic differential equations when considering the optimal control problems with complete information [4]. On the other hand, [4] postulated that systems' outcomes or conditions could not be precisely described due to numerous indeterminate factors in the systems' dynamics when considering optimal control problems with inadequate information [4].

Optimal control is one of the areas in mathematics where generic uncertainty issues must be handled cautiously. Applying probability theory in optimal control theory gave birth to stochastic optimal control theory. On the other hand, the application of uncertainty theory in optimal control theory led to the emergence of uncertain optimal control theory. Uncertain optimal control theory and stochastic optimal control theory can be used to address optimal control problems with inadequate information. Basically, uncertain optimal control theory and stochastic optimal control theory are used to solve control problems with subjective indeterminacy and objective indeterminacy, respectively. Stochastic differential equations are crucial in stochastic optimal control theory [12–16]. The application of stochastic optimal control in finance was initiated by [17]. For more information concerning stochastic optimal control, the reader is referred to the works of, but not limited to, [17–23]. Uncertain differential equations are vital in uncertain optimal control theory [24–28]. For more expositions on uncertain optimal control, the reader is referred to, among other sources, [29, 30].

When randomness and uncertainty concurrently appear in dynamic systems, chance theory is an efficient framework to deal with optimal control problems. In the existing literature, there are limited studies that examine uncertain random optimal control problems under the chance theory framework [4, 31]. Premised on chance theory, [32] presented the optimal control model for a multistage uncertain random system. As alluded to earlier, uncertain stochastic differential equations play a critical role in chance theory and, interestingly, in uncertain random markets. [30, 33, 34] are some authors who have examined the dynamic principle for optimal control of uncertain stochastic differential equations in uncertain random markets.

This study examines an uncertain stochastic optimal control problem premised on the notion of uncertain stochastic process. We implement the Bellman's principle of optimality in dynamic programming to derive the principle of optimality, and then the resulting Hamilton-Jacobi-Bellman equation (the equation of optimality in uncertain stochastic optimal control) is used to solve a proposed portfolio selection problem. Previously, [17] examined a portfolio selection problem using stochastic differential equations, while [24] addressed a portfolio selection problem by applying uncertain differential equations. Therefore, this proposed method is a new paradigm for solving optimal control problems in Itô-Liu financial markets.

The results of this study show that the dynamic programming principle for optimal control of uncertain stochastic differential equations can be applied in optimal portfolio selection. Also, the study results indicate that the optimal fraction of investment is independent of wealth. The results are valuable for solving the optimal portfolio selection problem in Itô-Liu financial markets. The main conclusion of

this study is that, in Itô-Liu financial markets, the dynamic programming principle for optimal control of uncertain stochastic differential equations can be applied in solving the optimal portfolio selection problem.

The entire paper is organised in the following order. Section 2 contains the preliminaries. In Section 3, an uncertain random optimal control problem is proposed, and the equation of optimality and the principle of optimality are derived and proven. In Section 4, an examination of the portfolio selection problem is done using the dynamic programming approach. Finally, conclusions are articulated in Section 5.

Preliminaries

Some important definitions relating to the concept of uncertain random processes are presented in this section. Let $(\Gamma, \mathcal{L}, M)$ be the universal set on an uncertain space, a σ-algebra, and an uncertain measure, respectively. Also, let $(\Omega, \mathcal{F}, P)$ be the universal set on a probability space, a σ-algebra, and a probability measure, respectively. The chance space is given by $(\Gamma, \mathcal{L}, M) \times (\Omega, \mathcal{F}, P)$.

The normality, duality, and monotonicity properties of a chance space were verified by [10].

Definition 1 [10] Given a chance space $(\Gamma, \mathcal{L}, M) \times (\Omega, \mathcal{F}, P)$, if $\theta \in \mathcal{L} \otimes \mathcal{F}$ is an event, then

$$Ch(\theta) = \int_0^1 P\{\omega \in \Omega \mid \mathcal{M}\{\gamma \in \Gamma \mid (\gamma, \omega) \int \theta\} \geq x\} dx,$$

where $(\Omega, \mathcal{F}, P) and (\Gamma, \mathcal{L}, M)$ are a probability space and an uncertainty space in that order.

Definition 2 [10] An uncertain random variable refers to a function ξ from a chance space $(\Gamma, \mathcal{L}, M) \times (\Omega, \mathcal{F}, P)$ to the set $\mathcal{R}$ such that $\varepsilon \in B$ is an event in $\mathcal{L} \otimes \mathcal{F}$ for every Borel set B of real numbers.

Definition 3 [10] For a measurable function ψ, if $F(x)$ is the cumulative distribution function of a random variable κ, τ denotes an uncertain variable and $\psi(x, \tau)$ has an uncertainty distribution $\Psi(x, y)$, the chance distribution of $\psi(\kappa, \tau)$ is given by

$$\Phi(y) = \int_{-\infty}^{\infty} \Psi(x, y) dF(x),$$

where x and y are the realisations of κ and τ, respectively.

Definition 4 [11] Let $(\Gamma, \mathcal{L}, M) \times (\Omega, \mathcal{F}, P)$ be a chance space, and let T refer to a totally ordered set. An uncertain random process refers to a function $X_t(\gamma, \omega)$ from $T \times (\Gamma, \mathcal{L}, M) \times (\Omega, \mathcal{F}, P)$ to the set of real numbers such that $\{X_t \in B\}$ is an event in $\mathcal{L} \otimes \mathcal{F}$ for every Borel set *B* of real numbers at each time *t*.

Definition 5 [11] Assume X_t is an uncertain random process on a chance space $(\Gamma, \mathcal{L}, M) \times (\Omega, \mathcal{F}, P)$. Then, for each fixed $\gamma^* \in \Gamma$ and $\omega^* \in \Omega$, the function $X_t(\gamma^*, \omega^*)$ is called a sample path of the uncertain random process of X_t.

Definition 6 [11] An uncertain random process G_t is a stationary increment uncertain random process if, for $t > 0$, the increment $G_{t+s} - G_s$ are identically distributed uncertain random variables for $s > 0$.

Definition 7 [6] Let C_t and B_t be a one-dimensional canonical process and one-dimensional Brownian motion, respectively, and let Y_t be an uncertain random process. For given functions f, h and g, the differential equation

$$dY_t = f(t, Y_t)dt + g(t, Y_t)dC_t + h(t, Y_t)dB_t,$$

is called an uncertain stochastic differential equation.

Definition 8 [2] Let $X_t = (Z_t, Y_t)^T$ be an uncertain random process. For any partition $P = a = t_1, t_2, t_3 \ldots, t_{k+1} = b$ of the closed interval $[a, b]$, with $a = t_1, t_2, t_3 \ldots, t_{k+1} = b$, the mesh is written as $\Delta = \max_{1<i<k} |t_{i+1} - t_i|$. The Itô-Liu integral of X_t regarding $G_t = (B_t, C_t)$ is defined as follows

$$\int_a^b X_S \mathrm{d}G_S = \lim_{\Delta \to 0} \sum_{i=1}^{N} Z_{t_i} \left(B_{t_{i+1}} - B_{t_i} \right) + \lim_{\Delta \to 0} \sum_{i=1}^{N} Y_{t_i} \left(C_{t_{i+1}} - C_{t_i} \right). \quad (1)$$

given that it exists in mean square and is an uncertain random variable where C_t and B_t are a one-dimensional canonical process and a one-dimensional Wiener process, respectively. In this case, X_t is called Itô-Liu integrable. In particular, when $Y_t \equiv 0$, X_t is called Liu integrable.

Uncertain random optimal control

The problem of optimal control in uncertain random environments concerns choosing a decision that optimizes an objective function associated with an uncertain stochastic process. In the problem, the state variable evolves as an uncertain stochastic differential equation. The concept of an uncertain stochastic integral plays a pivotal role in solving uncertain stochastic differential equations.

Suppose that at any given time s, an uncertain random process $X_s \in \mathcal{R}^k$ defined on a chance space $(\Gamma, \mathcal{L}, M) \times (\Omega, \mathcal{F}, P)$ can be influenced by a choice of a parameter ζ, which is the decision variable also referred to as the control. The control variable ζ represents the function $\zeta(s, X_s)$ of time s and state X_s.

Let the performance function be

$$J(t,x,\zeta) \equiv E\left[\int_t^T f(s, X_s, \zeta)ds + Q(X_T, T)\right], \tag{2}$$

which represents the anticipated expected optimal reward $J(t,x,\zeta)$ available in $[t,T]$ given that X_s is the state variable. The function $f(s, X_s, \zeta)$ represents the objective function and $Q(X_T, T)$ represents the terminal utility function. The state variable can be expressed as

$$X_s = \int_0^s e(t, X_t, \zeta)dt + \int_0^s \sigma_2(t, X_t, \zeta)dC_t + \int_0^s \sigma_1(t, X_t, \zeta)dB_t.$$

Given $(t,x) \in [0,T] \times \mathcal{R}$, the state equation for $s \in [t,T]$ is given by

$$dX_s = e(s, X_s, \zeta)ds + \sigma_2(s, X_s, \zeta)dC_s + \sigma_1(s, X_s, \zeta)dB_s,\ X_t = x. \tag{3}$$

where $e, \sigma_1 \text{ and } \sigma_2$ are functions of X_s, ζ and time s. Equation (2) is assumed to have a unique solution X_t^*. The value function is given by

$$V(t,x) \equiv \sup_{\zeta} J(t,x,\zeta). \tag{4}$$

Using Equations (1), (2) and (3) above, an uncertain random optimal control problem can be expressed as

$$\begin{cases} V(t,x) \equiv \sup\limits_{\zeta} E\left[\int_t^T f(s, X_s, \zeta)ds + Q(X_T, T)\right] \\ \text{subject to} \\ dX_s = e(s, X_s, \zeta)ds + \sigma_2(s, X_s, \zeta)dC_s + \sigma_1(s, X_s, \zeta)dB_s, \\ X_t = x. \end{cases} \tag{5}$$

The basic principle of dynamic programming is called the principle of optimality. Richard Bellman developed it, and it describes the property of an optimal policy. The principle of optimality for this problem is outlined below.

Note that in the following computations, we use the simplified notation for $e(s, X_s, \zeta)$, $\sigma_2(s, X_s, \zeta) \text{ and } \sigma_1(s, X_s, \zeta)$, i.e., we use $e, \sigma_2 \text{ and } \sigma_1$.

Theorem 1 (Principle of optimality) Let $(t,x) \in [0,T] \times \mathcal{R}$, $\Delta t > 0 \text{ and } t + \Delta t < T$. The value function $V(t,x)$ can be expressed as

$$V(t,x) = \sup_{\zeta} E\left[\int_t^{t+\Delta t} f(s, X_s, \zeta)ds + V(t + \Delta t, x + \Delta X_t)\right] \tag{6}$$

given that $x + \Delta X_t = X_{t+\Delta t}$.

Proof 1 Let $\delta = t + \Delta t, \mu = x + \Delta X_t$ and

$$V^*(t,x) = \sup_{\zeta} E\left[\int_t^{\partial} f(s, X_s, \zeta) ds + V(\delta, \mu)\right].$$

From the definition of $V(t,x)$, we have

$$V(t,x) \geq E\left[\int_t^{\delta} f\left(s, X_s, \zeta|_{[t,\delta)}\right) ds + \int_{\delta}^{T} f\left(s, X_s, \zeta|_{[\delta,T]}\right) ds + Q(X_T, T)\right] \tag{7}$$

given a control process ζ. The values of the quantity that the decision-maker controls are represented by ζ. On the intervals $[t,\delta)$ and $[\delta,T]$, these values can be expressed as $\zeta|_{[t,\delta)}$ and $\zeta|_{[\delta,T]}$ in that order. The integrals represented by

$$\int_t^{\delta} f\left(s, X_s, \zeta|_{[t,\delta)}\right) ds$$

and

$$\int_{\delta}^{T} f\left(s, X_s, \zeta|_{[\delta,T]}\right) ds$$

are autonomous from each other since uncertain stochastic processes

$$G\_\{t\} = (dB_t, dC_t)(s \in [t,\delta))$$

and

$$G\_\{t\} = (dB_t, dC_t)(s \in [t,\delta])$$

are also autonomous from each other. Applying theorem 5 in [35] to Equation (6), we get

$$V(t,x) \geq E\left[\int_t^{\delta} f\left(s, X_s, \zeta|_{[t,\delta)}\right) ds\right] + E\left[\int_{\delta}^{T} f\left(s, X_s, \zeta|_{[\delta,T]}\right) ds + Q(X_T, T)\right]. \tag{8}$$

If we take the supremum of the right-hand side in Equation (7) with respect to $\zeta|_{[t,\delta)}$ and $\zeta|_{[\delta,T]}$, it can be concluded that $V(t,x) \geq V^*(t,x)$. However,

$$E\left[\int_t^{T} f(s, X_s, \zeta) ds + Q(X_t, T)\right] = E\left[\int_t^{\delta} f\left(s, X_s, \zeta|_{[t,\delta)}\right) ds\right] +$$

$$+ E\left[E\left[\int_{\delta}^{T} f\left(s, X_s, \zeta|_{[\delta,T]}\right) ds + Q(X_T, T)\right]\right] \leq E\left[\int_t^{\delta} f(s, X_s, \zeta) ds + V(\delta, \mu)\right] \leq V^*(t,x).$$

This means $V(t,x) \leq V^*(t,x)$, thus $V(t,x) = V^*(t,x)$, which concludes the proof. For an uncertain random optimal control problem in Equation (4), the optimality equation is presented in the following theorem.

Theorem 2 (Equation of optimality) If $V(t,x) : [0,\ T] \times \mathcal{R} \to \mathcal{R}$ is a twice continuously differentiable function,

$$-V_t(t,x) = \sup_{\zeta}\left[f(t,x,\zeta) + V_x(t,x)e(t,x,\zeta) + \frac{1}{2}V_{xx}(t,x)\sigma_1^{\,2}(t,x,\zeta)\right].$$

Proof 2 If $\Delta t > 0$,

$$\int_t^{\delta} f(s, X_s, \zeta) ds = f(t,x,\zeta)\Delta t + o(\Delta t).$$

Using the Taylor series technique, the result is

$$V(\delta,\mu)=V(t,x)+V_t(t,x)\Delta t+V_x(t,x)\Delta X_t+$$
$$+\frac{1}{2}V_{tt}(t,x)(\Delta t)^2+\frac{1}{2}V_{xx}(t,x)(\Delta X_t)^2+V_{xt}(t,x)\Delta t\Delta X_t+o(\Delta t).$$

From Equation (5), we get

$$V(t,x)=\sup_{\zeta}E\left[\int_t^{\delta}f(s,X_s,\zeta)ds+V(\delta,\mu)\right]=\sup_{\zeta}\{f(t,x,\zeta)\Delta t+V(t,x)+V_t(t,x)\Delta t+E\{V_x(t,x)\Delta X_t+$$
$$+\frac{1}{2}V_{tt}(t,x)(\Delta t)^2+\frac{1}{2}V_{xx}(t,x)(\Delta X_t)^2+V_{xt}(t,x)\Delta t\Delta X_t\}+o(\Delta t)\}.$$

Collecting like terms, we have

$$V(t,x)-V(t,x)=\sup_{\zeta}\{f(t,x,\zeta)\Delta t+V_t(t,x)\Delta t+E\left\{\begin{array}{c}V_x(t,x)\Delta X_t+\frac{1}{2}V_{tt}(t,x)(\Delta t)^2+\\+\frac{1}{2}V_{xx}(t,x)(\Delta X_t)^2+V_{xt}(t,x)\Delta t\Delta X_t\end{array}\right\}+o(\Delta t)\}=0.$$

From Equation (2), we have

$$(\Delta X_t)^2=e^2(\Delta t)^2+\sigma_2{}^2(\Delta C_t)^2+\sigma_1{}^2(\Delta B_t)^2+$$
$$+2\sigma_2{}^2\sigma_1{}^2\Delta C_t\Delta B_t+2e\sigma_2\Delta t\Delta C_t+2e\sigma_1\Delta t\Delta B_t,$$
$$\Delta t\Delta X_t=e(\Delta t)^2+\sigma_2\Delta t\Delta C_t+\sigma_1\Delta t\Delta B_t.$$

and

$$\Delta X_t=e(\Delta t)+\sigma_2\Delta C_t+\sigma_q\Delta B_t.$$

Replacing $(\Delta t)^2,(\Delta C_t)^2,\Delta t\Delta B_t,\Delta t\Delta C_t$ *and* $\Delta C_t\Delta B_t$ *by* 0 *and setting* $(\Delta B_t)^2=\Delta t$ *in the equations of* $(\Delta X_t)^2$ *and* $\Delta t\Delta X_t$ *yields* $\Delta t\Delta X_t=0$ *and* $(\Delta X_t)^2=\sigma_1{}^2\Delta t$, *respectively*. This means

$$-V_t(t,x)\Delta t=\sup_{\zeta}\{f(t,x,\zeta)\Delta t+E\{V_x(t,x)\Delta X_t+\frac{1}{2}V_{tt}(t,x)(\Delta t)^2=$$
$$=\sup_{\zeta}\{f(t,x,\zeta)\Delta t+V_x(t,x)E\left[\Delta X_t\right]+\frac{1}{2}V_{tt}(t,x)(\Delta t)^2+$$
$$+\frac{1}{2}V_{xx}(t,x)E\left[(\Delta X_t)^2\right]+V_{xt}(t,x)E\left[\Delta t\Delta X_t\right]+o(\Delta t)\}=$$
$$=\sup_{\zeta}\{f(t,x,\zeta)\Delta t+V_x(t,x)e\Delta t+E\left[\sigma_2\Delta C_t+\sigma_1\Delta B_t\right]+\frac{1}{2}V_{xx}(t,x)E\left[\sigma_1{}^2\Delta t\right]+o(\Delta t)\}=$$
$$=\sup_{\zeta}\{f(t,x,\zeta)\Delta t+V_x(t,x)e\Delta t+\frac{1}{2}V_{xx}(t,x)\sigma_1{}^2\Delta t\}=$$
$$=\Delta t\sup_{\zeta}\{f(t,x,\zeta)+V_x(t,x)e+\frac{1}{2}V_{xx}(t,x)\sigma_1{}^2\}$$

since

$$E\left[\sigma_2\Delta C_t+\sigma_1\Delta B_t\right]=0$$

and

$$E\left[\sigma_1{}^2\Delta t\right]=\sigma_1{}^2\Delta t.$$

If we divide both sides by Δt, we get

$$-V_t(t,x)=\sup_{\zeta}\{f(t,x,\zeta)+V_x(t,x)e(t,x,\zeta)+\frac{1}{2}V_{xx}(t,x)\sigma_1{}^2(t,x,\zeta)\}.$$

Thus, the theorem has been proven.

The following section applies the above concepts to solve a portfolio selection problem in uncertain random markets.

Dynamic programming with applications to the portfolio selection model in uncertain random environments

Consider an uncertain random financial market with bond price S_t^* and stock price S_t described by

$$\begin{cases} dS_t^* = rS_t^* dt \\ dS_t = eS_t dt + \sigma_2 S_t dC_t + \sigma_1 S_t dB_t \end{cases}$$

where the risk-less interest rate is given by r, the mean rate of return for the risky asset is e, σ_2 is uncertain variance, and σ_1 is stochastic variance.

If X_t is the investor's wealth at time t, and the investor allocates $1-\eta(t)$ to represent the fraction of a sure asset, the fraction $\eta(t)$ caters for the risky asset. Let $Z_t = X^{\eta(t)}$ be an uncertain random wealth process for an investment strategy ζ. Suppose $Z_t = X^{\eta(t)}$, the wealth process given the risky asset return

$$\frac{dS_t}{S_t} = edt + \sigma_2 dC_t + \sigma_1 dB_t$$

in the interval $(t, t+dt]$ is

$$\begin{aligned} dZ_t &= r(1-\eta(t))Z_t dt + \frac{dS_t}{S_t}\eta(t)Z_t = \\ &= Z_t\left[r\eta(t)+e(1-\eta(t))\right]dt + \\ &+ [\sigma_2 Z_t dC_t + \sigma_1 Z_t dB_t]\eta(t). \end{aligned}$$

Choosing the power utility function similar to equation (11.2.52) in [21], and assuming that there is no bequest, the portfolio selection model for an investor who is concerned with maximizing the expected utility on an infinite time interval is given by

$$\begin{cases} V(t,x) \equiv \max\limits_{\eta(t)}\left[\int_0^T \exp(-\gamma t)\frac{(Z_t)^\lambda}{\lambda}dt\right] \\ \text{subject to} \\ dZ_t = Z_t\left[r\eta(t)+e(1-\eta(t))\right]dt + [\sigma_2 Z_t dC_t + \sigma_1 Z_t dB_t]\eta(t). \end{cases} \tag{9}$$

The value function in equation (9) is obtained from equation (5), when $Q(X_T, T)$ *is assumed to be* 0. Under equation (9), γ is taken to be greater than 0, that is $\gamma > 0$, and λ is considered to lie between 0 and 1, i.e., $0 < \lambda < 1$. Applying the equation in Theorem 3.2, we get

$$-V_t(t,x)=\sup_{\zeta}\left[\exp(-\gamma t)\frac{z^\lambda}{\lambda}+z\left[r\eta(t)+e(1-\eta(t))\right]V_z+\frac{1}{2}V_{zz}\sigma_1{}^2 z^2\eta(t)^2\right]. \tag{10}$$

Let

$$\begin{aligned} L(\eta(t)) &= \exp(-\gamma t)\frac{z^\lambda}{\lambda}+z\left[r\eta(t)+e(1-\eta(t))\right]V_z+\frac{1}{2}V_{zz}\sigma_1{}^2 z^2\eta(t)^2 = \\ &= \exp(-\gamma t)\frac{z^\lambda}{\lambda}+z\left[e+(r-e)\eta(t)\right]V_z+\frac{1}{2}V_{zz}\sigma_1{}^2 z^2\eta(t)^2. \end{aligned}$$

An optimal $\eta(t)$ satisfies

$$\frac{\partial L(\eta(t))}{\partial \eta(t)} = (r-e)zV_z + V_{zz}\sigma_1{}^2 z^2 \eta(t) = 0.$$

Thus

$$\eta(t) = -\frac{(r-e)V_z}{z\sigma_1{}^2 V_{zz}}. \tag{11}$$

Substituting $\eta(t)$ into Equation (10), we get

$$-V_t = \exp(-\gamma t)\frac{z^\lambda}{\lambda} + z\left[e + (r-e)\left(-\frac{(r-e)V_z}{z\sigma_1{}^2 V_{zz}}\right)\right]V_z +$$

$$+\frac{1}{2}V_{zz}\sigma_1{}^2 z^2\left(-\frac{(r-e)V_z}{z\sigma_1{}^2 V_{zz}}\right)^2 =$$

$$= \exp(-\gamma t)\frac{z^{\prime\prime}}{\lambda} + zeV_z - \left(\frac{(r-e)^2 V_z{}^2}{2y_1{}^2 V_{zz}}\right). \tag{12}$$

If we make a conjuncture that $V(t,z) = kz^\lambda \exp(-\gamma t)$, then we get

$$V_t = -k\gamma z^{\prime\prime} \exp(-\gamma t),$$

$$V_z = k\lambda z^{\lambda-1} \exp(-\gamma t)$$

and

$$V_{zz} = k\lambda(\lambda-1)z^{\lambda-2} \exp(-\gamma t).$$

After multiplying Equation (12) by $\exp(\gamma t)$ throughout, we get

$$-V_t \exp(\gamma t) = \frac{z^\lambda}{\lambda} + zeV_z \exp(\gamma t) - \left(\frac{(r-e)^2 V_z{}^2}{2\sigma_1{}^2 V_{zz}}\right)\exp(\gamma t). \tag{13}$$

Substituting $V_t, Vzz,$ and V_z in Equation (13), we obtain

$$k\gamma z^\lambda = \frac{z^\lambda}{\lambda} + ek\lambda z^\lambda - \left(\frac{(r-e)^2 k\lambda z^\lambda}{2\sigma_1{}^2(\lambda-1)}\right). \tag{14}$$

Dividing by kz^λ, we get

$$\gamma = \frac{1}{k\lambda} + e\lambda - \left(\frac{(r-e)^2 \lambda}{2\sigma_1{}^2(\lambda-1)}\right).$$

If V_t, V_{zz} and V_z are substituted in Equation (11), the fraction of investment in a risky asset that is optimal becomes

$$\eta(t) = \frac{(r-e)}{\sigma_1^2(\lambda-1)}.$$

The above optimal fraction of investment is independent of the total wealth. This fraction of investment in a risky asset that is optimal is the same as the one obtained by [21].

Conclusions

This study analyzed an uncertain stochastic optimal control problem premised on the notion of an uncertain stochastic process. Further, the Bellman's principle of optimality in dynamic programming was implemented to deduce the principle of optimality, and then the resulting Hamilton-Jacobi-Bellman equation (the equation of optimality in uncertain stochastic optimal control) was applied to solve a proposed portfolio selection problem.

The results of this study indicate that the dynamic programming principle for optimal control of USDEs can be applied in optimal portfolio selection. Also, the study results show that the optimal fraction of investment is independent of wealth. The results are valuable for solving the optimal portfolio selection problem in Itô-Liu financial markets. The main conclusion of this study is that, in Itô-Liu financial markets, the dynamic programming principle for optimal control of USDEs can be applied in solving the optimal portfolio selection problem. Even though this study has produced interesting results, there is room for extension. The study can be extended by solving the optimal portfolio selection model with jumps for Itô-Liu financial markets.

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ABOUT THE AUTHORS / ИНФОРМАЦИЯ ОБ АВТОРАХ

Justin Chirima — PhD in Mathematics of Finance, Lecturer, Department of Mathematical Sciences, University of Malawi, Zomba, Malawi
Джастин Чирима — PhD по математике финансов, преподаватель кафедры математических наук, Университет Малави, Зомба, Малави
https://orcid.org/0000-0002-0542-9661
Corresponding author
chirimaj@gmail.com

Frank Ranganai Matenda — PhD in Finance, Postdoctoral Research Fellow, School of Accounting, Economics and Finance, University of KwaZulu-Natal, Durban, South Africa
Франк Ранганай Матенда — PhD в области финансов, научный сотрудник (постдок), Школа бухгалтерского учета, экономики и финансов, Университет Квазулу-Натал, Дурбан, Южная Африка
https://orcid.org/0000-0001-7571-7231
MatendaF@ukzn.ac.za

Eriyoti Chikodza — PhD in Mathematics of Finance, Senior Lecturer, Department of Mathematics, University of Botswana, Gaborone, Botswana
Эриоти Чикодза — PhD в области финансовой математики, старший преподаватель кафедры математики, Университет Ботсваны, Габороне, Ботсвана
Chikodzae@ub.ac.bw

Mabutho Sibanda — PhD in Finance, Professor and Head of School, School of Accounting, Economics and Finance, University of KwaZulu-Natal, Durban, South Africa
Мабуто Сибанда — PhD в области финансов, профессор и руководитель школы, факультет бухгалтерского учета, экономики и финансов, Университет Квазулу-Натал, Дурбан, Южная Африка
https://orcid.org/0000-0002-8656-7539
sibandam@ukzn.ac.za

Authors' declared contributions:
Justin Chirima — conceptualization, critical analysis of literature, results presentation, and the initial draft of the manuscript.
Frank Ranganai Matenda — critical analysis of literature, results presentation, editing, and funding acquisition.
Eriyoti Chikodza — critical analysis of literature and editing.
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Organizational Environment and Management Skills in Small and Medium-Sized Enterprises

S.M. Wagan, S. Sidra, M.U. Hoque
Sichuan University, Chengdu, China

ABSTRACT

At present, managers need to acquire and master various management skills that contribute to a positive organizational environment. **The aim** of this study is to investigate the association between management skills and the organizational environment of small and medium-sized enterprises (SMEs) in Karachi, Pakistan. The primary **objective** is to determine how various management skills — negotiation, decision-making, leadership, communication, and teamwork — affect the organizational environment within SMEs. **Scientific methods** for research adopt a descriptive and quantitative approach, utilizing a questionnaire administered to managers of 253 SMEs. Data analysis was conducted using structural equation modeling (SEM) via the partial least squares (PLS) method, employing SmartPLS 4 software. **Findings** of the study reveal that the latent variables of negotiation and leadership significantly impact the organizational environment, with an R-square value of 0.854. The effect size (F-square) indicates a high impact of negotiation (F-square = 0.720) on the organizational environment, while leadership has a lower but still significant effect (F-square = 0.103). Other management skills, such as decision-making, communication, and teamwork, also show positive associations with the organizational environment, although to lower degrees. **Conclusions.** The study emphasizes the significance of management skills, particularly effective negotiation and leadership, in fostering a productive organizational environment in SMEs. Also, it suggests that training and development in these areas could significantly improve performance.
Keywords: organizational environment; management; management skills; SMEs; negotiation; leadership; SEM-PLS; Pakistan

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ОРИГИНАЛЬНАЯ СТАТЬЯ

Организационная среда и управленческие навыки на малых и средних предприятиях

С.М. Ваган, С. Сидра, М.У. Хоке
Сычуаньский университет, Чэнду, Китай

АННОТАЦИЯ

В настоящее время руководителям необходимо приобретать и совершенствовать различные управленческие навыки, которые способствуют созданию позитивной организационной среды. **Целью** данного исследования является изучение связи между управленческими навыками и организационной средой малых и средних предприятий (МСП) в Карачи, Пакистан. Основная задача состоит в том, чтобы определить, как различные управленческие навыки — ведение переговоров, принятие решений, лидерство, коммуникация и командная работа — влияют на организационную среду в малых и средних предприятиях. Научные **методы** исследования основаны на описательном и количественном подходе с использованием анкетирования, проведенного среди руководителей 253 малых и средних предприятий. Анализ данных проводился с использованием структурных уравнений (SEM) методом частичных наименьших квадратов (PLS) и применением программного обеспечения SmartPLS 4. **Результаты** исследования показывают, что

латентные переменные, такие как ведение переговоров и лидерство, оказывают значительное влияние на организационную среду с коэффициентом R-квадрат, равным 0,854. Размер эффекта (F-квадрат) указывает на высокое влияние переговоров (F-квадрат = 0,720) на организационную среду, в то время как лидерство оказывает меньшее, но все же значительное влияние (F-квадрат = 0,103). Другие управленческие навыки, такие как принятие решений, коммуникация и командная работа, также демонстрируют положительную связь с организационной средой, хотя и в меньшей степени. **Выводы:** в исследовании подчеркивается важность управленческих навыков, особенно эффективных переговоров и лидерства, для создания продуктивной организационной среды на малых и средних предприятиях. Также предполагается, что обучение и повышение квалификации в этих областях могут значительно повысить эффективность работы.
Ключевые слова: организационная среда; менеджмент; управленческие навыки; малые и средние предприятия; переговоры, лидерство; SEM-PLS; Пакистан

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Introduction

The sustainability of small and medium-sized enterprises (SMEs) has been found to be influenced by a number of variables, including how managers and administrators use their newly acquired management abilities to establish productive work environments. Because of this, managers must figure out how to best utilize the particular skills held by their workforce. They must also emphasize the management role in making decisions by encouraging communication to create inspiring and motivating work environments. While it is true that the company wants to reap the greatest benefits, it also needs to consider how well managers are performing in terms of meeting corporate goals and maintaining positive organizational environments.

Different researchers have examined managers' skills and functions, which, while real, are similar. However, various studies have found evidence of a correlation between certain control skills and the prevalence of effective organizational environments. An employer should encourage the development of interpersonal relationships and work groups to foster synergy among coworkers within the organization. For this reason, they have a positive or negative correlation through their relationships that greatly affects how well they perform and achieve their goals.

Consequently, strong organizational environments may contribute to the company's high overall performance. This is particularly true in the current business environment, where organizations are undergoing rapid change and globalization, which calls for leaders with more advanced skills and attitudes who can effectively manage the administrative and operational procedures and processes that are essential to the business's profitability.

Some authors contend that because control skills promote management styles, knowledge, competencies, and decision-making abilities, they are essential for managers to develop as experts. It is crucial that people who lead businesses have the capabilities to fully follow client satisfaction and offer satisfactory careers. In Pakistan as of 2020, there was a wide variety of financial units totaling 6,487,061 of which 92.30% were microenterprises; 6.44% were small businesses; 0.99% were medium-sized groups; and 0.27% were large companies. It shows the vitality of management skills, especially recognizing that SMEs (451,628) make contributions of around 60% of the national GDP.

Studies conducted both domestically and internationally show that over 70% of business managers have developed a few control skills, such as communication, delegation of authority, cooperation, and leadership, which together create the optimal organizational environment.

The goal of this study is to investigate the relationship between managers' management competencies and the organizational environment of SMEs in Karachi, Sindh, Pakistan, using structural equation modeling (SEM) via the partial least squares (PLS) PLS-SEM method.

Literature review

Currently, the phenomenon of globalization drives and requires companies, including SMEs, to be extra green and powerful in achieving goals, with a purpose to meet the expectations of an increasingly stressful market [1]. There are numerous elements or variables, both endogenous and exogenous, that contribute to the success of economic gain for com-

panies. Among these, managers' managerial competencies stand out for their ability to sell perfect organizational environments [2]. It is pointed out that a supervisor's managerial skills must be global in nature [3]: organizational, which implies being green (minimizing costs) and effective (achieving amazing effects) [4]; assertive and improving relationships between staff and senior executives [5–6].

Pakistani SMEs that evaluate their organizational environment are better able to plan how to make adjustments that will enhance the collaborators' patterns of behavior and attitude that make up the organizational form [7]. This is especially important for managers, as it allows them to leverage their managerial skills to establish a more effective, flexible, and adaptable company, allowing employees to choose goals and preferences that may be specific to the company. In this way, the workforce becomes more involved in the business endeavor and reaps some long-term, competitive advantages [9]. In Pakistan, there's a perception that SMEs start from the idea of family business [10]. However, many of them come from entrepreneurial endeavors that are no longer based on family ties [11]. SMEs in Pakistan have low decision-making and control capabilities, flat organizational structures, and insufficient financial and managerial expertise [12, 13]. They also need to improve their control skills.

Nowadays, several theoretical and empirical research have demonstrated interconnectedness by focusing on understanding control capacities and organizational environments and how they interact [14].

Several studies affirm that diverse control talents shape the organizational environment [15]. In this sense, entrepreneurs focus on observing human behavior due to its significant economic and social impact across various sectors [16]. Numerous authors have approached the development of management abilities and the organizational environment from specific points of view [17].

Within years of their creation, 60% of SMEs in Pakistan fail or close, entering what is known as the "valley of death," where the majority of startups fail and die [18]. They do, however, continue to represent a platform of opportunity for enhanced financial system [19]. The scenario as described may be caused by a variety of factors, including a lack of investment and innovation [21], organizational practices that affect proper governance of the commercial firm [20], and a lack of strategic planning. As stated, because they are small entities, SMEs have more flexibility in the model, similar to facilitating communication approaches among the organizational structure and the managers, generating an advantageous effect on enterprise [22].

The overview of the literature allowed us to select variables that collectively determine the control capabilities for this examination. Every supervisor needs to develop, undertake, study, and perfect their managerial talents in communication, leadership, creativity, selection-making, time control, teamwork, and assertiveness, among others; as well as a sequence of attributes (attitudes, values, and talents) essential to effectively carry out control features.

Based on the above, the following are considered necessary management skills for this study: negotiation, decision-making, leadership, communication, and teamwork.

Negotiation

The process of negotiation involves two or more parties experiencing a common problem working together and trying to find a solution that will best serve their goals, aspirations, and desires while also using interpersonal communication techniques. In small and medium-sized companies, negotiation plays a crucial function in shaping the organizational environment. These companies often face specific demanding situations that require flexible negotiation strategies to secure assets, manage relationships with suppliers, and attract talented employees. Effective negotiation within these corporations can foster an organizational culture that is more collaborative and adaptable. Leaders who are skilled negotiators can foster an environment that helps innovation and responsiveness, which are critical for maintaining competitiveness and growth in a dynamic marketplace. Thus, studying the art of negotiation is not just about making deals — it is developing a thriving administrative center that could navigate and capitalize on the complexities of the business world. In this way, the capacity to influence a negotiation is a means of selling a solution to a conflict and improving the work environment for the employer. Under the preceding context, the abilities of the negotiator are vital so that the consequences are beneficial and not adverse to the company. This is how the primary hypothesis of the study is formulated:

H1. Negotiation is positively related to the organizational environment of the SME.

Decision-making

Decision-making is an essential technique in which the best option ought to be selected from several alternatives. In small and medium-sized companies (SMEs), decision-making processes are often exceptionally inspired by the organizational environment. These organizations generally benefit from more flexible decision-making structures as compared to large groups, bearing in mind faster responses to market changes and operationally demanding situations. Small and medium-sized enterprises typically have a close-knit organizational culture with brief and informal communication channels, which can enhance decision-making performance and flexibility. But this might also create difficult circumstances, such as limited resources for in-depth selection study and a dependence on the intuition and experience of a small number of individuals, which could undoubtedly result in biases or uncertain strategic routes. As a result, making decisions in SMEs effectively requires a balanced approach that takes use of their natural flexibility while also putting procedures in place to reduce the risks associated with limited oversight and assistance. The second study hypothesis is:

H2. Decision-making is positively related to the organizational environment of the SME.

Leadership (L)

Experts have determined that effective leadership plays a crucial role in creating optimal environments. Leadership within small and medium-sized enterprises performs a crucial role in shaping the organizational environment. In these corporations, leaders often wear multiple hats, influencing the corporation's culture, morale, and productivity. Effective management in SMEs commonly involves a high degree of adaptability, customized interactions with group contributors, and an emphasis on fostering a collaborative and innovative environment. Building strong, open relationships and ensuring that the business can quickly adapt to changes and obstacles are made possible by this close-knit control style, which is essential for the company's growth and sustainability in the competitive commercial enterprise landscape. The subsequent hypothesis is formulated:

H3. Leadership is positively associated with the organizational environment of the SME.

Communication (C)

Communication skills have become a necessary axis for any type of organization. Administrative communication is an effective bidirectional process of exchanging information with a specific purpose, improving the environment in the company, and achieving organizational objectives. Communication inside small and medium-sized corporations is critical for fostering a vibrant organizational environment. The close-knit character of those environments typically allows for more frequent and direct interactions between team members, which can enhance decision-making processes and promote transparency. Effective verbal exchange channels allow for the free float of thoughts, remarks, and facts, which is critical for innovation and hassle-fixing. Additionally, communication has a greater impact on smaller businesses due to its immediate influence on organizational culture, employee engagement, and the overall ability of the business to adapt to changing market conditions. These companies can cultivate a cooperative atmosphere that fosters development and employee satisfaction by placing a high value on candid and open communication. The fourth research hypothesis is the following:

H4. Communication is positively associated with the organizational environment of the SME.

Teamwork (T)

In companies, collaborative work can help people in the structure have an effective organizational environment that also meets the needs of the client. In SMEs, teamwork is essential to creating a vibrant and productive work environment. In SMEs, the near-knit structure allows for easier collaboration and communication among group members, resulting in quick decision-making techniques and extra flexibility in responding to market changes. This environment encourages personnel to put on multiple hats and often go into purposeful roles, enhancing their talents and boosting universal job satisfaction. Furthermore, the sense of network and shared desires in such setups strengthens employee engagement and loyalty, which are critical for using innovation and achieving sustainable growth in smaller businesses. Teamwork in a multidisciplinary environment promotes the improvement of general managerial capabilities,

which include interpersonal verbal exchange, moral experience. The fifth study hypothesis is:

H5. Teamwork is positively related to the organizational environment of the SME.

The organizational environment (O)

The authors propose that the organizational environment serves as a temporary substitute for human attitudes, while also acknowledging its connection to employees' perceptions of their work environment, which they can influence. Management skills in small and medium-sized companies are critical for navigating the specific challenges and opportunities these corporations face. Effective managers in these settings should excel in strategic planning and decision-making to optimize overall performance and growth. They frequently wear many hats, balancing operational responsibilities with leadership ones. The organizational environment in smaller corporations typically demands flexibility, adaptability, and a strong ability for alternate control. This environment frequently fosters a near-knit team environment, where conversation and collaboration are pivotal. Managers in these contexts have to cultivate a supportive subculture that encourages innovation and continuous improvement, essential for staying aggressive in dynamic markets. Change is contingent upon the relationships that take place.

Organizational culture

As a system of core values and codes of conduct within an enterprise, organizational culture is essential for building a positive and healthy working environment. Organizational culture has a direct impact on the competitiveness and long-term growth of SMEs, in addition to influencing the work attitudes and behavior patterns of employees. A positive organizational culture encourages open communication, teamwork and continuous innovation, so that employees can feel a sense of belonging and value recognition. By establishing common goals and values, organizational culture can stimulate the enthusiasm and creativity of employees and promote a good collaborative atmosphere within the enterprise, thereby bringing stronger market competitiveness and higher performance to the enterprise. Therefore, building and maintaining a positive organizational culture is an important task that every business manager cannot ignore.

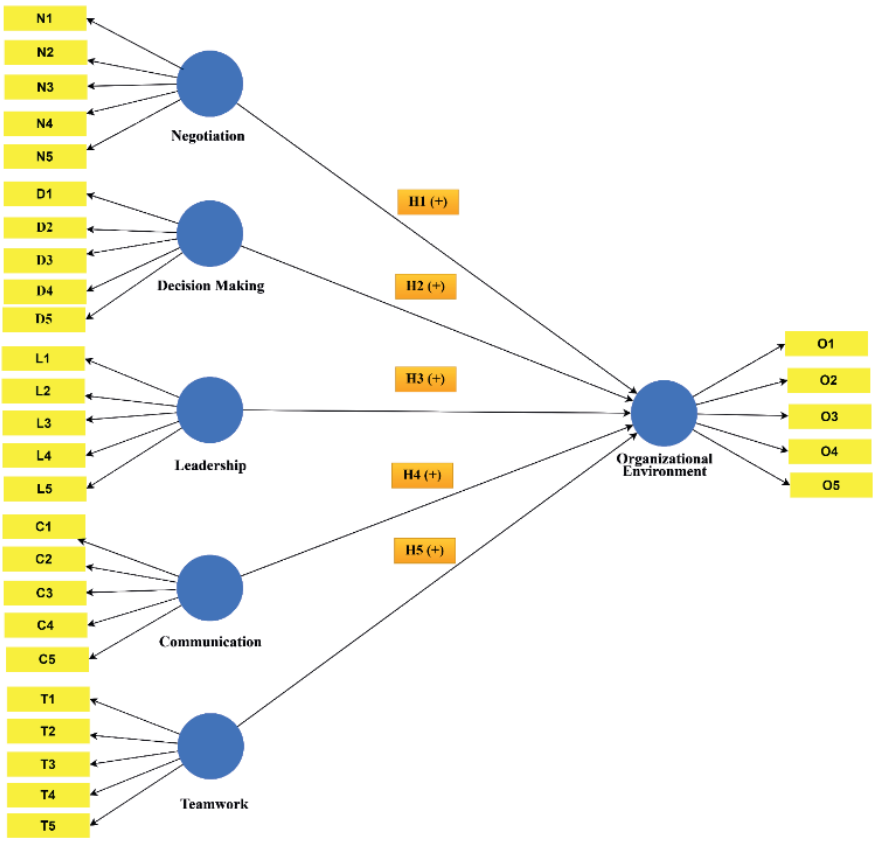

Fig. 1. **Proposed measurement model**

Source: Developed by the authors.

Table 1
Model description

Latent variable	Item	Statement
Organizational Environment (O)	Ítem1_(O_1)	The organizational tradition encourages open communication and collaboration among personnel
	Ítem2_(O_2)	The management team efficaciously communicates the corporation's imaginative prescient and strategic direction
	Ítem3_(O_3)	The organizational structure and methods help efficient decision-making and workflow
	Ítem4_(O_4)	The company actively adapts to adjustments in the external environment, along with marketplace trends and technological advancements
	Ítem5_(O_5)	The enterprise prioritizes employee improvement and provides possibilities for expert growth
Negotiation (N)	Ítem1_(N_1)	I am very well-prepared by gathering applicable statistics and figuring out my goals before entering into a negotiation
	Ítem2_(N_2)	I am inclined to compromise and discover innovative answers that deal with the pastimes of all parties involved
	Ítem3_(N_3)	During negotiations, I actively listen to the other party's issues and try and apprehend their angle
	Ítem4_(N_4)	I comply with agreements and commitments made through negotiations to ensure they are nicely applied
	Ítem5_(N_5)	I continue to be calm and expert, even when confronted with difficult or contentious situations at some stage in negotiations
Decision Making (D)	Ítem1_(D_1)	I carefully bear in mind all to be had records before making crucial decisions
	Ítem2_(D_2)	I generally tend to weigh the capability risks and advantages of each alternative before selecting a course of action
	Ítem3_(D_3)	When confronted with a tough decision, I am trying to find inputs from others who may have valuable perspectives
	Ítem4_(D_4)	I am snug in making decisions even if there may be some uncertainty or ambiguity
	Ítem5_(D_5)	I have an established method of decision-making that involves defining the problem, producing alternatives, and evaluating them against specific criteria
Leadership (L)	Ítem1_(L_1)	Leader/supervisor virtually communicates expectations
	Ítem2_(L_2)	Chief/manager demonstrates integrity and leads by example
	Ítem3_(L_3)	The chief/manager supports and facilitates the growth and success of my expertise
	Ítem4_(L_4)	Chief/manager efficiently manages conflicts and fosters a positive group environment
	Ítem5_(L_5)	The chief/supervisor is open to comments and suggestions from group participants
Communication (C)	Ítem1_(C_1)	I feel happy to express my ideas and opinions in conferences or group discussions
	Ítem2_(C_2)	The employer offers clear and well-timed conversations with vital updates or changes
	Ítem3_(C_3)	My colleagues actively listen and show respect for distinctive viewpoints during conversations
	Ítem4_(C_4)	There are efficient communication channels (such as email, messaging apps, and conferencing) available to make information exchange within the company easier
	Ítem5_(C_5)	Every day, I receive encouraging remarks from my manager or supervisor

Table 1 *(continued)*

Latent variable	Item	Statement
Teamwork (T)	Ítem1_(T_1)	I believe that my group contributors respect and cherish the contributions I make
	Ítem2_(T_2)	Team members share knowledge and understanding to help achieve shared objectives
	Ítem3_(T_3)	There is a strong sense of support and cooperation among group members
	Ítem4_(T_4)	On my team, we recognize and honor individual accomplishments as well as teamwork and character
	Ítem5_(T_5)	Conflicts or disagreements inside the team are addressed in a positive and respectful way

Source: Developed by the authors.

Theoretical model

The theoretical model arises from the review of the literature and is shown in *Fig. 1*, which proposes that the dimension version be contrasted. The model has 5 constructs or variables (diagram paths), where the hypotheses and objects for each of them can be seen.

The model includes the following constructs: negotiation, decision-making, leadership, communication, and teamwork are the independent variables (exogenous latent variables) and the organizational environment is a based variable (endogenous latent variable). The variables are presented in *Table 1*.

Research method

The research design was descriptive with a quantitative approach. Using the data gathered, analysis was done with an emphasis on immediately observable, quantitative, and measurable characteristics. The data were based on the perception of the managers. The SEM model was built using the partial least squares technique with the help of the SmartPLS software 4. The estimation of the model parameters was done using the PLS algorithm and the bootstrapping procedure to minimize standard errors. The model was estimated by applying the partial least squares procedure.

The research was conducted on SMEs working in the commerce sector of the municipal capital of Karachi, Sindh, Pakistan. Executive and managerial positions were included. The authors used the National Statistical Directory of Economic Units (DENUE) of the National Institute of Statistics and Geography, from which a population of 261 SMEs in the commerce sector was obtained. To calculate the sample size, the number and characteristics of the population were considered. The total sample for this study included 253 directors or managers of SMEs. The calculation was carried out for finite populations and non-probabilistic samples with a maximum acceptable sampling error of 5% and a confidence level of 95%. *Table 2* shows scientific notations used in the paper.

Table 2
Scientific notations and their meanings

n =	Sample size
N =	Population
$Z^2 \propto =$	Desired confidence level
$e^2 =$	Allowable error level
p =	The percentage of the population with the desired characteristic (success)
q =	Percentage of the population that fails to exhibit the desired trait

Source: Developed by the authors.

This study's analytical tool was the partial least squares approach, which has flexible assumption requirements and may be applied to any kind of data scale (nominal, ordinal, interval, and ratio). The internal or structural model used to measure the latent and observable variables was reflective since the indicators that cause the latent variable are not interchangeable.

For this study, the variables used are Negotiation (N), Decision Making (D), Leadership (L), Communication (C), and Teamwork (T), which are independent variables, while Organizational

Table 3
Detailed explanation of the research variables

Variable type	Name (symbol) and definition	Indicator
Independent or exogenous	Negotiation (N) is a method by which two or more parties with a shared issue try to find a solution that works for everyone by using interpersonal communication strategies	N_1, N_2, N_3, N_4, and N_5 Measured with Likert scale
	Decision Making (D) is thought of as the process of choosing between two or more options that may be somewhat significant in the advancement of the working life, with managers bearing a larger degree of responsibility in this regard	D_1, D_2, D_4, and D_5 Measured with Likert stale
	Leadership (L) is the capacity to impart knowledge, lead a group or institution in a certain manner, and contribute to the achievement of desired outcomes	L_1, L_2, L_3, L_4, and L_5 Measured with Likert stale
	Communication (C) is the emotional and intellectual aspect that results from man's yearning to connect with others and exchange ideas that take on importance or meaning based on shared experiences	C_1, C_2, C_3, C_4, and C_5 Measured with Likert stale
	Teamwork (T) is the assurance that the members' expertise, knowledge, skills, talents, and competencies will enable them to accomplish the suggested aims and goals	T_1, T_2, T_3, T_4, and T_5 Measured with Likert stale
Dependent or endogenous	Organizational environment (O) refers to the features of the workplace environment that its employees inhabit	O_1, O_2, O_3, and O_5 Measured with Likert scale

Source: Developed by the authors.

Environment (O) is the dependent variable. To explain and define the indicators used in the research, *Table 3* shows the concepts that have been operationalized as follows.

Using a Likert scale as a measure (from absolutely disagree to completely agree), a questionnaire coded for field work was applied as part of the inquiry technique to acquire the information. The multi-item Likert scale is used to gauge an individual's or group's attitudes, beliefs, and comprehension of social phenomena. Respondents' evaluation of the response attributes in this study was graded according to *Table 4*.

Findings

According to *Table 5,* the respondents included: 67% were men and 33% were women, with the age group of 25 to 45 years old being the most represented at 75%. Regarding to the duration of employment, 43% of the respondents indicated they had been employed by the firm for over 12 years, indicating a feeling of identification and affiliation with the organization, while 51% had been there for five to ten years. The respondent's highest level of education was a bachelor's degree (25%), followed by a postgraduate degree (21%). This indicates a high level of study and competency for the management positions within the firms. And industries were manufacturing 35.57%, services 28.85%, tech-

Table 4
Likert scale components

No.	Answer	Worth
1	Totally disagree	1
2	In disagreement	2
3	Partially disagree	3
4	Partially agree	4
5	OK	5
6	Totally agree	6

Source: Developed by the authors.

nology 15.8%, medical insurance 11.85%, and the other 7.9%. Lastly, medium-sized businesses accounted for 83% of the total, compared to 17% for small businesses, and company position manager 55.7% and director 44.3%.

Based on each of their latent variables (constructs), the measurement model examines the factor loadings in the variables that are observable (indicators). The validity and dependability of the suggested theoretical model are assessed using this framework. Cronbach's alpha (α) was employed as a reliability measure for this investigation, and all of the indicators had values greater than 0.80, which indicates a good level of reliability in the constructs, including the dependent variable, as is shown in *Table 6*.

The composite reliability (ρc) values are higher than 0.80, which indicates that the data are appropriate for confirmatory investigation. It displays the computation for the composite dependability (pc), which is more suited for the PLS approach than Cronbach's alpha since it does not imply uniform weighting for every indication. It also benefits from not being impacted by the quantity of objects on a scale. Both indices, however, have a fairly similar interpretation: values above 0.7 are regarded as "modest," whereas values above 0.8 indicate more robust levels of dependability.

Convergent and divergent validity may be assessed using the average variance extracted (AVE). The value in a reflecting model displays the aver-

Table 5
Descriptive statistics of respondents

Demographic Variable	Category	Frequency	Percentage, %
Gender	Male	170	67
	Female	83	33
Age	25–45	190	75
	46–60	63	25
Years of Employment	1–4 years	15	6
	5–10 years	129	51
	11–12 years	0	0
	Over 12 years	109	43
Education Level	High School	54	21
	Bachelor's Degree	63	25
	Master's Degree	0	0
	Postgraduate Degree	54	21
Organization Size	Small (1–50 employees)	43	17
	Medium (51–250 employees)	210	83
Industry	Manufacturing	90	35.57
	Services	73	28.85
	Technology (or technology industry)	40	15.8
	Medical insurance	30	11.85
	Other	20	7.9
Position	Manager	141	55.7
	Director	112	44.3

Source: Developed by the authors.

Table 6
Measurement model. Construct reliability

Construct/Indicator	Cronbach's alpha (α)	rho_A	Composite Reliability(ρc)	Extracted Variance Analysis (AVE)	Result
Negotiation (N)	0.856	0.876	0.935	0.683	Valid
Decision making (D)	0.889	0.924	0.903	0.667	Valid
Leadership (L)	0.936	0.938	0.907	0.718	Valid
Communication (C)	0.837	0.835	0.872	0.639	Valid
Teamwork (T)	0.913	0.903	0.906	0.785	Valid
Organizational Environment (O)	0.826	0.827	0.867	0.626	Valid

Source: Developed by the authors.

age communality for each of the components. The numbers displayed in *Table 4* are consistent with the premise that each component must account for more than half of the variation of its corresponding indicator, meaning that the AVE value must be more than 0.50. The factor's pathways toward its indicators indicate the loadings of the external models in the reflective model. The loads in the reflective models have to be greater than the calculated value of 0.707. At this level, the factor (community = λ2) accounts for half of the indicator's variation. If an indicator's loading falls between 0.40 and 0.70, it is advised to remove the indicator in order to increase composite dependability. The individual reliability of the causal model's indicators — which is the basis for the current study — is displayed in *Table 7*.

Similarly, and in line with *Table 7*, each indicator's factor loading is displayed via the structural diagram of the first suggested model, and the final model's structural diagram, which is generated using the PLS algorithm, displays the significant factor loading for the final indicators.

Discussion

The degree to which a construct differed from others was established by the discriminant validity study. Three steps were included in this analysis: The Fornell-Larcker criterion, cross-loadings between latent variables and indica-

Table 7
Individual reliability of the indicators of the proposed causal model

Build Indicator	Factor loading (λ)
Negotiation (N)	
N_1, N_2, N_3, N_4 and N_5	0.751; 0.839; 0.810; 0.722; 0.782
Decision making (D)	
D_1, D_2, D_3, D_4 and D_5	0.780; 0.742; 0.739; 0.725; 0.762
Leadership (L)	
L_1, L_2, L_3, L_4 and L_5	0.772; 0.741; 0.802; 0.736; 0.725
Communication (C)	
C_1, C_2, C_3, C_4 and C_5	0.766; 0.776; 0.753; 0.782; 0.722
Teamwork (T)	
T_1, T_2, T_3, T_4 and T_5	0.794; 0.755; 0.817; 0.815; 0.843
Organizational Environment (O)	
O_1, O_2, O_3, O_4 and O_5	0.770; 0.754; 0.779; 0.742; 0.720

Source: Developed by the authors.

Table 8
Discriminant validity (Fornell-Larcker criterion)

Construct	Organizational environment	Communication	Leadership	Negotiation	Decision making	Teamwork
Organizational Environment (O)	0.799					
Communication (C)	0.722	0.822				
Leadership (L)	0.729	0.756	0.825			
Negotiation (N)	0.708	0.684	0.653	0.821		
Decision Making (D)	0.742	0.719	0.739	0.712	0.799	
Teamwork (T)	0.759	0.760	0.770	0.510	0.716	0.854

Source: Developed by the authors.

tors, and the heterotrait-monotrail ratio of correlations (HTMT) are the first three criteria. The discriminant validity under the Fornell-Larcker criterion is displayed in *Table 8,* where the indicator loading value is greater than the correlations between the constructs.

Conversely, *Table 9* displays the cross-factor loadings of the indicators for a latent variable. Here, each item loads with its corresponding construct, providing a proof of the discriminant validity of the model across all of its components.

The validation of the structural model was carried out by analyzing the causal relationships of the variance explained by the coefficient of determination R^2 between the independent variables (exogenous) and the dependent variable (endogenous). From this statistical test, the organizational environment with $R^2 = 0.854$ has a very acceptable predictive power. In that sense, it is considered that an R^2 can have values of 0.75 (substantial), 0.50 (moderate), and 0.25 (weak). The result of R^2 for the proposed structural model indicates a very good value, which implies that 80.4% of the variance of the organizational environment variable in SMEs in the community of Karachi, Sindh, is explained by the variables: negotiation and leadership. *Table 10* shows the amount of variance of the dependent variable, which is explained by the predictor variables of the endogenous construct.

Regarding R^2 as a predictive criterion, they recommend evaluating the Stone-Geisser test as a Q^2 (cross-validated redundancy) criterion; In that sense, the value of $Q^2 = 0.689$ indicates a value above zero, which indicates a strong and satisfactory prediction for the proposed model. The F-Square is used to evaluate the contribution to R^2 of the independent variables that have been omitted from the model. For this case, the F-Square effect in the relationship between organizational environment and negotiation is high (F-Square = 0.720); while, in the case of the relationship between organizational environment and leadership, the effect is low (F-Square = 0.103), as shown in *Table 11*.

Table 12 shows the results of the PLS analysis of the structural model. Standardized regression coefficients indicate the relationships of the research model hypotheses. The beta coefficients (β) must reach or exceed a value of 0.2 to be considered significant.

In this sense, the causal relationships that have been proposed as research hypotheses meet the acceptance criterion. N → O is strong (0.677), the relationship between the constructs L → O is moderate (0.416), while the relationship between the constructs D → O; C → O; T → O, turned out to be non-significant.

Fig. 2 shows the path coefficients and p values of the structural model that were obtained from the Path-PLS algorithm as a prediction of causal hypotheses. It can be seen that the negotiation variable has the greatest effect on the organizational environment (0.677), while leadership (0.416) has less impact, but is still significant.

Practical significance

The results of this study have far-reaching significance for the management practice and education of small and medium-sized enterprises. First, for SME managers, the study emphasizes

Table 9
Cross-loadings of the constructs

Construct Indicator	Organizational environment	Negotiation	Decision making	Leadership	Communication	Teamwork
O_1	0.770	0.657	0.466	0.577	0.562	0.555
O_2	0.754	0.709	0.604	0.603	0.623	0.510
O_3	0.779	0.625	0.591	0.537	0.524	0.509
O_4	0.742	0.692	0.692	0.687	0.562	0.473
O_5	0.720	0.574	0.571	0.596	0.638	0.612
N_1	0.711	0.751	0.661	0.646	0.745	0.702
N_2	0.449	0.839	0.471	0.444	0.466	0.352
N_3	0.657	0.810	0.467	0.476	0.521	0.302
N_4	0.722	0.722	0.624	0.751	0.539	0.456
N_5	0.767	0.782	0.650	0.533	0.510	0.449
D_1	0.639	0.545	0.780	0.725	0.653	0.722
D_2	0.493	0.468	0.742	0.601	0.471	0.420
D_3	0.535	0.520	0.739	0.511	0.453	0.345
D_4	0.528	0.548	0.725	0.624	0.639	0.637
D_5	0.722	0.620	0.762	0.774	0.759	0.791
L_1	0.546	0.529	0.664	0.772	0.631	0.702
L_2	0.595	0.519	0.648	0.741	0.659	0.766
L_3	0.618	0.543	0.770	0.802	0.616	0.766
L_4	0.611	0.520	0.762	0.736	0.649	0.629
L_5	0.649	0.570	0.787	0.725	0.650	0.578
C_1	0.702	0.667	0.534	0.649	0.766	0.645
C_2	0.607	0.497	0.570	0.630	0.776	0.697
C_3	0.449	0.398	0.474	0.497	0.753	0.647
C_4	0.523	0.496	0.709	0.743	0.782	0.695
C_5	0.571	0.458	0.552	0.569	0.722	0.525
T_1	0.496	0.483	0.548	0.536	0.534	0.794
T_2	0.639	0.534	0.694	0.782	0.652	0.877
T_3	0.742	0.505	0.685	0.755	0.694	0.817
T_4	0.450	0.372	0.599	0.573	0.686	0.815
T_5	0.585	0.521	0.596	0.658	0.698	0.843

Source: Developed by the authors.

Table 10
Validation of the structural model

Dependent variable	R^2	R^2 adjusted	RMSE	MAE	Q^2 predict
Organizational environment	0.854	0.798	0.588	0.435	0.689

Source: Developed by the authors.

Table 11
Effect size of F-Square in the model

Construct	Organizational environment
Negotiation (N)	0.720
Decision Making (D)	0.002
Leadership (L)	0.103
Communication (C)	0.008
Teamwork (T)	0.004

Source: Developed by the authors.

Table 12
Results of the PLS analysis structural model

Hypothesis	Standardized path coefficient (β)	t value (Bootstrap)	P(value)
H1: Negotiation (N) → Organizational Environment (O)	0.677	4.483*	0.000
H2: Decision making (D) → Organizational Environment (O)	–0.023	0.151ns	0.442
H3: Leadership (L) → Organizational Environment (O)	0.416	1.762*	0.037
H4: Communication (C) → Organizational Environment (O)	0.079	0.467ns	0.316
H5: Teamwork (T) → Organizational Environment (O)	0.065	0.353ns	0.357

Note: * *t* value > 1.6766 ($p < 0.05$), ns = not significant.

Source: Developed by the authors.

the core role of negotiation and leadership skills in shaping a positive organizational environment. This provides a clear direction for enterprises to improve their internal management capabilities, prompting managers to pay attention to and strengthen the training and development of these key skills. Secondly, in the field of management education, the results of this study can guide educational institutions to design more targeted courses, especially for the needs of SME managers, and integrate the cultivation of negotiation and leadership skills into daily teaching, thereby improving the comprehensive quality and practical ability of future managers. Finally, through the practical application of this study, it can not only help SMEs stand out in the fiercely competitive market environment but also promote the optimization and improvement of the management education system, laying a solid foundation for the sustainable development of enterprises.

Conclusion

It is concluded that the management skills of negotiation (N) and leadership (L) turned out to have a positive and significant association with the organizational environment (O) in the internal (structural) model, which confirms what was found in the diverse literature that addresses the central topic of this study, especially the model. This conclusion is based on the problem statement, the stated objective, the theoretical basis, and the obtained findings. It was determined that 80.4% of the variability of the organizational environment variable (O) can be explained by the variables negotiation (N) and leadership (L). Nevertheless, given that the other variables (decision-making (D), communication (C), and

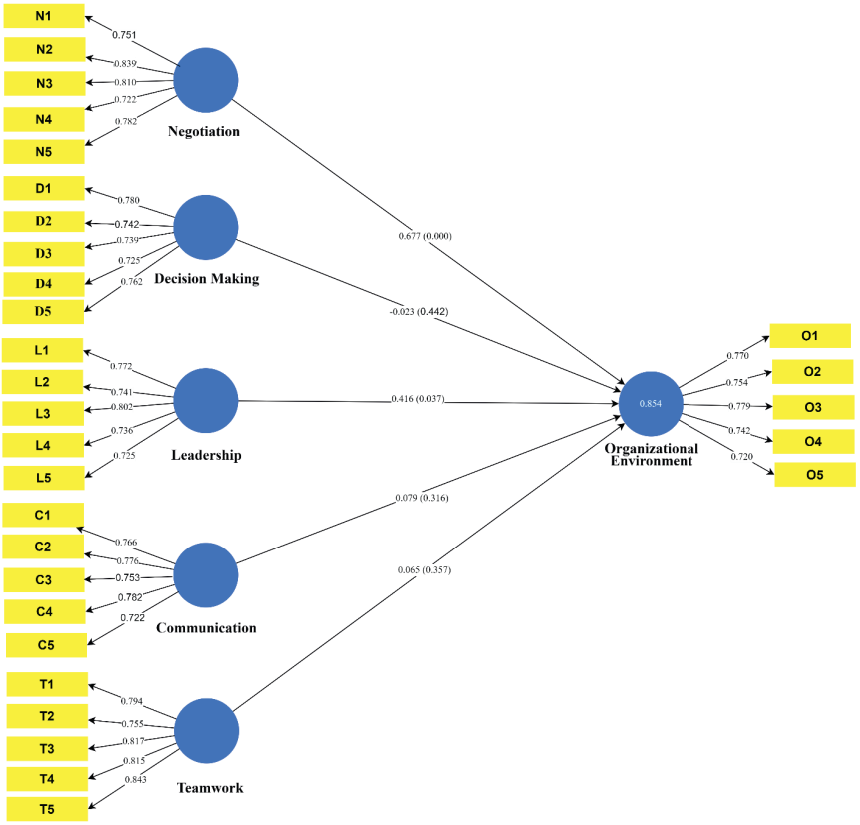

Fig. 2. **Path coefficients and p values of the structural model**

Source: Developed by the authors.

teamwork (T)) added to the measurement model did not seem to be significant, the suggested hypotheses can only be partially supported. The variable that has the most impact on the organizational environment is the negotiation variable (N, F-Square = 0.720), which determines the F-Square effects. The variable that has the least impact on the model is the leadership variable (L, F-Square = 0.103). After conducting a thorough examination of the literature, we were able to identify a number of characteristics that, when viewed through the lens of management abilities, might affect the organizational environment, particularly in SMEs located in Karachi, Sindh.

The current study adds to the body of knowledge in a number of ways. For instance, it uses the PLS-SEM approach to identify factors that were important for the measurement model and are associated with previous empirical studies that have been conducted.

First, it can be said that the ability to negotiate is necessary to get a commitment from all parties engaged in the business, which is what propels the accomplishment of corporate goals and objectives. The findings show that managers at a medium level have this ability, and further development is necessary to maintain good stability in the organizational environment. This is the basis for the positive association with the organizational environment ($\beta = 0.677$, $t = 4.483$, $p < 0.05$).

Second, research suggests that leadership is a management skill that promotes creating a positive organizational environment in businesses. This is supported by findings that leadership can be satisfying and motivating in the clear commitment to achieving the objectives and goals, and it has a positive association with the organizational environment ($\beta = 0.416$, $t = 0.037$, $p = 0.05$). This study provides empirical evidence for management practices in SMEs, highlighting the importance of negotiation and leadership skills in building a positive corporate environment. It can guide training programs and management education institutions to develop targeted courses for SMEs, promoting success in a competitive market.

Statement of relevance of research topic in the context of rapid changes and increasingly fierce competition in the global economy: small and medium-sized enterprises are an important part of the national economy, and their development status is directly related to the vitality and competitiveness of the national economy.

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ABOUT THE AUTHORS / ИНФОРМАЦИЯ ОБ АВТОРАХ

Shah Mehmood Wagan — PhD Researcher, Business School, Sichuan University, Chengdu, China
Шах Мехмуд Ваган — PhD, научный сотрудник, Школа бизнеса, Сычуаньский университет, Чэнду, Китай
https://orcid.org/0009-0003-0449-2655
Corresponding Author
shah.mehmood04@outlook.com

Sidra Sidra — Postgraduate Student, Business School, Sichuan University, Chengdu, China
Сидра Сидра — аспирант, Школа бизнеса, Сычуаньский университет, Чэнду, Китай
https://orcid.org/0009-0003-1689-3296
sidra_scu@outlook.com

Mohammad Mesba Ul Hoque — Postgraduate Student, Business School, Sichuan University, Chengdu, China
Мохаммад Месба Уль Хоке — аспирант, Школа бизнеса, Сычуаньского университета, Чэнду, Китай
https://orcid.org/0009-0006-0113-8644
mesbahoque@stu.scu.edu.cn

Authors' declared contribution:
Shah Mehmood Wagan — was responsible for defining the research project; described the evaluation methods; developed specific indicators related to the research; summarized and analyzed the survey results and described in detail the specific impact of each management skill on the organizational environment.
Sidra Sidra — conducted literature analysis and data statistics; proposed a solid theoretical foundation for the study; developed specific measurement criteria and indicators for different management; wrote the introduction, purpose and importance of the study; developed charts and tables to visualize the research results; drew the conclusions.
Mohammad Mesba Ul Hoque — identified the core question of the study; developed the overall concept of the article, constructed the theoretical model of the study, and identified the main variables and hypotheses; wrote the summary section of the study; was responsible for preparing the list of materials and list of references.

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Ehsan's Three Tables Model: A Comprehensive Guide for Identifying Research Gaps and Conducting Systematic Literature Reviews in Business and Economics Studies

E.S. Salih
Soran University, Soran, Iraq

ABSTRACT

The **aim** of this study is to introduce and assess Ehsan's Three Tables Model as a novel framework for conducting systematic literature reviews in business and economics studies. The primary challenge in this field lies in the inconsistent identification of research gaps, which often impedes knowledge advancement. To address this, Ehsan's Three Tables Model offers a structured and comprehensive approach designed to improve the precision and clarity of research gap identification. **Methods** employed include a systematic review of existing literature, deductive analysis, and the application of the Three Tables Model to categorize and analyze research gaps across various industries and regions. **Results** of the study demonstrate that this model offers a more rigorous methodology for organizing and analyzing literature, ensuring that identified gaps are both relevant and actionable. It moves beyond conventional approaches by employing a three-step process: compiling relevant studies, categorizing research gaps, and outlining how the current study fills these gaps. The author **concluded** that the proposed model contributes to the field of business and economics studies by presenting a fresh, structured perspective on literature reviews, providing researchers with an innovative tool to conduct more impactful and targeted studies.

Keywords: research methodology; research gap identification; gap analysis; systematic literature reviews; Ehsan's three tables model; evidence-based practice; business and economics studies; academic writing

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ОРИГИНАЛЬНАЯ СТАТЬЯ

Модель трех таблиц Эхсана: комплексное руководство по выявлению пробелов в исследованиях и проведению систематических обзоров литературы в области бизнеса и экономики

Э.Ш. Салих
Университет Сорана, Соран, Ирак

АННОТАЦИЯ

Целью данного исследования является представление и оценка модели трех таблиц Эхсана как новой структуры для проведения систематических обзоров литературы в исследованиях бизнеса и экономики.

Основная проблема в этой области заключается в непоследовательном выявлении пробелов в предыдущих исследованиях, что часто препятствует развитию знаний. Для решения этой проблемы модель трех таблиц Эхсана предлагает структурированный и комплексный подход, призванный повысить точность и наглядность выявления пробелов в исследованиях. Используемые **методы** включают систематический обзор существующей литературы, дедуктивный анализ и применение модели трех таблиц для классификации и анализа пробелов в исследованиях в различных отраслях и регионах. **Результаты** исследования показывают, что эта модель предлагает более строгую методологию для организации и анализа литературы, обеспечивая актуальность выявленных пробелов и возможность их устранения. Новый метод выходит за рамки традиционных подходов, используя трехэтапный процесс: обобщение соответствующих исследований, классификация пробелов в исследованиях и описание того, как текущее исследование восполняет эти пробелы. Автор пришел к **выводу**, что предложенная модель вносит вклад в область исследований бизнеса и экономики, представляя новый структурированный взгляд на обзоры литературы и предоставляя исследователям инновационный инструмент для проведения более эффективных и целенаправленных исследований.

Ключевые слова: методология исследований; выявление пробелов в исследованиях; анализ пробелов; систематические обзоры литературы; модель трех таблиц Эхсана; научно обоснованная практика; исследования в области бизнеса и экономики; академическое письмо

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Introduction

Identifying research gaps is crucial for advancing knowledge in business and economics studies, and ensuring that new research contributes meaningfully to the existing body of work. Accurate identification of these gaps prevents duplication and directs future research efforts towards unexplored areas. Traditionally, various approaches have been employed to identify research gaps, often relying on manual and qualitative methods. While these strategies provide some insights, they frequently lack structured methodologies, which can lead to tedious, biased, or inconsistent outcomes.

In the social sciences, several approaches have been developed to address these issues. For example, systematic literature reviews and meta-analyses have been used to identify gaps in knowledge by evaluating the breadth of existing research (e.g., Gough, et al. [1]; Siddaway, et al. [2]). These methods have proven effective in creating a structured approach to research gap identification. However, similar methodologies are underdeveloped in the context of business and economics studies.

Recent research highlights the challenge of identifying research gaps due to the ever-increasing volume of published articles, which complicates the evaluation of existing literature. For instance, Miles [3] discusses how the rapid growth of business research creates difficulties in comprehensively assessing research landscapes. This growth underscores the need for a more refined and systematic approach to research gap identification in business studies.

This paper aims to introduce Ehsan's Three Tables Model as a novel solution to this problem. This model provides a structured and repeatable methodology for identifying research gaps by employing three distinct tables: the first compiles relevant studies, the second categorizes gaps by industry and region, and the third demonstrates how the current study identifies these gaps. By offering a clear, systematic approach, Ehsan's Three Tables Model aims to enhance the precision and comprehensiveness of literature reviews in global business studies. This approach not only improves the quality of research gap identification but also optimizes the related tasks, fostering more targeted and innovative research initiatives. Ultimately, the model seeks to elevate the standards and applicability of scholarly work across different fields within business and economics studies.

Literature review

In the realm of business studies, identifying research gaps is crucial for advancing knowledge and informing practice. Ehsan's Three Tables Model offers a comprehensive framework for systematically identifying these gaps and conducting thorough literature reviews globally. Research gaps, as defined by Mueller-Bloch and Kranz [4], are areas where essential data or evidence

is absent, hindering the ability to draw definitive conclusions. Scott et al. [5] further elaborate that these gaps represent missing evidence that could otherwise inform decision-makers in the field. Rudan et al. [6] highlight that such gaps often arise due to uncertainties in existing estimates or a scarcity of available primary research, necessitating further investigation from a policy-making perspective. This model aims to provide researchers with a structured approach to uncovering these gaps, thereby facilitating more informed and impactful research in business and economics studies.

Considering that research gap identification is one of the most crucial steps in academic research, previous methodologies have differed significantly when it comes to identifying such gaps. Some conventional methods could include carrying out literature searches where the researcher physically searches for a variety of literature to find out the gaps that are yet to be investigated. Some of them, including meta-qualitative analyses, cross-sectional studies, case studies and reviews, among others, are intended to give a more organized review of literature and present gaps or discrepancies in research findings. However, these methods are often labor-intensive and subject to the biases and interpretive limitations of individual researchers.

Robinson et al. [7] sought to address the limitations of traditional methods by developing a structured framework for identifying research gaps from systematic reviews. Their framework was designed to incorporate elements from the PICO (Population, Intervention, Comparison, Outcomes) framework, expanded to include the setting (PICOS). This approach aimed to systematically identify why gaps exist by categorizing them into reasons such as insufficient or imprecise information, biased information, inconsistency or unknown consistency, and not the right information. By mapping these reasons to common evidence-grading systems, the framework facilitates a more rigorous and replicable method for gap identification.

In a study conducted by Peden et al. [8], the authors undertook a systematic literature review to identify research gaps in the context of fatal river drowning. Their review revealed significant gaps in epidemiological data, risk factor identification, and prevention strategies. Despite identifying numerous risk factors such as age, falls, swimming, use of watercraft, gender, and alcohol consumption, the study highlighted a lack of consensus on definitions and metrics, as well as insufficient research on prevention programs. This case study underscores the critical need for systematic frameworks that can provide a structured approach to identifying and addressing such gaps.

Farooq [9] emphasized the challenges faced by researchers, particularly novices, in identifying research gaps in social sciences and management. His study reviewed existing literature and highlighted the ambiguous and often vague criteria used for gap identification. Farooq [9] proposed a comprehensive framework based on systematic literature review methodologies, similar to those used in management research, to streamline the identification process and provide clearer guidelines for researchers.

Addressing these research gaps involves a structured approach, as outlined by Farooq [9]. The process begins with identifying gaps through extensive literature review and analysis, utilizing online databases and electronic resources. Various methods are employed for gap identification, including citation analysis, meta-analysis, content analysis, and systematic reviews. Each method offers unique insights into the existing literature, helping researchers pinpoint where additional investigation is needed.

In practical terms, Farooq [9] suggests that citation analysis provides a foundational understanding by examining frequently cited studies. Content analysis complements this by interpreting qualitative data from texts and documents. Meta-analysis offers a statistical overview, integrating findings from multiple studies to identify overarching trends or gaps in knowledge. Systematic reviews synthesize extensive research findings, providing a comprehensive view that supports or challenges existing conclusions.

In their study, Azeez and Elegunde [10] address the persistent challenge faced by researchers, particularly those at the outset of their careers, in pinpointing research gaps within their chosen field. Identifying these gaps is an essential step for establishing research agendas, securing funding, and designing informative studies. The authors emphasize the importance

of conducting in-depth literature reviews to refine a research area and critically analyze existing work. Their study utilizes content analysis to identify gaps within management science articles. However, a key insight emerges: researchers often concentrate on a single type of research gap, potentially overlooking others. To address this, Azeez and Elegunde [10] recommend that researchers in management sciences actively explore the diverse methods available for identifying research gaps within their field.

Development of Ehsan's three tables model

The development of Ehsan's Three Tables Model emerged from the recognized need to enhance the systematic identification and characterization of research gaps within business studies. This section details the structured approach and foundational principles underlying the model's design, emphasizing its innovative contributions to the field of research gap analysis in business studies globally.

Theoretical Foundations

Ehsan's Three Tables Model is underpinned by established principles from systematic review methodologies, evidence synthesis frameworks, and gap analysis techniques in business studies globally. At its core, the model integrates structured approaches to data synthesis and gap identification, drawing upon the following theoretical foundations:

- Systematic Literature Review: Leveraging systematic review principles to comprehensively gather and synthesize existing literature relevant to the study variables and research context.
- Evidence Synthesis: Incorporating methodologies for systematically integrating and analyzing empirical evidence to inform decision-making and identify knowledge gaps.
- Gap Analysis Techniques: Adapting established gap analysis frameworks to categorize and prioritize research gaps based on predefined criteria, ensuring systematic and transparent gap identification.

Components of Ehsan's three tables model

As it can be seen in *Figure*, this model consists of three distinct tables: (1) previous studies relevant to variables; (2) research gap of the current study; and (3) the bridge of the existing

Structure of Table 1

Variable and its role	Title and author(s)	Aim of the study	Sample size and place	Results and finding
Independent Variable				
Dependent Variable				
Mediate Variables				
Moderate Variables				
Relation between two or three of any Variables				

Structure of Tables 2 and 3

Titles of the study	Globally	Industry	Region	Industry in region

Fig. **Structure of Ehsan's three tables model**

Source: Developed by the author.

study gap by this study. Each table serves a specific purpose in elucidating existing knowledge, identifying gaps, and proposing how the current study will contribute to filling those gaps.

Table 1.

Previous studies relevant to variables

The purpose of this table is to systematically review and categorize previous studies based on their relevance to the key variables of the study. This table compiles relevant literature that pertains to the variables under investigation in the study, such as the independent variable, dependent variable, moderate variable, and the mediating variable. Studies are selected based on their exploration of these variables' roles and relationships. Thus, criteria for study selection are based on relevance to study variables.

Structure of the table comprises five columns (see *Figure*):

- Variable and Its Role: Identification of study variables (e.g., marketing as independent, value as dependent, organization as mediating).
- Title and Author(s): Citation details of selected studies.
- Aim of the Study: Objectives and scope of each study.
- Sample Size and Place: Characteristics of study samples and geographical locations.
- Results and Findings: Key outcomes and contributions of each study relevant to the model's focus.

Table 2:

Research gap of the current study (research)

Based on the findings from previous studies presented in model Table 1, model Table 2 can be generated to further elucidate the research gaps identified in the study. The main purpose of this table is to identify and categorize gaps in the existing literature. The number of rows in table two depends on the titles generated from the original study titles. The variables within the study title dictate the possible number of titles to be included in these rows. Each row represents a different version of the original title created by isolating each variable or removing one of the variables and focusing on the relationship between the remaining variables. Afterward, the table illustrates these generated titles and whether they have been conducted regarding four aspects represented by the columns (see *Figure*):

- Global: Whether the study was conducted worldwide.
- Chosen Industry: The industry the study focuses on.
- Geographical Regions: The geographical regions included in the study.
- Industry in Geographical Regions: Whether the study examined the chosen industry within specific regions.

This table showcases how the original title of a study can be broken down and analyzed across different categories. The table serves as a tool for identifying core concepts within the original title, understanding the study's scope (global vs. regional) and industry focus and analyzing specific elements being investigated. By using the "Gap" concept strategically, the table helps identify potential research gaps in several dimensions related to industry focus, geographical scope, and conceptual elements.

Table 3:

Bridging existing research gaps by this study (research)

Following the analysis of knowledge gaps in model Table 2, model Table 3 demonstrates how the current research directly addresses and resolves these identified limitations in existing literature highlighted in model Table 2. Model Table 3 mirrors the structure of Table 2; it utilizes familiar categories like "title of the study," "Global," "Chosen Industry," "Geographical Regions," and so on (see *Figure*). This consistent structure allows for a clear comparison between the gaps identified and the strategies employed by the current study to bridge them. Furthermore, model Table 3 goes beyond a simple comparison by showcasing the research's breadth. By encompassing a diverse set of industry sectors and geographical contexts, the table effectively illustrates how the current study contributes valuable insights that are applicable across a wider range of scenarios. This emphasis on both addressing specific gaps and achieving generalizability strengthens the overall impact of the research.

Application of Ehsan's three tables model

The application of Ehsan's Three Tables Model demonstrates its utility and effectiveness in identifying and addressing research gaps

within business field. This section illustrates how the model can be practically implemented in research studies to systematically pinpoint and bridge gaps in existing literature, thereby advancing the field and informing future research agendas.

An application example of the model is provided through a study under the title "The Impact of Entrepreneurial Marketing on Creating Shared Value with the Mediating Role of Organizational Ambidexterity". To illustrate the application of Ehsan's Three Tables Model, a study will be considered that focused on the impact of Entrepreneurial Marketing (EM) on Creating Shared Value (CSV) by the mediating role of Organizational Ambidexterity (OA) in the food and beverage industry, particularly in the context of the Kurdistan Region of Iraq (KRI).

Step 1: Populating model Table 1 — Previous studies relevant to variables

Objective: Compile a comprehensive list of previous studies that examine the key variables (EM, CSV, and OA) and their interrelationships.

Process:

1) Literature Search: Conduct a systematic literature search using databases such as PubMed, Scopus, and Google Scholar to identify relevant studies published in peer-reviewed journals.

2) Selection Criteria: Filter studies based on their examination of the independent variable (EM), dependent variable (CSV), and mediating variable (OA).

3) Data Extraction: Populate model Table 1 (see *Table 1*) with the following details:

- Variable and Its Role: Specify whether the study examines EM, CSV, or OA and their roles.
- Title and Author(s): Provide citation details.
- Aim of the Study: Summarize the study's objectives.
- Sample Size and Place: Note the sample characteristics and geographical location.
- Results and Findings: Summarize key outcomes relevant to the variables.

Table 1

Model Table 1 — Sample: Previous studies

Variable and its role	Title and author(s)	Aim of the study	Sample size and place
EM (independent)	Measuring the position of Entrepreneurial Marketing in small business organizations: A prospective study in a sample of mineral water plants in the Kurdistan Region – Iraq, Sadegh [11]	To assess the implementation of EM in plant mineral water companies	Mineral water plants in the Kurdistan Region — Iraq
EM (independent)	The Impact of Entrepreneurial Marketing on Customer Performance of Food Industry SMEs, Zand et al. [12]	To study the impacts of dimensions of this paradigm on customer performance of food industry SMEs	59 food industry SMEs' managers and owners in Tehran
EM (independent)	The effect of entrepreneurial marketing on halal food SMEs performance, Hendijani Fard, and Seyyed Amiri [13]	To investigate the impact of EM on the performance of Iranian halal food SMEs	384 managers of Iranian halal food SME producers
EM (independent)	The Impact of Entrepreneurial Marketing on The Firm Performance, Ouragini and Lakhal [14]	Understanding the EM concept and its dimensions' effect on the firm performance	328 SMEs and large firms from different sectors in the region of Sousse, Tunisia

Table 1 *(continued)*

Variable and its role	Title and author(s)	Aim of the study	Sample size and place
CSV (dependent)	Examining mechanisms for creating shared value by Asian firms, Khurshid, and Snell [15]	To examines the home-based CSV projects of multinational corporations (MNCs) and SMEs, analyzing their motives, resource acquisition, and utilization processes when implementing CSV	Two MNCs based in Hong Kong and three SMEs from Pakistan and Hong Kong, with one CSV project examined in each firm
CSV (dependent)	Analysis of Creating Shared Value in the Food and Beverage Industry, Saraswati [16]	To analyze the concept of CSV in the food and beverage industry	13 listed food and beverage companies in Indonesia from 2015 to 2017
CSV (dependent)	Creating Shared Value Through an Inclusive Development Lens, Ollivier de Leth and Ros-Tonen [17]	To examine the CSV discourse from an inclusive development perspective	Nestlé's CSV strategy in its cocoa supply chains in Ghana, interviews with value chain actors and stakeholders, and focus groups with farmers
OA (Mediate)	Institutional Pressures and Environmental Performance in the Global Automotive Industry: The Mediating Role of Organizational Ambidexterity, Lin and Ho [18]	To explore variations in environmental performance among firms in the same field, considering institutional pressures and OA as mediators	74 global automakers
OA (Mediate)	The relationship between dynamic capabilities and firm competitive advantage: The mediating role of organizational ambidexterity, Jurksiene, and Pundziene [19]	To offer a theoretical explanation of the relationship between dynamic capabilities, OA and firm competitive advantage	The review of research literature on dynamic capabilities and OA is presented
OA (Mediate)	Analyzing the mediating role of organizational ambidexterity and digital business transformation on industry 4.0 capabilities and sustainable supply chain performance, Belhadi et al. [20]	To explore the individual and combined effects of digital business transformation (DBT), OA, and circular business models (CBMs) on the relationship between Industry 4.0 capabilities and sustainable performance	306 organizations in Europe, Asia and Africa

Table 2
Model Table 2 — Sample: Study gap of the current study

Titles of the study	Globally	Food and beverage industry	Kurdistan Region of Iraq (KRI)	Food and beverage industry in KRI
The Impact of Entrepreneurial Marketing on Creating Shared Value with the Mediating Role of Organizational Ambidexterity (Title of this study)	Gap	Gap	Gap	Gap
The Impact of Entrepreneurial Marketing on Creating Shared Value	Gap	Gap	Gap	Gap
The Impact of Entrepreneurial Marketing on Organizational Ambidexterity	Gap	Gap	Gap	Gap
The Impact of Organizational Ambidexterity on Creating Shared Value	Gap	Gap	Gap	Gap
The Impact of Entrepreneurial Marketing	Many	some	some	Gap
Creating Shared Value	Many	some	one	Gap
Mediating Role of Organizational Ambidexterity	Many	Some	Gap	Gap

Step 2: Compiling model Table 2 — research gap of the current study

Objective: Identify and categorize gaps in the existing literature based on global industry relevance or geographical context.

Process:

1) Gap Identification: Review the populated *Table 1* to identify areas where empirical evidence or theoretical understanding is insufficient.

2) Generate a different version of the original title by isolating each variable or removing one of the variables and focusing on the relationship between the remaining variables.

3) Categorization: Classify identified gaps by global industry relevance or geographical context.

4) Data Entry: Populate model Table 2 (see *Table 2*) with the following details:

- Title of the study: Titles generated from the original study titles
- Global: Whether the study was conducted worldwide.
- Chosen Industry: The industry the study focuses on.

• Geographical Regions: The geographical regions included in the study.

• Industry in Geographical Regions: Whether the study examined the chosen industry within specific regions.

• Indicate each title of the study by many, some or gap which indicates the extent to which each title of the study has been conducted considering global industry relevance or geographical context.

Step 3: Developing model Table 3 — Bridging existing research gaps by this study

Objective: demonstrate how the study bridges various identified research gaps in existing literature, which are highlighted in model Table 2.

Process:

1) Bridge identification: Gap analysis review by Examine the gaps identified and categorized in *Table 2*.

2) Consistent Structuring: Ensure the structure of Table 3 mirrors that of Table 2 for straightforward comparison. The categories should include:

• Title of the Study
• Global
• Chosen Industry
• Geographical Regions
• Industry in Geographical Regions

3) Data Entry: Populate model Table 3 (see *Table 3*) with the following details:

• Title of the Study: Use the same titles as in Table 2 for direct comparison.

• Global: Indicate whether the current study has a global scope.

• Chosen Industry: Specify the industry focus of the current study.

• Geographical Regions: List the geographical regions covered by the current study.

• Industry in Geographical Regions: Indicate how the study examines the chosen industry within specific regions.

• Gap Bridging Approach: Detail the strategies and methodologies used by the current study to address the identified gaps.

4) Breadth and Generalizability: Highlight the diversity of industry sectors and geographical contexts covered by the current study, showcasing the generalizability and broad applicability of the research findings.

Discussion

The implementation of Ehsan's three tables model in identifying and addressing research gaps in business research globally offers several significant advantages over traditional approaches. First and foremost, the model provides a systematic identification of gaps in business studies globally. Unlike traditional methods that often rely on ad hoc and unsystematic reviews of the literature, Ehsan's three tables model provides a structured and comprehensive approach to identifying research gaps. This systematic methodology ensures that no critical gaps are overlooked, thereby enhancing the thoroughness of the literature review process. By ensuring that all relevant studies are considered, the model improves the reliability and validity of the research findings.

Another key benefit is the enhanced clarity and precision offered by the model. By organizing information into three distinct tables, the model enhances clarity and precision in identifying and categorizing research gaps. Each table serves a specific purpose, making it easier to track and analyze the relationships between variables and the existing gaps in the literature. This organization aids researchers in comprehending the complex interrelationships in their field of study, thereby facilitating more accurate and insightful analyses.

Furthermore, the model promotes a focused and relevant literature review. The first table ensures that only the most relevant studies are included, based on the role of each variable in the study and their relationship. This focus on relevant literature helps in building a solid foundation for business research and avoids the inclusion of peripheral studies that do not significantly contribute to the understanding of the key variables. By concentrating on the most pertinent research, the model increases the depth and quality of the literature review, which in turn strengthens the overall business research framework.

Potential Impact

The generalizability and applicability of Ehsan's three tables model are also noteworthy. By encompassing a diverse set of industry sectors and geographical contexts, the model ensures that the findings are broadly applicable. This generalizability enhances the impact of the research, making it relevant across business disci-

Table 3
Model Table 3 — Sample: The bridge of the exist study gap by this study

Titles of the study	**Globally**	**Food and beverage industry**	**Kurdistan Region of Iraq**	**Food and beverage industry in KRI**
The Impact of Entrepreneurial Marketing on Creating Shared Value with the Mediating Role of Organizational Ambidexterity	Bridge	Bridge	Bridge	Bridge
The Impact of Entrepreneurial Marketing on Creating Shared Value	Bridge	Bridge	Bridge	Bridge
The Impact of Entrepreneurial Marketing on Organizational Ambidexterity	Bridge	Bridge	Bridge	Bridge
The Impact of Organizational Ambidexterity on Creating Shared Value	Bridge	Bridge	Bridge	Bridge
The Impact of Entrepreneurial Marketing	Many	Some	Some	Bridge
Creating Shared Value	Many	Some	Two	Bridge
Mediating Role of Organizational Ambidexterity	Many	Some	Bridge	Bridge

plines. Researchers also from different fields can adapt the model to their specific needs, thereby promoting interdisciplinary collaboration and knowledge transfer.

The adoption of Ehsan's three tables model has the potential to significantly influence future research agendas and contribute to the advancement of knowledge in the business field. One of the most profound impacts is its potential in shaping research agendas. By providing a clear framework for identifying and addressing research gaps, the model can help shape future research agendas. Researchers can prioritize studies that address the most critical gaps, leading to more impactful and relevant research outcomes. This prioritization ensures that research efforts are directed towards areas with the greatest potential for advancing knowledge and solving real-world problems.

The model also plays a crucial role in advancing knowledge. The systematic identification and bridging of research gaps contribute to the continuous advancement of knowledge. By addressing gaps in the literature, researchers can develop new theories, refine existing ones, and generate new insights that propel the field forward. This ongoing process of gap identification and bridging fosters a dynamic and evolving body of knowledge that is responsive to emerging trends and challenges.

Furthermore, the model has significant implications for informing policy and practice. The model's ability to identify relevant gaps and bridge them can inform policy-making and practice. By highlighting areas where evidence is lacking or where current knowledge is insufficient, the model can guide decision-makers in developing policies and practices based on the latest and most comprehensive evidence. This evidence-based approach ensures that policies and practices are grounded in solid research, which can lead to more effective and sustainable outcomes.

The structured approach of the model also encourages rigorous and systematic research practices. By emphasizing the importance of a thorough literature review and the explicit identification of gaps, the model promotes high standards of research quality and integrity. Researchers are encouraged to adopt meticulous and transparent methods, which enhance the credibility and reliability of their findings. This rigor is essential for building a robust and trustworthy body of knowledge that can support evidence-based decision-making and practice.

Conclusion

Ehsan's Three Tables Model represents a significant advancement in the methodology for identifying and addressing research gaps in business and economics studies. By providing a structured and systematic approach, this model enhances the thoroughness and precision of literature reviews, ensuring that critical gaps are identified and addressed effectively. The model's ability to focus on relevant studies, categorize gaps by industry and geographical context, and explicitly demonstrate how these gaps are bridged by current research, offers numerous benefits over traditional approaches. These advantages include a more focused literature review, efficient use of resources, and broader applicability of research findings.

The potential impact of Ehsan's three tables model extends beyond individual studies, influencing future research agendas, promoting collaboration, and informing policy and practice. By encouraging rigorous and systematic research practices, the model contributes to the continuous advancement of knowledge in various fields. As researchers adopt and refine this model, it is expected to play a pivotal role in shaping the direction of future research and ensuring that new studies build upon a solid foundation of identified and addressed research gaps. In conclusion, Ehsan's three tables model offers a robust framework for advancing scholarly research, making it an invaluable tool for researchers across business and economics studies.

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ABOUT THE AUTHOR / ИНФОРМАЦИЯ ОБ АВТОРЕ

Ehsan Shareef Salih — PhD, Lecturer, Department of Business Management, Faculty of law, political science and management, Soran University, Soran, Iraq
Эхсан Шариф Салих — PhD, преподаватель, кафедра бизнес-менеджмента, факультет права, политологии и менеджмента, Университет Сорана, Соран, Ирак
https://orcid.org/0009-0006-9812-0407
ehsan.saleh@soran.edu.iq

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