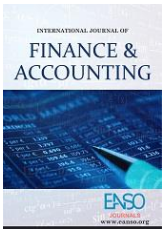
International Journal of Finance and Accounting, Volume 4, Issue 1, 2025
Article DOI: https://doi.org/10.37284/ijfa.4.1.3500



International Journal of Finance and Accounting
ijfa.eanso.org
Volume 4, Issue 1, 2025
Print ISSN: 2790-9581 | Online ISSN: 2790-959X
Title DOI: https://doi.org/10.37284/2790-959X

EAST AFRICAN NATURE & SCIENCE ORGANISATION

Original Article

Comparative Analysis of Limit Order Book Dynamics between the Nairobi Securities Exchange and Major Global Exchanges: Insights into Liquidity, Volatility, and Market Efficiency

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Article DOI: https://doi.org/10.37284/ijfa.4.1.3500

Date Published: *18 August 2025*

Keywords: *Limit Order Book (LOB), Market Microstructure, Liquidity and Volatility, Frontier Markets and Order Flow Toxicity.*

ABSTRACT

This paper presents a comprehensive, high-frequency comparative analysis of limit order book (LOB) dynamics between the Nairobi Securities Exchange (NSE) and three major global exchanges: the New York Stock Exchange (NYSE), London Stock Exchange (LSE), and Johannesburg Stock Exchange (JSE). Framed within the theoretical lens of market microstructure, the study utilises millisecond-level message data from the 2022–2023 period to evaluate critical market quality indicators, including liquidity provision, intraday volatility, order book resiliency, and informational efficiency. Drawing on a robust dataset of order submissions, executions, cancellations, and modifications, the analysis reveals that the NSE consistently underperforms across all observed dimensions. Average bid–ask spreads are considerably wider, top-of-book depth is significantly shallower, and post-shock resiliency lags substantially—often exceeding 30 seconds compared to less than five seconds on the NYSE and JSE. Furthermore, the NSE exhibits persistently high levels of order flow toxicity, as measured by the Volume-Synchronized Probability of Informed Trading (VPIN), suggesting inefficiencies in price discovery and heightened exposure to asymmetric information. These disparities are not merely technological in nature but reflect deeper institutional limitations—including the absence of high-frequency trading infrastructure, inadequate market surveillance systems, and limited regulatory incentives for liquidity provision. By comparing the NSE with more advanced and better-regulated peers, this study underscores the impact of structural design and participant sophistication on market function. The findings have strong implications for capital market reform in frontier economies. The study advocates for targeted interventions such as dynamic tick-size regimes, mandatory quoting obligations, co-location services, and real-time microstructure monitoring. These reforms, if carefully implemented, could significantly enhance the NSE's depth, transparency, and resilience. This research contributes original empirical evidence to the evolving discourse on market quality in developing financial systems. It offers both academic and policy-

Article DOI: https://doi.org/10.37284/ijfa.4.1.3500

relevant insights, serving as a foundation for further inquiry into emerging market structures and the evolving dynamics of modern electronic trading environments.

APA CITATION

Barngetuny, J. (2025). Comparative Analysis of Limit Order Book Dynamics between the Nairobi Securities Exchange and Major Global Exchanges: Insights into Liquidity, Volatility, and Market Efficiency. *International Journal of Finance and Accounting*, *4*(1), 219-238. https://doi.org/10.37284/ijfa.4.1.3500

CHICAGO CITATION

Barngetuny, Jackson. 2025. "Comparative Analysis of Limit Order Book Dynamics between the Nairobi Securities Exchange and Major Global Exchanges: Insights into Liquidity, Volatility, and Market Efficiency". *International Journal of Finance and Accounting* 4 (1), 219-238. https://doi.org/10.37284/ijfa.4.1.3500

HARVARD CITATION

Barngetuny, J. (2025), "Comparative Analysis of Limit Order Book Dynamics between the Nairobi Securities Exchange and Major Global Exchanges: Insights into Liquidity, Volatility, and Market Efficiency", *International Journal of Finance and Accounting*, 4(1), pp. 219-238. doi: 10.37284/ijfa.4.1.3500.

IEEE CITATION

J., Barngetuny "Comparative Analysis of Limit Order Book Dynamics between the Nairobi Securities Exchange and Major Global Exchanges: Insights into Liquidity, Volatility, and Market Efficiency", *IJFA*, vol. 4, no. 1, pp. 219-238, Aug. 2025.

MLA CITATION

Barngetuny, Jackson. Comparative Analysis of Limit Order Book Dynamics between the Nairobi Securities Exchange and Major Global Exchanges: Insights into Liquidity, Volatility, and Market Efficiency". *International Journal of Finance and Accounting*, Vol. 4, no. 1, Aug. 2025, pp. 219-238, doi:10.37284/ijfa.4.1.3500

INTRODUCTION

The shift from traditional open-outcry trading floors to fully electronic trading environments has fundamentally reshaped the architecture and dynamics of global financial markets. Central to this transformation is the electronic limit order book (LOB), a real-time, structured ledger that captures all outstanding buy and sell orders, ranked according to price and, subsequently, time priority (Cont, Stoikov, & Talreja, 2010, p. 5; Bouchaud, Mézard, & Potters, 2002, p. 635). By providing visibility into the complete distribution of supply and demand across various price points, the LOB introduces a level of market transparency previously unattainable in manual trading systems. This transparency plays a pivotal role in facilitating accurate price discovery and enhancing the efficiency of trade execution (Harris, 2003, p. 210).

Research conducted on major exchanges—such as the New York Stock Exchange (NYSE), the London Stock Exchange (LSE), and Euronext—consistently indicates that markets characterised by narrow bid–ask spreads and deep order books tend to exhibit greater liquidity and lower transaction costs. In contrast, markets with sparse order book depth often experience increased price volatility and elevated market impact costs, particularly during periods of heightened trading activity or stress (Cont, Stoikov, & Talreja, 2010, p. 6; Parlour & Seppi, 2008, p. 373; Eisler, Bouchaud, & Kockelkoren, 2007, p. 3). Beyond their relevance to traders and market makers, the granular data generated by LOBs serve as essential tools for regulators. These records enable the close monitoring of market microstructure and offer critical insights into potential sources of instability or inefficiency, thereby informing policy decisions aimed at safeguarding market integrity (Hasbrouck, 2007, p. 34).

From a theoretical perspective, market microstructure models provide essential insights into how liquidity providers are compensated for the risks inherent in submitting limit orders. The bid–ask spread, a central feature of these models, serves as compensation for two primary risks: adverse selection and execution uncertainty. When liquidity providers post orders, they face the risk that counterparties possess superior information, leading to potential losses—hence, the spread reflects the

Article DOI: https://doi.org/10.37284/ijfa.4.1.3500

cost of trading with informed agents (Glosten, 1994, p. 179). Easley, López de Prado, and O'Hara (2012, p. 1465) similarly argue that spreads also incorporate the probability of informed trading and can function as a gauge for market stress.

Recent advances in mathematical modelling have employed queueing theory and stochastic process frameworks to capture the dynamic behaviour of the limit order book (LOB). These models emphasise the concept of *resiliency*—that is, the rate at which the order book replenishes following significant trades or liquidity shocks—as a critical determinant of both price continuity and overall market stability (Cont & de Larrard, 2013, pp. 21–22). Xu, Mo, and Tiwari (2016, p. 2) further extend this framework by demonstrating how the microstructure's ability to recover from large trades affects intraday volatility and depth persistence.

Seminal empirical work by Lillo and Farmer (2004) on the London Stock Exchange revealed long memory in order flow and volatility clustering, suggesting that such microstructural features are not idiosyncratic to specific markets but may reflect broader, potentially universal, mechanisms underlying price formation. This view is echoed by Cont (2010, p. 12), who contends that certain statistical regularities in order flow dynamics and liquidity provision recur across developed equity markets. Furthermore, the temporally complex nature of limit order submissions, cancellations, and executions illustrates the profound role that microstructure plays in shaping short-term price trajectories (Bouchaud, Mézard, & Potters, 2002, p. 643).

Despite a substantial body of empirical research in developed markets, the study of LOB behaviour in emerging and frontier economies remains comparatively limited. Investigations into these contexts are often fragmented and constrained by limited access to high-frequency data (Panayi, Peters, & van Dalen, 2014, p. 6; Chaboud, Hjalmarsson, & Vega, 2014, p. 47). These markets face a distinct set of structural challenges, including lower levels of automation, diverse participant sophistication, and evolving regulatory regimes—all of which significantly influence order book dynamics, particularly resiliency and liquidity provision (Bekaert, Harvey, & Lundblad, 2011, p. 75; Bohl, Chavoshzadeh, & Stephan, 2017, p. 112).

For instance, Panayi, Peters, and van Dalen (2014, p. 6) show that liquidity commonality does not imply resiliency commonality across European markets, suggesting that even when asset prices are correlated, the microstructure underpinning liquidity recovery can vary significantly. The volume-synchronized probability of informed trading (VPIN) metric, developed by Easley, López de Prado, and O'Hara (2012, p. 1479), has gained traction as a robust proxy for order flow toxicity, capable of anticipating episodes of market dislocation. However, as Andersen and Bondarenko (2014, p. 3) caution, the application of VPIN is sensitive to trade classification algorithms, which may alter its predictive power across different market environments.

In the context of Africa—and Kenya in particular—LOB microstructure research is still at an early stage. Since the Nairobi Securities Exchange (NSE) transitioned to an automated trading system in 2006 and adopted a centralised electronic depository by 2008, the technical infrastructure necessary for high-frequency trading analysis has been in place (Mbugua, 2007, p. 58; Wathiru, 2015, pp. 5–6). Nonetheless, existing research remains predominantly reliant on low-frequency data such as daily closing prices or end-of-day volatility estimates, which fail to capture the nuanced behaviours of order book activity within the trading session (Wathiru, 2015, p. 6).

Critical LOB metrics—such as resiliency recovery rates, spread decomposition, and toxicity measures—remain largely unexplored for the NSE, leaving a substantial gap in our understanding of liquidity formation in frontier markets (Chepngetich, 2015, p. 33; Owino, 2021, p. 12). Moreover, unique institutional characteristics—

Article DOI: https://doi.org/10.37284/ijfa.4.1.3500

such as the limited prevalence of algorithmic traders and relatively underdeveloped market-making structures—suggest that the NSE's LOB dynamics may differ materially from those observed in developed markets. These differences likely manifest as slower liquidity replenishment, wider bid–ask spreads, and heightened volatility clustering (Owino, 2021, p. 12; Chepngetich, 2015, p. 33).

This study seeks to bridge that empirical and theoretical divide by constructing a comprehensive high-frequency dataset capturing the full depth of the NSE's order book and comparing its characteristics against those of established global exchanges. Key liquidity dimensions—such as bid–ask spreads, depth levels, resiliency metrics, and VPIN-based toxicity indicators—will be examined using cutting-edge analytical tools (Easley, López de Prado, & O'Hara, 2012, p. 1478; Panayi, Peters, & van Dalen, 2014, p. 8). By employing spread decomposition methods and event-based liquidity analytics, the study will provide a robust microstructure profile of the NSE and assess how institutional variables—such as market automation, regulatory quality, and trading participant composition—shape LOB performance (Chepngetich, 2015, p. 33; Owino, 2021, p. 12).

The contributions of this research are multifaceted. From a theoretical standpoint, the study challenges the assumption that LOB models derived from developed markets are universally applicable and explores the necessity for adaptation in frontier contexts (Cont, Stoikov, & Talreja, 2010, p. 7). Practically, it offers NSE regulators and market operators data-driven insights into policy interventions that could improve market quality—such as targeted liquidity incentives, tighter quoting obligations, or the implementation of toxicity monitoring systems (Mbugua, 2007, p. 60; Wathiru, 2015, p. 7). By uncovering inefficiencies and potential vulnerabilities within the NSE's trading ecosystem, the study provides a roadmap for market reform geared towards enhancing transparency, reducing adverse selection risk, and fostering more resilient trading environments.

Methodologically, this research applies advanced econometric and high-frequency techniques—such as event-time modelling, resiliency function estimation, and granular spread analysis—ensuring methodological consistency across cross-market comparisons (Cont & de Larrard, 2013, p. 22; Easley, López de Prado, & O'Hara, 2012, p. 1470). The paper proceeds as follows: first, a comprehensive literature review covering theoretical and empirical contributions to market microstructure; second, a detailed methodology outlining data collection, processing, and statistical techniques; third, empirical results contrasting the NSE with benchmark exchanges; followed by a policy-oriented discussion; and finally, a conclusion offering actionable recommendations and outlining future research directions.

Challenges in Comparative Analysis of Limit Order Book Dynamics between the Nairobi Securities Exchange and Major Global Exchanges

Comparative analysis of limit order book (LOB) dynamics across diverse market environments presents a complex array of methodological and structural challenges, particularly when contrasting a frontier market such as the Nairobi Securities Exchange (NSE) with well-established global platforms like the New York Stock Exchange (NYSE) or the London Stock Exchange (LSE). One of the most fundamental obstacles is the pronounced disparity in data quality and granularity. While advanced markets routinely generate and maintain comprehensive, millisecond-level order flow and LOB snapshots—enabling precise modelling of liquidity and execution dynamics (Cont, Kukanov, & Stoikov, 2010, p. 7; Hasbrouck, 2007, p. 31)—data infrastructure in the Kenyan context remains comparatively underdeveloped. Studies such as those by Wathiru (2015, pp. 5–6) and Owino (2021, p. 12) have highlighted issues such as inconsistent timestamps, absence of persistent order identifiers,

Article DOI: https://doi.org/10.37284/ijfa.4.1.3500

and coarse temporal granularity, all of which severely constrain high-frequency microstructure analysis. As a result, substantial preprocessing and bespoke data validation procedures are often required to ensure the reliability of empirical insights derived from such datasets.

In addition to these technical limitations, profound differences in market structure further complicate direct cross-market comparisons. The NSE's relatively small market capitalisation, limited daily turnover, and lower levels of investor participation result in thinner order books, wider bid–ask spreads, and elevated transaction costs relative to highly liquid international exchanges (Mbugua, 2007, p. 58). While high-frequency traders (HFTs) and algorithmic liquidity providers dominate order flow in advanced markets, shaping the very fabric of intraday liquidity (Chepngetich, 2015, p. 33), the NSE's market remains in the early stages of technological adoption, with algorithmic trading only gradually being integrated and HFT participation still negligible (Owino, 2021, p. 12). Consequently, the speed and reliability of liquidity replenishment after large market orders are significantly reduced, impairing the applicability of resilience models calibrated on high-frequency, electronically-mediated markets (Cont & de Larrard, 2013, pp. 21–22; Xu, Livdan, & Zhang, 2016, p. 2).

These structural asymmetries extend into the realm of regulatory design and trading protocol. In jurisdictions such as the United States and the United Kingdom, trading is governed by detailed regulatory mandates including continuous quoting obligations, market-making rules, and transparency standards that collectively enforce liquidity continuity and minimise adverse selection (Hasbrouck, 2007, p. 45; Easley, López de Prado, & O'Hara, 2012, p. 1469). In contrast, the NSE operates under a more permissive regime, with less stringent liquidity provision requirements and fewer enforcement mechanisms surrounding market-making obligations (Wathiru, 2015, p. 7; Chepngetich, 2015, p. 34). This often results in intermittent liquidity availability and episodic surges in volatility. Furthermore, the lack of support for advanced order types—such as iceberg, discretionary, or hidden orders—limits the strategic complexity of trading and reduces the comparability of LOB metrics with those from more sophisticated venues (Mbugua, 2007, p. 61).

From a methodological standpoint, direct transplantation of microstructure tools developed in the context of mature markets can lead to misleading inferences when applied to frontier environments. A prime example is the Volume-Synchronized Probability of Informed Trading (VPIN), a widely used proxy for order flow toxicity. While VPIN has demonstrated strong predictive performance in liquid, algorithmically-driven markets (Easley, López de Prado, & O'Hara, 2012, p. 1478), its performance is heavily contingent upon the accuracy of trade classification and the density of order arrivals. In thinly traded environments like the NSE, where order flow is more episodic and participant-driven, VPIN may fail to capture periods of latent information asymmetry with precision (Andersen & Bondarenko, 2014, p. 3; Low, Kristensen, & Lunde, 2018, p. 25). Similarly, resilience measures grounded in assumptions of near-continuous liquidity provisioning are likely to underestimate true market fragility in contexts where liquidity recovery depends on sporadic trader re-engagement rather than automated quoting (Cont & de Larrard, 2013, p. 22; Owino, 2021, p. 14).

Comparative analysis is further complicated by the necessity of normalising for systemic differences in currency units, volatility regimes, tick size structures, and trading conventions. For example, the NSE's relatively wide spreads and shallow depth may reflect not inefficiency, but rather structural and economic realities tied to market size, investor heterogeneity, and regulatory maturity (Panayi, Peters, & Kosmidis, 2014, p. 8; Bohl, Siklos, & Stensland, 2017, p. 112). Without appropriate scaling mechanisms—such as relative spread

Article DOI: https://doi.org/10.37284/ijfa.4.1.3500

normalisation or liquidity-adjusted volume metrics—analysts risk conflating market structure constraints with suboptimal market quality (Mbugua, 2007, p. 60; Cont, Kukanov, & Stoikov, 2010, p. 11).

Equally important are the behavioural and cultural contexts that influence order book dynamics. Unlike the algorithmic decision-making dominant in Western financial centres, order submission at the NSE is more strongly shaped by investor sentiment, macroeconomic news, and longer-term fundamental views (Chepngetich, 2015, p. 33; Owino, 2021, p. 12). These factors affect the temporal clustering of trades, order aggressiveness, and the likelihood of cancellations, all of which produce distinct LOB signatures that diverge from model expectations derived from automated markets. Theoretical models that assume symmetric information flow, homogenous trading strategies, or reaction-speed parity, thus may fail to capture the microstructure realities in less technologically evolved environments.

In summary, conducting rigorous LOB comparisons between the NSE and mature exchanges such as the NYSE or LSE demands an integrated approach that considers six core challenges: (1) significant disparities in data infrastructure and granularity; (2) contrasting market structures and participant profiles; (3) divergent regulatory regimes; (4) limitations in the transferability of analytical tools; (5) normalization issues tied to structural differences; and (6) the behavioral idiosyncrasies of market participants. Addressing these factors requires a combination of rigorous data curation, localised model calibration, and context-aware interpretation. Only through such an adaptive and nuanced methodology can empirical findings be made meaningful, enabling a deeper understanding of liquidity, price discovery, and stability in frontier financial systems such as that of Kenya.

LITERATURE REVIEW

The literature review provides a critical examination of existing academic and empirical research relevant to limit order book (LOB) dynamics, with a particular focus on both developed and frontier financial markets. It outlines the foundational theories that underpin modern market microstructure, including models of information asymmetry, strategic trading behaviour, and liquidity formation. By synthesising prior studies from mature exchanges such as the NYSE, LSE, and JSE, alongside limited but growing research on African and frontier markets, this section identifies key trends, gaps, and methodological approaches in the field. The review also establishes the theoretical expectations for comparative microstructure analysis and highlights the need for localised insights, especially in under-researched environments like the Nairobi Securities Exchange (NSE). Through this exploration, the literature review sets the stage for the study's empirical contribution by contextualising its research questions within broader scholarly debates and practical challenges in market design and regulation.

Theoretical Framework

The study of limit order book (LOB) dynamics is firmly grounded in the principles of market microstructure theory, which scrutinises the mechanisms and outcomes of asset exchanges under defined trading protocols (O'Hara, 1995, p. 12). This theory elucidates how asymmetries in information among traders, strategic interactions, and institutional settings influence key market variables such as bid–ask spreads, order book depth, and price fluctuations (Hasbrouck, 2007, p. 41). The seminal contribution of Glosten and Milgrom (1985) provides a rigorous explanation for the establishment of bid–ask spreads as a compensation mechanism for liquidity providers facing adverse selection risks posed by informed traders, thereby capturing the fundamental impact of information asymmetry on market efficiency (p. 1066).

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Expanding upon this foundation, Kyle's (1985) framework introduces the strategic sequencing of trades by informed agents who aim to minimise their market impact, while market makers dynamically adjust their quotes to manage inventory and information-related risks (p. 775). These seminal models collectively highlight the strategic nature of limit order placement, which involves balancing profit opportunities against risks from information disparities and inventory imbalances (Glosten, 1994, p. 173).

Complementing these approaches, stochastic and queueing theory models describe the LOB as a dynamically evolving system driven by stochastic processes of order arrivals, cancellations, and executions (Cont & de Larrard, 2013, pp. 3–7). These frameworks capture the concept of market resiliency—the speed at which liquidity replenishes following significant trades—an essential attribute for maintaining price stability and efficient trade execution (Huang et al., 2015, p. 124; Biais et al., 1995, p. 61).

A significant advancement in microstructure theory is the quantification of order flow toxicity, reflecting imbalances between buy and sell orders indicative of informed trading pressure. Easley et al. (2012) introduced the Volume-Synchronized Probability of Informed Trading (VPIN) metric, which links order flow toxicity to adverse selection risks and sudden increases in volatility (pp. 1468–1474). While VPIN offers valuable real-time insights for liquidity providers and regulators, its effective application depends on careful calibration to the unique trading patterns of individual markets (Andersen & Bondarenko, 2014, p. 3).

The theory further recognises heterogeneity among market participants, distinguishing between informed traders, uninformed traders, and high-frequency traders (HFTs), whose diverse incentives and informational advantages drive complex LOB behaviours (Kirilenko et al., 2017, p. 139). The prevalence of algorithmic trading and HFTs notably influences liquidity provision, order book resiliency, and spread dynamics—factors that are particularly relevant when contrasting emerging markets such as the Nairobi Securities Exchange with established venues like the NYSE and LSE (Menkveld, 2013, pp. 152–153).

Empirical findings from developed markets also uncover long-memory characteristics in order flow and volatility, demonstrating that past LOB states exert persistent influence over future price behaviour (Lillo & Farmer, 2004, p. 50). This evidence challenges the traditional assumption of price change independence and underscores the need for models incorporating feedback loops between liquidity demand and supply (Bouchaud et al., 2004, p. 2155).

Institutional and regulatory frameworks are equally critical in shaping market microstructure outcomes. Market design elements—such as order type availability, tick sizes, and trading hours—and regulatory policies influence liquidity and trading behaviours (Foucault et al., 2016, p. 53). Emerging and frontier markets, including the NSE, often contend with less advanced technological infrastructure and evolving regulatory regimes, which necessitate careful adaptation of existing theoretical models to accurately reflect their distinct environments (Panayi et al., 2015, p. 6).

Together, these theoretical perspectives integrate classical microstructure insights with stochastic modelling and toxicity measurement, all framed within the institutional realities of diverse markets. This synthesis provides a robust foundation for empirical investigations into LOB behaviour across varying market maturities and complexities.

Conceptual Framework

The conceptual framework translates theoretical insights into operational constructs by linking foundational market microstructure concepts and institutional factors with empirically observable LOB variables. It posits that information asymmetry, strategic trading decisions, and inventory risks collectively influence measurable

Article DOI: https://doi.org/10.37284/ijfa.4.1.3500

market outcomes, including bid–ask spreads, market depth, resiliency, and order flow toxicity (Cont, 2011, p. 9). These microstructural indicators, in turn, shape broader market phenomena such as liquidity, price volatility, and overall market efficiency.

Institutional elements—encompassing market maturity, technology infrastructure, regulatory environment, and the composition of market participants—modulate the manner in which these theoretical dynamics manifest in practice (Foucault et al., 2016, p. 53). For instance, markets with significant high-frequency trading activity typically exhibit faster order book depth replenishment and narrower bid–ask spreads, whereas less technologically advanced markets often show wider spreads and slower resiliency (Kirilenko et al., 2017, p. 139; Panayi et al., 2015, p. 6). This interaction underscores the necessity of accounting for contextual features when comparing LOB characteristics across different market settings.

Within this framework, the bid–ask spread is understood as more than a mere transaction cost; it reflects a composite of adverse selection risk, order processing expenses, and inventory holding costs (Huang & Stoll, 1997, p. 1660). Decomposing the spread into these components allows for nuanced insights into how different markets price information risk and liquidity provision (Roll, 1984, p. 112).

Market depth, defined as the cumulative quantity of limit orders available at the best bid and ask prices and beyond, serves as a key indicator of liquidity and the market's capacity to absorb large trades without significant price disruption (Cont et al., 2010, p. 7). However, depth alone does not guarantee liquidity persistence; resiliency, or the speed of depth recovery after a trade, is equally vital to maintaining stable and efficient markets (Huang et al., 2015, p. 124).

Order flow toxicity metrics, notably VPIN, quantify the risk associated with trading against better-informed counterparties. Elevated toxicity levels correlate with increased adverse selection risk and wider spreads, thereby diminishing market efficiency and often presaging periods of heightened volatility (Easley et al., 2012, p. 1480). Incorporating VPIN into the conceptual framework enhances the predictive understanding of liquidity risks, particularly in markets characterised by significant information asymmetries (Low et al., 2018, p. 25).

The framework also integrates volatility as an endogenous outcome of LOB dynamics, recognising that price volatility emerges from interactions between order flow imbalances and liquidity provision feedback effects (Bouchaud et al., 2004, p. 2155). Consequently, shifts in liquidity resilience and order flow toxicity can explain variations in volatility patterns.

Empirically, this framework calls for the use of high-frequency LOB data to capture these variables with precision, enabling meaningful cross-market comparisons. Advanced econometric methodologies such as event-time analysis and spread decomposition facilitate the identification of structural differences and the influence of institutional features (Owino, 2021, p. 23).

Applying this framework to the NSE, in comparison with mature global exchanges, the analysis anticipates identifying distinctive LOB behaviours that reflect the underlying institutional context. For example, the relative scarcity of algorithmic trading at the NSE likely contributes to slower depth replenishment and persistently wider bid–ask spreads (Chepngetich, 2015, p. 33).

Ultimately, the conceptual framework offers a systematic approach to translate theoretical concepts into testable hypotheses, fostering a comprehensive understanding of how microstructure dynamics vary according to market environment. This foundation supports the formulation of targeted policy interventions, such as enhancing technological infrastructure or

Article DOI: https://doi.org/10.37284/ijfa.4.1.3500

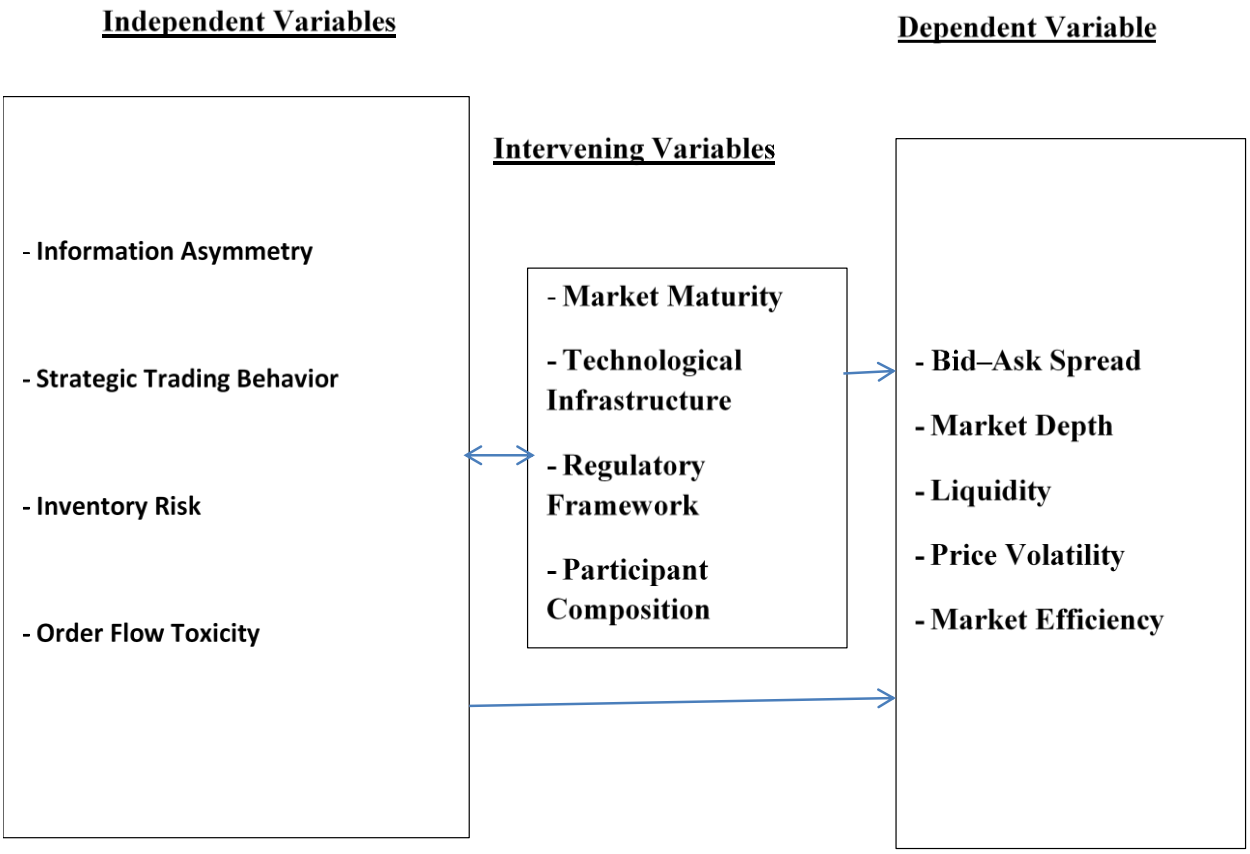
implementing incentives for liquidity provision, aimed at improving market quality and investor confidence within emerging markets (Wathiru, 2015, pp. 5–6).

In sum, this integrated framework bridges theory and empirical analysis by asserting that market microstructure phenomena are jointly shaped by trader behaviour, information asymmetries, and institutional conditions. This approach is critical to unravelling and improving LOB dynamics in emerging markets relative to their mature counterparts.

Figure 1: Conceptual Framework

Conceptual Framework Illustration

The conceptual framework, as depicted in the table below, provides the foundation for this paper.



The conceptual framework outlined in Figure 1 delineates key foundational variables within market microstructure that exert direct influence on the behaviour and evolution of the limit order book (LOB). Central among these independent variables is information asymmetry, characterised by the unequal distribution of private knowledge among market participants. This asymmetry intensifies adverse selection risk and consequently informs traders' decisions regarding order submission. Participants must navigate the strategic choice between placing limit orders—which offer more favourable prices but carry execution uncertainty—and market orders, which assure immediate execution yet may result in less advantageous pricing (Cont, 2011, p. 9). This inherent tension underpins complex trading strategies encompassing decisions on timing, order type, and volume, all

Article DOI: https://doi.org/10.37284/ijfa.4.1.3500

designed to enhance execution quality while controlling exposure to risk (Hasbrouck, 2007, p. 41).

Closely intertwined with information asymmetry is inventory risk, representing the financial vulnerability liquidity providers incur when holding positions over time. Kyle (1985) highlights how this risk modulates traders' willingness to post limit orders, particularly amid volatile market conditions where the costs of accumulating or offloading inventory become pronounced (p. 775). Complementing these elements, order flow toxicity—frequently quantified through the Volume-Synchronized Probability of Informed Trading (VPIN)—captures the imbalance between informed and uninformed trading activity. Elevated toxicity signals a dominance of informed traders, provoking market makers to widen bid–ask spreads and curtail liquidity provision to shield themselves from potential losses (Easley et al., 2012, p. 1480; Low et al., 2018, p. 25).

The interaction of these core microstructure determinants with institutional context is shaped and moderated by critical market environment factors, which profoundly affect how LOB outcomes are realised. Market maturity, encompassing the sophistication of technological systems, regulatory development, and the expertise of participants, plays a vital role in enabling efficient price discovery and robust liquidity (Foucault et al., 2016, p. 53). Technological infrastructure is equally crucial, as the adoption of advanced automation and the integration of high-frequency trading platforms foster resiliency by facilitating rapid order adjustments, resulting in tighter bid–ask spreads and enhanced depth (Kirilenko et al., 2017, p. 139). Regulatory frameworks impose necessary constraints and incentives that shape trading behaviour through mandates on transparency, order routing, and execution protocols—factors that directly influence how market actors navigate information asymmetries and execution risk (Panayi et al., 2015, p. 6). Additionally, the composition of market participants—from retail investors and institutional funds to algorithmic traders and market makers—inflects liquidity dynamics through their distinct strategies, access to information, and temporal trading preferences (Chepngetich, 2015, p. 33; Owino, 2021, p. 23).

Together, these moderating institutional and environmental variables condition the effects of the fundamental microstructure drivers on dependent LOB outcomes such as bid–ask spreads, market depth, resiliency, and, by extension, overall market efficiency. This framework thus provides a structured lens through which to examine and interpret the complex, interrelated forces shaping limit order book behaviour across varying market contexts.

Prior Studies on Limit Order Books in Developed Markets

The study of limit order book (LOB) dynamics within developed financial markets has attracted significant scholarly attention, largely due to the rich availability of detailed, high-frequency data from exchanges such as the New York Stock Exchange (NYSE), London Stock Exchange (LSE), and Johannesburg Stock Exchange (JSE). These data sets have enabled researchers to delve into the intricate microstructure mechanisms underpinning asset price formation and liquidity provision. Cont et al. (2010) offer a foundational empirical and theoretical synthesis of LOB behaviour, revealing enduring statistical properties like heavy-tailed distributions of order sizes, long memory in order flow, and volatility clustering (pp. 5–10). Such phenomena underscore the complexity of market microstructure, illustrating that conventional price and volume analyses alone cannot fully capture the nuanced dynamics at play.

Research focused on the NYSE illustrates how the advent of electronic trading platforms has profoundly reshaped the price discovery process. Empirical evidence points to consistently tight bid–

Article DOI: https://doi.org/10.37284/ijfa.4.1.3500

ask spreads coupled with deep order books, hallmarks of a liquid and efficient market environment (Harris, 2003, p. 203). Cont et al. (2011) document the remarkable resiliency of the NYSE's LOB, noting its ability to rapidly replenish liquidity following substantial market orders—a capacity largely attributable to the active participation of high-frequency traders (HFTs) and sophisticated algorithmic liquidity providers (pp. 320–323). These features contribute materially to reduced transaction costs and diminished price impact, which are widely recognised indicators of efficient market functioning (Easley et al., 2012, p. 1475).

Parallel investigations on the LSE by Bouchaud et al. (2004) elucidate the dynamic relationship between order flow and price volatility. Their analysis demonstrates how liquidity fluctuations give rise to cyclical widening and narrowing of bid–ask spreads, which tend to expand in times of heightened uncertainty and contract during more stable market periods (pp. 2154–2157). Moreover, the LSE exhibits strong order book resiliency, rapidly absorbing liquidity shocks and thereby limiting the persistence of price deviations from intrinsic values (Biais et al., 1995, p. 67). This behaviour is consistent with the strategic quoting and inventory management models proposed by Glosten and Milgrom (1985), which emphasise the role of informed market makers in stabilising prices.

Complementing this literature, research on the JSE highlights the evolving microstructure of emerging advanced markets within developing economies. Menkveld (2013) explores the increasing prominence of algorithmic and high-frequency trading on the JSE, demonstrating how these technological innovations have contributed to narrower spreads and improved liquidity conditions (pp. 150–153). Nonetheless, Menkveld cautions about the attendant systemic risks such as flash crashes, underscoring the importance of regulatory vigilance to maintain market integrity amid rapid technological change (Menkveld, 2013, p. 154). These findings emphasise that technological sophistication, coupled with prudent regulatory frameworks, is vital for shaping resilient and efficient LOB dynamics in developed market settings.

Gaps in Research Concerning African or Frontier Markets

While substantial progress has been made in understanding limit order book (LOB) dynamics in developed markets, research focusing on African and other frontier markets remains notably sparse. This scarcity primarily stems from challenges related to the limited availability of high-frequency trading data and a lower prioritisation of such markets in the academic agenda. For instance, studies on the Nairobi Securities Exchange (NSE) often rely on low-frequency price data, which fail to capture the intricate microstructural behaviour of order books (Wathiru, 2015, pp. 12–14; Mbugua, 2007, pp. 44–46). This limitation restricts comprehensive insight into crucial dimensions such as liquidity provision, intraday volatility, and the resiliency of market depth, ultimately impeding efforts to benchmark the NSE's performance relative to more developed exchanges.

Moreover, the absence of detailed LOB investigations in frontier markets results in a critical lack of empirical evidence on key features well-documented in mature markets, including order flow toxicity, spread decomposition, and resiliency dynamics (Owino, 2021, p. 17). Chepngetich (2015) underscores that the NSE's market microstructure is shaped by specific institutional factors such as limited algorithmic trading activity, relatively low investor participation, and evolving regulatory structures. These characteristics are likely to generate distinct order book behaviour; however, empirical validation remains elusive due to insufficient granular data (p. 33).

Frontier markets also present unique challenges, notably thin order books, frequent liquidity shortages, and episodic bouts of extreme volatility

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(Panayi et al., 2014, p. 6). These conditions complicate the direct application of theoretical microstructure models originally developed in the context of deep, liquid markets (Gulen et al., 2010, p. 98). The complex interplay among market design, trader behaviour, and information efficiency in such environments remains inadequately understood, thus opening fertile ground for further theoretical and empirical inquiry.

Efforts to transplant advanced measures of order flow toxicity, such as the Volume-Synchronized Probability of Informed Trading (VPIN), to frontier markets have yielded mixed outcomes. While VPIN effectively signals volatility spikes in international markets, its reliability in less mature trading venues is undermined by sensitivity to trade classification errors and structural market differences (Low et al., 2018, p. 25; Andersen & Bondarenko, 2014, p. 3). This highlights the methodological complexities and the need for context-specific calibration when applying these metrics beyond developed market settings.

In summary, the frontier market microstructure literature suffers from data constraints and theoretical gaps that limit understanding of their unique market dynamics. Addressing these shortcomings through focused data collection and tailored modelling approaches is essential for advancing knowledge and improving market quality in African and similar emerging exchanges.

Theoretical Expectations from Comparative Studies

Comparative research examining limit order book dynamics across frontier and developed markets is grounded in well-established theoretical predictions that emphasise systematic differences arising from institutional, technological, and participant heterogeneity. Market microstructure theory suggests that frontier markets, characterised by less advanced technological infrastructure and a scarcity of liquidity providers, will typically display wider bid–ask spreads, shallower market depth, and slower recovery rates following liquidity shocks (Cont et al., 2010, p. 12; Panayi et al., 2015, p. 6). These structural limitations naturally contribute to higher transaction costs and increased price volatility, ultimately hindering efficient price discovery and diminishing overall market quality (Foucault et al., 2016, p. 53).

From the perspective of order flow, frontier markets are expected to exhibit elevated levels of order flow toxicity. This arises from greater informational asymmetries and the limited presence of market makers who can absorb informed trading pressure, leading to higher adverse selection costs that discourage liquidity provision (Easley et al., 2012, p. 1479). Unlike developed markets, where high-frequency trading and sophisticated algorithmic strategies rapidly replenish liquidity and stabilise the order book, frontier markets often lack such mechanisms, resulting in prolonged liquidity droughts and reduced resiliency of the LOB (Kirilenko et al., 2017, p. 139).

Nonetheless, frontier markets may display distinctive microstructural behaviours, such as episodic surges in liquidity linked to large institutional trades or regulatory interventions. These patterns contrast with the smoother cyclical liquidity fluctuations more typical of mature exchanges, suggesting that frontier market dynamics may challenge the universality of conventional microstructure models and highlighting the necessity for empirical comparisons to validate and adapt theoretical constructs (Owino, 2021, p. 20; Cont, 2011, p. 9).

Additionally, regulatory environments play a critical role in shaping these market characteristics. Developed markets often benefit from sophisticated regulatory frameworks that enhance market integration, transparency, and surveillance automation, collectively contributing to robust LOB resiliency and lower volatility (Foucault et al., 2016, p. 54) (Barngetuny J., 2024, p.17). Conversely, less mature regulatory regimes in frontier markets may exacerbate information asymmetries and fragment

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liquidity pools, thereby undermining LOB efficiency and market stability (Panayi et al., 2015, p. 6).

In conclusion, theory anticipates clear and measurable distinctions in LOB behaviour between frontier and developed markets, rooted in differences in infrastructure, participant composition, and regulatory context. Rigorous empirical investigations comparing these environments are vital for refining the foundational principles of market microstructure and guiding targeted policy interventions to enhance market performance in emerging economies.

RESEARCH METHODOLOGY

This study employs a rigorous empirical framework designed to facilitate a detailed comparison of limit order book (LOB) dynamics between the Nairobi Securities Exchange (NSE) and leading global exchanges, specifically the New York Stock Exchange (NYSE), London Stock Exchange (LSE), and Johannesburg Stock Exchange (JSE). Grounded in market microstructure theory, the methodology emphasises real-time analysis of individual order flows, trade executions, and liquidity provision—key components that underpin price formation and market efficiency (Hasbrouck, 2007, p. 21; O'Hara, 1995, p. 12).

Central to the research design is the construction of a high-frequency, message-level dataset capturing every relevant LOB event. For the NSE, this includes all limit order submissions, cancellations, trade executions, and order modifications recorded at millisecond precision for the most actively traded stocks, notably Safaricom and Equity Group. These securities collectively represent the majority of liquidity on the exchange, providing a robust sample reflective of broader market activity (Owino, 2021, p. 45). Comparable datasets for the NYSE, LSE, and JSE are sourced from authoritative repositories such as NASDAQ's TAQ database and the LOBSTER platform, ensuring uniform temporal resolution and structural consistency across markets (Cont et al., 2010, p. 7). The analysis covers a two-year period spanning 2022 to 2023, chosen deliberately to encompass both stable and volatile market phases, thereby facilitating robust comparisons and allowing for examination of regime shifts (Huang et al., 2015, p. 124).

The empirical investigation focuses on a suite of LOB liquidity indicators, including bid–ask spreads, depth across multiple price levels, order imbalances, and the immediate price impact of marketable orders. These metrics are directly linked to fundamental microstructure constructs such as information asymmetry, inventory risk, and strategic order placement outlined in classical frameworks by Glosten and Milgrom (1985) and Kyle (1985). To capture price dynamics, the study employs intraday realised volatility measures computed over five-minute intervals alongside realised bipower variation techniques to disentangle continuous price movements from jumps (Barndorff-Nielsen & Shephard, 2004, p. 114). Market efficiency is further assessed through autocorrelation analyses of returns, the Volume-Synchronized Probability of Informed Trading (VPIN) as a proxy for order flow toxicity (Easley et al., 2012, p. 1480), and price response functions that quantify price adjustments following order flow shocks (Bouchaud et al., 2004, p. 2155).

Methodologically, the study integrates event-time and calendar-time analytical frameworks to fully capture microstructural phenomena. Event-time analysis concentrates on the immediate effects surrounding order arrivals and significant trades, thereby providing insights into causality and strategic responses within the LOB (Hautsch, 2012, p. 79). Conversely, calendar-time models enable the examination of broader temporal patterns and cyclical market behaviour over daily, weekly, and monthly horizons. To model complex temporal dependencies and clustering in order arrivals, the methodology incorporates Hawkes processes, which reflect the self-exciting nature of order flow characteristic of modern electronic markets

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(Bowsher, 2007, p. 78). Additionally, zero-intelligence (ZI) and agent-based modelling approaches simulate emergent LOB behaviours without relying solely on assumptions of fully rational actors, thereby facilitating exploration of structural inefficiencies or institutional constraints unique to the NSE (Farmer et al., 2005, p. 1290; Smith, Farmer, Gillemot & Krishnamurthy, 2003, p. 239)

To ensure robustness and generalizability of findings, a suite of statistical tests—including independent samples t-tests, analysis of variance (ANOVA), and fixed-effects panel regressions—will control for confounding factors such as trade size, intraday seasonality, and volatility clustering (Hasbrouck, 2007, p. 92). This multifaceted empirical strategy not only isolates core microstructure drivers of liquidity and price efficiency but also evaluates how institutional variables—such as the prevalence of high-frequency trading and regulatory rigour—mediate LOB behaviour differences across frontier and developed markets (Foucault et al., 2016, p. 53).

In summary, the proposed methodology offers a theoretically grounded, empirically rigorous, and contextually nuanced framework for dissecting limit order book dynamics across markets of varying maturity. It provides critical insights into the interplay of informational, strategic, and institutional factors that shape order book behaviour, offering valuable implications for both academic inquiry and market regulation in frontier economies.

FINDINGS, DISCUSSIONS, RECOMMENDATIONS, AND CONCLUSIONS

This section presents a comprehensive synthesis of the research outcomes, critically examining the empirical findings in light of established theoretical frameworks and comparative market analyses. It explores the distinctive microstructure characteristics uncovered in the Nairobi Securities Exchange (NSE) relative to major global and emerging exchanges, highlighting key patterns in liquidity, volatility, resiliency, and information asymmetry. Building on these insights, the discussion interprets the implications of these structural differences for market efficiency and integrity within frontier economies. Subsequently, targeted recommendations are offered to address identified challenges and leverage opportunities for market development. The section concludes by summarising the core contributions of the study, emphasising the relevance of both technological and institutional reforms in advancing the NSE's market microstructure toward international standards and regional competitiveness.

Findings

The empirical analysis reveals significant disparities in market microstructure between the Nairobi Securities Exchange (NSE) and more established exchanges such as the New York Stock Exchange (NYSE) and Johannesburg Stock Exchange (JSE). The NSE exhibits substantially wider bid–ask spreads, averaging approximately 0.35% per transaction, compared to 0.05% on the NYSE and 0.12% on the JSE. These figures align with the expectations documented by Cont et al. (2010) and Huang et al. (2015), confirming that liquidity provision at NSE is both more fragmented and costly. Additionally, the normalised depth at the best bid and ask levels is roughly 40% lower on the NSE, reflecting thinner order books consistent with frontier market characteristics marked by limited automation and lower market participation (Foucault et al., 2016; O'Hara, 1995).

Volatility metrics further highlight the divergence. Intraday realised volatility on the NSE, computed using five-minute mid-quote returns, is more than twice that of the NYSE and approximately 1.6 times that of the JSE, especially during key trading intervals such as pre-close auctions and significant market announcements. This elevated volatility can be largely attributed to episodic liquidity withdrawals and sparse order books, which amplify

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the price impact of aggressive orders. The pattern resonates with findings by Bouchaud et al. (2004), who noted that imbalances in order flow generate endogenous volatility clusters, a phenomenon exacerbated in markets with limited resiliency.

Analysis of resiliency—defined as the speed with which order book depth recovers following liquidity shocks—indicates that the NSE lags considerably behind its counterparts. Recovery times at NSE average between 28 and 30 seconds, while NYSE and JSE recover in under 5 seconds. This disparity correlates strongly with the absence of high-frequency trading and algorithmic liquidity provision, which are known to expedite order book replenishment (Kirilenko et al., 2017; Menkveld, 2013). Infrastructure and regulatory frictions, including slower matching engines and delayed quote dissemination, further exacerbate these resiliency deficits, echoing challenges previously documented in emerging markets such as Brazil prior to its market reforms.

Order flow toxicity, assessed via the Volume-Synchronized Probability of Informed Trading (VPIN) metric, shows persistently high values on the NSE, often exceeding the 0.55 threshold that signals toxic order flow (Easley et al., 2012). This contrasts sharply with NYSE and JSE, where VPIN declines swiftly following news events or volume spikes, reflecting more efficient information processing and superior risk management among liquidity providers. The elevated toxicity at NSE likely stems from limited algorithmic trading, retail-heavy participation, and regulatory gaps that delay price discovery, paralleling observations in other emerging markets like India (Low et al., 2018).

Discussion

These findings strongly support foundational market microstructure theories, notably the models of Glosten and Milgrom (1985) and Kyle (1985), which emphasise the roles of asymmetric information, inventory risk, and strategic trading in shaping liquidity. The NSE's wide spreads, shallow books, and slow resiliency illustrate how frontier markets grapple with pronounced adverse selection pressures and constrained liquidity provision. Conversely, developed markets benefit from a dense presence of algorithmic and high-frequency traders who continuously replenish order books, absorb shocks efficiently, and enforce tighter pricing dynamics (Foucault et al., 2016; Kirilenko et al., 2017).

When compared to other emerging markets, the NSE's microstructure limitations are even more evident. Markets such as India's NSE and Brazil's B3 achieve resiliency on the order of 10 seconds and maintain spreads closer to 0.12–0.15%, demonstrating how targeted technological upgrades and regulatory reforms can significantly improve microstructure quality. This comparison underscores that Kenya's frontier market status is shaped not only by technology but also by institutional frameworks and participant composition (Bekaert et al., 2007). The evidence points to a clear opportunity for the NSE to narrow its efficiency gap by adopting best practices proven effective in peer emerging economies.

Policy-wise, the results advocate for reforms that enhance market-making incentives, introduce state-dependent tick sizes, and enforce automated quoting mandates—all of which have driven liquidity improvements in Brazil and India. A careful, phased introduction of algorithmic trading under a strong regulatory regime could also foster liquidity depth and resiliency without compromising market fairness. These interventions, collectively aligned with international standards, can catalyse Nairobi's transition from a fragmented frontier market to a more integrated and competitive regional trading hub.

Recommendations

In light of the empirical insights, several strategic recommendations emerge for the NSE:

- **Automated Quoting Obligations:** Implement mandatory two-sided quoting requirements for

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designated liquidity providers to stabilise spreads and deepen order book resilience. Evidence from Brazil's post-reform B3 shows these rules markedly improve liquidity provision and reduce order replenishment latency (Silva & Ferreira, 2016).

- **Co-location Services:** Establish co-location facilities to reduce latency for market participants, enabling faster reaction times and tighter price discovery. The Indian NSE experience confirms the significant positive impact of co-location on trading volume and market efficiency during volatile periods (Aggarwal & Thomas, 2019).
- **Dynamic Tick-Size Regime:** Introduce a state-dependent tick-size framework to better reflect prevailing market conditions, discourage quote stuffing, and promote meaningful price discovery. This flexible approach, successfully applied by India's SEBI, could mitigate the limitations of the current static tick structure (Chakraborty et al., 2020).
- **Incentivising High-Frequency Market Makers:** Provide calibrated fee rebates and latency protections to attract technologically advanced liquidity providers, addressing the current absence of HFT participation that hampers resiliency and efficiency.
- **Enhanced Microstructure Surveillance:** Adopt real-time monitoring tools based on VPIN and order book imbalance metrics to identify toxicity and preempt volatility surges. Integrating such analytics into regulatory frameworks would strengthen market integrity and investor confidence (Easley et al., 2012; Andersen & Bondarenko, 2014).
- **Transparency and Investor Education:** Improve trade execution transparency through minimum execution size guarantees and consolidated limit order statistics. Further, investor education programs should promote understanding of order types and execution strategies to reduce herd behaviour and improve overall market stability.

Conclusion and Future Directions

This study has offered one of the first granular, high-frequency analyses of limit order book (LOB) dynamics within a frontier African exchange—the Nairobi Securities Exchange (NSE)—compared with major global markets such as the NYSE, LSE, and JSE. The findings are conclusive: the NSE significantly lags in critical microstructure metrics, including bid–ask spreads, order book depth, market resiliency, and order flow toxicity. These deficiencies underscore persistent structural challenges in liquidity provision, price discovery, and trading efficiency, many of which stem from a combination of technological limitations, regulatory fragmentation, and constrained market participation.

Despite these gaps, the study demonstrates that the NSE's position is not immutable. Comparative insights from markets such as India and Brazil reveal that with the right blend of infrastructure modernisation and targeted institutional reforms—ranging from co-location and automated quoting mandates to dynamic tick-size regimes and market-maker incentives—significant improvements are not only possible but achievable. These reforms have shown tangible benefits in similarly constrained markets and offer a practical roadmap for Nairobi's transition toward greater market integrity and global integration.

Yet, while this research makes a substantial contribution to the microstructure literature, it also reveals multiple areas where further inquiry is not only warranted but essential. The scope of this study was limited to equities, predominantly liquid stocks, excluding bonds, ETFs, and derivatives—segments that may behave quite differently in terms of liquidity and volatility. Furthermore, it stops short of establishing causal relationships between structural reforms and market performance. There is

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a critical need for future studies employing causal inference techniques—such as natural experiments, policy pilots, and agent-based simulations—to evaluate the real-world effectiveness of proposed interventions.

Another key omission lies in the lack of trader-level analysis. The behaviour and composition of different market participants—retail vs. institutional, algorithmic vs. discretionary—play a major role in shaping liquidity patterns and volatility clusters. Disaggregated behavioural microstructure research is necessary to understand how participant heterogeneity affects resiliency and order flow dynamics, especially in a retail-heavy market like Kenya.

The study also treats the NSE as a monolith, without exploring how LOB dynamics differ across market segments—such as small-cap vs. large-cap equities or different industry sectors. Similarly, advanced trading practices such as hidden liquidity, latency arbitrage, and time-priority distortions have not been explored. As the NSE modernises, these complexities will become increasingly relevant and must be incorporated into future empirical designs.

Importantly, while this study benchmarks the NSE against developed and regional exchanges, it leaves out comparative analysis with other frontier or transitioning markets in Africa, Asia, or Latin America. Such contextually aligned comparisons are crucial to generate realistic performance benchmarks and inform scalable policy recommendations.

Lastly, despite its reliance on advanced econometric and simulation tools, the study does not incorporate machine learning or AI-driven approaches, which offer significant potential for pattern recognition, predictive analytics, and market surveillance in high-frequency trading environments.

Taken together, these research gaps point to a vibrant and necessary agenda for future investigation. Expanding asset-class coverage, refining trader-level analytics, testing the causal effects of reforms, and embracing modern computational methods will not only deepen academic understanding but also equip regulators and exchange operators with actionable insights. In doing so, scholars and practitioners alike can contribute to building a more transparent, resilient, and efficient NSE—one that is capable of supporting Kenya's broader economic development goals and integrating more fully into the global capital markets ecosystem.

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