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ORIGINAL RESEARCH

Data envelopment analysis and accounting measures

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Abstract
This paper surveys the growing stream of DEA research that uses only accounting measures, which we term "FinDEA". Our analysis of 280 FinDEA studies from 1990 to 2023, identified 322 models using a diversity of firm performance constructs and accounting measures. The breadth of firm performance, nature and variety of accounting measures, and approaches used in this research stream introduce new challenges beyond those faced in conventional DEA research. We develop a hierarchical framework of FinDEA illustrating how various models focus on a range of hierarchical organisational aspects, leading to diverse interpretations of performance and differing selections of accounting measures. This diversity, however, is often unacknowledged by accounting researchers, where reliance on prior literature or direct adoption of FinDEA models is common. The hierarchical framework provides a continuum of firm performance constructs used in FinDEA research and highlights considerations and suggestions for future researchers and readers around model design and evaluation.

Keywords Data envelopment analysis · Accounting measures · Firm performance

1 Introduction

In recent years, a stream of Data Envelopment Analysis (DEA) research incorporating financial accounting measures exclusively, which we term FinDEA, has emerged to measure firm performance.[1] This stream of research has been stimulated by Demerjian et al. (2012), who used FinDEA to measure firm performance using large-scale financial accounting data from

[1] This paper is a tribute to the late Professor Rajiv Banker, recognizing his valuable contributions to the integration of Data Envelopment Analysis (DEA) and accounting (Anderson et al., 2023; Emrouznejad & Banker, 2010; Emrouznejad & Yang, 2018; Emrouznejad et al., 2008; Seiford, 1997).

[2] To the best of the authors' knowledge, Smith (1990) is the first study that only uses accounting measures in DEA.

[3] A two-stage model used the firm performance scores from their FinDEA model to evaluate Managerial Ability. We acknowledge the contribution of Professor Demerjian for providing the Managerial Ability scores at: https://community.bus.emory.edu/personal/PDEMERJ/Pages/Home.aspx. This data set has contributed to the development of FinDEA, especially in using accounting variables in DEA.

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annual reports.[2] As of October 2024, Demerjian et al. (2012) have been cited 2079 times, and Demerjian et al. (2013) have been cited 1481 times (Google Scholar).[3] A major advantage of FinDEA lies in its reliance on widely accessible accounting data published in corporate disclosures, ensuring the consistency and replicability of results (Demerjian et al., 2012). Furthermore, FinDEA models exhibit statistical robustness (Banker & Park, 2021; Banker et al., 2022).

These advantages of FinDEA have prompted its application across diverse areas of firm performance and accounting research published in leading journals (Banker et al., 2021; Schwab et al., 2022). At one end of the spectrum, FinDEA models have been employed to assess the overall performance of organisations, as demonstrated by Demerjian et al. (2012). At the other end of the spectrum, FinDEA has been adapted to more granular analyses, including evaluating specific production processes within originations (Seiford & Zhu, 1999).

Unlike conventional DEA, which typically uses physical measures, FinDEA uses accounting measures that inherently aggregate various quantities and unit prices. Further, the use of accounting measures aggregates multiple business activities (Banker et al., 2007; Bedford, 1968) and introduces additional factors into the DEA analysis due to accounting choices related to how accounting items are measured and how firms are grouped for analysis using industry classifications (Doumpos & Cohen, 2014; Rodríguez-Pérez et al., 2011).

Accounting measures thus enable FinDEA to capture a broad perspective of firm performance, such as financial efficiency (Demerjian et al., 2012), which transcends the technical efficiency traditionally measured by physical inputs and outputs in conventional DEA (Farrell, 1957; Shephard, 1970). However, it is worth noting that the use of aggregated accounting data might obscure the measurement of technical efficiency in conventional DEA, such as the efficiency of specific production lines. Furthermore, the nature of accounting measures requires consideration of possible issues in FinDEA results.

The broad scope of FinDEA applications highlights potential distortions in performance evaluation due to inherent differences between accounting and physical measures. Specifically, challenges arise from the distinctive characteristics of accounting variables, such as variations in prices, aggregation of prices and activities, accounting choices, and diverse industry classifications (Begen et al., 2023; Camanho et al., 2023; Färe & Grosskopf, 1985; Fukuyama & Weber, 2004; Portela, 2014; Rodríguez-Pérez et al., 2011). These factors exacerbate methodological considerations existing in conventional DEA, highlighting the importance of guidance in understanding FinDEA research to avoid or reduce biased performance evaluations (Banker et al., 2021; Bowlin, 1999; Demerjian, 2018; Demerjian et al., 2012; Harrison & Rouse, 2016; Smith, 1990).

These unique features of FinDEA motivated us to investigate the use of FinDEA in empirical research and theorise a framework to help organise the associated considerations. Our study examines two primary research questions:

1. What types of FinDEA models are used in research? This question explores the variety of ways firm performance is conceptualised within FinDEA studies, examining the breadth of accounting measures used to operationalise these performance constructs.
2. What methodological considerations does this diversity within FinDEA introduce? Here, we investigate both the challenges in conventional DEA that may be intensified within FinDEA and the unique considerations that arise due to the nature of accounting measures and the approaches commonly adopted in accounting research.

Our study analysed 322 FinDEA models from 280 published studies,[4] with selection criteria designed to capture the diversity of models in leading journals. The analysis provides

[4] A full list of which can be found in the supplementary material (S1).

a comprehensive overview of FinDEA applications across various research contexts. From the analysis, we developed a Hierarchical Framework to categorise the constructs of firm performance captured by FinDEA models, detailing performance at different organisational levels—production, operational, and firm levels. This framework reveals key differences in scope, the complexity of performance constructs, and the selection of accounting variables, all of which highlight challenges in identifying relevant methodological considerations across diverse FinDEA models.

This paper contributes to the literature in three ways. First, it offers a state-of-the-art overview of FinDEA models, with a focus on the diversity of models that incorporate various accounting inputs and outputs across multiple research settings (Demerjian & Lev, 2022; Demerjian et al., 2022; Wagner & Shimshak, 2007). By categorising these models according to different constructs of firm performance, we lay the groundwork for a Hierarchical Framework that aids in understanding FinDEA applications across organisational levels.

Second, we identify a range of methodological considerations that arise within FinDEA. These include both challenges inherent in traditional DEA that are accentuated within FinDEA and those specific to accounting data and approaches typical in accounting research. Unlike purely statistical examinations of FinDEA (Banker & Park, 2021; Banker et al., 2022), we outline the unique considerations encountered during the design of FinDEA research, introducing a perspective that integrates a continuum of organisational levels in the context of business.

Third, we provide some suggestions for each methodological consideration to aid researchers and readers of FinDEA in both the design and evaluation of FinDEA models. In this respect, we contextualise critical issues in FinDEA research design, some of which align with prior methodological recommendations for conventional DEA (Banker & Natarajan, 2008; Boussofiane et al., 1991; Dyson et al., 2001; Golany & Roll, 1989; Olesen & Petersen, 2016). For FinDEA researchers, this emphasises the diverse range of constructs of firm performance and accounting measures within FinDEA, examining how the use of accounting information across this broad scope introduces challenges in its application. It also encourages researchers to consider the limitations inherent in FinDEA. For FinDEA readers, the guidance offers a structured way to understand FinDEA's breadth, viewing firm performance evaluations as nested perspectives that span different organisational levels. This study helps readers synthesise FinDEA research while critically assessing its rigour.

The structure of the paper is as follows: Sect. 2 provides background on FinDEA. Section 3 details our survey of FinDEA models and the Hierarchical Framework used to organise performance constructs. Section 4 discusses the relationship between firm performance and accounting measures. Section 5 presents a guide of methodological questions and considerations for researchers and readers. Section 6 concludes.

2 Literature review

DEA assesses the relative performance of decision-making units (DMUs) using linear programming (Charnes et al., 1978, 1981) to obtain efficiency scores, comparing each DMU with a group. The most efficient DMUs (100%) constitute the efficient frontier, and inefficient DMUs can learn from peers with similar resources and goals to enhance performance (Charnes et al., 1984; Cooper et al., 2011). DEA has been widely applied to a range of industries and business scenarios, such as banking (Fukuyama et al., 2023a, 2023b), education

(Podinovski & Wan Husain, 2017; Podinovski et al., 2024), manufacturing (Li et al., 2019), government (Charnes et al., 1984), and mutual funds (Peykani et al., 2024).

In conventional DEA, when using physical quantities, technical efficiency is measured. When price information is given, allocative efficiency and overall efficiency can be calculated assuming these prices are static (Camanho et al., 2023; Kuosmanen et al., 2006; Portela & Thanassoulis, 2014; Ray et al., 2008).

FinDEA can also assess technical efficiency by using accounting measures as proxies to reflect physical quantities where inputs represent resources used to create outputs (Brown & Brignall, 2007). Alternatively, FinDEA can construct performance metrics, where accounting measures are attributes in their own right (Dutta et al., 2022), where "less-the-better" measures are inputs and "more-the-better" measures are outputs (Cook et al., 2014, page 2). However, FinDEA can raise methodological considerations (Banker & Park, 2021). The nature of accounting measures can distort performance evaluations and interpretations. This view is particularly relevant in performance measurement, discussed further in Sect. 4.

Further, the use of accounting data in FinDEA for productivity measurement presents challenges related to heterogeneity, a concern that has been acknowledged in the DEA literature. Dyson et al. (2001) highlighted that DEA relies on several homogeneity assumptions about the DMUs under evaluation. These include: (1) DMUs have access to a similar range of resources; (2) DMUs undertake comparable activities and produce similar products or services; and (3) DMUs operate within comparable environment or conditions (p. 247). Cook et al. (2013) further examined scenarios in which "the DMUs are plants within the same industry that may not all produce identical products" or instances where "a DMU has either opted not to produce a specific output or is unable to do so" (p. 666). Moreover, Chen et al. (2020) explored the issue of endogeneity arising from non-homogeneous operating environments, shedding light on its implications for DEA evaluations.

The DEA literature has proposed various methodological approaches to address heterogeneity. For instance, Banker and Natarajan (2008) explored the heterogeneity problem in DEA by employing second-stage regression techniques. More recently, Banker and Park (2021) conducted a comprehensive review of econometric methodologies, discussing their respective advantages and limitations for sample heterogeneity. Additionally, Olesen and Petersen (2016) suggested that stochastic DEA offers a robust framework for incorporating multiple variables to address sample heterogeneity, thereby enhancing the reliability of efficiency assessments.

Table 1 provides three illustrative examples of potential methodological challenges associated with the application of accounting variables in DEA. The examples progress from the production level (Panel A) to the operational level (Panel B) and finally to the firm level (Panel C). As FinDEA represents a stream of DEA, its formulation is inherently derived from conventional DEA. However, the distinctive nature of accounting measures can amplify some methodological complexities inherent in conventional DEA when accounting measures are used in FinDEA.

At the production level (Table 1, Panel A), one of the distinguishable features of FinDEA is that accounting measures aggregate various unit prices or costs and quantities. Specifically, an accounting measure for an item i is $p_i \times q_i$ where q denotes quantity and p is the unit price or cost. If there are n different items of materials, then the accounting measure of material is $\sum_{i=1}^{n} p_i q_i$. It is important to note that accounting measures can vary in both unit costs and quantities.

In Table 1, Panel A, the total material cost is $4250, which comprises three types of physical measures: 100 kg of metal costing $10 per kilogram; 50 L of fuel costing $5 per litre; and 150 m of cables costing $20 per metre. At this level, most accounting measures

Table 1 Simple example

Panel A Production Level (e.g. unit cost variation) for Production Line A

Materials	Unit Cost	Quantity	Unit	
Metal	$10	100	kilogram	$ 1000
Fuel	$ 5	50	litre	$ 250
Cable	$ 20	150	metre	$ 3000
Materials				**$ 4250**

Panel B Operational Level (e.g. aggregation of production lines) Production Department

	Materials	Depreciation	Employee Wages and Salaries	
Production Line A	$ 4250	$ 200	$ 1000	$ 5450
Production Line B	$ 2000	$ 500	$ 2000	$ 4500
Production Line C	$ 1000	$ 100	$ 3000	$ 4100
Operating Expenses				**$ 14,050**

Panel C Firm Level (e.g. holistic view at the firm level)

	Operating Expenses	Other Non-operating Expenses	Intangible Expenses	
Production Department	$ 14,050	$ 15,000	$ 3000	$ 32,050
Sales Department	$ 20,000	$ 10,000	$ 5000	$ 35,000
IT Department	$ 15,000	$ 5000	$ 9000	$ 29,000
Total Expenses				**$ 96,050**

are heterogeneous because they combine different quantities (often in different units) with different unit costs. For example, multiplying physical quantities such as metal, fuel, and cable by their respective unit costs highlights this heterogeneity.

Aggregation is also an issue in conventional DEA if quantities are calculated using differing units of measurement (e.g., the number of hamburgers and litres of milkshakes) or when the quality of inputs varies (e.g., senior versus junior full-time equivalent employees).The heterogeneity of accounting measures is not always so obvious at the production level owing to the inherent nature of accounting when aggregating physical units through costs.

At the operational level (Table 1, Panel B), the aggregation of multiple production lines conceals their distinct formulation. For example, Production Line A is material-intensive, incurring the highest material expense of $4250 among the three lines. In contrast, Production Line B demonstrates a capital-intensive nature, as reflected by its significant depreciation expense, the highest at $500. Meanwhile, Production Line C is labour-intensive, with employee salaries amounting to $3000, the highest labour cost across the production lines.

Despite these differences, the aggregation inherent in accounting variables, such as operating expenses, consolidates these distinct formulation into a single total value of $14,050 in operating expenses. This aggregation, however, conceals the specific intensity of production factors and the unique operational features of each production line. Consequently, the nuanced differences between the production lines are not explicitly represented in FinDEA when relying on aggregated operating expenses.

A notable limitation of accounting data derived from annual reports is its inability to accurately capture specific production elements. This limitation has been acknowledged in prior FinDEA studies. For instance, Demerjian and Lev (2019, p. 9) observed that "some valuable economic resources are not reported in the financial accounting system." Similarly, the aggregation inherent in operating expenses has been recognised by accounting standard boards. The IFRS (International Accounting Standards Board, 2022, p1) proposal to expand the explanation of expenses emphasises the need to "clarify how this involves allocating and aggregating operating expenses according to the activity to which the consumed economic resource relates."

In the context of FinDEA, where accounting measures are inherently aggregated, this limitation becomes more pronounced. The aggregation of accounting data may obscure the details of specific production processes, thereby reducing the precision of assessments when measuring the underlying production processes (Podinovski & Thanassoulis, 2007; Smith, 1990).

At the firm level, accounting variables are used for firm performance metrics, emphasising an overall perspective of the firm rather than the granular details of daily operations or tangible physical productivity. FinDEA models often employ financial resources as inputs and financial results as outputs (Demerjian et al., 2012, 2013), encompassing both operational and supporting departments to assess the firm performance holistically. A key example is the use of intangible assets in FinDEA, which, as defined by International Accounting Standard 38, are "identifiable non-monetary assets without physical substance" (International Accounting Standard Board, 2024).

In Table 1, Panel C, the total expenses at the firm level comprise operating expenses, non-operating expenses, and intangible expenses. Due to the differing functionalities of departments, the allocation of these expenses varies significantly. Notably, intangible expenses exhibit considerable variation across departments. For instance, the IT Department reports the highest intangible expenses ($9000), possibly attributed to investments in software and IT systems that support the firm's overall performance. Conversely, some intangible expenses are department-specific and directly tied to operational activities. For example, the Production Department incurs lower intangible expenses ($3000), perhaps reflecting specialised licenses required for the production process. Similarly, the Sales Department records intangible expenses of $5000, possibly associated with customer relationship management systems.

A defining characteristic of FinDEA models at the firm level is the aggregation of accounting variables from both operating and supporting activities. As demonstrated in Panel C, the aggregation of operating, non-operating, and intangible expenses into a single total obscures the unique focus and contributions of each category, potentially limiting the precision of firm-level assessments.

An additional consideration arises in industry-specific performance analysis. Industry definitions need to be narrow to meet DEA's homogeneity assumption (Demerjian, 2018; Demerjian et al., 2012), or the accuracy of the performance frontier will be compromised. A key assumption in DEA is that DMUs being compared are homogeneous, sharing similar resources, technologies, and operating environments (Cook et al., 2013; Dyson et al., 2001). This assumption may not hold where industry classifications are too broad, such as some Standard Industrial Classifications (Fama & French, 1997).

Also, accounting information is subject to financial statement quality (Demerjian et al., 2012) and accounting choices related to measuring items (Rodríguez-Pérez et al., 2011).

Factors such as large quantities of intangible assets and growth opportunities due to economic circumstances can affect financial reporting's qualitative formulation (Barth et al., 2023), such as the relevance and faithful representation of the financial measures.

2.1 Survey of FinDEA models

As noted above, using accounting measures in FinDEA can raise issues around aggregation, heterogeneity, selection of measures and accounting choices. To examine these issues, we surveyed empirical FinDEA studies and the FinDEA models to investigate the types of models used, measures used, and areas researched.

3 Research method

Our content analysis employed a two-step approach. First, we searched the Google Scholar and Scopus databases, using keywords such as "Data Envelopment Analysis," "Financial Report Analysis," "Financial," and "Accounting" in various combinations to identify relevant studies. However, this initial search yielded a relatively small sample due to the nascent state of FinDEA research.

Second, we employed snowball sampling by exploring studies citing or cited by the initially identified FinDEA literature.[5] This method allowed us to build a comprehensive FinDEA model sample. However, not all papers in this sample adhered to our FinDEA definition of using only accounting variables in DEA models. To address this, we manually analysed all the DEA models to identify FinDEA models using only accounting measures as inputs and outputs. This ensured the inclusion of only articles meeting our FinDEA definition. In addition, many articles identified used the FinDEA scores taken from Demerjian et al. (2012), without additional modification to the DEA model or data. Given the repetitive nature of these FinDEA models, we excluded them from our sample.

To enhance research accuracy and consistency, we conducted a manual verification process cross-referencing collected FinDEA models and accounting variable classifications. In total, there were 280 studies identified, incorporating 322 FinDEA models. The quality of the FinDEA studies is relatively high, with over half (52.49%) of the models published in A or A* journals, according to the Australian Business Deans' Council (ABDC) journal list (2019).

3.1 Categorising hierarchical firm performance constructs

In this section, we examine the accounting measures used in FinDEA models and organise the constructs of firm performance across hierarchical levels. This approach highlights the aggregative nature of accounting measures, which sets them apart from the physical measures typically used in conventional DEA. Although FinDEA relies solely on accounting data from financial statements, this does not preclude its application to assessing performance at various levels, including production, operational, and firm-wide scales. As discussed in Sect. 2, FinDEA models can use accounting measures both to calculate productivity at the production level and to establish performance metrics at the overall firm level.

[5] The snowballing sampling method is a multistage method starting with an initial sample where a set of criteria is applied repetitively (Krippendorff, 2013).

3.1.1 Production level

At the production level, FinDEA models employ accounting measures to represent the fundamental elements of a single, homogeneous production process focused on producing a specific type of product or service. This data is more likely to relate to parts of a firm or firms operating with single or similar production processes. In this context, these FinDEA models align closely with conventional DEA models based on the economic production function, using physical quantities to determine technical efficiency (Farrell, 1957). We identified two primary model types at the production level in the literature: production efficiency and intermediation efficiency.

Production efficiency models (25 models) adhere to the conventional DEA definition of technical efficiency (Farrell, 1957), where accounting measures closely mirror physical production components. At this level, inputs correspond to classic production factors, as represented in models such as the Cobb–Douglas function: labour and capital are the standard elements in the underlying production framework (Felipe & Adams, 2005).

FinDEA models have employed accounting measures to reflect core production inputs. Examples include costs associated with direct labour and fixed assets, which serve as proxies for physical inputs in evaluating technical efficiency. This approach is prevalent in the banking sector, partly due to the sector's longstanding adoption of DEA and partly because the sector's resources and outputs are inherently monetary, offering a high degree of homogeneity. For instance, Sathye (2001) applied inputs like labour cost, capital value, and loanable funds to assess outputs, such as loans and deposits, noting that: "Under the production approach, a financial institution is defined as a producer of services for account holders, that is, they perform transactions on deposit accounts and process documents such as loans… or their related transactions best measures output…The inputs include the number of employees and physical capital" (p. 618).

A defining feature of production efficiency in FinDEA is the one-to-one relationship between accounting measures and core production elements. For example, labour costs typically represent the labour input (e.g., full-time employees), fixed assets often proxy capital, and transaction values reflect output. Paradi et al. (2011) define production efficiency as "how a branch produces transaction services (outputs) based on the use of capital and labour (inputs)" (p. 101). Accordingly, FinDEA models at this level are more likely to use accounting data related to parts of a firm rather than firm-level data.

Beyond the banking sector, the use of accounting measures to represent production elements like labour and capital extends to other industries. However, most of the production efficiency models identified are focused on banks, with limited research available in other industries. This likely stems from the challenges of finding firms with a single, homogeneous, well-defined production process or obtaining less aggregated accounting data that corresponds to a specific or similar production process within a firm, such as accounting data that measures the operations of a sub-unit or department.

For instance, Aparicio and Kapelko (2019) used labour and material costs, capital carrying value, and gross capital investment as inputs, with revenue as the output to evaluate the productivity of dairy manufacturing firms. Similarly, Kapelko et al. (2014) applied material and labour costs alongside fixed assets to estimate total sales with stock value adjustments in the construction sector. These studies, however, introduce relatively greater heterogeneity within the FinDEA framework, as the outputs are not strictly uniform. For instance, dairy firms may produce a range of products such as milk, yoghurt, and cheese, while the construction sector outputs may vary between commercial and residential properties. Compared to the banking sector, where transactions are uniformly monetary, in other industries, accounting measures serve as proxies for product value, with inherent variations in price and quality.

At the production level, we also identified intermediation efficiency models (35 models) in FinDEA, which conceptualise banks as financial intermediaries. In these models, inputs primarily comprise funds collected (e.g., cash balances), while outputs represent investments (Paradi et al., 2011). This model type is unique to banking, as Abdesslem et al. (2022) noted: "When using this approach, we consider banks to act as financial intermediaries between depositors and borrowers. In doing so, banks collect liabilities and use labour and capital to transform these funds into loans and other assets" (Abdesslem et al., p. 5).

In this model, monetary values directly measure the underlying physical quantities of inputs and outputs, emphasising the financial and transactional nature of the banking sector. The intermediation process is therefore measured directly through accounting measures, as banks' inputs and outputs are inherently monetary. For instance, the total value of earning assets deployed to generate loans and deposits directly measures a bank's intermediation efficiency (Berger et al., 2009).

3.1.2 Operational level

At the operational level, operational efficiency models (50 models) aggregate various production processes to deliver diverse products or services. Unlike production-level models, accounting variables here do not retain a direct one-to-one alignment with physical production elements. Instead, one accounting measure tends to encompass multiple components across different processes, thereby introducing a higher degree of heterogeneity.

In contrast to production-level models, where labour expenses are directly tied to a single production process, operational-level models incorporate aggregated operating expenses, which combine various production elements such as labour and raw materials. As a result, the aggregated operational expenses obscure the direct link between accounting metrics and specific production inputs, limiting the ability to assess performance at the level of individual production lines.

For example, Banker et al., (2002, p. 215) investigated "how the use of IT can transform the way the (accounting) firm utilises the rest of the resources for output generation". Here, revenue, computed by allocating annual fees based on staff resources, serves as the output measure. Inputs include professional labour costs, covering salaries for different levels of accounting professionals within each office, and operating costs, encompassing all other operating expenses such as rent, utilities, travel, and administrative staff costs.

Furthermore, in our literature survey, four studies employed sales adjusted for inventory as a proxy for output. However, prior literature has suggested a more accurate measure of production volume would be the cost of goods sold adjusted for inventory changes (Harrison & Rouse, 2016). This measure offers two main advantages: first, it is unaffected by pricing margins that influence sales figures, and second, it accounts for the fact that not all units sold are produced within the same accounting period.

3.1.3 Firm level

At the firm level, FinDEA used accounting measures as attributes to construct metrics of overall firm performance. A notable characteristic of FinDEA models at this level is their versatility, as they are less constrained by industry specificity compared to models used at the production or operational levels. While FinDEA studies at the lower levels often concentrate on one or a few closely related industries, firm-level FinDEA models are applicable across a diverse range of sectors. For example, these models have been used across the Fama–French 48 industry classifications, which include sectors such as business services, energy, technology, retail, pharmaceuticals, and wholesale (Demerjian, 2018).

FinDEA models here typically use financial resources as inputs and financial outcomes as outputs. The entire firm is treated as a DMU, following the framework established by Demerjian et al., (2012, 2013). Inputs in this context encompass a combination of assets and expenses, including cost of goods sold; selling, general, and administrative expenses; net property, plant, and equipment; operating lease; research and development; goodwill; and other intangibles. The primary output measured is sales.

According to accounting definitions, assets and expenses are inherently distinct. Assets are "a present economic resource controlled by the entity as a result of past events, with the potential to produce economic benefits" (International Accounting Standards Board, 2018, paragraph 4.2). In contrast, expenses are defined as "decreases in assets, or increases in liabilities, that result in decreases in equity, excluding those related to equity distributions" (Conceptual Framework, 2018, paragraph 4.2). Assets are considered a stock measure, capturing value at a particular point in time, while expenses, such as depreciation, are flow form measures asset used over a specified period.

Our review of the literature reveals two subcategories within FinDEA models at the firm level: financial efficiency (156 models) and profitability efficiency (28 models). The primary distinction between these categories lies in the inclusion of profit as an output in the latter. Profitability efficiency models incorporate profit as a measure, whereas financial efficiency models do not.

One theoretical justification for including profit as an output is its role as a qualitative measure of revenue (Harrison & Rouse, 2016). When profit is included alongside revenue, the model aligns closely with financial efficiency. However, as profit represents the difference between revenue and costs, it serves as a reflection of cost control and management efficiency. Bowlin (1999) emphasised the importance of profit as an essential measure, describing it as "a product of the financial production process and widely considered a key indicator of a business entity's financial condition" (p. 294). Furthermore, Bowlin (2004, p. 695) highlighted the comprehensive nature of profit, noting that it "includes items omitted from operating income, such as unusual, infrequent, or extraordinary items, making it a more comprehensive measure of profitability". Another stream of literature employs profit as an output through the DuPont Ratio framework. For instance, Feroz (2003) noted that their analysis "disaggregates Return on Equity (ROE) using the DuPont model," wherein "sales, total assets, and common equity can be minimised as inputs, and net income can be maximised as an output."

3.2 Relationship between firm performance and accounting measures

We classify the accounting variables used in FinDEA models and organise the constructs of firm performance within a three-level Hierarchical Framework, capturing the aggregation across the organisational structure (Fig. 1 and Table 2). Although much of the FinDEA literature uses accounting variables from financial reports, this does not preclude the application of FinDEA models to assess performance at production and operational levels using less aggregated accounting measures.

Overall, Fig. 1 illustrates that FinDEA models can evaluate performance across three organisational levels within a firm, prompting consideration of whether the use of accounting measures renders FinDEA results less transparent for a production process. This potential

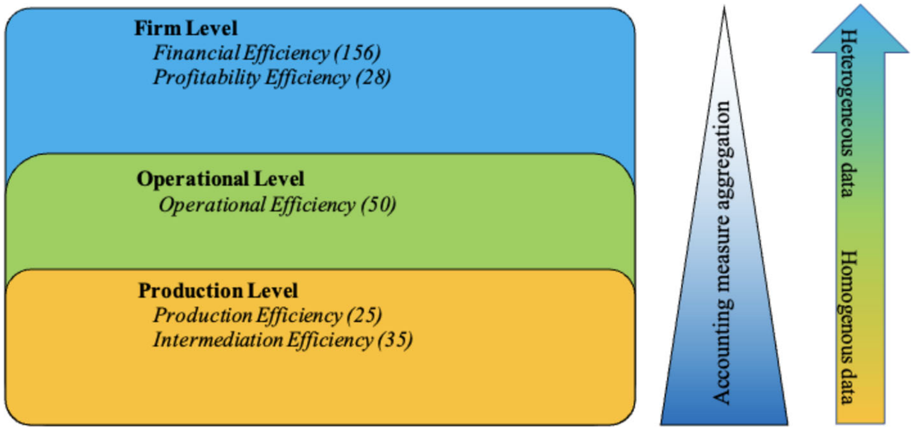

Fig. 1 Hierarchical framework

opacity arises because accounting measures may obscure certain nuances of underlying physical measures when aggregating diverse business activities. Additionally, accounting measures can introduce further heterogeneity due to factors such as price fluctuations and varied accounting choices. Consequently, substituting physical measures in conventional DEA with accounting measures in FinDEA may risk introducing bias by intensifying methodological challenges inherent in conventional DEA models.

As the focus shifts from the production level through to the firm level, the assessment of firm performance expands from the technical efficiency of specific production processes to a more comprehensive, holistic evaluation of overall firm performance. Accordingly, in Fig. 1, as accounting data is progressively aggregated from the production level up to the firm level, increased heterogeneity arises from the integration of multiple production processes and business activities. Also, the relationship between the construct of firm performance and accounting measures evolves as one moves from the production level, passing through the operational level to the firm level. This shift represents a transition from measures that indicate underlying productivity to those that form high-level performance metrics.

3.3 Production to operational level

Starting from the production level, firm performance constructs (such as production efficiency) are measured using accounting variables that reflect the physical production process, aligning with the principles of conventional DEA models. For instance, accounting measures that reflect core physical inputs, such as material costs, labour costs, and fixed asset costs, can reflect the consumption of material, labour, and capital in the production process (Al-Sharkas et al., 2008). In some cases, accounting variables provide a direct measurement of the production process, particularly in the banking sector, where inputs and outputs are monetary. For example, within the intermediation process of banks, funds are transferred between savers and investors, directly capturing this financial flow (Paradi et al., 2011).

When gradually moving from the production level to the operational level, a defining feature is that, in contrast to the production level, the one-to-one relationship between accounting measures and production elements becomes less distinct due to the aggregation of multiple production processes.

Table 2 Typical Inputs and Outputs in FinDEA Models

Level	Construct of Firm Performance	Typical Input	Typical Output	Industry	Literature Examples
Production	Production efficiency (25 models)	Separate accounting measures of physical inputs related to a single production process e.g., material cost, labour cost, fixed assets	Accounting measures of the physical outputs related to a single production process e.g., total sales plus the change in the value of the stock	Industries with a single manufacturing process e.g. banks, dairy manufacturing, construction	Sathye (2001) Paradi et al. (2011) Kapelko et al. (2014) Aparicio and Kapelko (2019)
Production	Intermediation efficiency (35 models)	Financial institution: accounting measures of funds collected e.g., cash balances, accruals, other liabilities, net non-performing loans, loan loss experience	Financial institution: accounting measures of investments e.g. wealth management, homeowner mortgages, consumer lending, commercial loans, commercial deposits Consumer deposits	Financial institutions only e.g. banks	Berger et al. (2009) Paradi et al. (2011) Abdesslem et al. (2022)
Operational	Operational efficiency (50 models)	Aggregated accounting measure of inputs for combined production processes e.g., operating expenses	Accounting measure of outputs for combined production processes e.g., cost of goods sold or sales adjusted for any change in inventory	Industries where firms have multiple production processes e.g. electric utility industry, fruit and vegetable sector	Delmas et al. (2007) Guzman & Arcas (2008)

Table 2 (continued)

Level	Construct of Firm Performance	Typical Input	Typical Output	Industry	Literature Examples
Firm	Financial efficiency (156 models)	Accounting measure of financial resources available e.g., asset values and expense values(Such as the cost of goods sold, selling and administrative expenses, net property plant and equipment, net operating leases, net research and development, purchased goodwill, and other intangible assets, used by Demerjian et al., (2012, 2013).)	Accounting measure of total firm output e.g., Total sales, total revenue	All industries	Demerjian et al. (2012) Demerjian et al. (2013)
Firm	Profitability efficiency (28 models)	Accounting measure of total firm fixed and operating expenses e.g., assets; property plant and equipment; liabilities; equity	Accounting measure of total firm profits e.g., operating profit, net profit before tax, net profit after tax	All industries	Manandhar and Tang (2002) Feroz et al. (2003) Bowlin (2004) Düzakin and Düzakin (2007) Kao and Hwang (2008)

Operating cost exemplifies the shift towards the operational level as illustrated by Banker et al. (2002), where operating expenses combine activities across various business lines. The International Financial Reporting Standards (IFRS) also address the level of detail for operating expenses, stating: "The principles of aggregation and disaggregation…allow for aggregation of functions, but only insofar as such aggregation provides a clear and understandable view of the entity's operating expenses" (International Financial Reporting Standard, 2021, p. 2).

As highlighted in Fig. 1, the transition along the hierarchy from the production level to the operational level is a continuum, representing relative and gradual shifts rather than a clear-cut, binary division. For instance, production efficiency is typically applied in single industries where a manufacturing process produces uniform products or services or to parts of a firm representing a single or similar production processes.

Additionally, in the transition from the production level to the operational level, firms occupy different relative positions based on their organisational formulation. For example, due to inherent differences between financial and non-financial sectors, they are located at different relative positions along the spectrum. The financial sector, particularly banks, tends to align more closely with the homogeneous end of the production level. This is largely due to the nature of financial industries, where most production elements are monetary. In these contexts, accounting measures serve as a direct measure of outputs, such as the value of transactions, thereby maintaining homogeneity since outputs are expressed in monetary terms.

In contrast, in non-financial sectors, accounting measures are proxies for physical outputs and often introduce heterogeneity when combining diverse products and services. Therefore, other industries are positioned further from the homogeneous end of the spectrum. This is because their output products are more diverse, and the aggregation of multiple products using accounting measures can introduce heterogeneity owing to factors such as price variation. For instance, Kapelko's (2019) study is carried out individually for meat manufacturing, fruit and vegetable manufacturing, dairy manufacturing, and bakery manufacturing. However, each of these sectors still encompasses a variety of distinct food products. (Table 2).

3.4 Operational to firm level

Moving from the operational level to the firm level, incremental aggregation continues to occur. A defining characteristic is that the inputs start including expenses and assets as financial resources when they get closer to the firm level. This combination further weakens the link to the underlying physical production process, as expenses relate to a single financial year, while assets, particularly fixed assets, are held over multiple years. The mixture of one-year expenses and multi-year assets complicates the relationship with revenue, which is generated within a single financial year. Consequently, financial efficiency models benchmark firm performance by maximising output (revenues) while minimising financial resources, encompassing expenses and assets, thereby combining flow and stock accounting measures.

When moving closer to the firm level, constructs of firm performance (e.g., financial efficiency) are measured through performance metrics formed by specific attributes of accounting variables. Here, firm performance is defined and structured by these accounting variables. Unlike at the production level, accounting variables do not directly correspond to production elements; instead, FinDEA models assess the holistic performance of the firm rather than individual operational processes.

For example, to evaluate financial performance across Fama and French 48 industries (Demerjian et al., 2012, 2013; Fama & French, 1997) used inputs such as cost of goods sold (COGS), selling, general, and administrative expenses (SG&A), net property, plant, and equipment (NPPE), operating leases, net research and development (Net R&D), goodwill, and other intangibles, with sales revenue serving as the output. Demerjian et al., (2012, p. 1229) interpret their FinDEA outcomes as measures of managerial efficiency, defined as the effectiveness in "transforming corporate resources into revenues."

However, as FinDEA models progress from the operational to the firm level, they begin to incorporate non-operational accounting variables, where the relevance of physical elements diminishes, and the tangible basis of resources becomes less distinct. For example, goodwill, research and development costs, and intangible assets are not directly tied to day-to-day operations. Specifically, firms' annual sales are not directly connected to research and development activities, as these non-current intangible assets are often held over multiple years, complicating the straightforward alignment of inputs and outputs typical in physical production processes. Rather, these accounting measures provide a broader overview of the firm as a whole, contributing to forming firm-level performance metrics.

In summary, the FinDEA models in our survey span a continuum from a physical production process to a broad view of firm performance. As the hierarchy ascends, accounting data supports incremental aggregation, allowing "the development of a value measure as an aggregation of a set of quantity measures" (Bedford, 1968, p. 277). However, this aggregation also introduces heterogeneity into FinDEA through accounting variables as models shift from production to firm level, intensifying the methodological challenges inherent in conventional DEA. It is suggested that when working with highly aggregated accounting variables at the firm level, interpreting FinDEA results requires a shift in focus from productivity measurement to benchmarking firm performance through optimising economic outcomes (such as revenue) while minimising economic resources (such as expenses and/or assets).

4 Methodological considerations for researchers and readers

Our literature survey and analysis have identified several methodological challenges in FinDEA, which may be further complicated when using large-scale data from annual financial report databases. We discuss below consideration [1] pertaining to the overall structuring within the Hierarchical Framework, focusing on determining the appropriate level for applying FinDEA models. Considerations [2] and [3] relating to FinDEA models are positioned closer to the production level, where accounting measures are more likely to reflect production elements within underlying processes directly. Considerations [4] and [5] pertaining to FinDEA models situated nearer to the firm level, where accounting measures are attributes forming holistic performance metrics.

4.1 [1]: Structure of the hierarchical framework

As outlined in Sect. 4, the Hierarchical Framework (Fig. 1) comprises three levels that structure a continuum of firm performance constructs as measured by FinDEA models. It is important to recognise that these three levels represent key points along a spectrum rather than distinct, binary divisions. For instance, FinDEA models that use accounting measures to capture production elements like labour and capital are positioned closer to the production level and are likely to use less aggregated accounting data. A FinDEA model focusing on a single product or service is closer to the homogeneous end of the spectrum and nearer to the production level than a model that uses aggregated accounting measures to incorporate data about multiple products or services. This aggregation, often represented by a single accounting measure like sales revenue, can introduce heterogeneity.

In this context, the financial sector, such as banking, typically exhibits less heterogeneity due to its intrinsic nature, where most products and services are monetary. Conversely, industries dealing with physical products may introduce more heterogeneity when aggregating outputs into sales revenue. For example, unit price variations, driven by supply and demand changes or differing quality, can be reflected within aggregated accounting measures. Consequently, researchers aiming to examine specific production processes may benefit from collecting accounting measures at the production process level that separately capture individual production elements and, where possible, differentiate sales across distinct products.

Furthermore, as FinDEA models approach the firm level, accounting variables transition from representing specific operational elements to providing a holistic view of overall firm performance. At this level, accounting variables serve as attributes related to not only immediate operational efficiency but also broader organisational factors, including strategic and long-term considerations.

In this context, accounting measures not directly tied to daily operations, such as intangible assets and research and development (R&D) expenses, may be incorporated into FinDEA models. These variables capture elements of a firm's long-term value and strategic focus, contributing to an understanding of overall performance that extends beyond operational outputs. For example, intangible assets, such as brand value, patents, and other resources can enhance a firm's competitive position over time, while R&D expenses indicate investment in future growth and innovation. Therefore, researchers aiming for a comprehensive analysis at the firm level might consider including these broader accounting measures to capture the full scope of firm performance. This approach allows for the assessment of both operational efficiency and overall performance, enabling a more comprehensive view of performance that integrates both operational outcomes and strategic positioning.

4.2 [2]: Aggregation of prices[6]

At the production level, accounting measures often maintain a one-to-one relationship with the production elements within the underlying production process. A primary distinction between accounting and physical measures is the impact of unit price variability. Such price fluctuations can arise from market dynamics, including supply and demand conditions or strategic pricing decisions. For instance, seasonal price changes are common in industries like agriculture (Sørensen, 2002) and hospitality (Alrawabdeh, 2022). However, these fluctuating prices for identical production elements are often aggregated into accounting measures, introducing a new layer of heterogeneity within FinDEA models and amplifying the inherent variability of accounting data.

Aggregating varied unit prices within annual accounting variables can introduce bias when calculating technical efficiency. In the absence of individual unit prices or stable pricing, using FinDEA to assess technical efficiency becomes challenging (Camanho et al., 2023). For example, in less competitive industries where prices vary significantly, firms may encounter price distortions that complicate the accurate measurement of technical efficiency. This contrasts with markets exhibiting perfect competition, where unit price stability reduces such distortions, allowing for a clearer assessment of production efficiency.

[6] Prices can be selling prices or cost prices.

This perspective contrasts with the cost and revenue models in conventional DEA, where price information is assumed to be known and uniform across all firms, aligning with the assumption of perfect market competition and DMUs acting as price takers (Camanho et al., 2023). In FinDEA applications, however, empirical data are sourced from annual reports where individual prices are not disclosed. Without an analysis of the industry structure, these price variations remain unobserved. The results may be skewed if FinDEA researchers assume price uniformity without considering industry-specific conditions.

For example, using rent as a proxy for occupancy space highlights this issue. As Sherman & Gold (1985, p. 305) noted, "[t]here may be some difficulty with using rent in the analysis. Rent will vary due to the desirability of locations." Differences in location desirability can lead to substantial rent variations for similar occupancy spaces, which, when used as input measures, yield different efficiency scores than physical measures like square metres. Thus, overlooking these industry-specific price variations can introduce significant bias, particularly when relying on aggregated financial data without adjustment for market conditions.

Researchers and readers are advised to consider price variations to ensure that FinDEA models accurately capture performance, particularly when technical efficiency is sensitive to changing market conditions (Camanho & Dyson, 2008; Cui et al., 2024; Färe & Grosskopf, 2006; Tone, 2002). Ignoring these variations can result in biased outcomes, as market price fluctuations may distort the relationship between inputs and outputs, obscuring a true representation of efficiency (Portela, 2014; Portela & Thanassoulis, 2014). Future research could investigate the impact of price fluctuations on FinDEA outcomes. It would be beneficial for FinDEA users to examine key factors influencing unit price variation, including shifts in supply and demand dynamics and differing pricing strategies across firms (Camanho et al., 2024). For instance, in industries where demand is highly seasonal, understanding how these fluctuations affect the cost structure could provide insight into the conditions under which FinDEA models perform most reliably. Additionally, researchers might consider segmenting data by industry characteristics, accounting for specific market structures or geographic factors that lead to price diversity (Ray et al., 2008). By incorporating these considerations, FinDEA users can enhance the robustness of their models, better capturing the nuanced economic realities that influence firm performance across varying market contexts.

4.3 [3]: Aggregation of production processes and business activities

The majority of FinDEA studies rely on accounting measures from annual financial reports, which aggregate multiple production processes and business activities. Some FinDEA research uses datasets structured around established accounting classifications, such as the Fama & French 48 industry groups (Fama & French, 1997) and the Standard Industrial Classification (SIC) codes issued by the US government (Demerjian et al., 2012, 2013). These groupings are not specifically designed for DEA applications and do not consider the compatibility of production processes or technologies across firms. This limitation applies also in conventional DEA, but can become more pronounced in FinDEA due to the nature of accounting measures, which appear consistent but vary significantly between industries.

The availability of extensive accounting data from electronic databases enables large-scale panel data analysis at the firm level, allowing FinDEA models to consider both cross-sectional and longitudinal comparisons. While this offers a powerful means of examining firm performance over time, it also introduces challenges related to the assumption of production process homogeneity. It is a straightforward requirement in conventional DEA but more challenging to fulfil in FinDEA due to the aggregated nature of accounting data.

For example, in cross-sectional studies, industry groupings such as SIC codes do not necessarily account for the compatibility of production processes, business activities, or technologies. Demerjian et al., (2012, p. 1235) noted: "We rely on imperfect industry groupings. We estimate …by industry according to Fama and French (1997), but most firms operate in several industries, and even within industries the relation between the accounting inputs and outputs can vary substantially depending on firms' asset and operations mix…they do introduce the potential for confounding effects on the efficiency score and, thus, the inferences of the study". Similarly, in longitudinal studies, researchers frequently pool firm-year data over long periods, without adjusting for technological advancements, which can lead to distorted results. Consequently, efficiency scores derived from such data may not accurately represent technical efficiency.

Future FinDEA studies could consider the heterogeneity introduced when combining varied production processes and business activities (Chen et al., 2020; Cook et al., 2013; Demerjian et al., 2012). Dividing large industries into more specific subgroups based on similar business processes or final products could improve the precision of DEA applications (Cao et al., 2022; Dyson et al., 2001). Future FinDEA research could refine dataset selection criteria by focusing on categorisations that reflect similarities in production processes or technology use rather than relying solely on broad industry classifications. For example, in the retail sector, refining categorisation by product types, such as food retail, apparel retail, home furnishings, or electronics, would allow a more nuanced analysis by capturing the distinct production dynamics within each subgroup, which aligns more closely with DEA's focus on technical efficiency. Researchers might also consider using a mixed-method approach that combines FinDEA with qualitative analysis to assess industry-specific factors influencing production processes. For instance, identifying critical production technologies or resource dependencies unique to certain subgroups could further ensure that DEA models measure real-world performance accurately.

4.4 [4]: Accounting measures – attributes of performance metrics

The construction of performance metrics can reduce measurement accuracy due to the selection of accounting variables. When accounting variables do not adequately represent the intended domain of the construct, the metrics can undermine the construct's validity.

Various FinDEA models measure financial performance metrics, such as Demerjian et al. (2012), who used cost of goods sold, selling and administrative expenses, net property plant and equipment, net operating leases, net research and development, purchased goodwill, and other intangible assets as inputs, while the sales revenue as the output. In comparison, Feroz et al. (2003), who also intended to measure the financial performance, incorporated "equity" as an additional input, while Baik et al. (2013) created a "parsimonious model" version of Demerjian et al. (2012) with only three inputs (cost of goods sold, selling and administrative expenses, net property plant and equipment). Since these three studies defined financial efficiency metrics with different models, these constructs of financial efficiency form distinct domains expected to deliver different measures of firm performance.

Consideration of how different combinations of accounting measures yield varied performance metrics is required when constructing FinDEA models. We suggest ensuring that accounting measures comprehensively cover the intended domain of the performance construct for more accurate and meaningful benchmarking. We also suggest that researchers explore how different combinations of accounting measures meet different research goals.

Ensuring that the selected accounting measures comprehensively represent the intended domain of performance will enhance the accuracy of the benchmark results.

4.5 [5]: Alternative accounting variables in performance metrics

Where accounting variables represent attributes used to form performance metrics, alternative accounting variables (or alternative forms of accounting variables) can change the domain of the constructs. For example, Joo et al. (2011) differentiated stock and flow forms of variables for fixed assets. Stock form accounting variables represent the value at a specific point in time (as detailed in the balance sheet) and include variables such as gross property plant and equipment (GPPE)[7] and net property plant and equipment (NPPE).[8] On the other hand, flow form accounting variables represent the value over a specific unit of time (e.g., a financial year) and involve variables such as depreciation[9] (as detailed in the income statement). It is likely that the selection of these alternative forms of accounting measures will affect the FinDEA performance measurement and should be considered in the construction of models for particular research goals (Cui et al., 2025). Prior FinDEA literature has noted the potential impact of accounting choices on the results (Doumpos & Cohen, 2014; Rodríguez-Pérez et al., 2011). Future FinDEA applications could investigate the impact of substituting alternative accounting variables, for example, replacing assets for expenses, and explore the potential impact on performance metrics.

Additionally, while general-purpose FinDEA models enable cross-sectional comparisons, investigating industry-specific performance (Banker & Park, 2021; Fukuyama et al., 2023a, 2023b), industry-specific models that are tailored for differences in production processes would enhance precision by including or excluding industry-specific variables (Dyson et al., 2001). For instance, including fixed assets would be suitable for capital-intensive industries but not labour-intensive ones.

5 Conclusion

The widespread availability of accounting measures from annual financial reports has driven a significant increase in DEA models using large-scale accounting data, which is named FinDEA in this study. This paper responds to the growing popularity of FinDEA as a tool for measuring firm performance, providing some thoughts and guidance for both future FinDEA research and readers engaging with this literature.

To address the first research question, *"What types of FinDEA models are used in research?"*, we introduce a Hierarchical Framework, which delineates five key constructs: production efficiency, intermediation efficiency, operational efficiency, financial efficiency, and profitability efficiency. They are organised across three structural levels of the firm.

Production level: This level aligns closely with the foundational principles of conventional DEA, as accounting measures reflect elements tied directly to physical production processes.

[7] GPPE is defined by the IAS, paragraph 6 as "the amount of cash or cash equivalents paid, or the fair value of the other consideration given to acquire an asset at the time of its acquisition or construction" (IASB, 2020).

[8] NPPE is defined by the IAS paragraph 6 as "the amount that an asset is recognized after deducting any accumulated depreciation and accumulated impairment losses" (IASB, 2020).

[9] Depreciation is defined by the International Accounting Standard (IAS) 16, paragraph 6 as "the systematic allocation of the depreciable amount of an asset over its useful life." (IASB, 2020).

Operational level: This level aggregates multiple production processes, capturing a broader view of operational activities.
Firm level: At this level, FinDEA offers a holistic, firm-wide perspective, using accounting variables to construct comprehensive performance metrics that capture the overall performance of the firm.

To address the second research question, “What methodological considerations does this diversity within FinDEA introduce?”, we explore challenges that arise from integrating accounting measures, often present in accounting research, and can intensify conventional DEA issues. We propose five methodological considerations to enhance the reliability and validity of future FinDEA studies, suggesting areas where researchers should focus when navigating the complexities within FinDEA applications.

Our paper makes three significant contributions to the literature. First, we offer a comprehensive survey of FinDEA studies. Unlike previous reviews, which have largely focused on models based on Demerjian et al. (2012), our analysis captures the full range of FinDEA models used by researchers, delineating the current landscape of FinDEA applications.

Second, we introduce a Hierarchical Framework, categorising constructs of firm performance by organisational structure, progressing from the production level to the firm level. At the production level, accounting variables are proxies for physical elements of a production process; at the firm level, accounting variables are attributes of firm performance. This hierarchy corresponds to increasing data heterogeneity as the analysis advances from production to the firm level.

Third, we outline five methodological considerations for future FinDEA research and readers. For researchers, these highlight the range of performance constructs and accounting measures in FinDEA, examining how these introduce specific methodological challenges. It offers readers a structured approach to understanding FinDEA’s scope, viewing performance evaluations as layered across organisational levels.

Our study is based on existing FinDEA models, acknowledging that not all potential constructs of firm performance are fully represented. For instance, financial statements often lack detailed data on human resource activities, as remuneration information is typically private. Further, many FinDEA studies use firm-level data, but these models can also be applied using less aggregated accounting measures.

There are several promising avenues for future FinDEA research, particularly in methodological considerations. For example, future researchers could examine the degree of price variability and its influence on FinDEA results. Further, researchers could examine the impact of competitive intensity on different industries, as this factor may significantly impact findings. FinDEA applications could also consider the impact on performance measures from aggregating physical units across diverse production processes. Researchers could also investigate the extent to which price variability and activity aggregation cause FinDEA results to diverge from physical productivity measures.

The hierarchical continuum demonstrates how heterogeneity through aggregated activities and quantities can affect FinDEA modelling. Conversely, applying FinDEA to internal subunits within organisations that follow similar business processes, such as individual stores within a fast-food chain like McDonald’s, might reduce heterogeneity. Future research could explore how and to what extent these factors impact FinDEA outcomes.

Finally, for those using FinDEA to benchmark firm-wide performance, we recommend distinguishing whether the aim is to measure productivity specifically or to provide a broader benchmarking perspective. Different combinations of accounting measures yield varied performance metrics. For example, researchers could investigate the impact of substituting assets for expenses on performance metrics. We suggest ensuring that accounting measures comprehensively cover the intended domain of the performance construct for more accurate and meaningful benchmarking.

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