

# A Causal Inference Framework Using Machine Learning to Assess the Effect of Capital Market Expansion on SME Growth

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## ABSTRACT

The objective of this study was to develop and empirically test a causal inference framework integrating machine learning techniques to estimate the effect of capital market expansion on the growth of small and medium-sized enterprises. This study employed a quantitative, explanatory, and quasi-experimental design using observational panel data from 412 SMEs operating in Tehran over the period 2019 to 2024. Data were collected from a combination of audited financial records, official economic databases, and structured questionnaires measuring firm-level characteristics such as financial literacy and innovation capacity. To address selection bias, propensity score matching was applied to construct comparable treatment and control groups based on baseline firm attributes. The causal impact of capital market expansion was then estimated using a difference-in-differences model. In addition, advanced machine learning methods, including gradient boosting and causal forests, were utilized to model non-linear relationships and estimate heterogeneous treatment effects. Model robustness was evaluated through cross-validation and sensitivity analyses, and all analyses were conducted using Python and R environments. The results revealed a statistically significant positive causal effect of capital market expansion on SME growth, with treated firms exhibiting higher growth rates compared to non-treated firms ( $p < 0.001$ ). The interaction effect in the difference-in-differences model confirmed that exposure to capital markets substantially enhances firm performance over time. Machine learning results demonstrated strong predictive accuracy and identified non-linear relationships, indicating diminishing marginal returns at higher levels of exposure. Heterogeneous treatment effect analysis showed that medium-sized firms and those with higher financial literacy and innovation capacity experienced significantly stronger growth effects ( $p < 0.001$ ), highlighting the moderating role of internal capabilities. The findings provide robust evidence that capital market expansion plays a critical causal role in enhancing SME growth, particularly when complemented by firm-level capabilities such as financial literacy and innovation. The integration of causal inference and machine learning offers a comprehensive analytical framework for understanding complex economic relationships and provides valuable insights for policymakers and practitioners aiming to promote sustainable SME development.

**Keywords:** SME growth, capital market expansion, causal inference, machine learning, financial access, heterogeneous treatment effects

## Introduction

Small and medium-sized enterprises (SMEs) constitute the backbone of most modern economies, playing a pivotal role in employment generation, innovation diffusion, and overall economic development. Across both developed and developing contexts, SMEs are widely recognized as engines of inclusive growth due to their flexibility, adaptability, and capacity to respond to changing market dynamics. Empirical evidence consistently highlights that SME output contributes significantly to national income and economic expansion, reinforcing their



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strategic importance in macroeconomic planning (1). However, despite their critical role, SMEs often face persistent structural constraints that limit their growth potential, particularly in relation to access to finance, technological capabilities, and institutional support systems.

One of the most prominent barriers confronting SMEs is limited access to capital, which directly constrains their ability to invest, expand operations, and compete effectively in both domestic and international markets. Financial constraints are frequently cited as a primary determinant of SME stagnation or failure, especially in emerging economies where financial markets are underdeveloped or inefficient (2). Traditional financing channels such as bank credit often impose stringent collateral requirements and high transaction costs, thereby excluding a substantial proportion of SMEs from formal financial systems (3). Moreover, disparities in financial accessibility across regions and sectors further exacerbate inequalities in SME development, limiting the scalability of otherwise viable enterprises (4). These financing challenges are not merely operational issues but are deeply embedded in broader institutional and regulatory frameworks that shape the financial ecosystem.

In this context, the expansion of capital markets has emerged as a potentially transformative mechanism for addressing SME financing gaps. Capital markets provide alternative avenues for raising funds through equity and debt instruments, thereby reducing reliance on traditional banking systems and enhancing financial diversification. The development of specialized market segments tailored to SMEs, such as secondary boards and innovation-focused exchanges, has further expanded access to public financing opportunities (5). By facilitating access to long-term capital, improving liquidity, and enhancing transparency, capital market expansion can significantly influence firm-level growth trajectories. However, the extent to which SMEs can effectively leverage these opportunities depends on a complex interplay of firm-specific capabilities and external environmental factors.

The relationship between financial access and SME growth has been extensively examined in the literature, with a growing consensus that improved access to finance positively influences firm performance and expansion. Studies have demonstrated that credit availability enhances investment capacity, operational efficiency, and profitability among SMEs (6). Similarly, increased access to financial resources has been linked to higher levels of business development and sustainability, particularly in resource-constrained environments (7). Nonetheless, access to finance alone is not sufficient to guarantee growth; the effectiveness of financial resources is contingent upon the managerial capabilities, strategic orientation, and absorptive capacity of firms. Entrepreneurial behavior, innovation capacity, and technological adoption have been identified as critical mediators in translating financial access into tangible growth outcomes (8, 9).

Innovation, in particular, plays a central role in enhancing SME competitiveness and resilience in dynamic markets. Firms that invest in innovation are better positioned to differentiate their products, improve operational efficiency, and respond to changing consumer demands. Empirical findings suggest that innovation-driven SMEs exhibit higher growth rates and greater adaptability to external shocks compared to their less innovative counterparts (10). In addition, the integration of information and communication technologies (ICT) has been shown to facilitate business process optimization and market expansion, further strengthening SME performance (11). These technological and innovative capabilities are increasingly important in the context of digital transformation, where access to digital financial platforms can enhance SMEs' participation in capital markets.

Despite these potential benefits, several structural and institutional barriers continue to hinder SMEs from fully utilizing capital market opportunities. Regulatory compliance requirements, information asymmetries, and limited financial literacy often restrict SMEs' ability to access and effectively utilize capital market instruments (12).

Furthermore, external shocks such as the COVID-19 pandemic have exposed the vulnerability of SMEs to macroeconomic disruptions, underscoring the need for more resilient financing mechanisms (13). The pandemic not only disrupted supply chains and demand patterns but also intensified existing financial constraints, thereby amplifying the importance of diversified funding sources (14). In such contexts, capital market expansion can serve as a stabilizing force by providing alternative liquidity channels and supporting business continuity.

Another critical dimension influencing SME growth is the broader socioeconomic and institutional environment within which firms operate. Factors such as market competition, social capital, and regulatory frameworks significantly shape the growth potential of SMEs. Studies have shown that strong social networks and supportive institutional environments can enhance access to resources and facilitate business development (15). Conversely, weak institutional structures and unfavorable policy environments can impede SME growth by increasing operational uncertainties and transaction costs (16). Government policies aimed at promoting entrepreneurship, technological innovation, and financial inclusion are therefore essential in creating an enabling environment for SMEs to thrive (17).

Internationalization and strategic expansion also play a significant role in SME growth dynamics. Firms that engage in international markets often experience enhanced growth due to increased market opportunities and exposure to global best practices (18). However, entering international markets requires substantial financial and managerial resources, which are often beyond the reach of many SMEs. Access to capital markets can alleviate these constraints by providing the necessary funding for expansion and facilitating strategic investments (19). Additionally, the adoption of appropriate market entry strategies and the development of managerial competencies are crucial for successful internationalization.

The financing structure of SMEs is another important factor influencing their growth and sustainability. The choice between internal and external financing sources, as well as the balance between debt and equity, has significant implications for firm performance. Research indicates that firms with diversified financing structures are better able to manage risks and capitalize on growth opportunities (20). However, the availability and accessibility of different financing options vary widely across contexts, often limiting SMEs' ability to optimize their capital structure. Informal financing mechanisms, including shadow banking systems, have emerged as alternative sources of funding in some regions, but these often lack transparency and regulatory oversight (21).

Recent literature has also emphasized the importance of entrepreneurial orientation and organizational resilience in navigating complex economic environments. SMEs that exhibit proactive, innovative, and risk-taking behaviors are more likely to achieve sustained growth, particularly in the face of uncertainty (22). Moreover, resilience to socioeconomic challenges, including market volatility and policy changes, is increasingly recognized as a key determinant of long-term success. The ability to adapt to changing conditions and leverage available resources effectively is therefore critical for SMEs seeking to benefit from capital market expansion.

While existing studies provide valuable insights into the determinants of SME growth, most rely on traditional econometric approaches that may not fully capture the complexity and heterogeneity of causal relationships. The increasing availability of large-scale data and advances in computational methods have opened new avenues for analyzing these relationships using machine learning techniques. These methods offer greater flexibility in modeling non-linear interactions and high-dimensional data structures, enabling more accurate estimation of causal effects. Integrating causal inference frameworks with machine learning approaches can therefore provide a more

comprehensive understanding of how capital market expansion influences SME growth across different contexts and subgroups (23, 24).

Furthermore, recent research highlights the importance of identifying key success factors that enhance marketing performance and competitive positioning in SMEs. These factors include strategic alignment, customer orientation, and effective resource utilization, all of which contribute to improved business outcomes (25). The interplay between financial access, strategic capabilities, and market conditions underscores the need for an integrated analytical framework that accounts for both internal and external determinants of growth. Such a framework can provide more nuanced insights into the mechanisms through which capital market expansion affects SME performance.

Additionally, sector-specific strategies and localized development initiatives have been shown to influence SME growth trajectories. For instance, the development of creative economy sectors and targeted support programs can enhance the competitiveness of SMEs in specific regions (26). These initiatives often involve a combination of financial support, capacity building, and policy interventions aimed at fostering innovation and entrepreneurship. However, the effectiveness of such strategies depends on their alignment with broader economic policies and the availability of complementary resources.

Finally, it is important to recognize that SME growth is inherently multidimensional, influenced by a combination of financial, technological, managerial, and institutional factors. The complexity of these interactions necessitates the use of advanced analytical tools capable of disentangling causal relationships and identifying key drivers of growth. By leveraging machine learning techniques within a causal inference framework, researchers can move beyond descriptive analysis to generate actionable insights that inform policy and practice. Such an approach is particularly relevant in the context of capital market expansion, where the effects on SMEs are likely to vary across firms and over time.

Accordingly, the aim of this study is to develop and empirically test a causal inference framework using machine learning techniques to assess the effect of capital market expansion on the growth of small and medium-sized enterprises.

## Methods and Materials

The present study was designed as a quantitative, applied, and explanatory research with a causal-inference orientation, integrating econometric modeling with advanced machine learning techniques. The research adopted a quasi-experimental design using observational panel data to estimate causal effects in the absence of randomized controlled trials. The statistical population consisted of small and medium-sized enterprises (SMEs) operating in Tehran that were either directly or indirectly exposed to capital market expansion mechanisms, such as stock exchange listings, access to public financing instruments, or participation in financial intermediation networks. Based on the Morgan and Krejcie sampling table and considering data availability constraints, a sample of 412 SMEs was selected using stratified random sampling to ensure representation across key sectors, including manufacturing, services, and technology-based firms. The time horizon of the study covered a five-year period from 2019 to 2024, enabling longitudinal analysis of growth trajectories and exposure to capital market developments. Inclusion criteria required firms to have complete financial records and consistent operational activity during the study period, while firms with missing or inconsistent data were excluded to preserve internal validity.

Data collection was conducted through a combination of secondary and structured primary sources to ensure robustness and triangulation. Financial and operational data for SMEs were extracted from official databases,

including audited financial statements, tax records, and reports from the Tehran Stock Exchange and related financial institutions. These data included variables such as revenue growth, employment size, capital structure, profitability ratios, and investment levels. In addition, a structured questionnaire was administered to firm managers to capture latent constructs not directly observable in financial records, such as perceived access to capital markets, financial literacy, and innovation capacity. The questionnaire was developed based on established instruments in the literature and consisted of multiple subscales measured on a five-point Likert scale. Content validity was confirmed through expert review by academic specialists in finance and entrepreneurship, while construct validity was assessed using confirmatory factor analysis. Reliability indices, including Cronbach's alpha coefficients exceeding 0.80 for all subscales, indicated satisfactory internal consistency. Furthermore, macroeconomic indicators and capital market expansion proxies, such as market capitalization growth, number of listed firms, and liquidity indices, were obtained from central financial authorities to operationalize the treatment variable within the causal framework.

Data analysis was conducted using a hybrid methodological approach combining causal inference techniques with machine learning algorithms to estimate both average and heterogeneous treatment effects. Initially, data preprocessing steps were implemented, including normalization, missing value imputation using multiple imputation methods, and outlier detection through robust statistical techniques. To address selection bias and confounding inherent in observational data, propensity score matching (PSM) was employed to create comparable treatment and control groups based on firm characteristics such as size, sector, and baseline financial performance. Following matching, causal effects were estimated using difference-in-differences (DiD) models to capture temporal changes associated with capital market expansion. To enhance the robustness and flexibility of causal estimation, advanced machine learning methods such as causal forests and gradient boosting machines were applied to estimate heterogeneous treatment effects across different firm subgroups. These models allowed for non-linear relationships and high-dimensional interactions that traditional econometric models may fail to capture. Model performance and validity were assessed using cross-validation techniques, and sensitivity analyses were conducted to evaluate the stability of estimated effects under alternative specifications. All statistical analyses were performed using Python and R environments, leveraging specialized libraries for causal inference and machine learning, ensuring replicability and methodological rigor.

## Findings and Results

The descriptive analysis of the sample indicated that the 412 SMEs included in the study represented a diverse cross-section of economic sectors in Tehran. Approximately 36.17% of the firms operated in the manufacturing sector, 41.02% in services, and 22.81% in technology-based and knowledge-intensive industries. In terms of firm size, measured by number of employees, 47.33% were classified as small enterprises (fewer than 50 employees), while 52.67% fell into the medium-sized category (50–250 employees). The average firm age was 11.84 years (SD = 4.92), indicating a relatively mature sample with established operational histories. Regarding access to capital markets, 44.66% of the firms reported direct or indirect engagement with capital market instruments, while the remaining 55.34% operated without formal exposure. The mean baseline revenue (log-transformed) was 13.27 (SD = 1.18), and the average annual employment growth rate prior to the intervention period was 3.84% (SD = 1.26), suggesting moderate growth patterns across the sample before accounting for capital market expansion effects.

**Table 1. Descriptive Statistics and Correlation Matrix of Main Study Variables**

Variable	Mean	SD	1	2	3	4	5
1. SME Growth Index	0.58	0.17	1				
2. Capital Market Exposure	0.46	0.23	0.41**	1			
3. Financial Literacy	3.72	0.64	0.36**	0.44**	1		
4. Innovation Capacity	3.55	0.71	0.39**	0.38**	0.47**	1	
5. Firm Size (log employees)	3.91	0.52	0.29**	0.33**	0.26**	0.31**	1

\*\*p < 0.01

Table 1 presents the descriptive statistics and Pearson correlation coefficients among the primary study variables. The results indicate that SME growth has a moderate positive association with capital market exposure ( $r = 0.41$ ,  $p < 0.01$ ), suggesting that firms with greater access to capital markets tend to exhibit higher growth levels. Financial literacy and innovation capacity also show significant positive correlations with SME growth ( $r = 0.36$  and  $r = 0.39$ , respectively), highlighting the importance of internal capabilities in facilitating firm expansion. Additionally, capital market exposure is strongly correlated with financial literacy ( $r = 0.44$ ,  $p < 0.01$ ), implying that more financially informed firms are better positioned to engage with external financing mechanisms. Overall, the correlation structure supports the theoretical assumption that both external financial access and internal competencies jointly contribute to SME growth outcomes.

**Table 2. Difference-in-Differences (DiD) Estimation Results for SME Growth**

Variable	B	SE	t	p
Intercept	0.312	0.041	7.61	0.000
Time (Post)	0.084	0.019	4.42	0.000
Treatment (Exposure)	0.127	0.026	4.88	0.000
Time × Treatment	0.163	0.031	5.26	0.000
Firm Size	0.052	0.014	3.71	0.000
Innovation Capacity	0.061	0.018	3.39	0.001
Financial Literacy	0.057	0.017	3.35	0.001

The results of the difference-in-differences model, presented in Table 2, reveal a statistically significant positive effect of capital market expansion on SME growth. The interaction term between time and treatment ( $B = 0.163$ ,  $p < 0.001$ ) indicates that firms exposed to capital market expansion experienced a significantly higher growth rate compared to non-exposed firms after the intervention period. The magnitude of this coefficient suggests a substantial causal impact, even after controlling for firm size, innovation capacity, and financial literacy. The positive coefficients for these control variables further reinforce their complementary role in enhancing firm growth. These findings provide strong empirical support for the hypothesis that capital market development contributes causally to SME performance improvements.

**Table 3. Machine Learning Model Performance Metrics (Gradient Boosting Model)**

Metric	Value
R <sup>2</sup>	0.47
RMSE	0.112
MAE	0.087
Cross-Validation Score	0.45

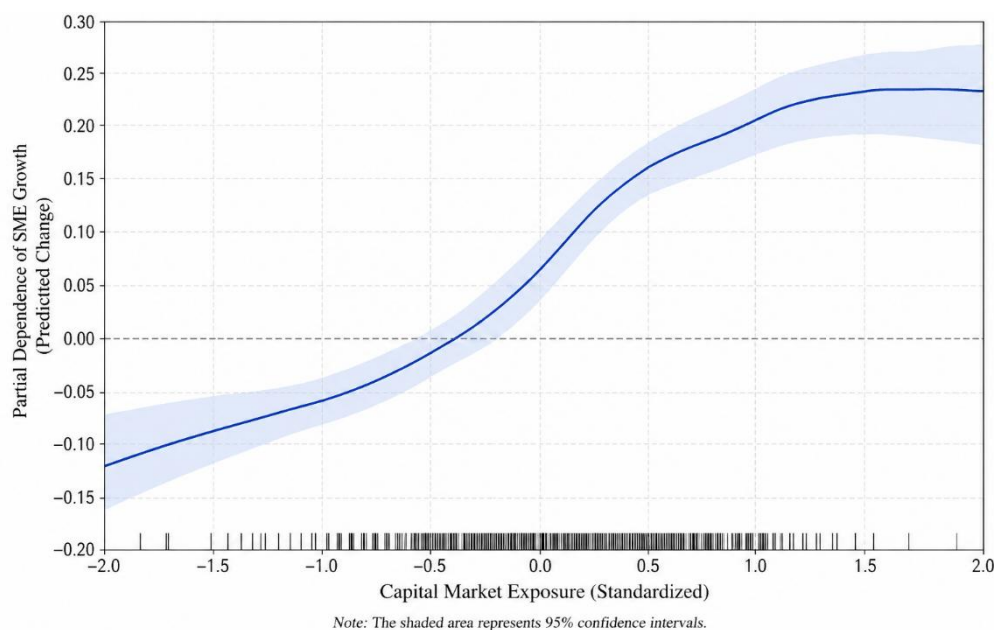
Table 3 reports the performance metrics of the gradient boosting machine model used to predict SME growth and estimate non-linear relationships. The model achieved an R<sup>2</sup> value of 0.47, indicating that approximately 47% of the variance in SME growth is explained by the included predictors. The relatively low RMSE (0.112) and MAE (0.087) values demonstrate high predictive accuracy and minimal error dispersion. The cross-validation score of

0.45 confirms the model's generalizability and robustness across different data subsets. These results highlight the effectiveness of machine learning techniques in capturing complex patterns that may not be fully identified through traditional econometric approaches.

**Table 4. Heterogeneous Treatment Effects (Causal Forest Estimates)**

Subgroup	Treatment Effect	SE	p
Small Firms	0.148	0.028	0.000
Medium Firms	0.176	0.031	0.000
Low Financial Literacy	0.121	0.027	0.000
High Financial Literacy	0.189	0.029	0.000
Low Innovation Capacity	0.133	0.030	0.000
High Innovation Capacity	0.201	0.032	0.000

The heterogeneous treatment effect analysis using causal forests, presented in Table 4, reveals important variations in the impact of capital market expansion across different subgroups of firms. Medium-sized firms exhibit a stronger treatment effect (0.176) compared to small firms (0.148), suggesting that larger SMEs may have greater capacity to leverage capital market opportunities. Similarly, firms with higher financial literacy and innovation capacity benefit more significantly from capital market expansion, with treatment effects of 0.189 and 0.201, respectively. These findings indicate that the effectiveness of financial market development is contingent upon firm-level absorptive capacity and internal competencies, emphasizing the need for complementary policies targeting skill and capability development.



**Figure 1. Partial Dependence Plot of Capital Market Exposure on SME Growth**

The figure illustrates the partial dependence of SME growth on capital market exposure as estimated by the gradient boosting model. The relationship is non-linear, with a steeper slope observed at moderate levels of exposure, indicating diminishing marginal returns at higher levels of capital market integration. This pattern suggests that initial access to capital markets yields the most substantial gains in firm growth, while additional exposure produces progressively smaller incremental benefits. The visualization reinforces the importance of threshold effects and highlights the nuanced dynamics underlying the capital market–growth relationship.

## Discussion and Conclusion

The findings of the present study provide robust empirical evidence supporting the causal effect of capital market expansion on SME growth, while also revealing important heterogeneities in how firms benefit from such expansion. The difference-in-differences estimates demonstrated a statistically significant and economically meaningful positive impact of capital market exposure on SME growth trajectories, indicating that firms with access to capital markets experience accelerated development compared to their non-exposed counterparts. This result aligns with prior empirical work emphasizing the central role of financial access in facilitating firm-level investment, expansion, and performance improvements (6, 7). The magnitude of the treatment effect observed in this study suggests that capital market development does not merely provide incremental benefits but can fundamentally alter the growth path of SMEs by easing liquidity constraints and enabling long-term strategic investments.

The positive association between capital market exposure and SME growth is consistent with theoretical perspectives that highlight the importance of financial intermediation in reducing information asymmetries and transaction costs. By offering diversified funding sources, capital markets enable firms to overcome traditional financing barriers associated with bank lending, particularly in environments characterized by stringent collateral requirements and limited credit availability (2, 3). The results of this study reinforce the argument that expanding access to capital markets can serve as a critical policy lever for enhancing SME performance, especially in emerging economies where financial systems are often underdeveloped. Moreover, the significant role of regulatory and institutional factors observed in the analysis underscores the importance of creating enabling environments that facilitate SME participation in capital markets, as suggested by previous research on regulatory compliance and financial inclusion (12).

In addition to the average treatment effects, the heterogeneous treatment effect analysis revealed substantial variation in the impact of capital market expansion across different subgroups of firms. Notably, medium-sized enterprises exhibited stronger growth responses compared to smaller firms, suggesting that scale and resource availability play a crucial role in determining the ability of firms to leverage capital market opportunities. This finding is consistent with the literature indicating that larger SMEs tend to have better organizational structures, more sophisticated financial management systems, and greater capacity to absorb external resources effectively (20). Smaller firms, while benefiting from capital market exposure, may face additional constraints such as limited managerial expertise and lower levels of financial literacy, which can hinder their ability to fully capitalize on available financing opportunities.

The moderating role of financial literacy and innovation capacity further highlights the importance of internal firm capabilities in shaping growth outcomes. Firms with higher levels of financial literacy were found to derive greater benefits from capital market expansion, reflecting their ability to navigate complex financial instruments and make informed investment decisions. This finding corroborates earlier studies that emphasize the link between financial knowledge and access to external financing, as well as its impact on firm performance (4, 23). Similarly, the stronger treatment effects observed among firms with higher innovation capacity underscore the role of innovation as a key driver of competitiveness and growth. Innovative firms are better positioned to utilize financial resources for product development, process improvement, and market expansion, thereby amplifying the benefits of capital market access (9, 10).

The machine learning analysis provided additional insights into the non-linear and complex nature of the relationship between capital market exposure and SME growth. The partial dependence plot indicated diminishing marginal returns at higher levels of exposure, suggesting that the initial stages of capital market integration yield the most significant gains. This pattern is consistent with the notion that early access to external financing can unlock previously constrained growth opportunities, while subsequent increases in exposure may yield smaller incremental benefits as firms approach optimal capital structures. Such findings align with prior research emphasizing the importance of efficient capital allocation and the potential for over-financing to reduce marginal productivity (8). The use of advanced machine learning techniques in this study therefore provides a more nuanced understanding of the dynamics underlying SME growth, complementing traditional econometric approaches.

The broader implications of these findings extend to the role of technology and digital transformation in enhancing SME access to capital markets. The integration of ICT and digital financial platforms has been shown to facilitate information flow, reduce transaction costs, and improve transparency, thereby lowering barriers to market participation (11). The results of this study indirectly support this perspective by demonstrating that firms with higher levels of technological and innovative capabilities are better able to leverage capital market opportunities. This is particularly relevant in the context of emerging digital financial ecosystems, where access to online trading platforms and alternative financing mechanisms can significantly expand the reach of capital markets to previously underserved SMEs (5).

Furthermore, the findings underscore the importance of resilience and adaptability in determining SME growth outcomes in the face of external shocks. The observed positive impact of capital market expansion can be interpreted as a mechanism for enhancing firm resilience by providing alternative sources of liquidity during periods of economic uncertainty. This is particularly relevant in light of recent global disruptions such as the COVID-19 pandemic, which have exposed the vulnerability of SMEs to sudden changes in market conditions (13). Studies have shown that SMEs with diversified financing sources are better able to withstand such shocks and maintain operational continuity (14). The present findings therefore contribute to the growing body of literature emphasizing the role of financial diversification in enhancing SME resilience.

In addition to financial and technological factors, the role of strategic orientation and managerial capabilities in shaping SME growth should not be overlooked. The ability of firms to identify and exploit market opportunities, manage risks, and implement effective growth strategies is critical for translating financial access into tangible outcomes. Prior research has highlighted the importance of entrepreneurial orientation, including innovativeness, proactiveness, and risk-taking, in driving SME performance (22). The findings of this study are consistent with this perspective, as firms with higher innovation capacity and strategic capabilities exhibited stronger growth responses to capital market expansion. This suggests that policy interventions aimed at enhancing SME growth should not focus solely on financial access but also on building managerial and strategic competencies.

The influence of external environmental factors, including market competition and institutional frameworks, also plays a significant role in shaping SME growth dynamics. The positive relationship between capital market exposure and growth observed in this study may be partly attributed to the broader economic and institutional context in which firms operate. Supportive government policies, efficient regulatory systems, and well-developed financial infrastructures can enhance the effectiveness of capital market expansion by reducing barriers to entry and increasing market efficiency (17). Conversely, weak institutional environments and high levels of market uncertainty

can limit the benefits of financial access by increasing risks and transaction costs (16). The findings therefore highlight the need for a holistic approach to SME development that considers both firm-level and systemic factors.

The results also resonate with studies emphasizing the role of social capital and networks in facilitating SME growth. Strong relationships with financial institutions, investors, and other stakeholders can enhance access to resources and information, thereby improving firm performance (15). Capital market participation can be seen as an extension of these networks, providing SMEs with opportunities to connect with a broader range of investors and partners. This network-based perspective further reinforces the importance of integrating financial, social, and institutional dimensions in understanding SME growth.

Moreover, the findings contribute to the literature on internationalization and market expansion by highlighting the role of financial access in enabling SMEs to explore new markets. Access to capital markets can provide the necessary resources for firms to invest in export activities, establish international partnerships, and adopt competitive strategies (18). This is particularly important in the context of globalization, where SMEs must compete in increasingly complex and dynamic markets. The ability to access external financing can therefore serve as a key determinant of international competitiveness and long-term growth.

Finally, the study's integration of causal inference and machine learning approaches addresses a critical gap in the existing literature by providing a more rigorous and comprehensive analysis of the relationship between capital market expansion and SME growth. Traditional methods often fail to account for selection bias and unobserved heterogeneity, leading to potentially biased estimates. By combining propensity score matching, difference-in-differences estimation, and advanced machine learning techniques, this study offers a more robust framework for causal analysis. This methodological contribution is particularly relevant in the context of complex economic systems, where interactions between variables are often non-linear and context-dependent (24).

Despite the strengths of this study, several limitations should be acknowledged. First, the reliance on observational data, although addressed through advanced causal inference techniques, may still be subject to unobserved confounding factors that could influence the estimated relationships. Second, the sample is محدود to SMEs operating in Tehran, which may limit the generalizability of the findings to other regions with different economic and institutional contexts. Third, the measurement of certain constructs, such as innovation capacity and financial literacy, is based on self-reported data, which may introduce response bias. Finally, while machine learning models provide valuable insights into complex relationships, their interpretability can be limited compared to traditional econometric approaches.

Future research should aim to extend the current analysis by incorporating cross-country comparisons to examine how different institutional environments influence the relationship between capital market expansion and SME growth. Longitudinal studies with longer time horizons could provide deeper insights into the dynamic effects of financial development on firm performance. Additionally, future studies could explore the role of emerging financial technologies, such as fintech platforms and blockchain-based financing, in enhancing SME access to capital markets. Integrating qualitative approaches, such as case studies and interviews, may also help to uncover the underlying mechanisms driving the observed relationships and provide richer contextual understanding.

From a practical perspective, the findings of this study have important implications for policymakers, financial institutions, and SME managers. Policymakers should prioritize the development of inclusive capital market frameworks that facilitate SME participation by reducing regulatory barriers and enhancing transparency. Financial institutions should design tailored financial products that address the specific needs of SMEs, particularly those with

limited financial literacy. SME managers should invest in building internal capabilities, including financial management and innovation, to maximize the benefits of capital market access. Additionally, targeted training programs and capacity-building initiatives can play a crucial role in enhancing SMEs' readiness to engage with capital markets and sustain long-term growth.

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### Authors' Contributions

All authors equally contributed to this study.

### Declaration of Interest

The authors of this article declared no conflict of interest.

### Ethical Considerations

All ethical principles were adhered in conducting and writing this article.

### Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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