RESEARCH ARTICLE

Impact of AI-Blockchain Adoption on Annual Revenue Growth: An Empirical Analysis of Small and Medium-sized Enterprises in the United States

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O31 - Innovation and Invention: Processes and Incentives
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ABSTRACT

United States economy relies heavily on the contributions of Small and Medium-sized Enterprises (SMEs) which play a big role in job creation, innovation, and overall economic growth. While technology adoption has long been considered a key factor in business performance, the emergence of Artificial Intelligence (AI) and blockchain technologies offers new avenues for operational efficiency and growth. This research aimed to identify the determinants of annual revenue growth among SMEs in the United States, with a particular focus on the impact of AI-based blockchain adoption on revenue growth. Using data from 422 SMEs surveyed in 2020, multiple statistical and machine learning models, including Multiple Regression, Multi-layer Perceptrons, and Gradient Boosting Machines, were employed to analyze the relationship between various independent variables and annual revenue growth. The study found a statistically significant relationship between the adoption of AI-Blockchain and revenue growth. The findings suggest that the adoption the technology could provide SMEs a competitive advantage. Additionally, the variables business age, owner experience, and owner education were significantly correlated with annual revenue growth. however, variables such as family business, owner age, and owner gender were not statistically significant, raising questions about the effectiveness of demographic-focused policies grants for revenue generation among SMEs. Market competition and road proximity exhibited inconsistent significance depending on the analytical model, suggesting their impact may vary by industry or geography. Funding source and exporting status also showed mixed results across different models. Notably, adoption of AI-Blockchain had low feature importance in machine learning models, despite its statistical significance in traditional models. These technologies are still in a nascent phase, undergoing rapid developments and improvements. As a result, the broader economic and operational implications for SMEs may not be entirely evident yet. This early stage of technology could account for why the technology shows statistical significance in traditional models but low feature-importance in machine learning models, which often capture more complex interactions. The findings of the study cloud be relevant for SMEs, especially those that are considering substantial investments in AI-based blockchain technologies.

Keywords: Artificial Intelligence, Blockchain, Revenue Growth, Small and Medium-sized Enterprises, Technology Adoption, United States Economy

INTRODUCTION

Small and Medium Enterprises (SMEs) are fundamental to many economies around the world [1], [2]. They make up the majority of businesses in most countries, showcasing their importance in economic growth and stability. SMEs are flexible and adaptable, capable of serving various market needs and providing goods and services to a wide range of consumers. Furthermore, their role in job creation is significant. The vast presence of SMEs in the business landscape means they provide employment for a significant portion of the workforce.

The definition of SMEs often depends on the number of employees, and this definition can vary between countries. In the European Union, a business with fewer than 250 employees is considered an SME. In contrast, in the United States, this category includes businesses with up to 500 employees. There are further classifications within the broad SME category, with small firms usually having under 50 employees and micro-enterprises even fewer, often ten or five employees. Some definitions also take financial assets into account, but the number of employees remains a common standard [3], [4].

These variations in definitions highlight the differences in business scales and structures across various economic landscapes. Regardless of their size or the specific definition used, SMEs have a significant role in economies. They contribute to local markets, adapt to changes quickly, and provide employment opportunities. Their importance in economic growth and stability is clear, and as economies change and develop, the role of SMEs is likely to remain significant.

The Small Business Administration (SBA) has specific criteria for defining a small business, highlighting its autonomy and modest stature in its respective industry. By the SBA's standards, a small business is one that is independently owned and operated. Such a business does not have a dominant presence or significant influence over its industry. Furthermore, in most scenarios, a company classified as a small business will employ fewer than five

hundred individuals [5], [6]. This clear classification ensures that the right businesses benefit from programs and policies tailored to support and nurture smaller enterprises.

Small businesses play an outsized role in the U.S. economy, and their significance cannot be understated. Approximately twenty-seven million of these businesses exist in the country, and collectively, they contribute to roughly 50 percent of the United States' Gross Domestic Product (GDP). This substantial contribution underscores the pivotal role small businesses play in driving the nation's economic engine, emphasizing their importance in overall economic health and stability [7], [8].

Small businesses in the United States serve as crucial agents of growth and dynamism in numerous facets of economic and socioeconomic progress. For one, small businesses are significant job creators, providing employment opportunities to millions of Americans. Furthermore, they often serve as hotbeds for innovation, introducing novel products, services, and processes that can reshape entire industries. Notably, small businesses also play a crucial role in promoting inclusivity and diversity. They offer opportunities for women and minorities, allowing them to pursue entrepreneurial endeavors, attain financial success, and achieve greater autonomy and independence in the business world [9], [10].

Small businesses have a unique advantage when it comes to innovation and agility. Their structures often allow them to invent new products or refine existing processes more efficiently than larger corporations might. This efficiency is largely due to their ability to make decisions more swiftly, without the layers of bureaucracy and red tape that can slow down larger entities. Additionally, their research initiatives tend to be more targeted and streamlined, allowing them to hone in on specific areas of interest or improvement. The compensation structures in many of these businesses are also set up in a way that incentivizes and rewards standout performances [11], [12]. This can lead to a highly motivated workforce that is driven to innovate, excel, and contribute meaningfully to the company's growth and evolution.

Furthermore, small firms play an indispensable role in the supply chain of many large corporations. These businesses are often the behind-the-scenes heroes, providing essential components and materials that big companies rely on for their operations. Beyond merely supplying parts, small firms offer a plethora of services that cater to the needs of their larger counterparts. From accounting, legal, and insurance services to more specialized offerings, these businesses fill essential roles that help big companies run smoothly. Their adaptability and expertise in niche areas make them invaluable partners in the corporate ecosystem.

Numerous small companies offer outsourcing services to large corporations, taking on specific projects or handling particular aspects of business functions. This can range from IT services to human resources functions. Moreover, many small entities, like automotive dealerships, serve as the face of big businesses to the end consumer. They represent large corporations' products, acting as the bridge between the producer and the customer, ensuring that products find their way into the hands of those who need and want them [13], [14].

The 2019 Small Business Profiles indicate that, during the most recent year analyzed, small businesses in the United States created a net increase of 1.8 million jobs. There are 30.7 million small businesses in the country, and they account for 47.3 percent of the private sector's employment. The three leading industries in the U.S. where small businesses employ the most people are health care and social assistance, followed by accommodation and food services, and then retail trade.

Blockchain can be defined as a decentralized and distributed digital ledger system that records transactions across multiple computers in a way that ensures the data's security, transparency, and immutability [15]. Originating from the words "block" and "chain", the term "blockchain" illustrates the fundamental structure: a series of data blocks that are sequentially linked. Each block typically contains a cryptographic hash of the previous block, a timestamp, and a collection of transactions. This structure ensures that once a block has been added to the blockchain, its contents are resistant to modification. Thus, the blockchain serves as a definitive record of events or transactions that is transparent to all participants in the network but cannot be altered retroactively without altering subsequent blocks and achieving consensus of the network majority [16], [17].

At the heart of the blockchain are the blocks themselves. Each block contains a collection of data, typically a list of transactions. These transactions are recorded in the block in a format determined by the specific type of blockchain (e.g., the format for a Bitcoin transaction differs from an Ethereum transaction). Additionally, each block contains a unique code called a hash. If someone tries to change the information inside the block, the hash will change, indicating potential foul play. Furthermore, blocks also contain the hash of the previous block, creating an unbreakable chain of records.

A node is an internet-connected device that participates in the blockchain network. Nodes can serve various functions: storing copies of the blockchain, validating transactions, or even creating new blocks, as in the case of miners in proof-of-work systems. Due to the decentralized nature of blockchain, there's no central authority or server managing the database or verifying transactions. Instead, every participant (node) in the network has access to the complete database and the complete transaction history [18], [19].

Consensus Mechanisms is the method through which blockchain networks achieve agreement about the validity of transactions. Different blockchain systems may employ different consensus mechanisms. Some of the most popular ones include Proof-of-Work (PoW), used by Bitcoin, where participants (miners) solve complex mathematical puzzles to validate transactions and create new blocks. Another example is Proof-of-Stake (PoS), where participants lock up a certain amount of their cryptocurrency to be chosen to validate transactions and create new blocks based on the amount they have staked.

AI specializes in data analysis, pattern recognition, and predictive modeling, whereas blockchain provides a tamper-proof, transparent ledger system. When these two are integrated, the potential applications are expansive. For instance, AI algorithms require vast amounts of data for training and optimization, and blockchain can ensure the data's credibility, traceability, and security. On the other hand, blockchain networks, particularly those using proof-of-work consensus mechanisms, are resource-intensive. AI can enhance these processes, making them more efficient and less energy-consuming.

Smart contracts, self-executing contracts with the agreement directly written into code lines, are a hallmark feature of many blockchain platforms. While traditional smart contracts execute based on predefined conditions, integrating AI can allow these contracts to make data-driven decisions based on patterns, anomalies, or predictions. This paves the way for more dynamic and adaptive contract systems. Blockchain can facilitate the creation of decentralized marketplaces for AI models and algorithms. This not only democratizes access to AI solutions but also ensures transparency in AI development [20], [21]. For example, developers can be rewarded in a transparent manner using cryptocurrency for contributing to a collaborative AI model, while users can trust the provenance of the AI tools they're accessing. AI-driven security solutions can detect and mitigate threats in blockchain networks, making them even more resilient to attacks. Conversely, blockchain can be used to enhance the privacy of AI operations, especially in sensitive applications like personalized recommendations or healthcare predictions.

Figure 1. contributions of AI-based blockchain

The convergence of blockchain and artificial intelligence (AI) presents a unique solution to enhancing the authenticity and transparency of data-driven processes. One of the critical issues that has plagued the AI industry is the notion of "explainable AI," where the decision-making process behind machine learning algorithms is often opaque. Blockchain technology can be used to alleviate this problem by providing an immutable digital record of the AI models, including the data sets and processes used to train them. By storing this information on a blockchain, a transparent and unchangeable audit trail is created. This ensures that any stakeholders can trace back and understand the decisions made by AI, thereby fostering trust in the integrity of the data and the recommendations or actions initiated by AI. Moreover, utilizing blockchain for this purpose further fortifies data security, as unauthorized changes to the data or the model are virtually impossible.

AI's capacity for rapid and large-scale data analysis brings additional intelligence to blockchain systems. Blockchain, in turn, provides a decentralized and secure platform that facilitates data sharing both within and outside organizational boundaries. This mutual enhancement allows for a more expansive and accurate understanding of patterns and insights, thereby augmenting decision-making processes. For example, in a supply chain managed by a blockchain, AI can quickly correlate large sets of data points to identify bottlenecks or inefficiencies. Blockchain ensures the provenance and integrity of this data, offering stakeholders verified and actionable insights. Thus, the integration of blockchain and AI can pave the way for a more transparent, reliable, and insightful data economy [22].

The combination of AI and blockchain technologies can significantly optimize multi-party business processes. One practical application is the use of smart contracts on a blockchain to automate various transactional activities. These smart contracts can be embedded with AI models to conduct complex decision-making tasks. For example, a smart contract could be designed to automatically initiate product recalls for expired items, execute re-orders based on

inventory levels, and even manage payment processes. Moreover, these AI-embedded smart contracts could be employed to resolve disputes by analyzing data and events leading up to the conflict, or to identify the most efficient and sustainable shipping methods based on multiple variables. The immutable nature of blockchain ensures that all these automated processes are transparent, secure, and verifiable by all parties involved, thereby enhancing speed and reducing friction in business operations [23], [24].

IMPACTS OF AI-BASED BLOCKCHAIN ON REVENUE GROWTH OF SMEs

Small and Medium-sized Enterprises (SMEs) face unique challenges that include limited resources, less negotiating power with suppliers, and greater susceptibility to disruptions [25]. Implementing AI-based blockchain systems can significantly ameliorate these challenges by providing a transparent and secure way to track the movement and authenticity of products across the supply chain. Blockchain serves as an immutable ledger where every transaction is recorded. This can help in ensuring the integrity and authenticity of products by enabling end-to-end visibility, starting from raw material sourcing to the retail shelf. This level of traceability is particularly important in industries where product authenticity is crucial, such as pharmaceuticals and food production. The decentralized nature of blockchain ensures that no single entity has control over the entire chain, reducing the risk of fraud or data tampering.

Artificial Intelligence (AI) adds another capability to blockchain systems in SCM [18], [19]. Through machine learning algorithms and data analytics, AI can automatically verify transactions, reducing the need for manual checks and thereby speeding up processes. Beyond transaction verification, AI can analyze data to identify inefficiencies, bottlenecks, or anomalies in the supply chain. It can, for example, flag when a shipment is delayed and automatically reroute other shipments to avoid cascading delays. AI can also predict future bottlenecks by analyzing historical data and provide recommendations for proactive actions. This real-time analysis and problem-solving can lead to more agile and responsive supply chain operations.

The integration of Artificial Intelligence (AI) algorithms with blockchain technology offers significant advancements in financial management for Small and Medium-sized Enterprises (SMEs). One of the most valuable applications is in the area of financial analysis. Traditional financial analysis relies heavily on historical data and often requires manual interpretation to make future projections. AI algorithms, trained on vast datasets, can sift through enormous amounts of financial data to identify trends, anomalies, and opportunities much more rapidly and accurately than human analysts. The AI can flag areas for human review where strategic decisions are needed. These insights can then be securely and transparently recorded on a blockchain, making them easily auditable and resistant to tampering.

Risk assessment is another area that can significantly benefit from the synergy between AI and blockchain. Credit risk, market risk, and operational risks are some of the types of financial risks SMEs face regularly. AI algorithms can predict these risks by analyzing various data points like market conditions, customer behavior, and internal operational metrics. Once identified, the risks can be quantified and strategies can be implemented to mitigate them. All these transactions and risk assessments can be securely logged in a blockchain. This decentralized digital ledger ensures that the records are immutable and transparent, which in turn, provides a more reliable basis for compliance with financial regulations and audits.

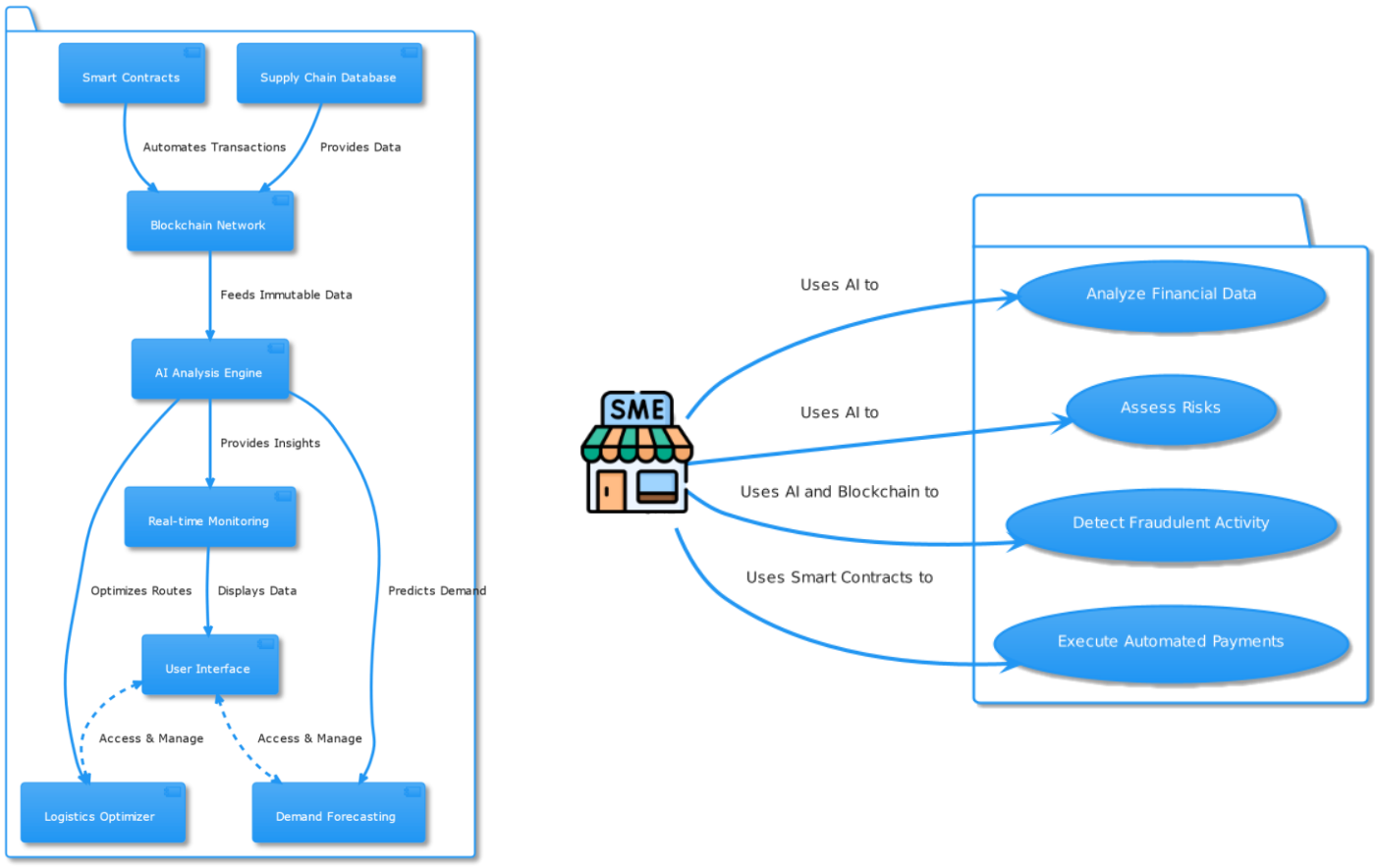
Data security is of paramount importance for Small and Medium-sized Enterprises (SMEs), and the combination of Artificial Intelligence (AI) and blockchain technologies provides a robust framework for safeguarding critical business data. AI algorithms are proficient in monitoring and analyzing large volumes of data and user behavior in real time. This capability is particularly useful for detecting unusual access patterns or potential security vulnerabilities. For instance, AI can continuously monitor the network for suspicious activities such as multiple failed login attempts, unexpected data transfers, or irregular access to sensitive databases. Once such activities are identified, the system can take immediate automated actions, such as blocking the suspicious user, triggering multifactor authentication, or alerting system administrators, thereby providing an extra layer of security.

Blockchain technology, on the other hand, contributes by offering a decentralized and immutable record-keeping system. Each transaction or data exchange is recorded as a block and added to a chain that is distributed across multiple nodes. Due to its decentralized nature, it is highly resistant to attacks that usually target centralized databases. Furthermore, once a block has been added to the blockchain, altering that information retroactively becomes computationally expensive and practically unfeasible. This immutability property ensures that historical data remains untampered, offering a secure and transparent platform for storing critical business data, including financial records, customer information, and proprietary algorithms.

The synergistic relationship between AI and blockchain can result in a safe data security environment. While AI serves to proactively monitor and identify potential security risks, blockchain serves as a reactive measure, ensuring that past data remains secure and unaltered. In cases of detected vulnerabilities or attacks, the AI system can not only take immediate action but can also record the incident securely and transparently on the blockchain. This record can serve as an indisputable log for auditing and compliance checks, ensuring that both the organization and regulatory bodies can review the incident for future improvements in the security infrastructure. This robust mechanism places SMEs in a stronger position to protect their critical data, ensuring both operational stability and regulatory compliance.

AI algorithms can analyze customer data, such as purchasing history, interactions, and preferences, to generate insights that facilitate more targeted and personalized marketing strategies, customer service, and product development. For example, machine learning models can identify cross-selling and upselling opportunities based on individual customer behavior, thereby potentially increasing revenue streams. In addition, chatbots and automated customer service tools can provide real-time assistance and problem-solving capabilities tailored to individual customer needs. When customer data is stored in a blockchain, the benefits are two-fold: the decentralized structure ensures a higher level of data security, as it eliminates the risks associated with centralized databases; and the transparent nature of blockchain ensures that customer data is easily auditable, facilitating regulatory compliance and enhancing customer trust.

Figure 2. the contributions of AI-based blockchain on SMEs



AI algorithms can be trained to automatically analyze the quality of products or services. These algorithms can evaluate a range of parameters, such as material quality, manufacturing consistency, and compliance with specifications, to determine whether a product meets predefined quality standards. The use of AI in this manner can dramatically reduce the costs associated with manual quality checks and also minimize human error, leading to more consistent and reliable products. Storing these QA metrics and evaluations on a blockchain adds an extra layer of transparency and security. Every QA check can be logged as an immutable record on the blockchain, providing both the company and the end consumers with an indisputable history of product quality. This can be especially useful in industries where traceability and verification of quality are mandatory, such as in pharmaceuticals and food production.

Both CRM and QA applications benefit from the increased security and transparency offered by blockchain technology, coupled with the analytical power and automation capabilities of AI. While AI's data analysis allows SMEs to make informed and timely decisions, blockchain's decentralized and immutable nature ensures that these decisions are executed in a secure and transparent environment. These integrated systems not only enhance operational efficiency but also add value by building customer trust and ensuring product quality, crucial elements for the competitiveness and sustainability of SMEs.

METHODS

The integration of artificial intelligence (AI) and blockchain into SMEs can have profound impacts on their revenue growth. AI assists in data analysis, pattern recognition, and automation of repetitive tasks, improving efficiency, reducing errors, and enhancing customer experience. Blockchain, on the other hand, can transform supply chain management, ensure data integrity, and facilitate peer-to-peer transactions. By adopting both technologies, SMEs can significantly optimize their operations, introduce new business models, and open up avenues for revenue generation. However, the adoption requires a financial and technical commitment which might strain SMEs with limited resources.

The level of market competition can substantially affect an SME's potential for revenue growth. In a highly competitive market, SMEs must constantly innovate, improve efficiency, and reduce costs to remain profitable. While competition can stimulate innovation and growth, it also means narrower profit margins and a constant need to stay ahead of rivals. On the other hand, SMEs operating in markets with low competition can enjoy more significant profit margins and can prioritize long-term growth strategies over short-term competitive tactics. However, they must be wary of becoming complacent [26].

The age of a business can be an indicator of its stability, reputation, and experience in the market. Older SMEs may have established customer bases, robust operational processes, and a better understanding of market dynamics, aiding revenue growth. Conversely, newer SMEs, while agile and often more open to adopting new technologies, might lack the brand recognition and trust that takes years to build. Yet, their novelty can also make them more adaptable to market shifts, potentially enabling rapid growth if they can identify and exploit new market opportunities [27], [28].

The location of an SME, especially its proximity to main roads, can be a significant factor in its operational efficiency, logistics, and accessibility to customers. Being near main roads can reduce transportation costs, ensure timely deliveries, and attract more footfall if the SME relies on direct customer interaction [29], [30]. Similarly, SMEs that export their products or services can tap into larger markets, diversifying their revenue streams. Exporting also exposes SMEs to global market dynamics, which can be both an opportunity for growth and a challenge due to varied regulations and cultural differences [31].

The source of an SME's funding can have implications for its growth trajectory. Those relying on credit institutions might have access to larger capital, enabling bigger investments and potentially higher returns. However, this comes with the obligation of repaying loans and possibly relinquishing some control over business decisions. Family-owned businesses, while benefiting from close-knit decision-making, might sometimes struggle with professionalizing operations. The education, experience, age, and gender of the owner can also play roles in the business's approach to risk, innovation, and growth strategies. A well-educated owner might bring innovative ideas, while an experienced one might have better industry insights. Different age groups and genders might have diverse perspectives on market trends and business operations, influencing the SME's growth trajectory.

Table 1. Variables and descriptions

SL	Variable Name	Notation	Type	Description	Group
1	Annual Revenue growth	***R***	Continuous, Dependent	Annual revenue growth for a given business	N/A
2	AI-Blockchain Adoption	***AIB***	Dummy, Independent	Adopted AI and blockchain: 0=no, 1=yes	Technological and Operational
3	Market Competition	***MC***	Dummy, Independent	Level of competition: 0=low, 1=high	Technological and Operational
4	Business Age	***BA***	Continuous, Independent	Age of the business in years	Technological and Operational
5	Road Proximity	***RP***	Dummy, Independent	Near main road: 0=no, 1=yes	Technological and Operational
6	Exporting Status	***ES***	Dummy, Independent	Exports products/services: 0=no, 1=yes	Technological and Operational
7	Funding Source	***FS***	Dummy, Independent	Source of funding: 0=self, 1=credit institution	Financial and Ownership
8	Family Business	***FB***	Dummy, Independent	Family-owned: 0=no, 1=yes	Financial and Ownership
9	Owner Education	***OE***	Continuous, Independent	Education level of business owner(s)	Owner Demographics and Skills
10	Owner Experience	***OX***	Continuous, Independent	Experience of business owner(s) in years	Owner Demographics and Skills
11	Owner Age	***OA***	Continuous, Independent	Age of the business owner	Owner Demographics and Skills
12	Owner Gender	***OG***	Dummy, Independent	Gender of the business owner(s): 0=female, 1=male	Owner Demographics and Skills

Results

Table 2 shows the results of multiple regression analysis conducted to examine the impact of various variables on the Annual Revenue (R), a majority of the variables demonstrated statistical significance at the 1% level. Specifically, the variables AI-Blockchain Adoption (AIB), Market Competition (MC), Business Age (BA), Road Proximity (RP), Exporting Status (ES), Funding Source (FS), Owner Education (OE), and Owner Experience (OX) yielded high t-statistic values and, consequently, low p-values, which make it unlikely that the observed effects are due to random chance. For example, the variable AIB had a coefficient of 0.275703 and a low standard error of 0.007869, resulting in a notably high t-statistic of 35.03765. Conversely, MC had a negative coefficient of -0.259299 and a standard error of 0.007780, with a t-statistic of -33.32967, indicating that high levels of market competition are associated with reduced Annual Revenue. This affirms that these variables are crucial determinants of revenue growth of SEMs in the sample tested.

Table 2. Multiple regression results

Dependent Variable: Revenue growth
Method: Least Squares
Sample: 1 422
Included observations: 422

Variable	Coefficient	Std. Error	t-Statistic	Prob.
AIB	0.275703	0.007869	35.03765	<0.01
MC	-0.259299	0.007780	-33.32967	<0.01
BA	0.267107	0.000265	1006.757	<0.01
RP	0.271693	0.007818	34.75229	<0.01
ES	0.264179	0.007785	33.93602	<0.01
FS	0.275831	0.007876	35.02204	<0.01
OE	0.266520	0.000695	383.3628	<0.01
OX	0.267468	0.000457	585.0191	<0.01
FB	0.003971	0.007874	0.504295	0.6143
OA	-3.47E-05	0.000263	-0.131675	0.8953
OG	0.001472	0.007856	0.187368	0.8515
C	0.102101	0.019763	5.166325	<0.01

Table 3. Multiple regression model performance

R-squared	0.731235	Mean dependent var	24.45773
Adjusted R-squared	0.724024	S.D. dependent var	5.891222
S.E. of regression	3.094861	Akaike info criterion	5.125387
Sum squared resid	3927.048	Schwarz criterion	5.240411
Log likelihood	-1069.457	Hannan-Quinn criter.	5.170841
F-statistic	101.4085	Durbin-Watson stat	2.019528
Prob(F-statistic)	<0.01		

On the other hand, the variables Family Business (FB), Owner Age (OA), and Owner Gender (OG) did not show statistical significance, as indicated by their high p-values of 0.6143, 0.8953, and 0.8515 respectively. FB's low t-statistic value of 0.504295 suggests that the inclusion of this variable may not offer meaningful insights into predicting or explaining variations in revenue growth. Similar non-significant impact is found with OA and OG, which have t-statistic values of -0.131675 and 0.187368, respectively. These p-values and t-statistics suggest that within the scope of the tested sample, FB, OA, and OG are not significant determinants of Annual Revenue.

The model's goodness-of-fit was measured by the R-squared and Adjusted R-squared values, as shown in table 3. The R-squared value of 0.731235 indicates that approximately 73.12% of the variance in the dependent variable 'R' is explained by the independent variables in the model. This is a relatively high value, suggesting a good fit of the model to the observed data. The Adjusted R-squared value of 0.724024 takes into account the number of predictors in the model. The Adjusted R-squared is slightly lower but still indicates a substantial explanatory power of the model. The F-statistic is 101.4085, and the probability of this F-statistic is less than 0.01, indicating that the model is statistically significant. This confirms that the independent variables collectively have a significant impact on the dependent variable. Additionally, the Durbin-Watson statistic of 2.019528 suggests that there is no significant autocorrelation in the residuals, further affirming the reliability of the model.

Figure 3. Stability of parameters in the revenue model

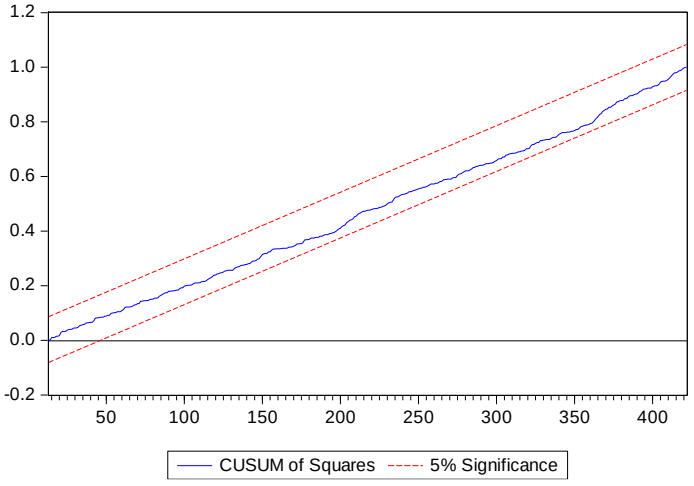


Table 4. Performances of machine learning models

Multi-layer Perceptrons (MLPs)
Mean Absolute Error (MAE): ≈ 0.639
Explained Variance Score: ≈ 0.975
Gradient Boosting Machines
Mean Squared Error (MSE): ≈ 0.518
R2 Score: Approximately 0.979
Mean Absolute Error (MAE): ≈ 0.598
Explained Variance Score: ≈ 0.979

In table 4, two models were compared: Multi-layer Perceptrons (MLPs) and Gradient Boosting Machines. For the MLP model, the Mean Absolute Error (MAE) was approximately 0.639, and the Explained Variance Score was approximately 0.975. These metrics suggest that the MLP model has a relatively low average error in its predictions and explains a high percentage of the variance in the dependent variable. In contrast, the Gradient Boosting Machines demonstrated a Mean Squared Error (MSE) of approximately 0.518, an R2 Score of approximately 0.979, a MAE of approximately 0.598, and an Explained Variance Score of approximately 0.979. The Gradient Boosting model thus appears to outperform the MLP model slightly, as evidenced by lower MAE and MSE values, along with marginally higher R2 and Explained Variance Scores. This indicates a more accurate and consistent prediction of the dependent variable by the Gradient Boosting model.

Figure 4. Feature Importance Comparison between MLP and GBM

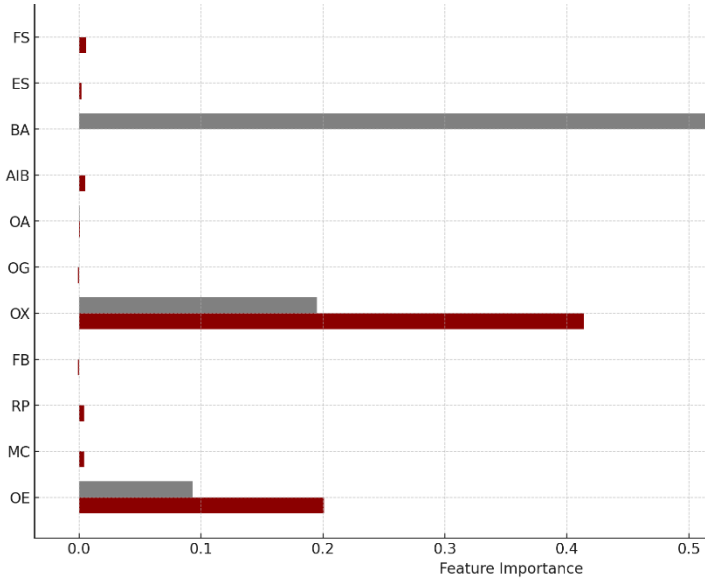
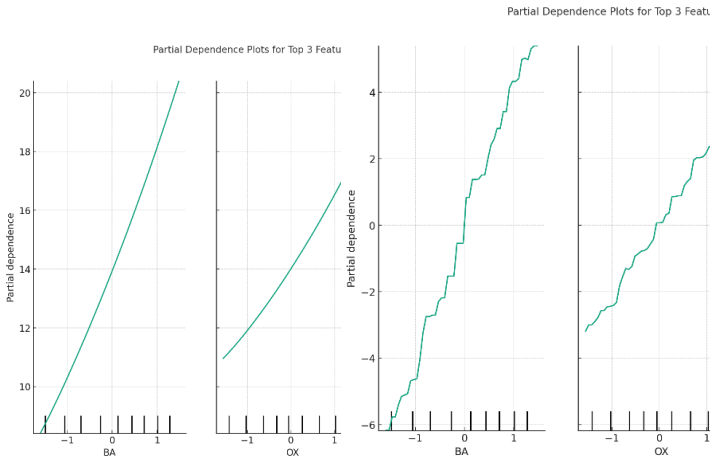


Figure 5. partial dependence of the top 2 significant variables



Both Multi-layer Perceptrons (MLPs) and Gradient Boosting Machines were examined for feature importance using permutation importance. The findings are presented in figure 4 and figure 5. For the MLP model, the variables Business Age (BA), Owner Experience (OX), and Owner Education (OE) emerged as highly important, scoring 1.388, 0.414, and 0.201, respectively. This underscores the pivotal role these variables play in influencing the model's output. Interestingly, other variables like Funding Source (FS), AI-Blockchain Adoption (AIB), Market Competition (MC), Road Proximity (RP), and Exporting Status (ES) had scores less than 0.01, rendering them almost inconsequential in the model's predictive performance. Moreover, Family Business (FB) and Owner Gender (OG) recorded negative importance scores, implying that they could adversely affect the model's accuracy.

Similarly, the Gradient Boosting Machines model also revealed BA, OX, and OE as significantly impactful, but with different scores—0.710 for BA, 0.195 for OX, and 0.093 for OE. In contrast to the MLP model, the Gradient Boosting Machines model displayed an even more pronounced decrease in importance for the other variables; all of them had scores less than 0.001. This suggests that these variables, including Owner Age (OA), Exporting Status (ES), Funding Source (FS), Owner Gender (OG), AI-Blockchain Adoption (AIB), Market Competition (MC), Road Proximity (RP), and Family Business (FB), have negligible influence on the dependent variable when using this model.

The findings indicate that while certain variables like BA, OX, and OE are consistent drivers of predictive performance across both machine learning models, the importance of other variables can vary significantly depending on the modeling technique employed. Particularly, the low or negative feature importance scores for certain variables may suggest that these are not universal influencers of the dependent variable across different modeling approaches.

CONCLUSION

The economic structure of the United States is significantly influenced by the activities of Small and Medium-sized Enterprises (SMEs). These entities are crucial drivers in various sectors such as employment generation, innovative development, and the amplification of the nation's overall economic output. Their role cannot be minimized in the shaping of economic resilience and dynamism. As businesses aim to improve their operational efficacy, the role of technological advancements comes into focus. The incorporation of technology has consistently been identified as a critical element that can positively affect a business's overall performance metrics.

In recent years, emergent technologies such as Artificial Intelligence (AI) and blockchain have presented new pathways for achieving greater operational efficiency and revenue growth. Given these developments, the research in question sought to examine the specific variables that influence annual revenue expansion among SMEs in the United States, concentrating especially on the implications of adopting AI-integrated blockchain systems. To achieve this, the study utilized data collected from 422 American SMEs in the year 2020. Both statistical and machine learning methodologies such as Multiple Regression techniques, Multi-layer Perceptrons, and Gradient Boosting Machines were applied for the analysis.The objective was to examine the relation between multiple independent variables and the growth rate of annual revenue in SMEs.

The variable AI-Blockchain Adoption (AIB) was found to be statistically significant at the 1% level, demonstrating a significant impact on the annual revenue of Small and Medium-sized Enterprises (SMEs) in the United States. Specifically, AIB had a positive coefficient of 0.275703, implying that the adoption of these technologies positively impacts the annual revenue growth. The t-statistic value was 35.03765, far exceeding the thresholds generally used to reject the null hypothesis. This result corroborates the growing body of literature that suggests technology adoption, particularly cutting-edge technologies like AI-blockchain, can offer a competitive advantage. For SMEs, which often lack the resources to invest heavily in R&D or other forms of innovation, adopting existing advanced technologies may serve as an alternative route to improve performance and revenue.

Given that the research specifically pertains to Small and Medium-sized Enterprises (SMEs) in the USA, the findings become particularly relevant for business development agencies, and local governments that aim to foster SME growth. The strong relationship between Business Age (BA), Owner Experience (OX), and Owner Education (OE) with annual revenue indicates the importance of these variables for SME success. In the US economy, where entrepreneurship is often promoted as a route to economic mobility, these results highlight areas that can be prioritized for targeted programs or incentives, such as business longevity and owner skill-building.

Contrarily, the lack of statistical significance in Family Business (FB), Owner Age (OA), and Owner Gender (OG) suggests that demographic-focused policies or family business grants may not be the most efficient routes for revenue generation among SMEs. This is especially critical in a resource-constrained environment where targeting the most impactful variables is necessary. It suggests that broad-brush approaches or policies that aim to universally support all demographic groups or family businesses might not provide the desired impact on SME revenue within the USA.

The other technological and operational variables like Market Competition (MC), and Road Proximity (RP) showed significant variance in their importance depending on the analytical model used. This could mean that, for American SMEs, the relevance of technological adoption and operational factors might vary based on industry, geography, or other contextual factors. Therefore, caution should be exercised before rolling out nationwide initiatives promoting technological adoption without first understanding the nuances specific to various sectors or regions.

The financial variables such as Funding Source (FS) and Exporting Status (ES) also provide a nuanced picture. While they showed statistical significance in one model, their low feature importance in machine learning models suggests their impact on annual revenue could be complex. Given the diverse financial landscapes that American SMEs operate in, varying from self-funded startups to those supported by venture capital or loans, it may be essential to understand how different funding mechanisms interact with other variables to affect revenue.

The emphasis on Owner Experience (OX) and Owner Education (OE) across models advocates for a reevaluation of professional development programs for SME owners. Educational institutions, vocational training centers, and business development agencies can collaborate to create more focused curricula and training programs, which not only improve business skills but also contribute to the overall competency of the American SME sector. This could also involve partnerships with industry bodies to ensure that the education and training are aligned with real-world needs, thereby increasing the likelihood of revenue growth for SMEs.

AIB's feature importance was low, scoring less than 0.01. This contrast in feature importance between traditional statistical methods and machine learning models raises important considerations for American SMEs. While the statistical significance of AIB suggests that investment in AI-blockchain technologies could positively impact revenue, the low feature importance in machine learning models suggests caution. It implies that the positive influence of adopting these technologies may be moderated by other factors that are specific to the individual SME or its operating environment. It suggests that businesses should conduct additional, possibly sector-specific, analyses to better understand how these technologies can be most effectively implemented in their particular context. Given the complexity and costs associated with adopting AI-based blockchain, this nuanced approach will be essential for ensuring that the investment translates into meaningful revenue growth.

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