International Review of Management and Marketing

ISSN: 2146-4405

available at http: www.econjournals.com

International Review of Management and Marketing, 2025, 15(3), 352-390.

A Review of the Impact of Institutions on Public Sector Efficiency

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Received: 29 December 2024 **Accepted:** 01 April 2025 **DOI:** https://doi.org/10.32479/irmm.19428

ABSTRACT

This study integrates insights from governance studies, public choice theory, and institutional economics to examine how formal (e.g., rule of law, regulatory quality) and informal institutions (e.g., cultural norms) influence public sector efficiency. Specifically, it looks into how formal institutions—like the rule of law, regulatory quality, and corruption control- shape governance results—and informal institutions—like cultural norms and practices. From a methodological standpoint, the review critically assesses the measure and analysis of institutional effects on public sector performance using both quantitative techniques, such as Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA), Artificial Intelligence (AI), and Machine Learning (ML), as well as qualitative techniques, such as surveys and interviews. 90,643 academic publications were subjected to a bibliometric study, emphasizing fields such as environmental management, healthcare, and education. This review highlights the integration of AI and qualitative frameworks with traditional econometric models to deepen understanding of public sector efficiency. It also explores complex theories, such as the "grease the wheel" theory, which challenges the notion that corruption is universally harmful. The study identifies gaps in current research, including conceptual, data, and methodological limitations, and offers practical suggestions for future work. This analysis underscores the need for flexible and context-specific governance approaches by combining diverse methodologies and frameworks to present a unified view of the link between institutions and public sector efficiency.

Keywords: Public Sector Efficiency, Institutions, Sustainability, Healthcare, Data Envelopment Analysis
JEL Classifications: C00, D7, H75

1. INTRODUCTION

Public sector efficiency (PSE) has long been a subject of intense scrutiny among policymakers, researchers, and practitioners. Efficient public sector operations are essential for delivering high-quality services, fostering sustainable economic growth, and ensuring societal welfare.

1.1. Importance of Public Sector Efficiency Measurement

Efficient public sector operations directly impact economic growth, social stability, and citizen well-being (Afonso & Furceri, 2010). Afonso et al. (2005) state that PSE is the ratio of public spending to desired results, such as high-quality healthcare and education. Effective governance improves the quality of public services and decreases resource waste (Hall and Jones, 1999). Additionally, ineffective systems frequently result in budget deficits and a decline in public confidence in governing bodies (Pérez-López et al., 2015).

In a globalized world where governments are expected to do more with fewer resources, measuring the efficiency of the public sector has become increasingly important. Furthermore, the requirement for strong evaluation frameworks is highlighted by the economic repercussions of inefficiency, which include decreased competitiveness and less-than-ideal resource allocation

(Smith and Mayston, 1987). These frameworks are essential for spotting inefficiencies, establishing standards, and directing legislative choices that guarantee the best possible use of available resources. Furthermore, there is an inherent connection between PSE measurement and more general goals of accountability and openness. The public demands effective use of public expenditures, and governments are expected to prove their worth by producing quantifiable results (Afonso et al., 2010). Efficiency indicators are, therefore, a fundamental component of governance and policy-making since they represent economic priorities and correspond with social imperatives.

1.2. Dimensions of Public Sector Efficiency

PSE includes many aspects, such as social, economic, and administrative efficiency. According to Afonso et al. (2005), there are two main measures of PSE: "opportunity" indicators (such as infrastructure, healthcare, and educational quality) and "Musgravian" indicators (such as economic stability and income distribution). These factors demonstrate the complexity of public sector operations, necessitating specialized methods for improvement and measurement.

PSE is especially important when it comes to how government entities operate internally. The effectiveness of service delivery is mostly determined by factors including resource allocation efficiency, decision-making speed, and bureaucratic procedures (Elston et al., 2018). Conversely, economic efficiency emphasizes the wider results of public sector operations, like economic growth and fiscal sustainability. According to Fernández-Gutiérrez et al. (2019), efficiency is greatly influenced by both individual values and administrative cultures. Furthermore, cooperative agreements can enhance economies of scale and tackle intricate policy issues, especially in sectors like health and education. PSE requires constant observation and adjustment since it is dynamic and changes in response to societal demands, technological advancements, and economic circumstances.

Social efficiency, a different PSE dimension, examines how much public sector operations support social cohesiveness and well-being (Ravallion, 2005). This feature emphasizes how crucial it is to match government programs with social goals like fostering inclusion and lowering inequality (Afonso et al., 2005). Combining these many aspects can provide a comprehensive understanding of PSE.

A bibliometric network based on 90,643 results retrieved from the ProQuest database using the keywords "Public sector," "Efficiency," and "Institutions" is depicted in Figure 1 below. This bibliographic search was restricted to books and articles published in academic journals in English. The most often researched aspects of the public sector include sustainability, energy, healthcare, education, economic growth, and environmental performance, as illustrated in Figure 1. Additionally, the relationship between institutions and the public sector has been thoroughly examined in the literature that is now available.

1.3. The Impact of Institutions on Public Sector Efficiency

Institutions are crucial in determining the effectiveness of the public sector. North (1990) states that institutions are the "rules of the game" that control social and economic relationships. Sturdy institutions increase efficiency by fostering accountability, lowering transaction costs, and facilitating openness. According to Acemoglu et al. (2014), nations with robust institutions tend to have more efficient public service delivery and governance systems.

Indicators like the Worldwide Governance Indicators (WGI), which gauge aspects including the rule of law, regulatory quality, and corruption control, are frequently used to evaluate the quality of institutions (Kaufmann et al., 1999). These metrics offer insightful information on the effects of governance frameworks on productivity. For example, robust legal systems protect contracts and property rights, creating an environment conducive to efficiency, and efficient regulatory frameworks guarantee that resources are distributed to their most productive uses (Hall and Jones, 1999).

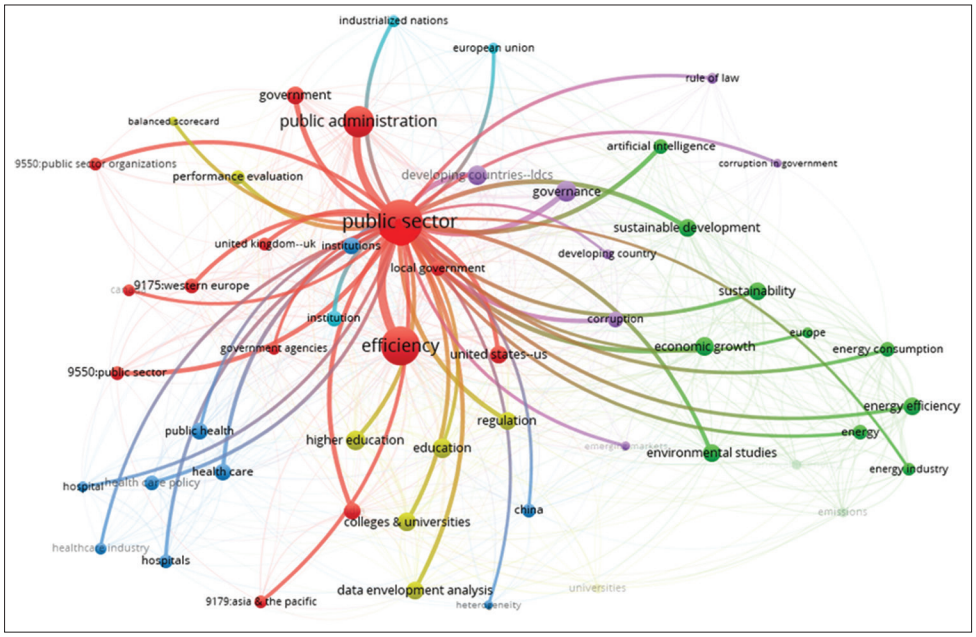
Because it distorts resource allocation and raises transaction costs, corruption—a byproduct of weak institutions—significantly reduces efficiency (Aidt, 2009). Although the "grease the wheel" theory (Huntington, 1996; Méon and Weill, 2010; Alshehhi and Zervopoulos, 2023; Alshehhi and Zervopoulos, 2024; Alshehhi and Zervopoulos, 2024) contends that corruption can occasionally bypass bureaucratic inefficiencies, empirical data indicates that its drawbacks exceed any potential advantages (Mauro, 1995; Méon and Weill, 2005). Therefore, improving institutional quality is crucial to increasing productivity and reducing the negative impacts of corruption.

Additionally, it has been demonstrated that institutional changes aimed at enhancing accountability and openness boost public sector performance. For instance, initiatives like performance-based budgeting and e-governance have shown great promise in lowering inefficiencies and fostering improved service delivery (Afonso et al., 2010). These changes emphasize the need for ongoing development by highlighting the dynamic interaction between institutional quality and PSE.

1.4. Techniques for Measuring Public Sector Efficiency

Various approaches, each with unique benefits and drawbacks, have been devised to gauge the effectiveness of the public sector. Two of the most popular methods for assessing technical and allocative efficiency are Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) (Afonso et al., 2010; Ruggiero, 1996). They are regarded as "frontier" methods, as both evaluate the efficiency of homogeneous units against a production frontier—empirical in the case of DEA and theoretical in the case of SFA. DEA is a deterministic technique based on linear programming, whereas SFA is a stochastic approach that requires assumptions about the production frontier and the distributions of inefficiency and random noise (Lampe and Hilgers, 2015). Additionally, DEA does not explicitly account for noise or distinguish inefficiency from noise, as SFA does (Coelli et al., 2005; Lin and Theng, 2005). Despite the non-parametric nature of DEA, Banker (1993) demonstrated its statistical properties and proved that the efficiency scores it generates are consistent estimates of the true efficiency

Figure 1: Dimensions of public sector efficiency



scores for convex sets. Furthermore, according to Lampe and Hilgers (2015), DEA has gained significantly greater popularity than SFA.

By considering sampling biases and exogenous factors, innovative approaches like Bayesian DEA have improved the validity of efficiencies (Zervopoulos et al., 2023). Furthermore, "frontier" techniques provide critical insights into areas for resource optimization and performance improvement (Halkos and Tzeremes, 2010). However, selecting appropriate metrics and methods often depends on the specific context and objectives of the evaluation.

Recent technological developments have also made more thorough and precise efficiency evaluations possible. For example, real-time performance monitoring of the public sector is made possible by big data analytics and machine learning algorithms, which give policymakers useful information (Medeiros and Schwierz, 2015). In addition to improving measurement precision, these technologies facilitate evidence-based decision-making, guaranteeing efficient resource allocation.

1.5. Novelties and Roadmap

This systematic literature review is regarded as a cross-disciplinary synthesis. It integrates insights from institutional economics, public choice theory, and governance studies to provide a unified understanding of how institutions influence PSE. Furthermore, it emphasizes analyzing and evaluating the strengths and limitations of widely used quantitative methods (e.g., Data Envelopment Analysis, Stochastic Frontier Analysis, Artificial Intelligence, and Machine Learning) and qualitative approaches, such as surveys and interviews, for measuring institutional impacts on public sector performance. Additionally, it critically examines widely held assumptions, such as the universal negativity of corruption, by exploring nuanced perspectives like the "grease the wheel" hypothesis. Finally, it summarizes key conceptual limitations, data collection challenges, and methodological constraints.

This systematic literature review is organized as follows: Section 2 identifies formal and informal institutions, explores their role in PSE, and examines the interplay between various theoretical frameworks, including institutional economics, public choice theory, and governance studies. Section 3 reviews the key methodologies used to measure PSE, including Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA), Artificial Intelligence (AI), Machine Learning (ML), and qualitative approaches such as surveys and interviews while highlighting common applications. Finally, Section 4 concludes the study by summarizing its findings and discussing its limitations and directions for future research.

2. CONCEPTUAL FRAMEWORK

2.1. Definitions and Types of Institutions

According to North (1990), institutions are humanly devised constraints that structure political, economic, and social interactions. These constraints can be informal, like customs, traditions, and norms, or formal, like laws, constitutions, and property rights. Adding to this description, Hodgson (2006) proposes that institutions are made up of established social rules that govern human interactions. These rules influence behavior, create order, and reduce uncertainty in human interactions, ensuring a stable societal cooperation framework.

Legal frameworks, courts, and regulatory agencies are examples of official procedures that codify and enforce formal institutions. These organizations provide the framework for political and economic activity by defining property rights, upholding contracts, and controlling markets. Conversely, informal institutions are not codified and are enforced by social approval. They consist of social trust, shared values, customs, and cultural standards,

which frequently function in tandem with formal institutions. Informal institutions influence behaviors and practices subtly but significantly, whereas formal organizations offer clear regulations. To ensure institutional effectiveness, official and informal institutions must interact. Musole (2009) emphasizes that inefficiencies can result from discrepancies between official rules and unwritten standards, particularly when strongly ingrained customs conflict with written legislation. Furthermore, North (1990) highlights the dynamic nature of institutions by emphasizing their gradual evolution, which draws from historical practices while adjusting to current demands.

Additionally, Acemoglu et al. (2014) contend that formal and informal institutions significantly determine economic performance. While informal institutions shape behaviors and promote social cohesiveness and trust, formal institutions set the structural foundation for economic transactions and government. This dualism guarantees institutions can handle complicated societal issues by fusing explicit governance procedures with implicit cultural norms.

According to the Worldwide Governance Indicators (WGI) database, the key formal institutional factors are (a) voice and accountability, (b) political stability and absence of violence/terrorism, (c) government effectiveness, (d) regulatory quality, (e) rule of law, and (f) control of corruption. These institutional factors are among the most widely referenced in the literature (Kaufmann et al., 1999; Méon and Weill, 2005; Aparicio et al., 2016; Nedić et al., 2020; Acheampong et al., 2021; Alshehhi and Zervopoulos, 2023).

Corruption, the rule of law, regulation, and government efficacy are among the formal institutions that are frequently discussed in the literature on PSE, as shown in Figure 2. Furthermore, this body of literature has studied certain elements of formal institutions, especially those pertaining to the rule of law, such as accountability, equality, justice, and transparency.

2.2. Indicators of Institutional Quality

The quality of institutions strongly impacts PSE and governance outcomes. One important metric is regulatory quality, which shows how well a government can create and carry out sensible regulations that support the expansion of the private sector and economic expansion. Effective regulatory frameworks promote innovation and competition, improve transparency, and lessen bureaucratic inefficiencies. For instance, Kaufmann et al. (1999) point out that well-crafted laws foster an atmosphere conducive to business, guaranteeing fair competition and stable market conditions.

Another crucial indicator of institutional quality is the control of corruption. Corruption erodes public trust and diverts resources from beneficial purposes, undermining the legitimacy and effectiveness of institutions. According to Aidt (2009), corruption reduces the overall effectiveness of public sector operations, distorts resource allocation, and raises transaction costs. While some theories, like Huntington's (1996) "grease the wheel," contend that corruption may temporarily alleviate inefficiencies, the overwhelming weight of empirical data shows that corruption has a negative influence on governance and economic development (Méon and Weill, 2005).

A key component of institutional reliability is the rule of law, which gauges how closely people and institutions follow the law. According to North (1990), upholding the rule of law promotes trust, lowers uncertainty, and establishes an atmosphere that is favorable to investment and economic progress. High adherence guarantees the protection of property rights, the enforcement of contracts, and the equitable and predictable resolution of disputes. Strong rule-of-law regimes are linked to greater degrees of social trust and economic stability, as Kunčič (2014) emphasizes.

The degree of policy implementation, civil servant proficiency, and the caliber of public services are all reflected in government effectiveness. It shows how well a government can carry out its responsibilities, distribute funds, and attend to the demands of its constituents. According to Hauner and Kyobe (2010), effective governments are essential to maintaining the smooth operation of public institutions, which directly impacts the performance of the public sector. Furthermore, the effectiveness of a government is frequently regarded as a proxy for its institutions' overall reliability and efficiency.

The degree to which citizens can engage in governance processes is reflected in voice and accountability. Trust is typically increased, and conflict is less likely in institutions that support openness, freedom of speech, and public involvement. Acemoglu and Robinson (2012) emphasize the importance of accountability in lowering corruption and guaranteeing fair resource distribution, while Kaufmann et al. (1999) contend that participatory governance techniques improve institutional legitimacy and credibility.

When taken as a whole, these metrics offer a thorough framework for assessing institutional excellence. Good institutions create stable social and economic activity conditions, build trust, and lessen uncertainty. Strong institutions, for example, help nations manage fiscal restraint, handle economic shocks, and guarantee sustainable development paths (North, 1990; Acemoglu et al., 2014). How these factors interact emphasizes how crucial institutions are to economic development and governance.

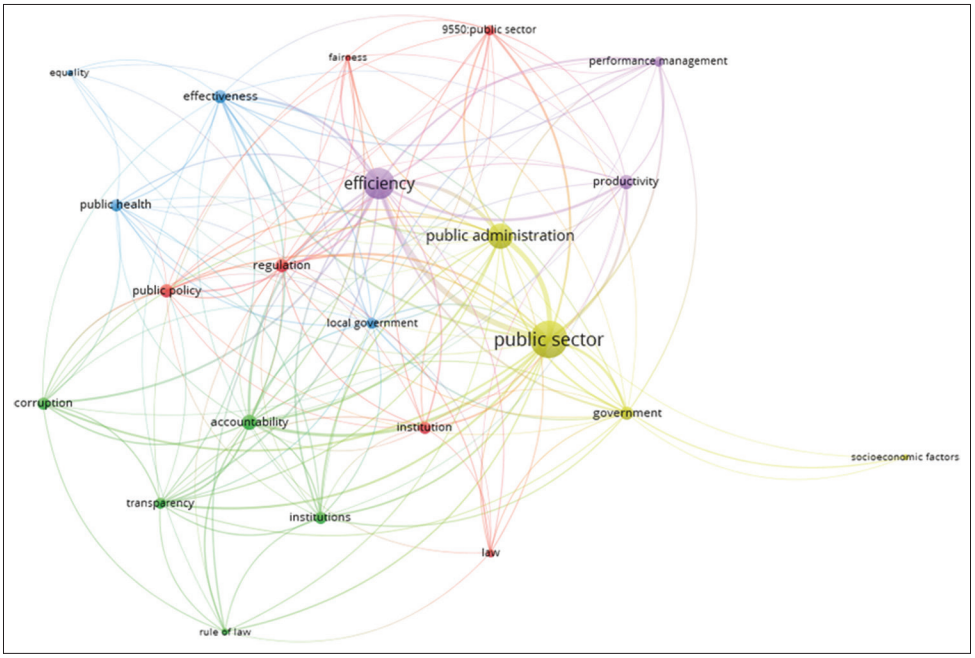
In conclusion, understanding institutions' definitions, types, and quality indicators provides a robust framework for analyzing their impact on PSE. This conceptual foundation highlights the nuanced relationship between institutional structures and governance outcomes, paving the way for further exploration into the dynamics of institutional effectiveness.

2.3. Interplay between Theoretical Frameworks and Institutions

2.3.1. The role of institutional economics in public sector institutions

According to New Institutional Economics (NIE), institutions—both official and informal standards guiding behavior—play a crucial role in determining the outcomes of the public sector. Understanding public administration and economic performance

Figure 2: Formal institutions and PSE



requires an awareness of key institutional elements, including voice and accountability, regulatory quality, governance effectiveness, and corruption control (North, 1986; Acemoglu and Robinson, 2012). NIE offers a thorough framework for examining the effectiveness and efficiency of the public sector by combining these factors (Richter, 2005; Dollety, 2001).

The effectiveness of the public sector and the development of citizen-government trust are supported by corruption control. Corruption threatens the government by misallocating resources, undermining institutional credibility, and escalating inequality (Buitrago et al., 2024; Acemoglu and Robinson, 2012). To reduce corruption, NIE emphasizes the significance of establishing vigorous institutional checks and balances, such as open procurement procedures, impartial anti-corruption organizations, and public accountability systems (Richter, 2005; Furubotn and Richter, 1992).

A key component of institutional performance is governance effectiveness, which gauges the standard of public services, the application of policies, and the ability of institutions to manage resources efficiently. NIE shows how organizations with robust governance practices lower transaction costs and enhance public sector service delivery (Meramveliotakis, 2020; North, 1986). For example, responsiveness and public satisfaction are improved by efficient administrative processes and clearly defined accountability structures (Dollety, 2001; Buitrago et al., 2024).

Another crucial institutional factor is regulatory quality, which measures how well the government can design and carry out sensible laws that safeguard the interests of the general public and encourage the growth of the private sector. While well-designed rules lower transaction costs and promote economic stability, poor regulations frequently result in inefficiencies (Acemoglu and Robinson, 2012; Richter, 2005). NIE offers resources for evaluating regulatory frameworks and recommends changes to improve stakeholder participation and transparency (Furubotn and Richter, 1992; Buitrago et al., 2024).

The power of citizens to express their opinions, select their government, and hold institutions responsible is referred to as voice and accountability. NIE emphasizes how crucial participatory institutions are to improving the legitimacy and effectiveness of the public sector (Meramveliotakis, 2020; North, 1986). Information asymmetries are decreased, and institutional outcomes are enhanced by inclusive governance arrangements encouraging citizen participation, such as transparent electoral processes and participatory budgeting (Richter, 2005; Dollety, 2001).

Actionable insights for transforming public sector institutions are provided by the interaction of these institutional dimensions: voice and accountability, regulatory quality, governance effectiveness, and corruption control. Addressing systemic issues, including inequality, inefficiency, and informality, requires strong institutions (Buitrago et al., 2024; Meramveliotakis, 2020). NIE provides a road map for building transparent, accountable, and effective public sector organizations by integrating these aspects into public governance (Acemoglu and Robinson, 2012; Furubotn and Richter, 1992).

In conclusion, improving public sector performance requires institutional factors, including voice and accountability, regulatory quality, governance efficacy, and corruption control. According to NIE, these organizations enhance public administration equity, engagement, and citizen trust and influence economic outcomes (Richter, 2005; Buitrago et al., 2024).

2.3.2. The role of public choice theory in public sector institutions

By applying economic concepts to the analysis of political conduct, public choice theory provides valuable insights into

the difficulties and operations of public sector organizations. This theory provides insight into the decision-making processes that influence governance structures, policy outcomes, and institutional performance by examining the incentives and motives of people working in the public sector (Leeson and Thompson, 2023; Piano, 2019).

Public choice theory posits that individuals within public sector institutions—whether politicians, bureaucrats, or voters—are motivated by self-interest, much like actors in the private sector. This viewpoint questions the conventional wisdom that social welfare is a top priority for public servants (Piano, 2019). Rather, their actions frequently mirror incentives shaped by the institutional setting. For instance, whereas robust supervision systems can match individual incentives with the group's welfare, insufficient accountability measures may promote rent-seeking behaviors (Richter, 2005; Lee and Azis, 2024).

The concept of state capacity—the ability of public institutions to create and carry out successful policies—is also clarified by public choice theory. According to Piano (2019), rulers' motivations to promote economic progress rather than seize money for their own benefit determine the state's ability to provide public goods. Olson's (1993) "stationary bandit" theory, which views rulers as revenue-maximizers whose long-term objectives may coincide with public welfare given specific institutional conditions, is consistent with this realization. State capture risks can be reduced, and state capacity can be increased by institutions that support accountability, openness, and competition in governance (Besley and Persson, 2010).

One of the core applications of public choice theory in public sector institutions is its role in combating corruption. Corruption thrives when institutional incentives promote exploitative behavior, and oversight is inadequate (Lee and Azis, 2024). To reduce corruption and boost institutional confidence, public choice theory supports measures including independent anti-corruption organizations, competitive elections, and performance-based accountability frameworks (Leeson and Thompson, 2023; Montes and Luna, 2021).

The theory likewise emphasizes the significance of regulatory quality in public sector organizations. While poorly crafted regulations can result in unexpected consequences and bureaucratic inefficiencies, effective regulations lower transaction costs and foster economic efficiency (Pham et al., 2024; Piano, 2019). Public choice theory offers a useful framework for assessing and enhancing regulatory systems by viewing regulatory frameworks as products of political bargaining processes.

Public choice theory emphasizes how important it is to create institutions that balance societal goals and individual incentives. Among the main suggestions are bolstering accountability and transparency systems, encouraging competition in governance frameworks, and ensuring institutional frameworks promote collective welfare rather than personal benefit (Lee and Azis, 2024; Richter, 2005).

In conclusion, public choice theory offers a strong theoretical foundation for comprehending the workings of public sector organizations. Actionable insights for increasing governance effectiveness, decreasing corruption, and boosting public sector performance can be obtained by concentrating on individual incentives and institutional design.

2.3.3. The role of governance studies in public sector institutions

By examining the structures, procedures, and dynamics that support decision-making and the provision of public services, governance studies are essential to comprehending and enhancing public sector organizations. These studies assess the effectiveness of formal and informal procedures in tackling intricate societal challenges.

Governance is increasingly viewed as a dynamic, multifaceted framework that entails coordinating various institutions and players to accomplish policy goals. The change in governance from hierarchical state-centric models to more network-based strategies incorporating various stakeholders, such as the private sector and civil society, has been emphasized by scholars (Rayner, 2015; Korosteleva and Flockhart, 2020). This shift highlights the importance of participatory governance systems that prioritize accountability, openness, and equity.

Robust institutional structures that can adjust to shifting sociopolitical conditions are necessary for effective governance. According to studies, public sector performance is greatly enhanced by organizations with good regulatory quality, accountability, and transparency (Da Silva, 2024; Börzel and Risse, 2016). These characteristics guarantee that governance structures are inclusive, equitable, and effective.

Studies of governance also concentrate on regions with limited or dysfunctional statehood, where conventional state processes are ineffective at providing public goods. In these situations, community-based trust networks and informal institutions frequently appear as functional stand-ins, guaranteeing fundamental governance and service provision (Börzel and Risse, 2016). These results highlight how crucial it is to comprehend local dynamics and integrate community-driven strategies into governing systems.

To respond to crises and promote long-term sustainability, governance systems must be resilient (Fernández-Gutiérrez et al., 2019). According to Korosteleva and Flockhart (2020), resilient governance is the capacity to adjust and recover from disruptions while preserving legitimacy and functionality. This perspective encourages integrating various approaches to address complex difficulties by highlighting the interaction between local and global governing institutions.

With a focus on the necessity of institutional reforms that increase accountability and promote participatory decision-making, governance studies provide policymakers with practical insights. Future studies should concentrate on how formal and informal institutions interact, how technology might improve governance,

and how local practices are affected by global governance principles (Prakash and Potoski, 2016).

2.3.4. Directions for the role of institutions in public sector performance

Public choice theory, governance studies, and institutional economics offer unique but complementary frameworks for evaluating and enhancing public sector organizations. Every strategy highlights how important formal and informal institutions are in influencing public sector performance, encouraging accountability, and resolving issues involving collective action. These viewpoints emphasize the importance of building strong institutional frameworks that balance societal needs, governance processes, and individual motivations (North, 1990; Leeson and Thompson, 2023; Korosteleva and Flockhart, 2020).

According to institutional economics, reducing transaction costs, defending property rights, and coordinating institutional regulations with economic efficiency are all crucial (Richter, 2005). Good institutions ensure improved resource allocation and service delivery by reducing uncertainty and establishing a stable environment for public administration (North, 1990; Börzel and Risse, 2016). The main emphasis of public choice theory is the importance of personal incentives and self-interest in public institution decision-making. Public choice theory provides insights into creating systems that align public officials' behavior with community goals, addressing issues like rent-seeking, corruption, and inefficiency (Leeson and Thompson, 2023; Piano, 2019). By integrating resilience, decentralization, and multi-stakeholder participation into institutional frameworks, governance studies broaden our understanding of public sector performance. In governance processes, it highlights the significance of accountability, transparency, and inclusivity (Korosteleva and Flockhart, 2020; Da Silva, 2024).

All of these models emphasize that there is no one-size-fits-all approach to institutional design. Instead, context-specific strategies that consider sociopolitical, economic, and cultural aspects are necessary for effective governance. Mechanisms that improve accountability and transparency, like independent monitoring bodies, participatory governance, and digital tools for citizen interaction, must be implemented by public institutions. These actions boost public trust and lessen corruption (Prakash and Potoski, 2016; Börzel and Risse, 2016). Institutions can also prioritize resilience by integrating responsiveness and flexibility into governance systems. This is especially important when dealing with crises like economic shocks, public health catastrophes, and climate change (Korosteleva and Flockhart, 2020).

The interaction between formal rules (laws, regulations) and informal norms (trust, culture) must be taken into consideration while designing an institution. Informal institutions frequently compensate for inadequate formal structures in unstable or constrained statehood environments, guaranteeing fundamental governance and service provision (Börzel and Risse, 2016; Peng and Sauerwald, 2012). Digital transformation, through e-governance and data-driven decision-making, offers new opportunities to enhance PSE (Piano, 2019; Da Silva, 2024).

Developed and emerging nations require different strategies to strengthen public sector institutions. Enhancing efficiency, cutting bureaucracy, and integrating multi-level governing structures are common goals of institutional changes in developed countries. Despite having formal institutions in place, some nations struggle to uphold confidence and adjust to intricate policy contexts (Prakash and Potoski, 2016; Korosteleva and Flockhart, 2020). Developing nations, on the other hand, prioritize promoting inclusive government, decreasing corruption, and strengthening institutional capacity. Political stability and the provision of essential services are frequently prioritized by informal institutions, which are more effective at compensating for inadequate formal frameworks (Leeson and Thompson, 2023; Börzel and Risse, 2016).

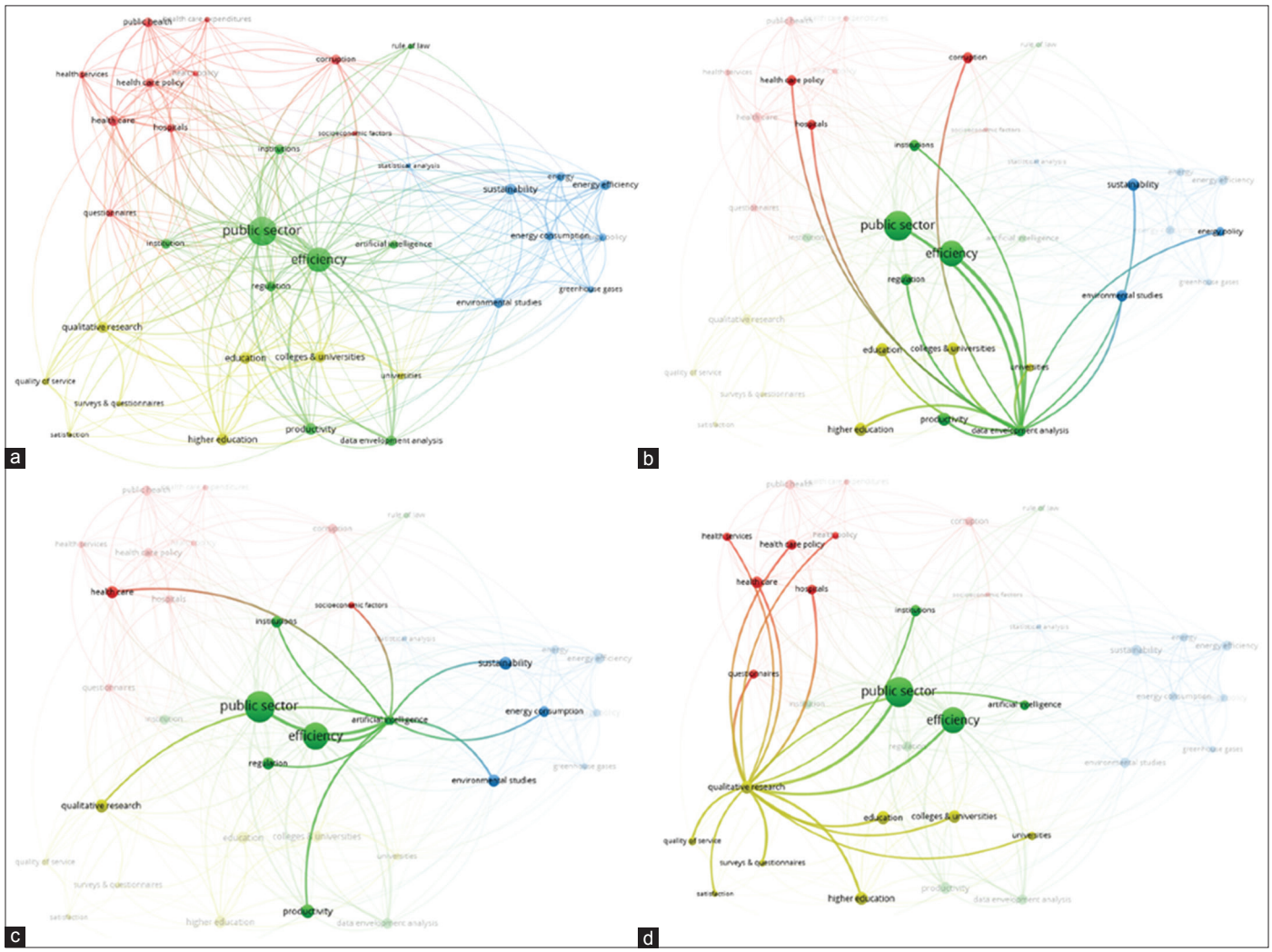
While developing nations frequently struggle with inadequate state capacity and give priority to foundational changes, developed nations typically have better institutional frameworks that allow them to concentrate on efficiency and innovation. Corruption is more common in emerging nations, necessitating more robust anti-corruption measures and initiatives to foster trust. Although not impervious, developed countries often have stronger checks and balances (Börzel and Risse, 2016; Da Silva, 2024). Additionally, the extent of institutional reforms is constrained by resource shortages in emerging nations, calling for creative and economical solutions. Developed nations are able to make larger investments in cutting-edge governance frameworks and technologies. While industrialized nations enjoy the advantages of well-established participation processes, decentralized governance might be challenging in developing countries due to capacity constraints (Prakash and Potoski, 2016).

In summary, public choice theory, institutional economics, and governance studies provide important insights into institutions' critical role in the operation of the public sector. In the future, the focus should be on creating inclusive, transparent, and flexible institutions that can adapt to the difficulties developed and developing countries face. Public sector organizations can increase their effectiveness and legitimacy in a world that is becoming more complicated by utilizing technology, achieving a balance between formal and informal procedures, and building resilience (North, 1990; Korosteleva and Flockhart, 2020; Leeson and Thompson, 2023).

3. METHODOLOGICAL PERSPECTIVES ON PUBLIC SECTOR EFFICIENCY AND INSTITUTIONAL INTERPLAY

Data envelopment analysis (DEA), stochastic frontier analysis (SFA), artificial intelligence (AI)-based techniques, surveys, and qualitative research are the most commonly used methodological approaches in the PSE literature, based on the body of existing literature (Figure 3a). DEA is the only one used across all of the main public sector divisions, including healthcare, education, and environmental management (Figure 3b). As shown in Table A1 in the Appendix, SFA, the econometric equivalent of DEA, has also been widely used to assess public sector performance. Qualitative research, questionnaires, and AI-based methods have all become

Figure 3: The most widely used methodological approaches in the PSE literature (a) PSE indicators and methodological approaches, (b) PSE indicators and data envelopment analysis, (c) PSE indicators and artificial intelligence, (d) PSE indicators, qualitative analysis, and surveys



very popular in certain public sector areas. Specifically, while surveys and qualitative research have mostly been used in the healthcare and education sectors, AI-based applications are mostly found in the healthcare and energy sectors. Furthermore, as Figure 3c and d demonstrate, AI-based methods have frequently been used in conjunction with questionnaires and qualitative research, underscoring their complimentary use in evaluating the effectiveness of the public sector.

3.1. Articles Using DEA or Mixed DEA-Based Methods

A non-parametric technique called data envelopment analysis (DEA) assesses how well decision-making units (DMUs) perform when there are numerous inputs and outputs. DEA, which was first presented by Charnes et al. in 1978, uses linear programming to form an efficient frontier that enables the relative efficiency measurement of the sample DMUs. Unlike traditional econometric techniques, DEA can effectively manage complicated production processes with various inputs and outputs since it does not require specific functional forms or statistical assumptions. While later models, such as the BCC model introduced by Banker et al. (1984), take variable returns to scale into account, increasing the flexibility of efficiency analysis across a variety of sectors, the original DEA model, known as the CCR model, concentrates on constant returns to scale (Banker et al., 1984).

DEA is often compared to Stochastic Frontier Analysis (SFA) in the broader literature. DEA is favored for its flexibility in handling multiple inputs and outputs without stochastic noise considerations (Lampe and Hilgers, 2015). Recent developments have concentrated on improving the methodology of DEA by adding elements such as fuzzy set theory integration, dynamic efficiency assessment, and sensitivity analysis (Emrouznejad et al., 2008; Liu et al., 2013). According to bibliometric studies, DEA applications have been steadily increasing in both the public and private sectors, including healthcare, banking, education, and environmental research (Ulucan and Atıcı, 2010; Liu et al., 2013). DEA's place as a premier instrument in performance evaluation and operational efficiency analysis is maintained by its adaptability and continuous methodological advancements.

Ruggiero (1996) addressed biases in classic DEA models brought on by unaccounted-for exogenous elements by extending DEA by integrating environmental variables into examining school district efficiency. This study exemplifies how flexible DEA

is when assessing public sector performance in challenging circumstances. Hauner (2008) investigated the effectiveness of the public sector in Russia's local governments using DEA in conjunction with econometric methods. The study thoroughly evaluated regional differences by considering spending and governance information. Using DEA, Sahin and Ozcan (2000) assessed the efficiency of Turkey's public hospitals by combining inputs like staff, beds, and expenses with outputs like outpatient visits and patient discharges. Significant inefficiencies were found in their research, which also included policy recommendations for resource efficiency. To investigate the effect of advanced medical technology on intensive care unit efficiency in Greece, Tsekouras et al. (2010) used a bootstrapped DEA model. By taking into consideration stochastic variations in efficiency estimates, this approach allowed for a thorough assessment of resource allocation. Similarly, Haelermans and Ruggiero (2013) highlighted the significance of considering environmental factors when using a conditional DEA model to evaluate technical and allocative efficiency in Dutch schools. In order to better match resource utilization with service demand, Athanassopoulos (2004) used DEA to reorganize branch networks in the public sector and incorporate service quality limitations into the efficiency framework. By creating chance-constrained production frontiers—which handle data noise and are determined solely by units that satisfy threshold targets for both inputs and outputs—Mitropoulos et al. (2020) assessed the performance of healthcare units. With an emphasis on public e-services, Reggi et al. (2014) integrated DEA into developing composite indicators for ICT adoption in Italian regions. The study highlighted regional differences in ICT development and offered practical policy recommendations by integrating DEA with expert perspectives and robustness tests. To give a more thorough assessment of service units, especially at Citizen Service Centers, Zervopoulos and Palaskas (2011) and Zervopoulos (2014) suggested a quality-driven efficiency-adjusted DEA model (QE-DEA), which combines classic DEA with service quality measurements obtained from surveys.

3.2. Articles Using Other Quantitative Techniques

Globally, public sector operations are being rapidly transformed by artificial intelligence (AI) and machine learning (ML), which provide creative ways to increase productivity, transparency, and decision-making. Natural language processing, cognitive robotics, and machine learning algorithms—which examine data to find patterns and facilitate predictive modeling—are just a few examples of the wide spectrum of technologies that fall under the umbrella of artificial intelligence (AI) (Wirtz et al., 2019; Brynjolfsson and McAfee, 2017). As a branch of artificial intelligence, machine learning (ML) is concerned with creating algorithms that let systems learn from data and improve over time without explicit programming (Silva and Crispim, 2024; Jordan and Mitchell, 2015). Public administration increasingly uses these technologies to improve data-driven policymaking, automate repetitive operations, and allocate resources as efficiently as possible (Mergel et al., 2023; Janssen and Kuk, 2016).

There are several advantages to integrating AI and ML into public sector governance, especially when it comes to enhancing internal administrative effectiveness and public service delivery. For instance, AI applications improve the accuracy of fraud detection systems, automate citizen services through chatbots, and speed up data analysis for well-informed decision-making (Wirtz et al., 2019; Eggers and Schatsky, 2017). While law enforcement organizations use AI-driven technologies for criminal pattern analysis and resource deployment optimization, the healthcare industry has used AI for illness surveillance and predictive analytics (Wenzelburger et al., 2022; Sun and Medaglia, 2019). By offering transparent, data-supported insights into public sector performance, these technologies increase operational efficiency and promote better accountability (Williamson, 2014; Kankanhalli et al., 2019).

Notwithstanding these benefits, there are still obstacles to overcome before AI and ML can be widely used in government. Concerns about algorithmic prejudice, data privacy, and the moral ramifications of automated decision-making are important challenges (Kuziemski and Misuraca, 2020). Lack of technological know-how, inadequate data infrastructure, and the requirement for strong legislative frameworks to control AI use are common challenges for public sector enterprises (Mergel et al., 2023; Zuboff, 2019). Furthermore, using AI to make essential decisions raises concerns about accountability, particularly when automated systems result in biased or unexpected outcomes (Silva and Crispim, 2024; Eubanks, 2018).

Comprehensive solutions that tackle these issues must be developed to maximize AI and ML's potential to improve PSE. Establishing explicit ethical standards, encouraging cross-sector partnerships to exchange best practices, and funding technical and digital literacy training for public sector workers are all examples of this (Wirtz et al., 2019; Misuraca and Viscusi, 2013). Furthermore, continuously monitoring and assessing AI systems is essential to ensure they support public interest objectives and adjust to changing social demands (Mergel et al., 2023; Floridi et al., 2018). AI and ML can greatly enhance the modernity and effectiveness of public sector governance, provided a balanced strategy is implemented that takes advantage of technology breakthroughs while preserving moral and democratic principles (Williamson, 2014; Bovens and Zouridis, 2002).

Zekić-Sušac et al. (2020) used machine learning techniques, including regression trees and random forests, to forecast energy usage in public sector buildings as part of smart city programs. Their research offered a cutting-edge energy management method in public administration by fusing big data, IoT, and predictive analytics. Delgado (2005) investigated using artificial neural networks (ANNs) as a substitute for DEA in assessing operational efficiency in the public sector. According to the study, ANNs provided additional insights and were useful for rating decision-making units, even though they were less accurate at measuring efficiency.

Additionally, Alyammahi et al. (2024) examined the interplay of entrepreneurial orientation, learning orientation, and organizational structure in fostering government growth. Their conceptual framework emphasized the critical role of organizational

determinants in achieving competitive and efficient government operations (Alyammahi et al., 2024).

3.3. Articles Using Surveys and Interviews

Qualitative techniques like surveys and interviews are essential when analyzing public sector performance, particularly when determining PSE. Both organized and semi-structured interviews offer profound insights into the perspectives and experiences of stakeholders, enabling a thorough comprehension of administrative procedures, governance quality, and policy implementation (Qu and Dumay, 2011; Sumiyana et al., 2023). By using these techniques, evaluators can investigate intricate occurrences, record a range of viewpoints, and identify the fundamental causes affecting the performance of the public sector. In-depth interviews with Indonesian auditors, for instance, highlighted the influence of political hegemony on performance auditing and showed how outside influences might influence auditing results (Sumiyana et al., 2023).

On the other hand, surveys provide a systematic approach to gathering information from a large population, which makes them essential for gauging administrative effectiveness, public service quality, and citizen happiness (Chatzoglou et al., 2013; Gould-Williams et al., 2013). Alyammahi et al. (2024) investigated how organizational structure, learning orientation, and entrepreneurial orientation interact to promote government expansion. The importance of organizational determinants in attaining competitive and effective government operations was highlighted in their conceptual framework. A thorough understanding of public service delivery is provided by the SERVQUAL model, which is widely used for assessments in the public sector and evaluates service quality based on factors including responsiveness, empathy, and dependability (Donnelly et al., 2006). Additionally, surveys make it easier to compare various administrative divisions and geographical locations, which helps policymakers pinpoint areas that want reform as well as best practices.

By capturing subjective efficiency aspects, including corporate culture, employee engagement, and governance procedures, incorporating qualitative approaches into performance measurement frameworks improves the evaluation process (Di Meglio et al., 2015; Antonelli and De Bonis, 2018). Rich contextual data is provided by case studies, including document analysis and interviews, demonstrating how qualitative insights enhance quantitative performance indicators. This mixed-methods approach offers a comprehensive knowledge of PSE, which emphasizes the interaction between human behavior and structural elements.

Reggi et al. (2014) assessed ICT adoption and e-service development in Italy using a combination of quantitative DEA approaches and qualitative expert judgments. This hybrid methodology pinpointed areas for public sector innovation improvement and offered a comprehensive view of regional inequalities. In their DEA study, Sahin and Ozcan (2000) included qualitative comments on policy issues in Turkish hospitals, such as resource misallocation and structural inefficiencies. Tsekouras et al. (2010) discussed contextual factors such as labor composition and spatial distribution in Greek intensive care units (ICUs) and incorporated qualitative observations into their bootstrapped DEA investigation. Hauner (2008) thoroughly analyzed efficiency differences across Russia's regions by adding qualitative commentary on governance, democratic control, and public spending to the DEA data. Zervopoulos (2014) and Zervopoulos and Palaskas (2011) incorporated service quality surveys into efficiency metrics. In order to ensure long-term sustainability and effectiveness, their strategy emphasized the need to balance operational efficiency and user happiness (Zervopoulos and Palaskas, 2011). Alyammahi et al. (2024) also highlighted the integration of contextual and organizational insights and promoted a comprehensive method for evaluating public sector performance.

In conclusion, qualitative techniques like surveys and interviews offer insightful contextual information, while quantitative techniques offer crucial indicators for assessing the effectiveness of the public sector. Qualitative research enhances the assessment of PSE by capturing the subtleties of administrative procedures and stakeholders' lived experiences. Combining the two methods guarantees a more thorough evaluation, which promotes wise choices and successful policy creation (Røge and Lennon, 2018; Otia and Bracci, 2022).

3.4. Stochastic Frontier Analysis

A popular econometric method for assessing decision-making units' (DMUs') efficiency that takes statistical noise and inefficiency into account is called stochastic frontier analysis (SFA). SFA uses a composite error model, which was first presented by Aigner et al. (1977) and Meeusen and van den Broeck (1977). Deviations from the frontier are divided into two parts: capturing random noise and inefficiency. Using stochastic variability resulting from measurement error or outside shocks, SFA can overcome the drawbacks of deterministic techniques like Data Envelopment Analysis (DEA) (Ondrich and Ruggiero, 2001; Tsionas, 2002).

SFA is frequently used when estimating the production, cost, or profit frontiers is necessary. For instance, Sun et al. (2015) presented a semiparametric stochastic frontier model that offers more flexibility in analyzing complex datasets by considering firm-specific and time-specific inefficiencies. Anaya and Pollitt (2017) have shown how SFA might be used in power distribution, evaluating efficiency by considering weather and other environmental factors. As Tsionas (2002) demonstrated in efficiency assessments of US airlines, recent developments, such as Bayesian techniques, have further improved SFA's robustness by including previous efficiency estimates from DEA models.

Notwithstanding its benefits, SFA has drawbacks, such as sensitivity to model specifications and presumptions regarding the production frontier's functional form. Furthermore, because it depends on parametric techniques, the distributional assumptions for error terms must be carefully verified. Extensions such as semiparametric models and hybrid strategies that combine DEA and SFA have been put forth to overcome these constraints, offering a more thorough framework for efficiency analysis (Tsionas, 2021; Sun et al., 2015). These advancements demonstrate

SFA's versatility and applicability across various industries, including energy markets and agriculture.

SFA is a flexible approach for assessing efficiency in various fields, including public infrastructure, healthcare, and education (Kumbhakar and Lovell, 2000; Worthington, 2004). SFA has been widely used in the healthcare industry to examine hospital efficiency, emphasizing patient outcomes and resource use (Kiadaliri et al., 2013; Neri et al., 2022). Primary care research, for example, highlights the need to increase efficiency in the face of rising patient demands and constrained resources. Neri et al. (2022) systematic literature review emphasized how SFA aids in measuring technical efficiency while considering patient population characteristics and service complexity. Similarly, Kiadaliri et al. (2013) evaluated Iranian hospitals using SFA and showed inefficiencies resulting from structural inequities and inadequate resource allocation. By identifying the causes of inefficiencies and encouraging changes to budget allocation, these evaluations help policymakers optimize healthcare delivery.

Applications of SFA in the education sector concentrate on outputs like academic performance and inputs like faculty-student ratios. In order to better resource management, Delgado et al. (2014) emphasized the method's usefulness in finding inefficiencies among educational institutions. According to Adam et al. (2011), the approach has also been used to examine the efficiency of public spending in OECD nations, demonstrating the impact of managerial techniques and socioeconomic contexts on the effectiveness of the public sector. Targeted interventions are made possible by SFA's nuanced approach, distinguishing inefficiencies resulting from environmental causes from those caused by managerial behaviors. Applications of SFA in the public sector include municipal PSE and transportation. In assessing the efficiency of the railway industry, Holvad (2020) identified economies of scale and external market factors as important determinants. The application was expanded to municipal governments by Adam et al. (2011), who showed how managerial inefficiencies and administrative changes led to differences in resource use. These uses highlight how well SFA integrates random noise and environmental elements into efficiency assessments, providing a thorough understanding of operational performance across industries.

4. CONCLUDING REMARKS

Given its critical role in resource optimization, social welfare, and economic growth, PSE remains a top priority for policymakers, scholars, and practitioners (Afonso et al., 2005; Hall and Jones, 1999). In assessing and improving public sector performance, the literature emphasizes the value of sound methodologies like Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA), and Artificial Intelligence (AI)-based approaches (Ruggiero, 1996; Medeiros and Schwierz, 2015). These approaches give governments practical insights to enhance public service delivery, advance equity, and maintain economic stability by reducing inefficiencies and guaranteeing accountability. This review's explanation of the relationship between institutions and PSE emphasizes how crucial institutional quality is to accomplish these goals (Acemoglu et al., 2014; Kaufmann et al., 1999).

Institutions significantly shape the effectiveness of public sector activities. Robust institutions improve the overall governance framework by promoting accountability, transparency, and regulatory excellence (North, 1990; Acemoglu and Robinson, 2012). On the other hand, ineffective institutions frequently result in inefficient use of resources and a decline in public confidence (Mauro, 1995; Aidt, 2009). According to the literature, public sector performance can be considerably enhanced by institutional reforms like performance-based budgeting and e-governance (Afonso et al., 2010; Méon and Weill, 2005). However, more research is needed to fully understand how governance systems, cultural norms, and social values interact to affect efficiency in the interaction between formal and informal institutions (Hodgson, 2006; Börzel and Risse, 2016).

The techniques used to evaluate the effectiveness of the public sector have changed over time, with DEA and SFA emerging as the most popular methods (Charnes et al., 1978; Aigner et al., 1977). DEA and SFA are essential methods for assessing efficiency due to their versatility in managing various inputs and outputs and their capacity to include stochastic elements (Lampe and Hilgers, 2015; Kumbhakar and Lovell, 2000). The robustness of these approaches has been further improved by recent developments, such as hybrid DEA-SFA models and Bayesian DEA (Tsionas, 2002; Zervopoulos et al., 2023). Furthermore, machine learning algorithms and AI-based approaches are increasingly utilized for predictive analytics and real-time monitoring, providing creative answers to challenging problems in the public sector (Wirtz et al., 2019; Brynjolfsson and McAfee, 2017). A thorough evaluation framework incorporating operational indicators and stakeholder viewpoints is ensured by combining quantitative techniques with qualitative methodologies, such as surveys and interviews (Qu and Dumay, 2011; Sumiyana et al., 2023).

Despite significant progress, there are still obstacles to attaining long-term PSE. Performance is nevertheless hampered by corruption, bureaucratic inertia, and misaligned incentives in many settings, especially in developing countries (Aidt, 2009; Kaufmann et al., 1999). Targeted institutional reforms, capacity training, and the implementation of creative governance mechanisms are necessary to address these issues (Mauro, 1995; Acemoglu et al., 2014). Furthermore, public sector approaches must be able to adapt to a variety of socioeconomic conditions. Achieving significant and long-lasting changes requires customized strategies considering regional settings, cultural quirks, and financial limitations (Börzel and Risse, 2016; Peng and Sauerwald, 2012).

In conclusion, there is room for more study and creative policymaking at the nexus of institutional quality and PSE. A multifaceted strategy incorporating strong methodology, institutional reforms, and stakeholder participation is needed to advance this field (North, 1990; Leeson and Thompson, 2023). Public sector organizations can increase their effectiveness and legitimacy by encouraging transparency, utilizing technology, and supporting participatory governance (Acemoglu and Robinson, 2012; Korosteleva and Flockhart, 2020). Future research could examine the dynamic interaction between institutions and techniques to address new issues and ensure that public sector

performance satisfies social demands and expectations (Wirtz et al., 2019; Prakash and Potoski, 2016).

4.1. Limitations and Future Research

Numerous methodological, conceptual, and data-related problems limit using techniques like DEA and SFA to quantify PSE. One significant problem is that classic DEA frequently produces skewed efficiency estimates due to its incapacity to appropriately account for external or environmental influences. For example, because DEA is deterministic and does not assume random noise, it is sensitive to the quality of the data as well as outside factors like institutional structures or socioeconomic conditions (Afonso and Aubyn, 2005; Hollingsworth, 2008). Similarly, SFA's dependence on parametric assumptions for the efficiency frontier presents difficulties concerning the model formulation and handling heterogeneity among DMUs (Worthington, 2000). Because efficiency variables are multifaceted and intangible, it is conceptually challenging to define and measure them, such as health outcomes or educational advantages (Simpson, 2009). When used across industries or nations with different features, this complexity frequently leads to partial or erroneous efficiency representations (Afonso et al., 2005). Cross-country comparisons and the generalizability of findings are further hampered by data-related issues such as the scarcity of comparable or high-quality datasets, the difficulty of defining input-output variables, and the limitations in data availability for particular sectors or regions (Narbón-Perpiñá and De Witte, 2018).

Future research areas seek to overcome these constraints through improved data-gathering techniques, enlarged analytical frameworks, and methodological developments. The reliability and application of efficiency assessments could be greatly increased by integrating sophisticated models, such as network DEA, bootstrapping strategies, or hybrid approaches that combine DEA with SFA or regression analysis (Emrouznejad and Yang, 2018). These models can better handle the impact of environmental conditions and consider efficiency's dynamic nature. For instance, bootstrapping can increase the statistical reliability of efficiency rankings, while network DEA techniques can assess interconnected processes within sectors (Simões and Marques, 2012). Ensuring comparability and precise causal inference across research requires addressing endogeneity concerns and creating uniform classifications for environmental variables (Ruggiero, 1996). Expanding efficiency evaluations to low- and middle-income nations is essential, as most current research focuses on developed economies, limiting its global relevance (Giorgio et al., 2016). The dependability of efficiency measures should be improved by better data-gathering procedures, especially for underrepresented industries like public health and education. This involves adding variables that measure qualitative aspects, like public service delivery standards or the quality of governance (Afonso et al., 2023).

Future research should focus on developing practical frameworks and user-friendly tools to help policymakers apply these techniques effectively. To help close the gap between technical assessments and practical insights, for instance, accessible software or decision-support tools can be developed (Emrouznejad and Dey, 2011). A more thorough grasp of public sector performance can be obtained by researching the integration of efficiency and effectiveness measurements, especially in fields like public infrastructure, healthcare, and education (Holvad, 2020). Additionally, relating efficiency studies to current issues like sustainability objectives and the effects of digital transformation may increase the approaches' application and relevance (Ma et al., 2023). Future research should combine methodological rigor with practical relevance to support informed policymaking and improve public sector outcomes.

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APPENDIX

Table A1: Overview of methodological approaches for measuring public sector efficiency, their limitations, and future research recommendations

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Hajiagha et al. (2023)	PCA, FA, DEA	Regions: Iran Level: Sector-specific (Healthcare)	- Methodological constraints: The constraint on the number of inputs/outputs relative to the number of DMUs in traditional DEA methods. - Methodological constraints: Limited discriminatory power of classical DEA methods, improved by the proposed PCA-FA-TLDEA approach.	No specific recommendations for future research
Zelenyuk and Zhao (2024)	DEA	Regions: Scope not specified Level: Scope not specified Time Period: Scope not specified	- Methodological constraints: Popular technical efficiency measures do not account for potential slacks in inputs or outputs, leading to possible misrepresentation of inefficiency. - Conceptual limitations: The precise relationship among many efficiency measurement methods is not always clear, posing challenges in understanding and comparison	No specific recommendations for future research
Malul et al. (2009)	DEA	Regions: Scope not specified Level: Scope not specified Time Period: Scope not specified	- The addition of the Gini index and environmental performance significantly affects rankings, indicating a limitation in current measurement approaches for developing countries. - Conventional ranking methods are only suitable for developed countries, suggesting comparability issues across different country types. - The need to apply the methodology to more countries and consider additional parameters indicates a limitation in scope and comprehensiveness.	- Apply the developed methodology to more countries, both developed and developing. - Consider inclusion of additional ranking parameters.
Cheng and Zervopoulos (2014)	GDDF-DEA	Regions: Global (171 countries) Level: National Time Period: 2010		No specific recommendations for future research
Mergoni and De Witte (2022)	DEA	Regions: Scope not specified Level: Sector-specific (Education, Health, Environment)		- Explore patterns in fields of application, applied efficiency models, and analysis of efficiency determinants. - Integrate frontier techniques with policy perspectives in public sector performance analysis. - Focus on combining efficiency and effectiveness in evaluating public interventions, especially in education, health, and environment sectors.

(Contd...)

Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Tsekouras et al. (2010)	DEA, bootstrapping	Regions: Greece Level: Sector-specific (Healthcare/ICUs) Time Period: 2004	- Methodological constraints: The DEA approach requires small white noise in estimation, and bootstrapping is used to address this limitation. - Conceptual limitations: The study focuses only on quantitative measures, not examining the quality of outputs. - Data collection challenges: Accounting for environmental variables impacting efficiency. - Conceptual limitations: Investments in medical equipment did not significantly affect scale efficiency, indicating limitations in addressing capacity utilization.	- Future research should focus on The qualitative effects of new technology medical equipment on The efficiency of ICUs, mainly through The redefinition of inputs and produced outputs of The ICU system.
Emrouznejad et al. (2023)	DEA	Regions: China, USA, Korea, Finland Level: National/ Regional/Sector-specific Time Period: 1989-2022		- Develop a practical framework or software for policymakers to use with minimal technical information. - Conduct further research on productivity changes over time using the Malmquist-Luenberger productivity index (MPI). - Continue methodological improvements in DEA for eco-efficiency measurement. - Explore emerging research fronts and issues identified between 2000 and 2022.
Varabyova and Müller (2016)	DEA; SFA	Regions: OECD countries Level: National	- Methodological constraints: Large differences in study designs and methods, and low correlations between country rankings indicate a lack of internal validity. - Comparability issues: Methodological problems in cross-country comparisons question the ability to provide meaningful guidance to policy-makers	No specific recommendations for future research
Afonso et al. (2005)	FDH	Regions: 23 industrialised OECD countries Level: National Time Period: 1990-2000	- Methodological constraints: The measurement of public sector performance and efficiency is limited, and the use of a non-parametric approach does not statistically assess differences across countries. - Conceptual limitations: The influence of tax and regulatory policies on efficiency is not fully accounted for, and the assumption that production costs are proportionate to GDP per capita may not be accurate. - Data collection challenges: It is difficult to separate the effects of public spending from other influences. - Comparability issues: Public spending is not always fully comparable across countries	No specific recommendations for future research
Jacobs et al. (2006)	DEA	Regions: Scope not specified Level: Scope not specified Time Period: Scope not specified		No specific recommendations for future research

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Narbón-Perpiñá and De Witte (2018)	DEA, FDH, Malmquist Productivity Index, SFA	Regions: Global (specific focus on Europe, including Spain, Belgium, Germany) Level: National Time Period: 1990-2016	- Data collection challenges: Difficulty in collecting data and measuring local services. - Comparability issues: Diverse measures used across studies, even within the same country. - Conceptual limitations: Complexity in accurately defining inputs and outputs for local governments. - Methodological constraints: Issues with endogenous data and the impact of using a single methodology on results interpretation.	- Consider alternative input-output models to assess heterogeneity among local governments and the impact of output numbers on efficiency scores. - Develop better proxy variables and quality indicators for local government services to improve measurement accuracy. - Address endogeneity issues in data interpretation to improve causal inference in efficiency studies. - Apply more advanced techniques beyond DEA, FDH, or SFA for measuring efficiency.
Lansink and Wall (2014)	DEA, SFA	Regions: Scope not specified Level: Scope not specified Time Period: Scope not specified		No specific recommendations for future research
Narayanan et al. (2024)	DEA, bootstrapping, SBM-DEA, NDEA, Dynamic NDEA, Super-Efficiency DEA	Regions: Scope not specified Level: National Time Period: Scope not specified		- Pay more attention to the extended DEA model, including bootstrapping, slack-based models, relational networks, dynamic networks, and super efficiency for more reliable efficiency values. - Focus on non-oriented approaches in DEA to deal with flexible measures. - Use variable return to scale (VRS) due to the heterogeneity of innovation developments across countries. - Prioritize institutional, infrastructural, and market sophistication indicators as input variables and creative output indicators as output variables in innovation efficiency measurement. - Conduct future studies focusing on the efficiency of low-middle and low-income countries. - Perform comparative cross-country analyses to allow NIS to compare themselves with high-calibre innovators and enhance innovation performance

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Ma et al. (2023)	DEA, SFA	Regions: China, Finland, Spain, Vietnam, Laos, Ethiopia Level: Global/ Regional (urban agglomeration, river basin, megacity, provincial, municipal, mountain town) Time Period: 2005-2022		- Construct large and complex models incorporating geospatial effects, big data, and computer technology. - Conduct land use efficiency research on a global scale to align with SDGs. - Integrate geospatial mechanisms into land use efficiency assessment models. - Explore spatiotemporal variation characteristics of land use efficiency at a global scale. - Align land use efficiency research with the SDGs to guide evaluation index systems and analysis perspectives
Emrouznejad and Dey (2011)	DEA, SFA, Tobit regression, bootstrap DEA, Artificial Newral Network DEA	Regions: Spain (Extremadura), Chile, New Zealand, Lebanon Level: Regional (Spain), Sector-specific (Chile, New Zealand, Lebanon) Time Period: Scope not specified	- Conceptual limitations: The health services sector is complex and multidimensional, making it difficult to measure performance using a single method. - Data collection challenges: While data collection and analysis are within the quantitative skill set of organizations, translating this data into actionable information for managers requires a different skill set.	No specific recommendations for future research
Grigoli (2015)	DEA, SFA	Regions: Emerging and developing economies, especially in Africa Level: Sector-specific (secondary education) Time Period: Not specified	- Methodological constraints: The measurement of The efficiency of public education expenditure using parametric and non-parametric methods has proven challenging.	No specific recommendations for future research
Worthington and Dollery (2002)	DEA	Regions: New South Wales, Australia Level: Regional/ Sector-specific Time Period: Scope not specified	- Methodological constraints: The study highlights the challenge of incorporating non-discretionary factors in DEA, as different approaches yield significantly correlated but varied efficiency scores. - Comparability issues: There is significant variation in the distributions of efficiency scores and the number of councils assessed as perfectly technically efficient across different approaches, indicating challenges in achieving consistent and comparable results.	No specific recommendations for future research
Stone (2002)	DEA, SFA	Regions: Scope not specified Level: Sector-specific (police force) Time Period: Not specified	- Conceptual limitations: The use of data envelopment analysis or stochastic frontier analysis techniques for assessing police force efficiency is questioned in terms of sense and realism.	No specific recommendations for future research

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Häkkinen and Joumard (2007)	SFA	Regions: OECD countries (including Finland, Sweden, United States, Germany, United Kingdom) Level: National/ Sector-specific Time Period: Not explicitly defined, but references suggest early 2000s to 2008	- Methodological constraints: Lack of an agreed framework for applying concepts like QALYs across OECD countries. - Data collection challenges: Absence of data on QALYs and institutional data at the disease level; insufficient input and output data for international comparisons in some sub-sectors. - Conceptual limitations: Current outcome measures only partly reflect health care policy objectives. - Comparability issues: Difficulties in securing cross-country comparability due to heterogeneity in case-mix systems and lack of consistent international databases.	- Develop methodologies to control for non-policy factors in system-wide efficiency analysis. - Expand data collection and analysis for disease-based approaches to reduce selectivity. - Investigate the relationship between outputs and health outcomes in sub-sector analyses. - Conduct further research on institutional factors affecting sub-sector efficiency. - Integrate complementary approaches for a more comprehensive understanding of healthcare efficiency
Zervopoulos (2014)	DEA	Regions: Greece Level: Sector-specific (public organizations providing administrative services) Time Period: Before and after 2011	- Methodological constraint: The current methodology does not measure interrelationships among exogenous variables, limiting comprehensive efficiency analysis. - Conceptual limitation: The methodology could be expanded to include additional exogenous variables, indicating potential gaps in capturing all relevant factors. - Challenge in maintaining efficiency: Downsizing and structural reforms can negatively impact performance unless mitigated by improvements in intangible factors.	- Measure interrelationships among exogenous variables: The current methodology quantifies relationships between exogenous variables and efficiency but does not measure interrelationships among exogenous variables. Further research is needed in this area. - Extend methodology with additional exogenous variables: The methodology could be applied to both for-profit and not-for-profit organizations by incorporating additional exogenous variables that may be positively or negatively related to the endogenous and exogenous variables. This could provide important managerial implications and extend the method.
Foo et al. (2015)	DEA, Tobit regression	Regions: Malaysia Level: Sector-specific (Ophthalmology services) Time Period: 2011-2012	- Methodological constraints: DEA depends heavily on data accuracy and assumes correct capture of inputs and outputs. - Data collection challenges: Data quality is imperfect, and not all inputs/outputs are captured, such as workforce variations and ad-hoc services. - Conceptual limitations: Uncertainty in determining exact levels and scope of inputs/outputs.	- Investigate the effectiveness of different strategies for promoting efficient behaviors, such as organizational changes and scaling of DMUs. - Improve data reliability by capturing full-time equivalent workforce numbers and developing a robust case-mix system.

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Alfiero et al. (2017)	SBM-DEA	Regions: Italy Level: Sector-specific (Waste Management) Time Period: 2010	- Conceptual limitations: The "publicness effect" significantly impacts managerial efficiency, indicating challenges in isolating and measuring this effect. - Comparability issues: Ongoing debates about ownership influence on efficiency suggest difficulties in comparing public and private sector efficiency. - Methodological constraints: Unexpected findings regarding managerial inefficiency in private versus public companies imply potential challenges in capturing accurate efficiency metrics.	No specific recommendations for future research
Smith (1994)	DEA	Regions: England Level: Sector-specific (Education and Prisons/Remand Centres) Time Period: Not specified		No specific recommendations for future research
Jung et al. (2023)	DEA, Game Theory, Propensity Score Matching.	Regions: China, Iran, Brazil, Taiwan, and other countries as part of multi-country studies Level: National Time Period: 2017-2022		- Expand DEA methodology by using advanced models like network DEA or Metafrontier DEA and combining DEA with other methods such as SFA or game theory. - Conduct cross-country comparisons of public and private medical care efficiency. - Analyze efficiency changes over time regarding COVID-19 to identify factors that mitigate its impact. - Research the efficiency of new healthcare systems, including digital healthcare, and examine the healthcare supply chain from a broad perspective
Ganesha et al. (2019)	DEA, SFA	Regions: Scope not specified Level: Scope not specified Time Period: Scope not specified		No specific recommendations for future research
Negri and Dincă (2023)	DEA, Quantile regression	Regions: European Union (27 member states) Level: National Time Period: 2005-2020	- Restricted sample size: The study is limited by the period of analysis (2005-2020), which restricts the sample size. - Complexity of variable correlations: The significant correlations between numerous variables could lead to multiple independent econometric models, complicating the analysis.	- Conduct an in-depth subnational and regional approach for examining public efficiency from a quality of governance perspective, due to increasing regional discrepancies in The European Union.

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Hussey et al. (2009)	DEA, SFA	Regions: United States Level: Sector-specific (e.g., hospitals, Medicare program) Time Period: 1990-2008	- Methodological constraints: Efficiency measures lack rigorous evaluations of reliability and validity, and there are unresolved issues in their specification, such as risk adjustment and attribution. - Data collection challenges: Exclusion of non-U.S. data sources and concerns about the transparency of proprietary measures. - Conceptual limitations: Potential differences in the quality of outputs used in efficiency measurement. - Comparability issues: Differences between proprietary grouper methodologies and the lack of scientific soundness in measures.	- Conduct rigorous evaluations of reliability and validity for existing efficiency measures to improve their scientific soundness. - Develop methods to better account for quality of care in efficiency measurements, addressing the potential variations in quality across different groups. - Improve efficiency metrics in controlled laboratory settings before implementing them in operational uses to avoid producing misleading information. - Address unresolved issues such as risk adjustment of episode-based measures, attribution of outputs to specific providers, and differences between proprietary methodologies
Afonso et al. (2010)	DEA, Tobit analysis	Regions: New EU member states, Emerging markets Level: National Time Period: 1999-2003	- Methodological constraints: Difficulty in measuring costs, identifying goals, and assessing efficiency through appropriate cost and outcome measures. - Conceptual limitations: Challenges in accurately identifying the effects of public sector spending on outcomes and separating these effects from other influences. - Comparability issues: Assumption that production costs for public services are proportionate to GDP per capita when comparing expenditure ratios across countries. - Ignoring nondiscretionary factors: Analysis assumes efficiency is purely the result of discretionary inputs, not accounting for exogenous factors	No specific recommendations for future research
Husain et al. (2000)	DEA	Regions: Selangor, Malaysia Level: Sector-specific Time Period: Not specified	- Methodological constraints: Lack of proper systems and procedures to address overall efficiency within and between organizations or sectors. - Conceptual limitations: Reliance on centrally evaluated cost-weighted activity indices as performance measures, which may not fully capture efficiency	No specific recommendations for future research
Afonso et al. (2005)	FDH	Regions: 23 industrialised OECD countries Level: National Time Period: 1990-2000	- Limited measurement of public sector performance and efficiency: The study acknowledges that the measurement of these metrics is still very limited. - Influence of tax and regulatory policies: These factors affect efficiency but are not fully accounted for in the analysis. - Difficulty in isolating effects: It is challenging to separate the impact of public spending from other influences like climate or dietary habits. - Comparability issues: Public spending data across countries may not be fully comparable due to differences in recording and taxation.	No specific recommendations for future research

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
			- Assumption on production costs: The assumption that production costs are proportionate to GDP per capita is a conceptual limitation. - Non-parametric approach limitations: The FDH method does not statistically assess differences across countries	
Nepomuceno et al. (2022)	DEA, SFA, Malmquist Productivity Index	Regions: Europe, Asia, North America, Africa, Henan (China), Valencian Community (Spain), Madhya Pradesh (India), Seoul (South Korea) Level: Sector-specific (Healthcare/Hospitals) Time Period: 1996-2022		No specific recommendations for future research
Cichowicz et al. (2021)	DEA	Regions: Mazovia province, Poland Level: Sector-specific (Public Employment Services) Time Period: 2019	- Methodological constraints: lack of appropriate evaluation methods for The applied labor market policy instruments.	No specific recommendations for future research
Pedraja-Chaparro et al. (2005)	DEA	Regions: Scope not specified Level: Scope not specified Time Period: Scope not specified	- Conceptual limitations: Public sector activities have multiple goals beyond efficiency, leading to trade-offs among objectives. - Data collection challenges: Outputs are not traded on the market, complicating measurement; lack of competition and bankruptcy threat affects traditional efficiency measures. - Methodological constraints: Problems in measuring outputs and inputs, and uncertainty regarding technology, require adjustments in efficiency measurement techniques	No specific recommendations for future research
D'Elia and Ferro (2019)	DEA, SFA	Regions: United Kingdom, Italy, Germany, Spain, Greece, Sweden, Poland, United States, Australia, China, Taiwan, Malaysia, India, Mexico, Brazil, Colombia, Argentina Level: Sector-specific (Higher Education) Time Period: 1997-2018	- Methodological constraints: The choice of an adequate functional form is challenging, and DEA is sensitive to outliers. - Data collection challenges: Difficulty in obtaining data to specify adequate input measures and defining outputs clearly. - Conceptual limitations: The absence of profit motivation and diversity of goals complicate efficiency measurement. - Comparability issues: Multiple objectives and outcomes with public good characteristics complicate comparisons	No specific recommendations for future research
Lachowska (2017)	Synthetic Measure of Development (SMD), Ward's method, k-means method	Regions: West Pomeranian Voivodship, Poland Level: Sector-specific (Primary Health Care) Time Period: 2009-2010	- Methodological constraints: Lack of comprehensive research on efficiency methods in the Polish healthcare system. - Conceptual limitations: Research gap in distinguishing between public and nonpublic provider efficiency. - Comparability issues: Questioning the legitimacy of using certain indicators for measuring efficiency.	- Further research and analysis of the differences in the public and nonpublic parts of the healthcare sector. - Expand research to cover a larger population and longer research period for more comprehensive conclusions. - Continue testing and implementing the efficiency measurement model in practice to verify its usefulness.

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Walker et al. (2021)	Hicks-Moorsteen Productivity Index (HMPI)	Regions: United Kingdom Level: Sector-specific (Water and Sewage Companies) Time Period: 2014-2018	- Methodological constraints: The choice of variables significantly influences perceived efficiency, and results are confined to yearly values due to limited temporal sample range. - Data collection challenges: Small sample size limits the number of indicators that can be used. - Conceptual limitations: Capital expenditure benefits can lag, leading to poor short-term performance. - Comparability issues: Limited sample size affects the ability to provide a holistic representation of sustainability	- Future studies should consider using a larger sample size to allow for more indicators to be evaluated. - Future research can build upon the framework of the Hicks-Moorsteen Productivity Index (HMPI) as applied in this study. - Explore implications on policy, regulation, water management, and potential collaborators for sharing best practices as additional research directions.
Sommersguter-Reichmann (2022)	DEA	Regions: Scope not specified (broad spectrum from emerging to highly developed countries) Level: National/ Regional/Sector-specific Time Period: 1980-2020	- Methodological constraints: The choice of database and keywords may affect the inclusion of studies, potentially leading to bias or incompleteness. - Conceptual limitations: The dynamic nature of publication activity and new methods (conditional approaches) may lead to shifts in research focus not captured in the review. - Comparability issues: The subjective assignment of quality indicators to quality dimensions affects the conclusions drawn in the review.	No specific recommendations for future research
Afonso and Aubyn (2005)	FDH, DEA	Regions: OECD countries (including Finland, Japan, Korea, Sweden) Level: National Time Period: Scope not specified	- Conceptual limitation: a country may be technically efficient but appear inefficient if The inputs it uses are expensive, indicating a limitation in how efficiency is measured. No other limitations explicitly discussed.	No specific recommendations for future research
Adam et al. (2011)	DEA, SFA	Regions: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Luxembourg, Norway, Portugal, Spain, Sweden, Switzerland, The Netherlands, United Kingdom, United States Level: National Time Period: 1980-2000	- Methodological constraint: Difficulty in distinguishing inefficiency due to managerial practices from inefficiency due to socioeconomic environments or luck. - Data collection challenge: Missing data for certain countries and periods, preventing complete efficiency estimates. - Conceptual limitation: Exclusion of defense spending due to difficulty in substantiating its output. - Conceptual limitation: Difficulty in considering all social and economic objectives, limiting comprehensiveness. - Reporting constraint: Space constraints prevent comprehensive reporting of results	- Examine the interrelationship between the efficiency of public spending, growth, and economic volatility. - Explore the implications of estimated scores for bureaucratic efficiency and capacity. - Investigate the link between democratic institutions and the public sector. - Assess the potential benefits of political reform.
Kiadaliri et al. (2013)	DEA, SFA	Regions: Iran (with a focus on Tehran and other provinces) Level: Sector-specific (hospital efficiency) Time Period: 1996-2010	- Methodological constraints: No adjustment for case mix and quality of care differences; aggregation of input categories; focus on curative functions. - Data collection challenges: Lack of data on a broad range of hospital functions and quality of care in Iranian hospital databases.	- Improve data collection and processing in Iranian hospital databases to enhance research quality. - Address methodological deficiencies such as aggregation of input categories, focus on curative functions, and lack of adjustments for case mix and quality of care.

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
			- Conceptual limitations: Little adjustment for heterogeneity in the sample; no attempt to examine causes of inefficiency or evaluate model misspecification. - Comparability issues: Methodological deficiencies and data limitations affect validity and reliability for policy-making.	- Develop a critical assessment tool to evaluate the quality of efficiency studies. - Broaden the scope of data to include a wider range of hospital functions and improve researchers' understanding of these functions.
Afonso et al. (2023)	DEA	Regions: 36 OECD countries Level: National Time Period: 2006-2017		No specific recommendations for future research
Viitala and Hänninen (1998)	DEA, Tobit models	Regions: Scope not specified Level: Regional/ Sector-specific Time Period: Scope not specified		No specific recommendations for future research
Msann and Saad (2020)	DEA	Regions: MENA region (including United Arab Emirates, Qatar, Iran, and 11 other unspecified countries) Level: National Time Period: 2004-2015		No specific recommendations for future research
Günay and Dulupçu (2019)	DEA, MPI	Regions: Turkey Level: Sector-specific (Public Universities) Time Period: 2004-2013		No specific recommendations for future research
Cooper and Ray (2007)	DEA, SFA	Regions: England and Wales Level: Sector-specific (Police districts) Time Period: Not specified		No specific recommendations for future research
Dusansky and and Wilson (1995)	DEA	Regions: Nebraska (Lancaster County, Butler, Gage, Jefferson, Nemaha, Otoe, Saline, Saunders Counties) Level: Sector-specific Time Period: 1986	- Data collection challenges: The study is limited by the available data, requiring more detailed and panel data for further research and better cost control. - Methodological constraints: The current data does not allow for examining the effects of policy changes, and aggregation of inputs is necessary due to lack of detailed data. - Conceptual limitations: No attempts were made to measure output allocative efficiency due to fixed outputs and lack of price information.	- Additional data collection: The study is limited by the available data, and additional data are required for further research. Panel data are recommended to examine the effects of policy changes. - Detailed data collection over time: More detailed data collected over time would help identify potential sources of savings and provide a basis for cost control. - Reduction in input aggregation: More detailed data would reduce the need for aggregation of inputs, allowing administrators to focus on specific items being wasted.

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Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Drei and Angulo-Meza (2023)	DEA	Regions: Latin America Level: Sector-specific (healthcare) Time Period: Not specified		- Integration of DEA with complementary tools in other Latin American countries and different facets of the healthcare domain (additional research directions). - Building upon existing literature insights to introduce innovative approaches (methodological improvements and conceptual refinements)
Dunleavy (2017)	Regression analysis, DEA, TFP	Regions: OECD countries (including Australia, US, UK, Sweden) Level: National/Cross-national Time Period: Not specified (mentions recent research from 2016)	- Conceptual limitations: There is a failure of imagination and focused effort in developing effective measures for public sector productivity. - Data collection challenges: Sustained resistance from civil servants and public sector professionals to the application of productivity measures. - Methodological constraints: The generation of very aggregate numbers that are static over time, making it difficult to capture dynamic changes. - Comparability issues: Difficulty in standardizing productivity data across countries due to different political and policy environments.	- OECD should establish working parties to develop an international consensus on improving productivity measurement in government. - Develop productivity measures for large central government departments and agencies, focusing on completing essential steps without measuring service quality directly. - Progress on measuring productivity for central government organizations with complex outputs, addressing challenges in unit denomination. - Develop productivity measures for large N analyses in sectors like healthcare, social care, and education. - Create comparative data for less salient services with good data sources, leveraging existing technical norms. - Improve national statistics and whole service-sector productivity numbers for broader methodological advancements
Mbau et al. (2023)	DEA, SFA, FDH	Regions: OECD countries, WHO member states, Eastern European countries, Asian countries, Latin America and Caribbean countries, Sub Saharan Africa, China, South Africa, Saudi Arabia, Switzerland, Brazil, Finland, India, Zambia, Mozambique Level: National and Sub-national Time Period: 2000-2021	- Data collection challenge: The review may have missed key literature as it only searched two databases. - Methodological constraint: The review provides a qualitative evaluation rather than quantifying impacts. - Conceptual limitation: The study lacks quantitative synthesis, suggesting a need for meta-analysis. - Comparability issue: Heterogeneity of methods makes it challenging to summarize or compare findings.	- Conduct more studies on health system efficiency in low- and middle-income countries (LMICs) to address the current evidence asymmetry. - Incorporate mixed methods approaches in future research to deepen the understanding of efficiency and its determinants. - Broaden the search strategy in future reviews to include more databases and potentially uncover additional relevant literature. - Include meta-analyses in future research to quantify the impact of interventions on health system efficiency.

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Vitezić et al. (2019)	DEA, BSC	Regions: Croatia Level: Sector-specific (Public Health Services) Time Period: 2017	- Methodological constraint: The complexity of public health services limits the use of DEA to departments with at least twelve units. - Conceptual limitation: The necessity to express certain inputs and outputs through a common measurement unit. - Comparability issue: The need for a common measurement unit to ensure comparability between DMUs within and across institutes	- Methodological improvements: Develop methods to apply DEA in departments with fewer than twelve units. - Conceptual refinements: Establish common measurement units for inputs and outputs to enhance comparability. - Additional research directions: Explore the application of the DEABSC model in other public institutions
Afonso and St. Aubyn (2005)	FDH,DEA	Regions: OECD countries (including Finland, Japan, Korea, and Sweden) Level: Sector-specific (education and health) Time Period: Not specified	- Conceptual limitation: Traditional efficiency measurements may not account for the cost of inputs, leading to misinterpretation of a country's efficiency. No other limitations explicitly discussed.	No specific recommendations for future research
Moreno-Gómez et al. (2020)	DEA, Truncated regression	Regions: Colombia Level: Sector-specific (Higher Education) Time Period: 2015-2017	- Methodological constraint: The data do not permit a direct analysis of the impact of improvements in resources or capabilities on knowledge transfer. - Conceptual limitation: Policies and their efficiency may be influenced by differences in cultural contexts, regulatory frameworks, and knowledge transfer activities. - Comparability issue: The country specificity of this research study calls for caution when generalizing and interpreting its findings.	- Explore the impact of improvements in resources or capabilities on knowledge transfer, as current data do not permit direct analysis. - Investigate how cultural contexts, regulatory frameworks, and knowledge transfer activities influence policy efficiency. - Conduct studies in different countries or contexts to generalize and interpret findings beyond the Colombian context.
Simpson (2009)	DEA, SFA	Regions: United Kingdom Level: National Time Period: Not specified	- Methodological constraints: Efficiency measures and rankings can be sensitive to the techniques used. - Data collection challenges: Difficulty in capturing all outputs and outcomes valued by society. - Conceptual limitations: Absence of price information complicates aggregation and accurate measurement. - Comparability issues: Public sector output measures differ from private sector measures, complicating comparisons.	- Explore the use of public sector reforms and pilot schemes to identify causal effects on productivity. - Increase the scope of indicators collected to be more disaggregated and cover a wider range of outputs. - Improve measurement at the organizational level to understand the effects of competition, incentives, and other factors on productivity. - Ensure robustness in productivity measurement techniques by demonstrating results are consistent across different assumptions and methods. - Develop partial measures of productivity for specific conditions to capture output quality and assess technological impacts

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Zubir et al. (2024)	DEA	Regions: Scope not specified Level: Sector-specific (hospitals) Time Period: 2014-2022	- Conceptual limitations: The focus on hospital methodologies could limit the findings to this specific area. - Data collection challenges: Insufficient data was observed to support the usability of any DEA model in terms of fitting all model parameters.	- Explore DEA applications in areas beyond hospitals or from different perspectives, as the current focus may limit findings. - Investigate alternative approaches or techniques for determining input and output variables in DEA analysis. - Consider the proposed methodological principles for DEA as a basis for future research improvements.
Maroto et al. (2016)	DEA	Regions: European countries Level: National Time Period: Scope not specified		No specific recommendations for future research
Afonso and St. Aubyn (2005)	FDH, DEA	Regions: OECD countries Level: Sector-specific (Education and Health) Time Period: 2000	- Conceptual limitation: Measuring public sector performance is complex, especially with aggregate and international data. - Methodological constraint: Using expenditure as an input measure is problematic due to exchange rate issues and mixing inefficiency with cost differences. - Data collection challenge: Adjusting for cost differences is difficult with uncertain results, leading to reliance on physical inputs and outputs. - Conceptual limitation: Difficulty in measuring complex outcomes like health status and the assumption that "more is better" for outputs like infant mortality. - Methodological constraint: Increasing inputs and outputs in a small sample leads to more efficient by default observations. - Methodological constraint: Trade-off between the number of dimensions and meaningful results	- Investigate methodological improvements in efficiency measurement by considering both financial and physical resource allocations. - Explore additional research directions to explain why some countries are more efficient than others in education and health provision. - Examine the role of public sector inefficiency in service provision. - Investigate the impact of population density, GDP per head, and educational attainment on efficiency outcomes. - Study the interaction between public and private funding as a potential source of inefficiency.
Hollingsworth (2008)	DEA, SFA	Regions: Scope not specified Level: Sector-specific Time Period: Scope not specified		No specific recommendations for future research
Kapsoli et al. (2023)	DEA, SFA, bootstrap DEA	Regions: Latin America Level: National/ Sector-specific Time Period: 2008-2021	- Methodological constraints: Efficiency scores can vary depending on data availability and methodology used; non-parametric models are deterministic and do not account for uncontrollable factors. - Data collection challenges: Lack of comparable multi-country data on input prices; consistent public investment statistics are only available at an aggregate level. - Conceptual limitations: Difficulty in estimating allocative or cost efficiency measures; exclusion of certain infrastructure types due to private sector dominance. - Comparability issues: Presence of outliers in non-parametric models; lack of disaggregated data on public versus private infrastructure components	- Expand empirical applications to include more options discussed conceptually, contingent on data availability. - Investigate the drivers of investment inefficiencies and potential solutions. - Use estimates to explore the relationship between public investment efficiency and economic growth.

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Grosskopf et al. (2014)	DEA, SFA	Regions: Scope not specified Level: Sector-specific Time Period: Scope not specified		No specific recommendations for future research
Gangopadhyay et al. (2018)	DEA	Regions: India, Japan, USA, Germany Level: Sector-specific Time Period: Scope not specified	- Methodological constraint: The study relies on the DEA methodology, which may limit the analysis to the assumptions and capabilities of this method. - Conceptual limitation: There is a dichotomy between local and global efficiency scores, indicating issues with comparability due to scale size and regional disparities. - Data collection challenge: The approach's outcome depends on the correct selection of input and output variables and data availability.	No specific recommendations for future research
Młynarski and Kaliszewski (2018)	DEA, SFA	Regions: Poland Level: Sector-specific (Forest Management) Time Period: Early 1990s-1995	- Methodological constraints: The reliance on indices and linear ordering measures limits the depth and scope of efficiency assessments. - Conceptual limitations: The approach to efficiency assessment in Poland differs from current European and global trends, indicating a potential misalignment with more advanced practices. - Methodological constraints: Scarcity of studies using parametric and non-parametric methods, which are more advanced and provide opportunities for comprehensive analysis.	- Explore new methods for assessing the activities of State Forests' entities to improve management efficiency. - Continue studies using non-parametric evaluation methods, focusing on financial efficiency and economic resources. - Aim to determine the maximum forest-derived income from selling wood and the maximum possible wood production through these studies.
Herrera and Ouedraogo (2018)	FDH, DEA	Regions: Scope not specified Level: Sector-specific (education, health, and infrastructure) Time Period: 2006-16		No specific recommendations for future research
Ibáñez et al. (2020)	DEA	Regions: Scope not specified Level: Sector-specific (Defence) Time Period: Scope not specified	- Methodological constraint: Existing empirical research has hardly applied bootstrapping methods to remove bias from the estimates. - Conceptual limitation: No empirical work has applied an analysis of efficiency determinants by the inclusion of exogenous variables.	- Apply bootstrapping methods to remove bias from efficiency estimates. - Analyze efficiency determinants by including exogenous variables. - Examine the impact of efficiency improvements on reputation and institutional confidence. - Explore the link between Defence Economics and Corruption Economics.
Camanho et al. (2024)	DEA	Regions: Scope not specified Level: Sector-specific Time Period: 1978-2020		No specific recommendations for future research

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Witte and López-Torres (2017)	DEA, FDH, SFA, MPI, Bootstrapping, Metafrontier analysis	Regions: Scope not specified (multiple countries implied through use of international databases) Level: National/ Regional/Sector-specific (university, school/high school, district/county/city, national) Time Period: 1977-2015	- Methodological constraints: Difficulty in quantifying environmental variables accurately; conditional efficiency models are unsuitable for large datasets due to execution time. - Data collection challenges: Reliance on poor proxies for measuring student abilities and institutional finance; need for more detailed data on human resources, finance, ICT, etc. - Conceptual limitations: Lack of understanding of differences in educational outcomes between countries; need for better output indicators to capture long-term educational benefits.	- Properly quantify the influence of environmental variables on student outcomes to improve accuracy in efficiency estimates. - Conduct more research on differences in educational outcomes and system characteristics between countries to understand why some systems perform better. - Invest in better and more detailed data collection on human resources, finance, ICT, procurement, estates, and student services. - Investigate student added value by examining the evolution of students' educational levels over time
Neri et al. (2022)	DEA, SFA, MPI	Regions: UK, USA, Spain, Portugal, Germany, Greece, Canada, Brazil, Italy, Austria, China Level: Sector-specific (Primary care centres) Time Period: 1980s-2019	- Conceptual limitation: The definition of primary care output is often based on utilisation measures rather than valued health outcomes. - Methodological constraint: Measuring final health outcomes attributable to primary care is challenging, especially when controlling for exogenous factors. - Comparability issue: Differences in the organisation of primary care across countries make it difficult to compare efficiency measures.	- Improve the definition of output in primary care efficiency studies to better represent valued outputs. - Investigate the impact of technological change and skill mix on primary care efficiency. - Identify relevant intermediate health outcomes to predict and measure the overall impact on HRQoL. - Identify comprehensive dimensions that define primary care output. - Explore the impact of technological change on productivity and the scope for role substitution across staffing.
Herrera and Pang (2005)	FDH, DEA	Regions: Scope not specified Level: National Time Period: 1996-2002	- Methodological constraint: The challenge of measuring efficiency in public spending. - Conceptual limitation: The inability to infer causality from the exercise.	No specific recommendations for future research
Aristovnik (2009)	FDH, DEA	Regions: New EU Member States, Croatia Level: Sector-specific (education and health care) Time Period: Not specified	- Methodological constraints: Deficiencies relating to the employed techniques and definitions. - Data collection challenges: Lack of suitable data to apply those techniques. - Conceptual limitations: Issues with the precise definition of inputs, outputs, and outcomes.	No specific recommendations for future research
Estruch-Juan et al. (2020)	DEA, SFA	Regions: Portugal Level: Sector-specific (Water services) Time Period: 2015	- Methodological constraints: DEA is very sensitive to data uncertainty, affecting utility rankings. Both DEA and SFA have limitations on the number of variables they can handle. - Data collection challenges: The water sector is known for data inaccuracies, impacting model results.	No specific recommendations for future research

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
			- Conceptual limitations: These methods are complex and hard for average users to understand, discouraging public participation. - Comparability issues: Significant differences in efficiency values and rankings between DEA and SFA can lead to questioning of regulatory decisions.	
Simões and Marques (2012)	DEA, SFA	Regions: Scope not specified Level: Sector-specific Time Period: 1965-Present (as of 2012)		No specific recommendations for future research
Lampe and Hilgers (2015)	DEA, SFA	Regions: Scope not specified Level: Sector-specific Time Period: 1978-2012		No specific recommendations for future research
Cowie and Riddington (1996)	DEA, SFA	Regions: Scope not specified Level: Sector-specific Time Period: Scope not specified	- Methodological constraints: Popular methods like Data Envelopment Analysis and Corrected Ordinary Least Squares are potentially misleading; original approaches like Uniform efficiency distributions and Bayesian State Space techniques are also unreliable. - Conceptual limitations: Traditional measures such as profit and labour productivity are not suitable; accurate measurement of efficiency is deemed not possible. - Comparability issues: Comparison with other authors' results suggests inconsistencies across different methodologies.	No specific recommendations for future research
De la Cruz and Mergoni (2024)	FDH, DEA	Regions: Peru Level: Sector-specific Time Period: 2014		No specific recommendations for future research
Athanassopoulos (2004)	DEA	Regions: Greece Level: Sector-specific (Tobacco sector) Time Period: Not specified	- Methodological constraints: Efficiency assessments based solely on cost information can lead to misjudgments without considering service effectiveness. - Data collection challenges: Lack of quality indicators and resource-intensive nature of collecting missing information. - Conceptual limitations: Difficulty in assessing efficiency without full qualitative information, leading to potential bias. - Comparability issues: Data availability constraints affect input-output selection for efficiency assessment.	No specific recommendations for future research
Giorgio et al. (2016)	DEA	Regions: Low- and middle-income countries (LMICs) Level: Sector-specific (health service production) Time Period: Not specified (simulation study)	- Methodological constraints: Current estimation approaches may not be well suited for LMICs; estimating efficiency for multiple outputs requires greater complexity; certain tests cannot compare non-nested models. - Conceptual limitations: No consensus on the most appropriate models and methods; challenge in identifying the underlying multiple-output production function. - Comparability issues: Assumptions of competitive market characteristics may not generalize to LMICs.	- Test more flexible forms of the efficiency frontier, such as the transcendental logarithmic (translog) form. - Analyze a broader range of efficiency distributions, such as exponential or gamma distributions. - Study different distributions for inputs and outputs. - Incorporate the performance of rSDF-CD under different misspecification issues.

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Lotfi et al. (2022)	DEA	Regions: Iran Level: National Time Period: Scope not specified	- Methodological constraints: The conventional DEA methods were found to be simplistic and inaccurate for measuring health systems' efficiency.	- Adopt the modified DEA approach to increase accuracy and create more meaningful policy-oriented results (methodological improvement).
Pestieau (2009)	DEA, SFA	Regions: Scope not specified Level: Sector-specific Time Period: Scope not specified	- Conceptual limitations: There is a need to disentangle conceptual problems from data problems, indicating potential confusion or lack of clarity in defining and understanding performance metrics. - Data collection challenges: The mention of "real world data problems" and questioning the sense of measuring performance with available data highlights issues related to data availability and quality.	- Methodological improvements: Develop a clear definition and measurement approach for public sector performance. - Conceptual refinements: Disentangle conceptual and data problems in performance measurement. - Additional research directions: Investigate the feasibility of assessing public sector performance given data limitations. - Conceptual refinements: Focus on outcomes rather than inputs when analyzing the entire public sector's performance.
Erkoc (2015)	DEA, SFA	Regions: Turkey Level: Sector-specific (Public Higher Education Institutions) Time Period: 2005-2010	- Comparability issues: The study finds that efficiency estimation results diverge between parametric and non-parametric approaches, affecting mean efficiency values and rankings.	No specific recommendations for future research
Kalb (2010)	DEA, SFA	Regions: Scope not specified Level: Sector-specific (public sector examples like schools, hospitals, etc.) Time Period: Scope not specified	- Methodological constraints: Difficulty in generating the best practice frontier from a data set of DMUs. - Conceptual limitations: Challenge in distinguishing between "real" inefficiencies and deviations caused by measurement errors.	No specific recommendations for future research
Katharakis et al. (2013)	DEA, SFA, bootstrap DEA, Translog regression	Regions: Greece Level: Sector-specific (public hospital units) Time Period: Scope not specified	- Methodological constraints: The utility of frontier techniques in decision-making is limited by methodological questions concerning their application. - Comparability issues: DEA and SFA yield divergent efficiency estimates due to environmental variables and measurement error. - Data collection challenges: The nature and availability of data influence the measurement of efficiency, requiring specificity in choosing the mathematical form.	No specific recommendations for future research
Guru and Mahalik (2020)	DEA, Super-Efficiency DEA, Multiple Regression analysis	Regions: India Level: Sector-specific (Public Sector Banks) Time Period: 2015-2016		No specific recommendations for future research

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Aiello and Bonanno (2019)	DEA, FDH	Regions: Australia, Belgium, Brazil, Czech Republic, Germany, Greece, Indonesia, Israel, Italy, Japan, Korea, Macedonia, Malaysia, Morocco, Portugal, Serbia, Slovenia, South Africa, Spain, Taiwan, Turkey, USA Level: National/ Regional Time Period: 1993-2016	- Data quality issues: Many primary studies do not report details on their empirical settings, affecting robustness and comparability. - Methodological constraints: Lack of information on technological orientation and functional forms in parametric frontiers. - Data collection challenges: Insufficient data to determine efficiency differences based on municipality size. - Conceptual limitations: Lack of consensus on environmental determinants to include in analyses. - Comparability issues: Limited geographical distribution of studies, mainly focusing on EU countries.	- Ensure primary papers provide detailed explanations of their empirical settings to improve data quality and understanding. - Investigate whether heterogeneity in local government efficiency can be explained by orientation in technology or different functional forms in parametric frontiers. - Address the gap in understanding how efficiency differs according to the size of municipalities. - Explore the effect of environmental determinants on municipalities' efficiency, given the lack of consensus on variables. - Increase geographical diversity in studies by focusing on countries outside the EU.
Smith and Mayston (1987)	DEA	Regions: Scope not specified Level: Scope not specified Time Period: Scope not specified	- Comparability issues: The abstract mentions potential limitations of The technique for inter-agency comparison, suggesting challenges in comparing efficiency across different agencies. No specific details are provided in The abstract.	No specific recommendations for future research
Halaskova et al. (2020)	DEA, SBM-DEA, MPI	Regions: Belgium, Bulgaria, Czech Republic, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, the Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden, United Kingdom Level: Sector-specific (Public and Private sectors) Time Period: 2010-2013, 2014-2017		- Focus on efficiency evaluation of scientific, research, technological, and innovation activities in the context of Industry 4.0. - Support the creation of national and regional strategic and innovation plans. - Develop an international comparative platform for consistent and compatible R&D data across countries.
Worthington (2000)	DEA, SFA	Regions: New South Wales, Australia Level: Sector-specific (Local Government) Time Period: Not specified	- Comparability issues: The choice of reference technology affects efficiency levels and rankings, influencing policy implications. - Conceptual limitations: DEA and stochastic frontiers are complementary, indicating that neither method alone is sufficient for comprehensive analysis	No specific recommendations for future research

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Andrews and Emvalomatis (2024)	DEA, SFA	Regions: USA, Greece, Scotland, Switzerland, Taiwan, The Netherlands, Ukraine, Germany, Italy, China, Portugal, South Africa, New Zealand Level: National/ Regional/Sector-specific Time Period: Early 1990s-2020	- Methodological constraints: Lack of studies using both primal and dual approaches for TFP; absence of dynamic modeling for efficiency; use of proxies like the number of beds for capital measurement. - Data collection challenges: Variability in the application of inputs, outputs, and price variables; complexity in measuring healthcare inputs and outcomes. - Conceptual limitations: Complexity in measuring healthcare services; lack of control for unobserved heterogeneity in longitudinal studies. - Comparability issues: Variability in the application of inputs, outputs, and price variables across studies.	- Methodological improvements: Utilize DEA and SFA with longitudinal data to better capture performance over time. - Additional research directions: Apply both primal and dual approaches to measure TFP changes for a comprehensive analysis. - Conceptual refinements: Develop dynamic models that account for inter-temporal dependencies in inefficiencies. - Address unobserved heterogeneity in longitudinal studies to improve accuracy in efficiency measurements. - Explore more nuanced measures of healthcare outputs beyond traditional proxies like inpatient admissions.
Holvad (2020)	DEA, SFA	Regions: Scope not specified Level: Sector-specific (railway sector) Time Period: Scope not specified		No specific recommendations for future research
Panayides et al. (2009)	DEA	Regions: Scope not specified Level: Sector-specific Time Period: Scope not specified	- Methodological constraints: issues in The specification of parameters, The sampling domain, and The type of DEA to be applied.	- Consider variations of DEA not yet applied to The port sector for Methodological improvement.
Bartolacci et al. (2025)	DEA	Regions: Italy Level: Sector-specific (Waste Management) Time Period: Not specified	- Methodological constraints: Misleading targets due to outliers in datasets when using data envelopment analysis. - Data collection challenges: Issues related to data quality and the need for analytical tools that are easy to use from a managerial perspective, given the poor diffusion of technical skills in public organizations	No specific recommendations for future research
Flegl et al. (2024)	Bootstrap DEA	Regions: Northwest region of Mexico Level: Regional/ Sector-specific Time Period: Scope not specified		No specific recommendations for future research
Kumar and Gulati (2009)	DEA	Regions: India Level: Sector-specific Time Period: 2006-2007		No specific recommendations for future research
Victorino and Pena (2023)	DEA, SFA	Regions: Scope not specified Level: Sector-specific Time Period: Since 2017	- Conceptual limitations: Gaps in eco-efficiency and safety-related issues in empirical rail research. - Methodological constraints: Need for better investigation of variable choice and scale return assumptions	- Investigate eco-efficiency and safety-related issues in empirical rail research. - Conduct a better investigation of variable choice and scale return assumptions in rail systems.

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Hroncová et al. (2023)	DEA	Regions: Slovakia Level: Sector-specific Time Period: 2016-2019	- Methodological constraints: DEA analysis for sports activities is rare, and the DEA solver could not handle undesirable outputs. - Data collection challenges: Limited data availability and the need for manual data retrieval and processing. - Conceptual limitations: Not all inputs and outputs were equally relevant or informative, and some recommendations were unrealistic	No specific recommendations for future research
Geys and Moesen (2009)	FDH, DEA, Regression analysis	Regions: Flanders Level: Regional Time Period: 2000	- Methodological constraints: Various approaches exist to measure efficiency, each with different underlying assumptions. - Conceptual limitations: Different underlying assumptions in the approaches can affect the outcomes of efficiency studies. - Comparability issues: Methodological choices significantly affect performance measurement, necessitating robustness checks to avoid incorrect inferences.	No specific recommendations for future research
Solà and Prior (2001)	DEA, MPI	Regions: Catalonia Level: Sector-specific (Healthcare) Time Period: Scope not specified		No specific recommendations for future research
Stone (2002)	DEA, SFA	Regions: England and Wales Level: Sector-specific (Police) Time Period: Not specified		No specific recommendations for future research
Azadi et al. (2023)	NDEA, DDF-DEA	Regions: Scope not specified Level: Sector-specific Time Period: Scope not specified		No specific recommendations for future research
Narbón-Perpiñá and De Witte (2018)	DEA, FDH, SFA, Tobit regression, OLS regression	Regions: Scope not specified Level: Global Time Period: 1990-2016	- Influence of environmental variables: Efficiency estimations that do not account for environmental factors have limited value. - Lack of standard classification: There is no clear and standard classification for environmental variables, leading to comparability issues. - Endogeneity issues: Past studies often neglect endogeneity issues, affecting causal interpretations. - Omission of variables: Methodological and computational constraints lead to the omission of important variables. - unavailability: Challenges in data collection limit the inclusion of a comprehensive set of variables. - Need for advanced techniques: Current methods like two-stage analysis have limitations, necessitating more advanced techniques	- Consider the influence of environmental variables on efficiency to control for heterogeneity. - Develop a clear and standard classification for environmental variables in empirical efficiency analyses. - Address endogeneity issues in data to ensure reliable causal interpretations. - Apply more advanced techniques beyond traditional two-stage analysis to incorporate environmental variables effectively.

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Ruggiero (1996)	DEA	Regions: Scope not specified Level: Sector-specific (school districts) Time Period: Scope not specified	- Methodological constraints: Existing linear programming models do not properly control for environmental variables, leading to biased estimates. - Conceptual limitations: Not controlling for fixed factors results in biased estimates of technical efficiency. - Methodological constraints: The existing Data Envelopment Analysis model overestimates the level of technical inefficiency	No specific recommendations for future research
Yu (2011)	DEA, MPI	Regions: Scope not specified Level: Sector-specific Time Period: Scope not specified	- Conceptual limitations: Difficulties in defining health care output precisely. - Data collection challenges: Lack of observed output prices and appropriate input data for productivity calculation. - Methodological constraints: Technical challenges in statistical approaches and deficiencies in data envelopment analysis. - Conceptual limitations: Need for consistent output definitions and treatment of quality changes.	No specific recommendations for future research
Smith and Street (2005)	DEA, SFA	Regions: Scope not specified Level: Scope not specified Time Period: Scope not specified	- Methodological constraints: Issues with the specification of the statistical model and the treatment of dynamic effects. - Conceptual limitations: Challenges in the treatment of environmental influences on performance and the weights attached to public service outputs	No specific recommendations for future research
Aldalbahi et al. (2019)	DEA, SFA	Regions: Scope not specified Level: Scope not specified Time Period: Scope not specified		No specific recommendations for future research
Hollingsworth and Peacock (2008)	DEA, SFA	Regions: Scope not specified Level: Scope not specified Time Period: Scope not specified		No specific recommendations for future research
Zubir et al. (2023)	DEA	Regions: Scope not specified Level: Sector-specific (hospitals) Time Period: 2014-2022	- Conceptual limitation: The review's focus on hospital-specific approaches may limit its applicability to other sectors. - Methodological constraint: There is no evidence that one DEA model fits all parameters, indicating difficulty in standardizing efficiency measurement. - Conceptual limitation: The selection of variables in DEA studies is crucial and can lead to different results, affecting comparability. - Methodological constraint: The lack of a specific method for selecting input-output variables in DEA is both an advantage and a limitation.	No specific recommendations for future research
Murova and Khan (2017)	SFA	Regions: United States (individual states) Level: Regional (state-level), Sector-specific Time Period: Not specified (21 years)		No specific recommendations for future research

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Table A1: ***(Continued)***

Source	Methodological approach*	Scope, geographical context, and time period	Limitations	Recommendations for future research
Moradi-Motlagh and Emrouznejad (2022)	DEA, FDH	Regions: China, Italy, Spain, Brazil, United States Level: Sector-specific Time Period: Scope not specified		- Focus on enhancing the dissemination and application of new methods through workshops, seminars, lectures, co-authorship, and user-friendly software applications. - Consider direct training via PhD candidates or post-doctoral fellowships as a means to spread new methodologies and knowledge. - Develop strategies for effective dissemination of future methodological advancements
Haddad et al. (2021)	DEA, SFA	Regions: Scope not specified Level: Sector-specific (Education) Time Period: 2010-2021		No specific recommendations for future research
Worthington (2014)	DEA, SFA	Regions: Australia, UK, Spain, US, Mexico, Brazil, Canada, Germany, Italy, Malaysia, Slovenia Level: Sector-specific (urban water utilities) Time Period: Not specified		No specific recommendations for future research

*PCA: Principal component analysis, FA: Factor analysis, DEA: Data envelopment analysis, GDDF: Generalized directional distance function; FDH: Free disposal hull, SBM: Slack-based measure, NDEA: Network DEA, SMD: Synthetic measure of development, TFP: Total factor productivity, BSC: Balanced score card, MPI: Malmquist productivity index, DDF-DEA: Directional distance function DEA