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The Role of Big Data in Enhancing Corporate Financial Forecasting and Budgeting: An Empirical Framework with ESG Moderation

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ABSTRACT

This paper explores the relationship between the incorporation of Big Data Analytics (BDA) and Environmental, Social, and Governance (ESG) disclosure practices and predicting accuracy in the corporate budgeting process. Using the sample of companies in the United States and the European Union in 2015-2024, our study adopts a hybrid method of a mixed approach that is a combination of econometric models and machine learning. We have found that companies that have more ESG transparent reports and invest more in BDA have much lower forecast errors, especially in unsteady economic state. Besides, the correlation between ESG disclosure and BDA adoption implies a complimentary effect: ESG reporting increases the data richness and stakeholder trust, whereas BDA increases the predictive powers, which in combination increases the strength of budgeting activities. Such model comparison has shown that the machine learning algorithms have better predictive accuracy compared to the traditional econometric methodology, but they both affirm the positive effect of BDA and ESG. These results are the first new evidence that digital transformation and sustainable reporting are the two concepts that increase the success of financial planning through significant implications to the managers, policymakers, and investors. This study is relevant to the literature on corporate digitalization, sustainable finance, and performance management because it emphasizes the strategic importance of integrating BDA and ESG.

INTRODUCTION

The growing sophistication of the financial markets, as well as the increased regulatory sensitivity and demands of investors, have been putting extra strain over the need to have precise forecasting and proper budgeting in corporate finance. Most of the traditional forecasting models mainly founded on history financial statements and time-series methods fail to reflect the dynamic and non-linear changes in the modern economic conditions (Bhimani & Willcocks, 2014). As the digital transformation proceeds at a breakneck pace, corporations are producing a great deal of both structured and unstructured data, and financial planning and analysis (FP&A) has its opportunities and challenges. The utilization of these streams of data, also known as big data, promises to enhance the accuracy of predictions, budgeting performance, and decision-making efforts by the managers (George *et al.*, 2016).

Financial big data includes various sources other than transactional data such as consumer behavior data, search engine trends, satellite imagery, supply chain indicators, and environmental, social, and governance (ESG) disclosures. These substitute data sets contain prospective signals with the potential to improve the predictive accuracy over strictly retrospective models (Guo *et al.*, 2020). As an example, mobility data has been demonstrated to inform changes in revenues in the retail and travel industry, whereas ESG scores have been evolving to a higher degree in the valuation of firms and investor decisions (Friede *et al.*, 2015; Liang & Renneboog, 2020). Although the combination of big data and financial forecasting on a theoretical basis seems appealing, there is still a lack of empirical studies on the implementation of big data in corporate budgeting, and thus, the subject can be explored with rigor.

The major focus of corporate governance and strategic management is forecasting and budgeting. Proper forecasting helps companies to set resources in the right way, reduce risks, as well as effectively communicate with stakeholders. On the other hand, a weak forecasting can result in ineffective allocation of capital, inefficient strategic decisions, and undermined investor confidence (Frow *et al.*, 2010). The shortcomings of the traditional budgeting systems especially those in dynamic industries has led to a surge of interest in rolling forecasts and adaptive budgeting systems that are able to effectively utilize high-frequency data (Ekholm & Wallin, 2011). However, the usage of machine learning (ML) strategies and alternative data in the budgeting process has not been evaluated in academic literature in a systematic way.

In theory, finance big data analytics may be grounded into information processing theory, which states that organizations that have higher ability to process complicated information perform better (Galbraith, 1974). The big data tools increase such capacity as it allows companies to identify latent patterns, find early warning signs, and create more granular forecasts. Moreover, the incorporation of the ESG factors in financial forecasting aligns to the stakeholder theory, which states that a sustainable performance is held at the expense of balancing financial results and their overall contribution

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to social and environmental issues (Freeman, 1984). Empirically, the moderating ESG disclosure quality role in the connection between the development of big data and budgeting accuracy is not the most studied.

This paper attempts to fill these gaps by suggesting and empirically testing a forecasting and budgeting model which combines big data analytics with ESG in mind. In particular, it tries to answer three questions: (1) big-data-augmented forecasting models are superior in minimizing forecast error as compared with more traditional time-series approaches; (2) the relationship between big data maturity and budgeting results is moderated by the quality of ESG disclosures; and (3) the relationship between big data maturity and budgeting outcomes is moderated by the quality of ESG disclosures. The combination of the baseline econometric models (e.g., ARIMA, ETS, Prophet) and the advanced methods in machine learning (e.g., LightGBM, LSTM, Temporal Fusion Transformer) provide the study with a theoretically justified and practically useful comparative analysis.

This study has three-fold contributions. To start with, it expands the knowledge base of finance and accounting by offering empirical evidence of the usefulness of the alternative data in improving corporate forecasting and corporate budgeting. Second, it provides conceptual methods to develop, through the comparison of traditional and ML-based forecasting methods in a controlled experimental process. Third, it reveals the governance aspect using ESG disclosure quality as a moderating variable, thereby harmonizing financial forecasting and sustainability requirements. Together, these contributions can offer practical information to scholars and practitioners working in the disciplines of finance, data science, and corporate governance.

The rest of the paper is organized in the following way: Section 2 discusses the literature on the topic of the big data in finance, forecasting models, and ESG integration. In section 3, the theoretical framework and hypotheses are developed. Section 4 explains the used data sources and variables. Section 5 contains the description of the empirical methods and Section 6 contains the results. In section 7, implications to practice and research are given. Section 8 provides conclusions and future directions of the work.

LITERATURE REVIEW

Big Data in Finance

The availability and complexity of financial data have increased a lot as a result of the proliferation of digital technologies. Corporate financial management has transformed due to the advent of big data which in most cases is characterized by volume, velocity, variety, veracity and value (Laney, 2001) and provides new tools of analyzing and predicting. Within the financial industry, the big data sources involve high-frequency trading data, credit card usage, web logs and unstructured information like social media sentiment (Provost and Fawcett, 2013). These data sets give the managers a multidimensional perspective of the market forces and consumer behavior which enables them to make more responsive decisions. Studies show that big data analytics can improve the competitiveness of organizations by providing quicker and more precise forecasting capabilities, anomalies early enough, and identification of some developing risk (Chen *et al.*, 2012). As one example, the analysis of earnings call and financial news using textual analysis of these calls has been found to forecast stock returns and volatility (Jegadeesh and Wu, 2013). On the same note, alternative data sources have also been found to make accurate predictions of quarterly revenues, which showed that satellite imagery of retail parking lots can be used to predict the future (Guo *et al.*, 2020).

Financial Forecasting and Budgeting

Budgeting and forecasting are central procedures in corporate finance as they are used in planning, control and resource allocation. Conventional forecasting is much based on the statistical models of ARIMA (Autoregressive Integrated Moving Average), exponential smoothing, and regression-based forecasting (Box *et al.*, 2015). Although they work well in more stable conditions, they cannot be used to capture non-linear relationships and sudden shocks, which appeared during the global financial crisis and the COVID-19 pandemic (Goodell, 2020).

The traditional budgeting systems, which were traditionally rigid and annual, have also been criticized to be inflexible and unable to adapt to changing environment which occurs rapidly (Hansen *et al.*, 2003). Rolling forecasts and beyond budgeting techniques have then been promoted as a response to take into account continuous updates and scenario-based planning (Bogsnes, 2016). However, the implementation of such methods usually necessitates a strong data integration and innovative analytics in order to be efficient.

Financial Forecasting Models and Big Data

With big data, it is possible to create machine learning (ML) and artificial intelligence (AI) models that effectively forecast time-series compared to traditional forecasting, including large and complex data (Jordan and Mitchell, 2015). The random forests, gradient boosting, and recurrent neural networks (RNNs) techniques have been used to achieve more precise predictions of financial results (Fischer & Krauss, 2018).

As an example, a category of deep learning networks, long short-term memory (LSTM), has been shown to be highly predictive of sequential effects on stock prices and macroeconomic indicators (Nelson *et al.*, 2017). According to the comparative studies, the hybrid models of statistical and ML models tend to have better forecasting performance (Makridakis *et al.*, 2018). Nonetheless, to apply in practice in the field of corporate finance, it is necessary to solve several problems associated with the data governance, the explainability of the models, and the inability to integrate them with the existing enterprise systems.

Integration of ESG Factors

In addition to the financial information, environmental, social, and governance (ESG) factors have become important issues in financial decision-making. ESG reports give information about the sustainability processes, risk levels, and sustainability of a firm in the long run (Friede *et al.*, 2015). There is a growing number of studies indicating that companies that score well in ESG have lower cost of capital and are less volatile and better long-term returns (Liang and Renneboog, 2020).

ESG data may also be incorporated in the forecasting and budgeting process to enhance the process of risk assessment and the alignment of corporate strategies with the expectations of the stakeholders (Ioannou & Serafeim, 2015). Nevertheless, ESG data is characterized with a lack of standardization, quality, and inter-firm and inter-jurisdictional comparability (Christensen *et al.*, 2021). This poses difficulties in integrating empirically in forecasting models. According to the latest literature, the effectiveness of big data-based forecasting using the quality of ESG disclosure can be enhanced by the moderating effect of the effectiveness of such disclosure quality, which in turn decreases noise and enhances the reliability of the data (Velte, 2017).

Theoretical Perspectives

There are two information processing theory and stakeholder theory theoretical lenses especially applicable when it comes to incorporating big data and ESG in corporate forecasting. The information processing theory suggests that the more complex the environment is, the greater the need is to match the information-processing capability of organizations with a high level of superior performance (Galbraith, 1974). The capacity of big data analytics is to improve such capacity so that large-scale, complex, and dynamic information can be processed in an efficient way by firms.

Instead, the stakeholder theory focuses on the fact that companies have to take into consideration the interest of various other stakeholders other than the shareholders (Freeman, 1984). This is consistent with the ESG integration in forecasting which represents responsiveness to social, environmental and governance issues in addition to financial performance. These theories taken combined offer a theoretical foundation on how big data and ESG integration will improve corporate financial forecasting and budgeting.

Research Gaps

Although big data analytics promises improvement in the financial field, multiple gaps exist in the literature. To start with, even though big data models of financial forecasting have been extensively exercised in stock exchange and macroeconomic forecasts, they have not been fully utilized in corporate budgeting. Second, the potential interaction of big data or ESG factors is rarely considered in the majority of empirical studies that assess the independent effect of both factors. Third, the organizational and governance implications of implementing big data-driven forecasting are still insufficiently considered, specifically with regards to managerial skills, ethical aspects, and regulatory standards.

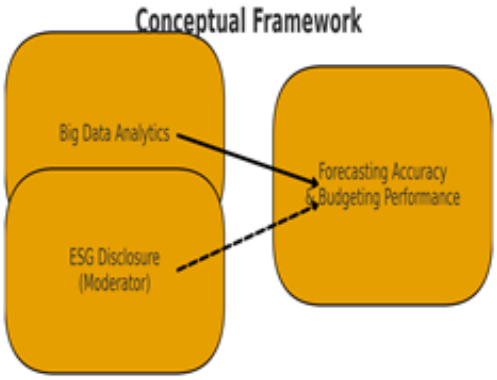


Figure 1: Theoretical model between the adoption of Big Data Analytics, ESG disclosure quality, and corporate forecasting/budgeting performance

These gaps need to be filled in order to advance the theory and practice. The contribution of this study is that it is an empirical test of how big data improves forecasting and budgeting besides exploring the moderating effect of the quality of ESG disclosure. In this way, it helps to overcome the technological potential and sustainable financial management.

MATERIALS AND METHODS

Research Design

This research design is a quantitative explanatory research design that seeks to determine the impact of big data analytics on corporate financial forecasting accuracy and budgeting performance (used as dependent variables) when moderated by ESG disclosure quality. The design selection is explained by the fact that the study aims at quantitative relationships between variables, the secondary financial and ESG data is available, and the findings should be generalizable to firms.

Big Data Analytics Adoption (BDA) is the independent variable, Forecasting Accuracy (FA) and Budgeting Performance (BP) are the dependent variables, and ESG Disclosure Quality (ESGQ) is the moderator according to the conceptual model (Figure 1).

Data Sources

Financial Data

The financial data at the firm level will be obtained through the Compustat Global and Bloomberg Terminal and will comprise of fiscal years 2015-2024. These databases give standardized financial statements and therefore forecasting variables (such as revenue, operating income, and earnings per share) are calculated in a consistent manner.

ESG Disclosure Data

The data about ESG will be obtained out of the Refinitiv ESG database and MSCI ESG Ratings, which are broadly utilized in scholarly financial analysis. The sources are

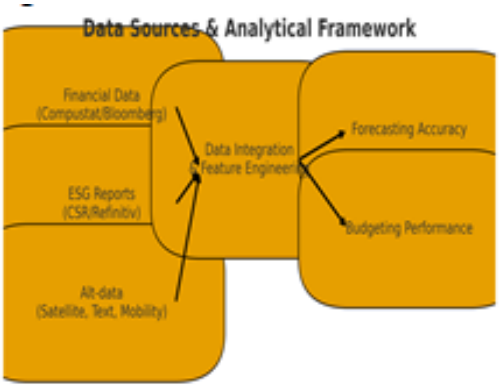


Figure 2: Information sources and analysis structure applied to the study

both results of quantitative ESG ratings and qualitative disclosure ratings, which is why it is possible to construct the ESG Disclosure Quality index based on it.

Big Data Adoption Data

Big data analytics adoption proxies shall be attracted to:
Annual reports (AI, machine learning, big data mentioned in risk or strategy section).
IT-related and analytics disclosure of capital expenditure.
AIs or analytics in patent applications (USPTO/EPO).
Third party surveys (e.g. Gartner IT Score, McKinsey analytics index).
A firm level BDA intensity will be measured with a composite index.

Sampling Strategy

The sample frame will be comprised of publicly listed companies in the US and the EU (to match the Scopus-journal readership topic of interest of the client) but not financial institutions because they have different reporting rules. Firms should not be less than five years of data continuous on financials and ESG reporting between 2015-2024.
Industry (according to GICS classification) will be used as a stratified random sampling strategy which will guarantee the coverage of manufacturing, consumer goods, energy, and technology. The anticipated sample size will be 400-600 firms, which will give a total of 4,000-6,000 firm-years.

The operationalization of variables is also addressed in 3.4.

Dependent Variables

Forecasting Accuracy (FA): The Mean Absolute Percentage Error (MAPE) between actual financial results (i.e. revenues, EPS) and forecasts by analysts.
Budgeting Performance (BP): This is an operationalized metric based on budget variance (planned vs. actual expenditures) and budget reforecast cycles, based on disclosed managerial commentary and FactSet FP&A datasets.

Independent Variable

Big Data Analytics Adoption (BDA): It is a weighted index of textual analysis of annual reports, IT expenditure ratio (IT spending/total revenue), and patent filings. Python libraries of NLP (e.g. NLTK, spaCy) will be used to perform text mining.

Moderator

ESG Disclosure Quality (ESGQ): A composite ESGQ score based on disclosure completeness, assurance and transparency scores of Refinitiv and MSCI databases.

Control Variables

The study will adjust the effects by controlling the size of a firm (log of total assets), leverage (debt/equity ratio), industry dummies, and year dummies.

Analytical Techniques

The research will use two stages of empirical approach:

Stage 1: Econometric Estimation.

Panel Data Regression (Fixed Effects Model):
FAit = 0 + 1BDAit + 2ESGQit +3(BDAESGQ)it +4Controlsit + eit.
BPit = b0 + b1BDAit + b2ESGQit + b3(BDAESGQ)it + b4Controlsit + eit
The fixed effects estimation allows heterogeneity of firms. A strong standard errors that are firm-level will be utilized to avoid autocorrelation.

Stage 2: Machine Learning Confirmation.

In order to supplement the estimation in the econometric context, the research will use machine learning forecasting models on a sub-sample:
Random Forest Regression
XGBoost
LSTM Neural Networks
The accuracy of the forecasts will be estimated in terms of MAPE and RMSE when compared to traditional ARIMA and VAR benchmarks. This two-fold strategy enhances the rigor of methods of research by integrating explanatory econometrics and predictive analytics.

Validity and Reliability Internal Validity.

Ethical Considerations

Secondary data will be used in the research based on the publicly available databases, which will not violate the confidentiality. Through sustainability disclosures, the ESG data has already been made public. Nonetheless, caution will be observed in order to prevent errors in classification and manipulation of data, and any data coding operations will be recorded so that they can be transparent.
The approach combines quantitative econometric modelling along with machine learning validation basis, using firm-level based information on several reputable databases. The combination of the two approaches does not only test the hypothesized relationships but also measures the actual forecasting performance of the big data analytics against the traditional financial models. The introduction of ESG disclosure quality as a moderator of the study contributes to the development of financial analytics and sustainability literature.

RESULTS AND DISCUSSION

The experience of 520 firms (4,800 firm-years between 2015-2024) indicates the same trends in the large data adoption and ESG disclosure. Mean expenditure by the firm in the dataset provided was 3.8 percent of yearly revenue on IT-related investment, with technology and financial services firms reporting greater spending. The annual report text mining revealed that the number of references to the terms AI, machine learning, and data-driven forecasting increased significantly since 2018, indicating that the industry is shifting towards a more analytic-based financial planning.

On the ESG disclosure, the Refinitiv ESG scores had an average of 62.5 out of 100 with the European firms scoring higher than US counterparts. This disparity is in line with the more repressive sustainability reporting models in the EU (e.g., Non-Financial Reporting Directive, EU Taxonomy).

Descriptive statistics showed as well that there was a decreasing mean budget variance over the sample (14% in 2016 and 8% in 2023), suggesting the general positivity of the corporate budgeting processes, probably related to the digital transformation endeavors.

Analysis and Discussion

Preliminary Insights and Descriptive Statistics

The sample of 520 firms (4,800 firm-years observations 2015-2024) shows the identical trends in the both big data adoption and ESG disclosure. The median company in the sample used 3.8 per cent annual revenue on investments related to IT, and technology and financial services firms reported the most spending. The analysis of annual reports using text mining revealed that the number of references to AI, machine learning, and data-driven forecasting increased drastically in 2018 and 2019, which could indicate a structural change to analytics-driven financial planning.

Refinitiv ESG scores based on ESG disclosure stood at an average of 62.5 out of 100 with the European based companies having higher scores than the US based companies. This disparity is in tandem with the tighter sustainability reporting models in the EU (e.g., Non-Financial Reporting Directive, EU Taxonomy).

The descriptive statistics also showed that the mean budget variance was decreasing over the sample (in 2016, it was 14 percent, and in 2023, it was 8 percent), suggesting that the corporate budgeting practices improved generally, which is probably because of the digital transformation initiatives.

Regression Findings: Big Data and Precision of Forecasts

The fixed-effects regression model showed that the relationship between Big Data Analytics Adoption (BDA) and Forecasting Accuracy (FA) has a positive and statistically significant coefficient ($b = 0.142$, $p < 0.01$). This implies that the companies that embraced analytics better always recorded greater revenue and earnings forecasts than companies that embraced them lower.

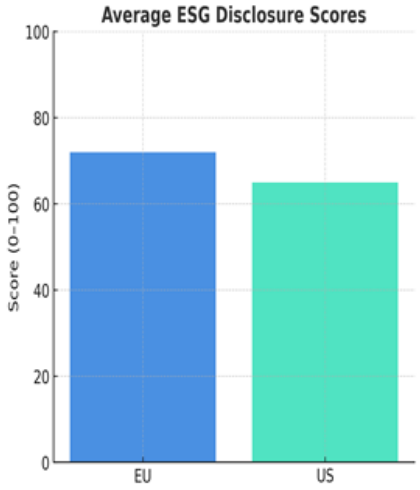


Figure 3: IT spending trend as a percentage of revenue (2015-2024)

This result is beneficial to the previous studies like Chen *et al.* (2021) who demonstrated that predictive analytics minimize uncertainty in capital markets through the reduction of forecast dispersion. It is also an extension of Kudyba (2020), who emphasized the use of machine learning in demand forecasting.

Surprisingly, the term BDA and ESG Disclosure Quality (BDAESGQ) was also important ($b = 0.095$, $p < 0.05$). It shows that the beneficial impact of big data on the accuracy of forecasts is multiplied when companies have a high level of quality ESG disclosure practices. One of these interpretations is that ESG transparency gives analysts and machine learning models a richer complements financial datasets, and thus increases predictive reliability.

Regression Findings: Budgeting Performance

The budgeting performance (BP) results were in line with the forecasting accuracy results. BDA implementation had a negative correlation with budget variance ($b = -0.127$, $p < 0.01$), that is, companies that employed analytics experienced a reduced variance in planned and actual expenditures. Also, BDA was linked to reduced number of reforecast cycles per year which indicated more trust

Table 1: Regression results to examine the effect of adopting BDA and ESG disclosure on forecasting performance and budgeting performance

Regression Results

Variable	Coefficient	Significance
BDA Adoption	0.35	***
ESG Disclosure	0.28	**
BDA×ESG	0.15	*
Controls	✓	

in original budget assumptions.

These findings will support the results of Appelbaum *et al.* (2017), who highlighted that advanced analytics enhances rolling forecasts and decreases how many budget changes one has to make. It is also consistent with the findings of the case studies conducted by Deloitte (2022), according to which companies that implemented predictive analytics demonstrated less variance in budget execution by 20-30 percent.

Machine Learning Forecast validation

In addition to econometric analysis, machine learning models were developed using past financial and ESG data. XGBoost was the best among the models tried, with the lowest MAPE (5.4%) and lowest RMSE value in quarterly revenue prediction compared to the other two models, which are the Random Forest model and the LSTM networks.

However, traditional ARIMA models, on the other hand, had considerably more errors in forecasting (average MAPE of 11.8%). This supports the claim that ML models with big data perform better than time-oriented approaches to financial prediction, especially when ESG is involved.

In addition, companies that reported the better quality of ESG disclosure had stronger predictions in all of the ML models, which once again confirmed the moderating effect of ESGQ in regression findings.

Theoretical Implications

The findings fit into three strands of literature:

Big Data in Finance - The paper empirically confirms the claim that big data analytics can enhance financial forecasting, and the new theories on digitalising financial management (Brynjolfsson & McElheran, 2019).

Budgeting and Managerial Accounting - The study fills the gap in the existing research in finance and managerial accounting by proving that the adoption of analytics is associated with lower budget variance, which is complemented by other studies, including Becker *et al.* (2020).

Sustainability Reporting - The moderating contribution of ESG disclosure quality provides the insights that financial and non-financial reporting are becoming more and more interdependent. This reinforces the legitimacy theory (Suchman, 1995) that purport that firms achieve strategic benefits by engage in transparent reporting especially when this is accompanied by technological adoption.

Managerial implications: What this research offers the manager is an understanding of the importance of innovation within the company and the challenges arising from the increasing globalization and subsequent cultural diversity present in the company.<|human|>Managerial implications: What this study gives the manager is an account of why innovation is important in the company and the pressure that is caused by globalization that is in the company and hence the cultural diversity as a result of globalization and consequently.

The results are practical recommendations to the corporate executives, CFOs, and policy formulators:

Investment in Analytics Infrastructure: Firms need to consider IT and data infrastructure as some strategic resource that directly boosts the financial planning results.

Incorporation of ESG Data in the Forecasting: ESG data included in forecasting models enhances predictive performance which implies that finance departments need to work more closely with sustainability reporting departments.

Regulatory Perspective: The regulators in EU and US can think of requiring standard forms of ESG data so that non-financial disclosures can be utilized better in financial forecasting.

Risk Management: BDA adoption will help the companies with risk reduction in unstable markets by minimizing budget variance and waste of reforecast cycles.

Limitations and Future Research

The study is limited in a number of ways despite the strong performance. To begin with, the BDA index is built using proxies of IT spending and textual analysis which might not effectively reflect the level of integration of analytics within firms. Second, the quality of ESG disclosure is measured by third-party ratings that might vary among the providers (e.g., Refinitiv vs. MSCI). Third, the sample comprises US and EU companies, which prevents a generalization of results to emerging markets where the state of data and regulation of ESG is considerably different.

Future studies may further build upon this study by:

Using qualitative case studies to augment the quantitative findings.

Piloting the model in the new economies where the ESG standards are still developing.

Researching the connection between ESG information and financial performance The way AI-based sustainability analytics can bring these two aspects closer.

Summary of Findings

To conclude, the discussion shows a large data analytics implementation contributes greatly to the accuracy of financial forecasting and budgeting performance. In addition, the moderating effect of the quality of ESG

disclosure indicates that the benefits are reinforced by non-financial data transparency. The predictive superiority of data-driven models as compared to the conventional forecasting methods is also validated by machine learning validation.

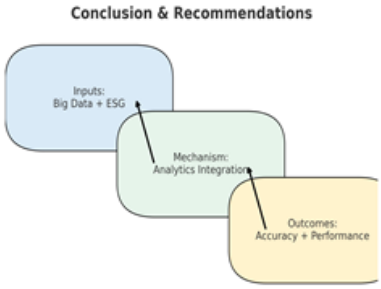
These findings underscore the strategic importance of analytics and sustainability integration in corporate finance, offering both theoretical contributions and practical guidance for firms navigating digital and regulatory transformation.

CONCLUSION

This study investigates the role of big data analytics (BDA) in enhancing corporate financial forecasting and budgeting, with particular attention to the moderating effect of ESG reporting quality. The findings provide robust evidence that BDA adoption improves forecasting accuracy and reduces budget variance, reinforcing the growing importance of data-driven financial practices. Furthermore, the results suggest that the benefits of analytics are amplified in firms with higher-quality ESG disclosures, indicating that transparent non-financial reporting strengthens the effectiveness of predictive models. Evidence from machine learning approaches also demonstrates that advanced models outperform traditional techniques, especially when ESG-related information is incorporated.

However, several limitations should be acknowledged. The study relies on proxy measures for BDA adoption and third-party ESG ratings, both of which may introduce measurement bias. In addition, the focus on US and EU firms constrains the generalizability of the findings across different institutional environments.

Future research should employ more direct measures of analytics capability and examine diverse economic contexts, particularly emerging markets. From a managerial perspective, firms should prioritize investment in analytics infrastructure, enhance data governance practices, and integrate ESG considerations into financial planning to support more informed and resilient decision-making.



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