systems

MDPI

Article

Digital Transformation Through Virtual Value Chains: An Exploratory Study of Grocery MSEs in Mexico

Eva Selene Hernández-Gress *, Alfredo Israel Ramírez Mejía, José Emmanuel Gómez-Rocha and Simge Deniz

Tecnologico de Monterrey, Engineering and Sciences School, Pachuca 42080, Hidalgo, Mexico; aisrael.ramirez@tec.mx (A.I.R.M.); emmanuel.gr@tec.mx (J.E.G.-R.); a008347789@tec.mx (S.D.)
* Correspondence: evahgress@tec.mx

Abstract

This study explores the readiness of Micro and Small Enterprises (MSEs) in Mexico, specifically grocery stores, to implement the Virtual Value Chain (VVC) through Information and Communication Technologies for Development (ICT4D). A mixed-methods approach was used, combining diagnostic tools, structured surveys, and interviews. Quantitative data were analyzed using descriptive statistics, correlation analysis, and machine learning to identify digital adoption patterns. The results indicate that limited technology adoption remains the main obstacle to VVC integration. Significant associations were found between digital engagement and the age and educational level of store managers. Key digital gaps persist in inventory control, supplier coordination, and demand forecasting. Although machine learning models did not significantly outperform baseline predictions on willingness to adopt technology, the findings emphasize the potential of targeted training and accessible mobile solutions. The study proposes a new diagnostic and predictive framework to assess VVC readiness in low-resource contexts. It shows that ICT, when strategically aligned with business operations and paired with adequate training, can enhance sustainability and livelihoods. Although the study is limited to one geographic area and one business sector, it offers a foundation for scaling similar initiatives. The findings support context-sensitive strategies and capacity-building efforts tailored to the realities of MSEs in emerging economies.

Keywords: micro and small enterprises (MSEs); virtual value chains (VVC); grocery retail; ICT for development; machine learning

Academic Editors: Towfique Rahman and Syed Mithun Ali

Received: 1 August 2025
Revised: 23 September 2025
Accepted: 25 September 2025
Published: 27 September 2025

Citation: Hernández-Gress, E.S.; Mejía, A.I.R.; Gómez-Rocha, J.E.; Deniz, S. Digital Transformation Through Virtual Value Chains: An Exploratory Study of Grocery MSEs in Mexico. *Systems* **2025**, *13*, 849. https://doi.org/10.3390/systems13100849

1. Introduction

Micro and Small Enterprises (MSEs), especially family-owned ones, rely heavily on the entrepreneurial and managerial skills of their owners [1]. In Mexico, enterprises are classified by employee count and annual sales: micro-enterprises have 1–10 employees, while small enterprises have 11–30 in commerce or services and 11–50 in manufacturing, with annual sales limits of 4 million MXN for micro-enterprises and 4–100 million MXN for small enterprises [2]. MSEs face challenges such as limited education, access to technology, capital, and expertise, often needing external support [1,3,4]. Given their prevalence, the study of MSEs is crucial to understanding economic development in emerging economies.

Approximately 90% of companies in Latin America are classified as micro firms, mainly in the wholesale and retail sectors [5]. In 2020, Mexico had around 4.7 million micro businesses. These firms contribute significantly to employment in commerce and services, while large companies dominate manufacturing. However, despite their quantitative

importance, research on MSEs, particularly in commerce, remains limited, restricting our understanding of their strategies compared to larger firms.

Following COVID-19, over 50% of Mexican SMEs still relied on traditional sales methods or short-term online strategies. For non-online SMEs, 35% emphasized digital communication (social networks, search engines, ads), and 16% aimed to digitize customer services [6]. Also, more than 60% of businesses in Mexico close within their first three years, largely due to cash flow difficulties, according to the National Institute of Statistics and Geography (INEGI). This evidence highlights persistent barriers to digital adoption, which have become a critical factor in resilience and competitiveness in the post-pandemic context [7].

Despite the growing body of research on Information and Communication Technologies (ICTs) and their role in development, few studies explore how MSEs adopt and benefit from ICTs in their value chains. Existing ICT4D literature often focuses on larger firms, overlooking MSEs, which face unique constraints in technology adoption. Moreover, the Virtual Value Chain (VVC) remains underexplored in MSE contexts, particularly in Latin America. This represents a clear research gap.

This study addresses the gap by asking: How does the adoption of the Virtual Value Chain (VVC) influence the operational practices and digital development of Micro and Small Enterprises (MSEs) in Mexico? By focusing on underrepresented grocery microenterprises, we contribute to ongoing ICT4D debates on digital inclusion, technological capability building, and grassroots innovation.

This research develops and applies a methodology to diagnose the level of VVC integration in MSEs. The methodology assesses essential factors to support these businesses in improving operations and ensuring survival through digital development, focusing on grocery stores in Pachuca, Hidalgo. Although the VVC concept is beneficial for enhancing SME operations, it is underexplored in MSE contexts.

It is important to note that this study is limited in scope to grocery SMEs in Mexico. These businesses primarily operate within downstream segments of the supply chain. The analysis does not extend to the entire value chain, which remains beyond the focus of this research.

This paper offers three main contributions to the ITD literature:

1. To the best of the author's knowledge, this is the first known empirical study on VVC adoption among MSEs.
2. It introduces an original instrument for assessing VVC stages in low-tech businesses.
3. It presents quantitative findings based on field data, analyzed through statistical and machine learning methods.

Finally, the paper is organized as follows: Section 2 presents the literature review, which covers the theoretical framework, including ICT for Development (ICT4D) and the Virtual Value Chain, as well as an overview of MSEs worldwide, their challenges, opportunities, and models. It also includes research on MSEs in Mexico and concludes with field studies on Virtual Value Chains (VVC). Section 3 outlines the methodology, explaining the context, instrument design, data collection, and analysis. Section 4 presents the results and discussion, and Section 5 provides the conclusions.

2. Literature Review

In recent decades, research in Information and Communication Technologies for Development (ICT4D) has explored how digital technologies can foster economic growth, enhance social inclusion, and support human development in low-resource settings. ICT has enabled small and medium enterprises (SMEs) to become more integrated and operate more efficiently; however, developing economies rarely have access to these resources [8–10].

According to Heeks [11], the developmental impact of ICT depends not only on access and infrastructure, but also on the relevance of these technologies to local needs and the capacity of organizations to absorb and integrate them. It also depends on social responsibility rather than the type of technology used. This perspective is particularly important in the context of Micro and Small Enterprises (MSEs), which often operate under significant constraints in capital, knowledge, and digital skills.

ICT4D studies show that technology only makes a real difference when it matches local needs and operates within existing social and institutional structures [12,13]. While early ICT4D literature focused on large-scale infrastructure and e-government programs, more recent studies have shifted attention to bottom-up, grassroots innovation, especially among small firms and informal actors [14,15]. However, little research has addressed issues related to small enterprises adopting ICT [16]. In these contexts, digital technologies can enable new forms of value creation, participation, and resilience.

In the context of ICT4D, the VVC model offers a promising framework for examining how MSEs in emerging economies can leverage ICTs to expand market access, optimize operations, and strengthen customer relationships. The VVC, developed by Weiber and Kollmann [17], provides a conceptual lens to understand how digital information can be used not just to support traditional value chains, but also to transform and virtualize business processes. Unlike the physical value chain, the VVC captures the generation, processing, and distribution of digital content as a source of economic value. This includes activities such as data collection, online interaction with customers and suppliers, and digital service delivery. However, as noted by Thapa and Sæbø [18], empirical studies of ICT use in underprivileged communities and among disadvantaged stakeholder groups remain scarce.

This study positions itself at the intersection of ICT4D theory and VVC research, aiming to investigate whether and how MSEs in Mexico, particularly grocery stores, are adopting elements of the VVC in their daily operations. In doing so, it contributes to ongoing scholarly debates on the developmental role of ICTs and addresses a critical empirical gap in the literature.

As this study focuses on exploring the potential of MSEs in Mexico, the literature review is divided into three sections: (1) MSEs worldwide, (2) MSEs in Mexico, and (3) studies on the Virtual Value Chain. It is important to note that the academic literature specifically addressing MSEs is limited. Therefore, selected studies on SMEs are included when relevant, ensuring that their inclusion does not compromise the generalizability or relevance of this research.

2.1. MSEs Worldwide

MSEs face challenges in adopting technologies. Bag and Pretorius [19] identified technology as a critical barrier, while Culot [20] emphasized data management and production technologies. In Ethiopia, Abagissa [21] highlighted the need for education, credit, and incentives. Funding constraints impact small service businesses [22]. Digitalization holds transformative potential for regional development [23], and technologies like big data, IoT, blockchain, and AI can enable supply chain digitalization in India [24].

In Latin America, Velázquez-Martínez and Tayaksi [8] linked supply chain management to MSE productivity. Chatterjee [25] suggested blockchain and AI for post-COVID-19 performance in India, and Trinugroho [26] found that digital adoption improved business in Indonesia. Mikhaylova et al. [27] examined digital strategies and Fintech, García-Salirrosas [28] presented the PERVAINCONSA Scale for online retail metrics in developing countries, and Garay-Rondero [29] proposed a digital supply chain model for mass customization.

The growing attention to the digital transformation of small businesses in emerging economies aligns with current ICT4D discussions, particularly regarding how technological capabilities contribute to inclusive economic growth [11,12]. A key question in this debate is whether ICTs directly drive development or whether they serve as enablers for operational improvements that create competitive advantages, such as through the implementation of VVC [11]. If ICTs are considered development drivers in themselves, then disparities in access often reflect structural inequalities based on location, age, gender, and other socio-economic factors. Nevertheless, most of these studies focus on SMEs or larger firms, leaving a significant gap in our understanding of how microenterprises engage with and benefit from ICT-based value creation.

2.2. MSEs in Mexico

In Mexico, most research on Small and Medium Enterprises (SMEs) has focused on identifying challenges and success factors, while studies specifically addressing Micro and Small Enterprises (MSEs) remain scarce and lack formal models. Tanoira and Valencia [30] emphasize the importance of knowledge transfer in Yucatan's support programs, noting finance and sales as key weaknesses [31]. Aguilar [31] also cites customer acquisition, staffing, and financial constraints as major issues. Hernández-Gracia and Duana-Avila [32] call for stronger entrepreneurial orientation and financing access. Success factors include economic knowledge and dynamism [33,34].

Digitalization strategies have been documented mainly for medium-sized enterprises, while MSEs remain underrepresented in both academic studies and national innovation policies. Mexican MSEs face ongoing challenges in innovation, operations, management, marketing, and technology, with no comprehensive studies on their supply chain or technological needs.

2.3. Virtual Value Chain

Technology-based companies are well-positioned for growth in competitive markets. Autio [35] suggests that small tech firms that leverage technology can be seen as smaller versions of large companies. The Virtual Value Chain (VVC), introduced by Weiber and Kollmann [17], allows companies to enhance their traditional market presence through effective digital activities. The VVC involves similar activities to the traditional value chain but uses digital information to unlock new market opportunities [17], as can be observed in Figure 1. Global market access enables small companies to compete with large firms by sharing information across suppliers, distributors, manufacturers, and retailers [36,37]. The Internet supports this information exchange, bolstering B2B and B2C relationships [38].

The Virtual Value Chain (VVC) offers advantages such as increased efficiency, ease in offering products and services, and better insights into customer needs [36,37]. It also helps businesses predict trends [37]. However, challenges include the need for creativity, flexible payment options, customer integration, and internet access [38]. Other issues involve knowledge management [39], security and privacy concerns, cultural factors, and complex software applications. Various case studies on VVC, as shown in Table 1, examine methodologies across micro, small, and medium enterprises.

Table 1 shows that the studies primarily focus on SMEs, with sample sizes ranging from 1 to 429 companies. Some studies aim to understand the client's perspective, while others explore factors influencing the Virtual Value Chain (VVC). Berrone [54] focuses on MSEs, examining whether human capital, innovation, and the use of own capital affect company performance. However, this study does not specifically address these factors in the context of the VVC.

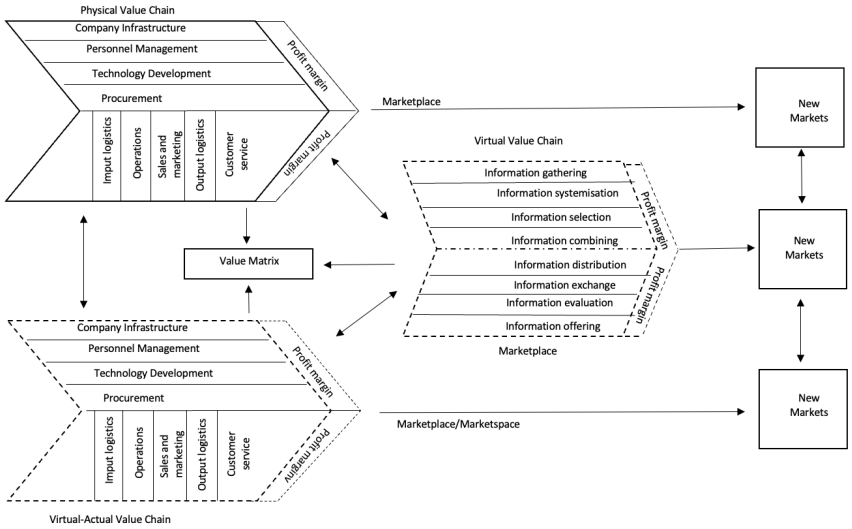

Figure 1. Virtual Value Chain. Source: Weiber and Kollmann [17].

Table 1. Field studies in VVC.

Author	Location	Methodology	Case Study	Purpose
Hongmei and Jincheng [40]	Thailand	Survey and analytic hierarchy process	Travel agencies (SMEs)	Build a VVC for travel agencies
Ramantoko et al. [41]	Indonesia	340 questionnaires with 9 dimensions	SMEs in three different regions in Indonesia.	Build a digital capability model, using the value chain analysis framework.
Corso et al. [39]	Piedmont and Lombardy	Questionnaire and cluster analysis	127 Italian SMEs	Contribute to sustainable organizations in terms of technology
Piscitello and Sgobbi [42]	Prato Italy	Empirical analysis and interviewing	Textile industry (12 SMEs)	Examining whether the industries are taking advantage of the e-business opportunities.
Arrifin et al. [43]	Malaysia	Focus Group Approach	Cattle beef and halal production (SMEs)	The effectiveness of VVC in cattle beef production
Fromhold-Eisebith et al. [44]	Germany	Workshop with 40 textile industries	Textile industries	Enablers' identification of Industry 4.0 in the German textile industry
Gyenge et al. [45]	Hungary	Surveys, clusters, and discriminant analysis	SMEs	Generate directions for SMEs to benefit from communications changes
Hermawan et al. [46]	Indonesia	Multivariate statistical study	168 consumers of online SMEs	To build an e-mail design concept that elaborates the physical and virtual value chain.
Hu et al. [47]	United States of America	Text mining data approach	0.72 million online customer reviews	To understand the Virtual Queue
Taherinia et al. [48]	Iran	Factor analysis and structural equation modeling	50 experts in marketing, management, e-commerce, human resources, and managers in Iran	Evaluate factors that influence the evolution of VC.
Zumstein et al. [49]	Switzerland	Surveys and descriptive statistics	365 online retailers	Compare practice before and after the COVID-19 station.
Liu et al. [50]	China	Collection, processing, transmission, storage, and feedback	1 company	Understand the path in the Virtual Chain considering digital technology.

Table 1. *Cont.*

Author	Location	Methodology	Case Study	Purpose
Eng et al. [51]	America, Europe, Africa, and Asia	Surveys, interviews, and hypothesis tests	500 companies of different sizes that use logistic apparel retailers' supply chains.	Understand ambidexterity and wireless information technology (IT) for enhancing innovative capacity.
García-Salirrosas et al. [28]	Perú, México and Colombia	KMO and Barlett test	238 questionnaires from users of online clothing stores	Validate an instrument design to measure Variable Value perception, purchase intention, trust, and satisfaction.
Omoruyi and Makaleng [52]	South Africa	Quantitative study and SMART PLS 3.0	439 SMEs	To determine if the supply chain has a disruption after COVID-19.
Sharma et al. [53]	India	30 experts from the electronic manufacturing of SMEs	Identify barriers for SMEs in adapting to the technologies of Industry 4.0	Fuzzy analytic hierarchy and PROMETHEE.

2.4. Research Gaps and Objectives

All previous studies have focused on the Virtual Value Chain (VVC) in SMEs, with limited attention to MSEs or Mexico's retail sector. García-Salirrosas [28] included Mexico in their research alongside Peru and Colombia, concentrating on online clothing stores. Gupta and Ramachandran [55] studied retailers in emerging economies, suggesting that differences between traditional and tech-focused retailers require further investigation. Others, such as Hwang and Kim [56] and Roth and Rosenzweig [57], highlighted a gap in quantitative and empirical studies on the topic. Moreover, Sharma and Dutta [58] found that the COVID-19 pandemic shifted retail strategies toward omnichannel models, requiring technological convergence, customer focus, and internal reorganization. Compared to previous studies, this study investigates the digital transformation and processes within the VVC, particularly for MSEs in the retail sector.

Although digitalization has been highlighted as a key element of the ITC4D [11], most frameworks focus on national or large-firm adoption, not the micro-level experiences of small grocery businesses. The studies that examined grocery retailing within the Virtual Value Chain (VVC) framework are scarce. This is particularly relevant given that digital transformation has been shown to positively influence business models [59], and digitalization further enhances that flexibility, enabling the company to better adapt to a changing or uncertain environment [60]. Weyer [61] observed that, due to the broad spectrum of available technological innovations and the limited resources characteristic of small businesses, it remains unclear which technologies should be prioritized or at which stages of the VVC they should be implemented. Similarly, Bierganz [62], in his doctoral dissertation, analyzed the challenges associated with leveraging the VVC in the UK grocery retail sector.

These gaps underscore the need to better understand how ICTs can promote development at the microenterprise level. This research aims to diagnose MSEs, with a particular focus on grocery stores in Mexico, to assess whether they are currently integrating technology into their business operations and whether they possess the necessary resources to implement the VVC. Our review of the existing literature revealed a lack of studies addressing the application of the VVC in the context of MSEs in Mexico, with emphasis on the retail grocery sector. As our main contribution, we have developed diagnostic tools and a survey instrument specifically designed to fill this gap. These tools not only support the evaluation of technological adoption among Mexican MSEs but are also adaptable for use in similar MSE contexts internationally.

Based on the identified research gaps, the objectives of this study are captured in the following research questions:

RQ1: Do grocery stores in Mexico possess sufficient technological advancements to implement VVC with their suppliers and customers?
RQ2: Is the ability to generate VVC positively correlated with the cultural and behavioral issues of grocery store managers in Mexico?
RQ3: Given specific characteristics of grocery store managers, can we predict their willingness to adopt technological changes?

3. Methodology

The scope of this research is restricted to grocery MSEs in Pachuca, Hidalgo, Mexico. These enterprises represent downstream actors in the supply chain, and the study does not attempt to cover the entire value chain.

In this study, the methodology developed by Sampieri [63] was adapted to answer the research objectives, as detailed in Figure 2. Summarizing the methodology, from the fundamental redefinitions of the final version, it begins with (1) designing the instrument, followed by (2) data collection, and concludes with (3) data analysis and machine learning predictions. Detailed measurements, estimation methods, and results are provided in the subsequent subsections.

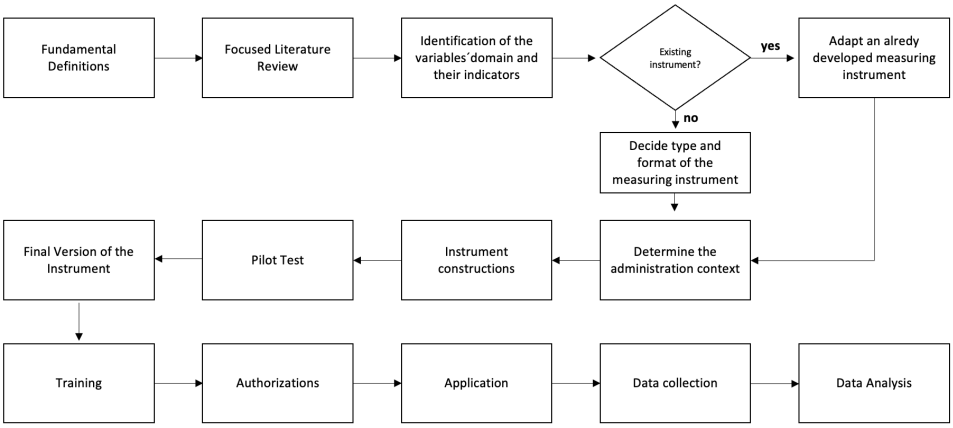

Figure 2. Methodology for study. Source: Adapted from Sampieri [63].

3.1. Design of the Instrument

This design was carried out in two phases. The first phase involved a qualitative analysis, where the study context was reviewed, and 10 MSEs in the retail sector were interviewed to understand their needs. The second phase consisted of a literature review to identify the areas to be included in the survey.

3.1.1. Context of the Study

Pachuca de Soto, the capital of Hidalgo, Mexico, covers 20,813 km^2 in the center-east of the country. In 2022, Hidalgo's economically active population was 1.46 million, with retail trade accounting for 45.6% of economic units, 71.8% of which are in informal employment. According to INEGI [64], there are 14,753 grocery stores in Hidalgo, with 1842 in Pachuca, highlighting their economic significance.

Before the research, 10 businesses were visited for interviews and process observations. Most were newly opened and financially unstable, facing challenges like low shelf fill levels and disorganization. To remain competitive, they sourced products from wholesalers or directly from large companies. Shelf organization was based on expiry dates but adjusted for supplier requests. While some stores used computer systems and barcode readers,

inventory tracking was often inaccurate. The customer base primarily consisted of local residents, emphasizing the role of personal relationships in sales and payment methods.

Additionally, inconsistent order quantities made it difficult to predict supplier orders. Most orders were placed in-store or via phone and WhatsApp, with store owners or 1–2 employees managing all operations. Due to a lack of financial support, they aimed to minimize costs, sometimes renting taxis and vehicles to avoid stockouts. Suppliers often faced difficulties finding parking for their vehicles. Figure 3 illustrates the supply chain, while Table 2 summarizes grocery store operations.

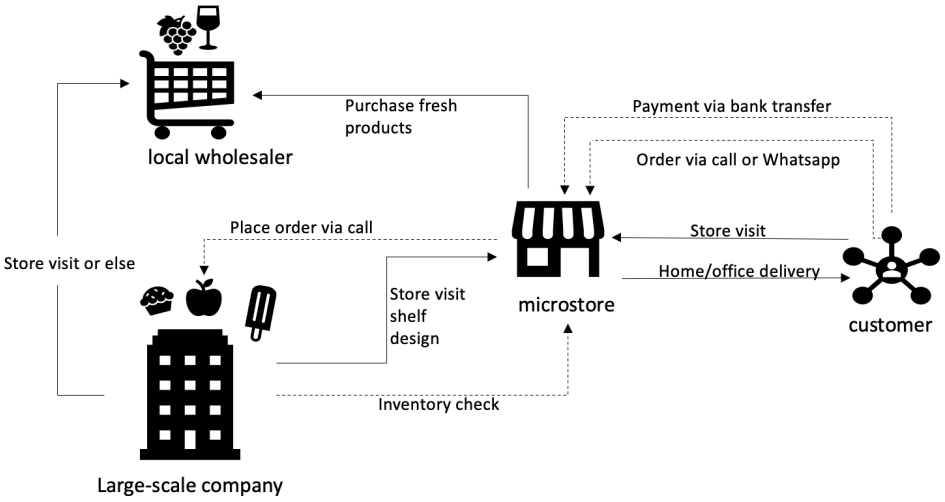

Figure 3. Supply chain network diagram of a micro store. Source: Own elaboration.

Table 2. Details of company infrastructure, personnel management, technology development, and procurement processes.

Dimension	Area	Description
Company infrastructure	Space	4×5 m^2 or less, no additional space
	Equipment	refrigerators and shelves
	Parking	no parking area
Personnel management	Management	the owner themselves or family members
	Employment	1–2 external employees
	Operations	assistance from suppliers (e.g., to accommodate shelves, etc.)
Technology (ICT4D)	Inventory tracking	computers (<10% of stores), barcode readers, mobile phones for calls and SMS to suppliers
	Payment	electronic payment with credit card, bank transfer
	CRM	mobile phones with Internet connection
Procurement	Sales tracking	notebook for tracking sales (<15% of stores)
	Purchase tracking	no record of available stock quantity
	Payment terms	mostly defined by large-scale supplier companies
	Products	preferably more economical and fresh products
	Supplier selection	preferably wholesalers (e.g., Walmart, Sam's, City Club, Central, etc.) or large-scale enterprises (e.g., Bimbo, Coca-Cola, etc.)
	Delivery terms	owned vehicles (e.g., automobiles or pick-up trucks), rented vehicles (e.g., taxi) or suppliers' choice (e.g., truck, van, etc.)

3.1.2. Measuring Instrument

To design the survey, a literature review was conducted, particularly focusing on VVC, identifying common areas across various studies. The survey was designed to evaluate eight areas; the questions are presented in Appendix A:

Profile: According to Piscitello and Sgobbi [42] and Gurdur [65], key variables include name, number of employees, working hours, and turnover.

Managerial characteristics: Gurdur [65], Peutz and Post [66], and Bierganz [62] identified name, gender, age, education level, and adaptability to change as important variables.

Personal management: Hongmei and Jincheng [40] and Zumstein et al. [49] highlighted teamwork, adaptability to change, learning, and organizational culture as relevant factors.

Company infrastructure: Merchán [67] emphasized the importance of shelf space, inventory, and transportation (e.g., van, car, motorcycle, bicycle) for SMEs.

Procurement: Gurdur [65], Zumstein et al. [49], and Hongmei and Jincheng [40] stressed the importance of information on top-selling products, inventory, daily sales, demand planning, and access to supplier data.

Technology: Corso et al. [39], Piscitello and Sgobbi [42], Elkhouly et al. [68], and Naimi-Sadigh et al. [69] identified key indicators such as internet access, Wi-Fi, sales and inventory systems, and devices like computers and mobile phones [12].

E-commerce: Zumstein et al. [49], Gyenge [45], Elkhouly et al. [68], and Bierganz [62] emphasized the significance of e-payment methods, websites, social media platforms, telephone sales, and digital marketplaces.

Challenges to introduce technology: Winkler [70], Peutz and Post [66], and Wasan et al. [71] identified challenges in technology adoption, including external support, government assistance, training, and issues related to payments and taxes. Additionally, Heeks [11] emphasized that ICT4D outcomes are influenced by contextual factors such as location, age, gender, and education level.

A self-administered questionnaire was chosen, and a pilot test was conducted with 30 randomly selected grocery stores. The survey achieved a Cronbach's alpha value of 0.8638, validating its reliability. The final version of the instrument is available in a repository [72] under surveyfinalingles.docx.

3.1.3. Sample Size

To ensure a representative sample, the formula described by Devore [73] was used. Inclusion criteria required grocery stores to be located in Pachuca, with respondents being company owners and of legal age. The formula is presented in Equation (1).

$$n = \frac{z^2 N \sigma^2}{(N-1)e^2 + z^2\sigma^2} \quad (1)$$

The sample size n was determined using the formula described by Devore [73], where N is the population size (1842 grocery stores in Pachuca, according to INEGI [64], σ is the standard deviation (typically assumed as 0.5 if unknown), z is the confidence level (1.96 for 95% confidence), and e is the acceptable error limit (5% for this study). Using (1), a sample size of 233 enterprises was obtained.

The sampling procedure was conducted with the support of undergraduate students, each of whom was assigned to distribute approximately 5 surveys. Students were instructed to approach grocery microenterprises located near their place of residence and to select stores in a non-systematic manner, avoiding repeated chains or pre-selected businesses. This procedure introduced a convenience component but also incorporated a random-like element at the local level, since students did not target specific stores a priori. In total, 233 surveys were distributed, of which 187 valid responses were obtained, corresponding to a non-response rate of approximately 19.7%

3.2. Data Analysis

Data analysis will be conducted in four steps: (1) data visualization using bar and pie charts, (2) descriptive statistics for proportion inferences, (3) inferential statistics with confidence intervals to estimate population fluctuations, and (4) relationship analysis between variables using Pearson correlation, chi-square test of independence, and ANOVA.

3.2.1. Data Visualization

To better understand the collected data, visualizations were created using matplotlib in Python 3.10. An example, shown in Figure 4, corresponds to question 32 in the survey. The complete set of visualizations is available in the repository under surveyresults.docx [72].

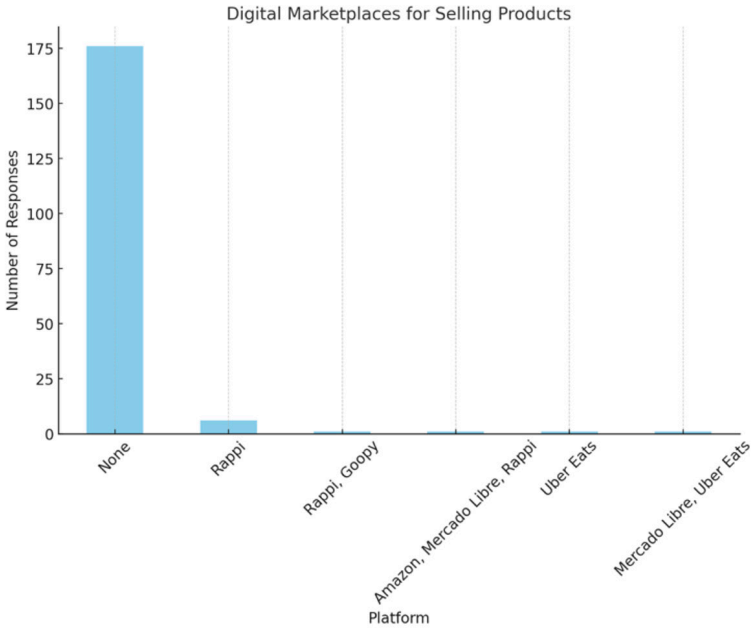

Figure 4. Data visualization. Source: Own elaboration.

3.2.2. Descriptive and Inferential Statistics

The descriptive statistics using Minitab 19.0, for the 187 respondents, reveal the following:

Profile: 60.96% of businesses have been operating for over 5 years (95% CI: 53.97, 67.95). 52.41% operate 8-12 h daily (95% CI: 45.25, 59.56).

Managerial characteristics: 33.16% of managers are aged 30-40 years (95% CI: 26.40, 39.91). 44.39% of managers have a high school education (95% CI: 37.26, 51.50). 47.06% of respondents are men (95% CI: 39.90, 54.21), and 52.94% are women (95% CI: 45.78, 60.09). 62.57% are willing to implement changes (95% CI: 55.63, 69.50). 53.4% expect to make changes within 6 months (95% CI: 46.32, 60.62).

Personnel management: 61% of businesses have staff (95% CI: 53.97, 67.95), with 60.42% having 2-5 employees (95% CI: 53.42, 67.44). 57.75% of employees collaborate (95% CI: 50.67, 64.83), and 57.21% can adapt to changes in under 3 months (95% CI: 50.13, 64.31). 52.94% offer training (95% CI: 45.79, 60.10).

Company infrastructure: 33.16% organize shelves by product type (95% CI: 26.41, 39.90). 57.22% receive merchandise directly (95% CI: 50.12, 64.31), and 29.41% use their own vehicles for transportation (95% CI: 22.88, 35.94). 77.01% have a car or small truck (95% CI: 70.97, 83.04). 68.98% lack a loading area (95% CI: 62.35, 75.61).

Inventory: 47.06% lack additional storage space, and 68.98% do not forecast sales (95% CI: 62.35, 75.61). 42.16% buy 10–30% of items from wholesalers. 55.1% do not track inventory (95% CI: 48.49, 62.73).

Technology: 60.43% have a cell phone (95% CI: 53.42, 67.44), and 36.90% have a computer (95% CI: 29.98, 43.81). 67.91% have internet access (95% CI: 61.22, 74.61). 44.92% lack a system for sales/inventory (95% CI: 37.79, 52.04), and 60.87% record sales manually (95% CI: 53.42, 67.44).

E-commerce: 58.82% accept electronic payments (95% CI: 51.77, 65.87), 66.2% have card terminals (95% CI: 59.53, 73.08), and 31.2% accept bank transfers (95% CI: 24.89, 38.21). 95.18% lack a website (95% CI: 92.11, 98.25), and 93.58% have never sold on platforms like Rappi or Uber Eats (95% CI: 90.07, 97.09). 71.66% have never sold via WhatsApp, phone, or Facebook (95% CI: 65.20, 78.12).

Challenges to introduce technology: 88.2% have never received government support (95% CI: 83.62, 92.85). 51.33% do not need help digitizing (95% CI: 44.17, 58.50), while 48.66% do (95% CI: 41.50, 55.82). The most needed assistance is training (48.96%) and infrastructure (47.92%).

3.2.3. Relationship Between Variables

The correlation matrix in Figure 5 highlights key relationships between demographic factors and business attributes. Significant associations (p-value < 0.05) include a strong link between Electronic Payment Methods and Educational Level, as well as between a Computerized Inventory System and Educational Level. Although no high correlations are found, ANOVA is used to explore the impact of the manager's profile on these variables. Additionally, one of the strongest correlations is observed between Sales on digital media and Sales on social media.

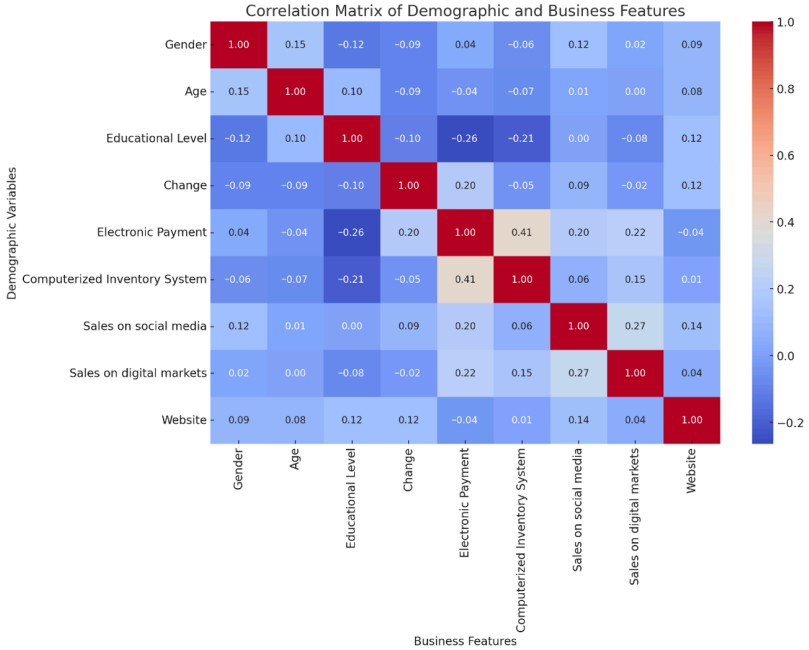

Figure 5. Matrix correlation. Source: Own elaboration.

To address RQ2 (Is the ability to generate VVC positively correlated with the cultural and behavioral issues of the MSE's managers in Mexico?), a variance analysis (ANOVA) was conducted, and the following relationships were tested:

Change vs. gender change and education level: ANOVA was applied to questions 5 (Gender, age, and educational level of the manager) and 6 from the database using Minitab 19). The results can be seen in Table 3. For the ANOVA, we tested the homogeneity of variances assumption using Levene's test (p = 0.997), which indicated that the groups did

not differ significantly in variance. This confirmed that the assumption of homogeneity was met, supporting the validity of the ANOVA results.

Table 3. Analysis of variance change vs. gender, age, and education level.

Source	DF	Adj SS	Adj MS	F-Value	*p*-Value
Regression	8	3.5645	0.4456	1.97	0.052
Gender	1	0.5833	0.5833	2.58	0.110
Age	4	2.0771	0.5193	2.30	0.061
Educational Level	3	1.2315	0.4105	1.82	0.146
Error	178	40.2323	0.2260		
Lack-of-Fit	22	2.8146	0.1279	0.53	0.957
Pure Error	156	37.4177	0.2399		
Total	186	43.7968			

In addition to the parametric ANOVA, we performed a robustness check using a rank-based factorial ANOVA (Conover–Iman approach). The response variable was transformed into mid-ranks and analyzed with a three-factor General Linear Model in Minitab 19. The results were consistent with the parametric ANOVA, showing no significant changes in the interpretation of factor effects (Gender: $p = 0.110$; Age: $p = 0.061$; Educational Level: $p = 0.146$). This analysis supports the robustness of our conclusions against violations of normality assumptions. It is important to mention that this analysis was made in every ANOVA.

The analysis indicates no statistically significant association between Educational Level and the willingness to implement Change, with a *p*-value of 0.324, above the 0.05 alpha level. Similarly, Change is not related to Gender, Age, or Educational Level at the 0.05 alpha level. However, the *p*-value for Age suggests a potential trend that might become significant with a larger sample size or different age group classification.

For electronic payments, ANOVA results show that only the manager's educational level affects the outcome, with a *p*-value of 0.00, as is observed in Table 4. Neither gender nor age has an impact. The mean effects plot in Figure 6 reveals that managers with a bachelor's or graduate degree are more willing to adopt electronic payments

Table 4. Analysis of variance, electronic payment vs. gender, age, and educational level.

Source	DF	Adj SS	Adj MS	F-Value	*p*-Value
Regression	8	6.0673	0.75842	3.44	0.001
Gender	1	0.0049	0.00493	0.02	0.881
Age	4	1.3911	0.34778	1.58	0.182
Educational Level	3	4.7396	1.57986	7.17	0
Error	178	39.2268	0.22038		
Lack-of-Fit	22	4.3914	0.19961	0.89	0.603
Pure Error	156	34.8354	0.2233		
Total	186	45.2941			

The analysis in Table 5 shows that both age and educational level significantly impact the likelihood of having a computerized inventory system (Questions 5 and 26 are utilized for this analysis), with *p*-values of 0.009 and 0.011, respectively. The main effects plot in Figure 7 reveals that younger individuals are more likely to use technology frequently for managing a computerized inventory.

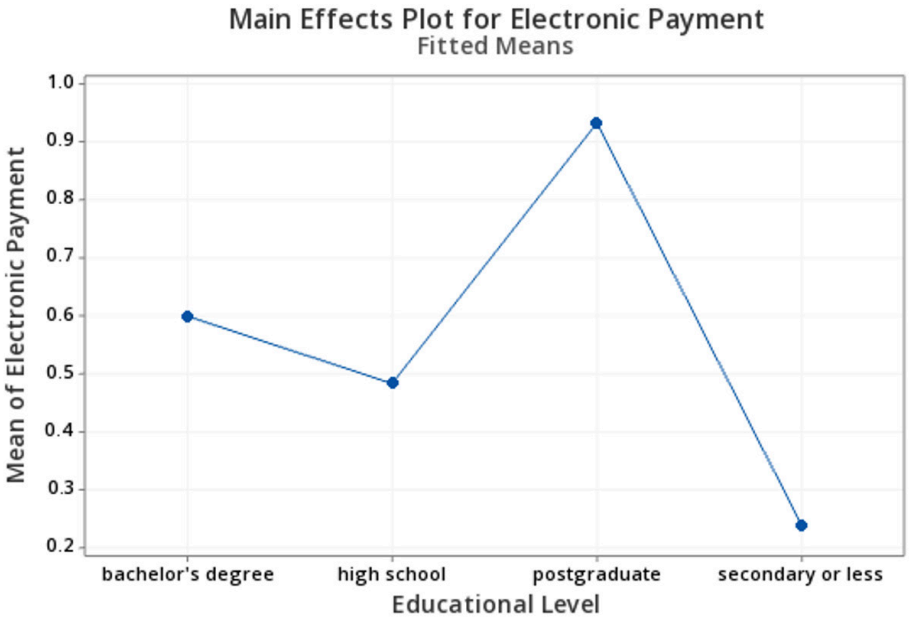

Figure 6. Main effect plot: electronic payment vs. educational level.

Table 5. Analysis of variance, computerized inventory vs. gender, age, and educational level.

Source	DF	Adj SS	Adj MS	F-Value	*p*-Value
Regression	8	5.8838	0.7355	3.79	0
Gender	1	0.1924	0.1924	0.99	0.32
Age	4	2.7114	0.6779	3.5	0.009
Educational Level	3	2.2185	0.7395	3.82	0.011
Error	178	34.5012	0.1938		
Lack-of-Fit	22	6.2854	0.2857	1.58	0.057
Pure Error	156	28.2158	0.1809		
Total	186	40.385			

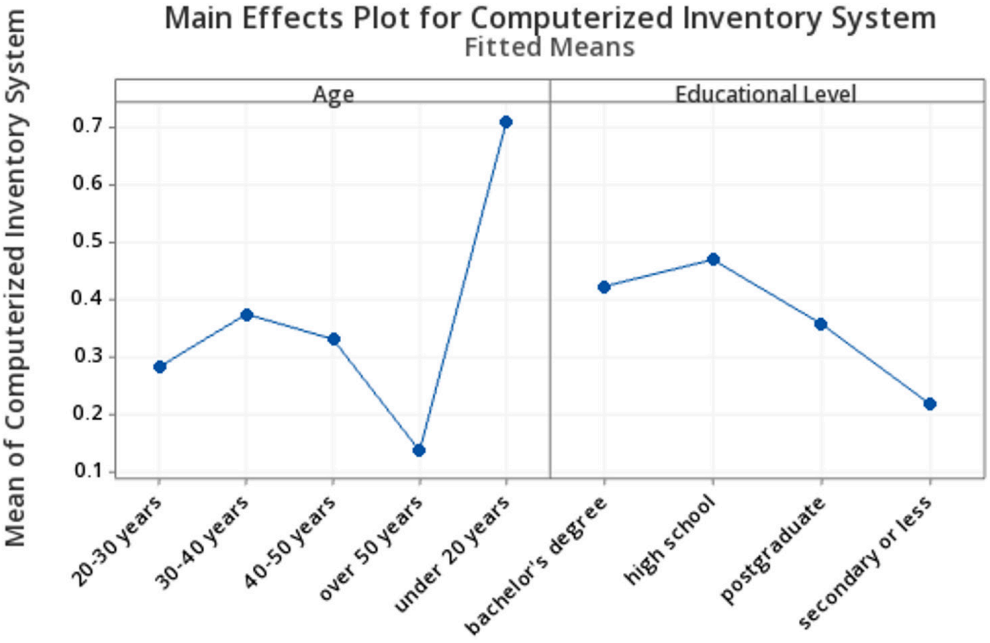

Figure 7. Main effect plot: computerized inventory vs. age and educational level.

For sales on social media regarding payment vs. gender, age, and educational level, Table 6 shows that none of the profile variables affect sales on social media platforms like Facebook and WhatsApp. Questions 5 and 31 were used for analysis.

Table 6. Analysis of variance, sales on social media: payment vs. gender, age, and educational level.

Source	DF	Adj SS	Adj MS	F-Value	*p*-Value
Regression	8	0.6252	0.07815	0.37	0.934
Gender	1	0.4952	0.495226	2.36	0.126
Age	4	0.0227	0.005664	0.03	0.999
Educational Level	3	0.0568	0.018926	0.09	0.965
Error	178	37.3534	0.209851		
Lack-of-Fit	22	5.9594	0.270882	1.35	0.15
Pure Error	156	31.394	0.201244		
Total	186	37.9786			

For sales on digital markets vs. gender, age, and educational level, in this case, questions 5 and 32 were used. Again, the level of education is the only variable that affects the outcome variable, as is observed in Table 7. Figure 8 shows that administrators with postgraduate degrees are the most determined to make sales on platforms like Rappi, Uber, etc.

Table 7. Analysis of variance, sales on digital markets vs. gender, age, and educational level.

Source	DF	Adj SS	Adj MS	F-Value	*p*-Value
Regression	8	0.7281	0.09102	1.54	0.145
Gender	1	0.0127	0.01268	0.21	0.643
Age	4	0.0912	0.02281	0.39	0.818
Educational Level	3	0.6514	0.21714	3.68	0.013
Error	178	10.5018	0.059		
Lack-of-Fit	22	1.7416	0.07917	1.41	0.117
Pure Error	156	8.7602	0.05615		
Total	186	11.2299			

The analysis of the website variable, using questions 5 and 30, shows that both age and educational level significantly affect the likelihood of having a website, with *p*-values of 0.000 and 0.099, respectively, as is observed in Table 8. The main effects plot in Figure 9 reveals that managers with postgraduate degrees are most likely to have a website. A chi-square test indicates that age is related to both the computerized inventory system and sales on websites, while educational level is associated with the computerized inventory system and sales on digital markets. Gender does not show a significant relation to any variable.

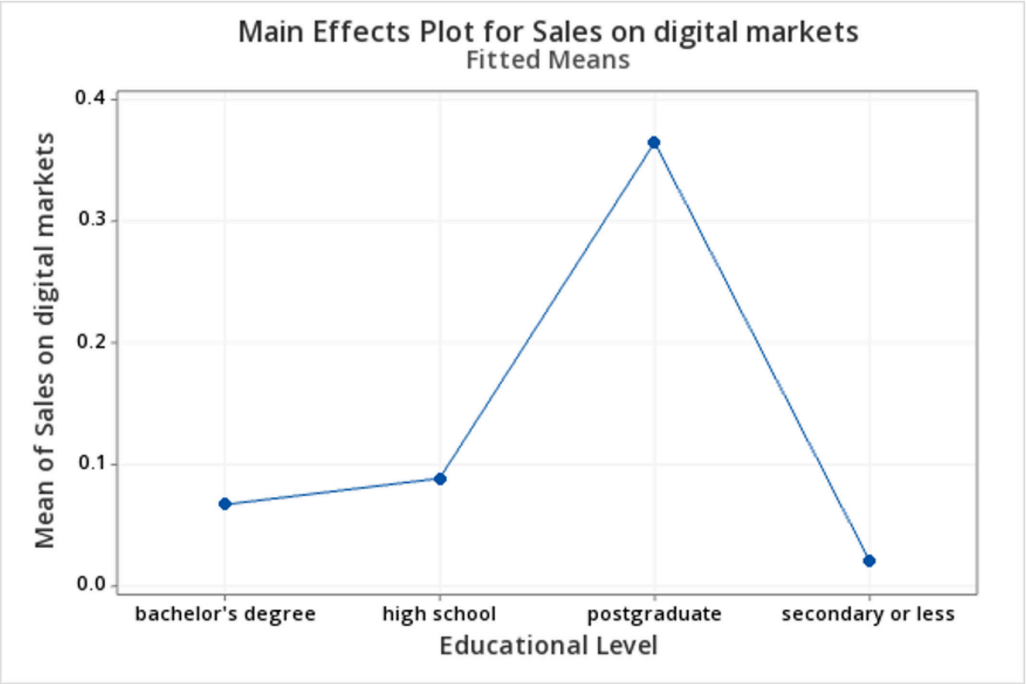

Figure 8. Main effect plot: sales on digital markets vs. educational level.

Table 8. Analysis of variance, website vs. gender, age, and educational level.

Source	DF	Adj SS	Adj MS	F-Value	*p*-Value
Regression	8	1.17406	0.14676	3.53	0.001
Gender	1	0.07372	0.07372	1.78	0.184
Age	4	0.88907	0.22227	5.35	0
Educational Level	3	0.26492	0.08831	2.13	0.099
Error	178	7.39278	0.04153		
Lack-of-Fit	22	2.33564	0.10617	3.27	0
Pure Error	156	5.05714	0.03242		
Total	186	8.56684			

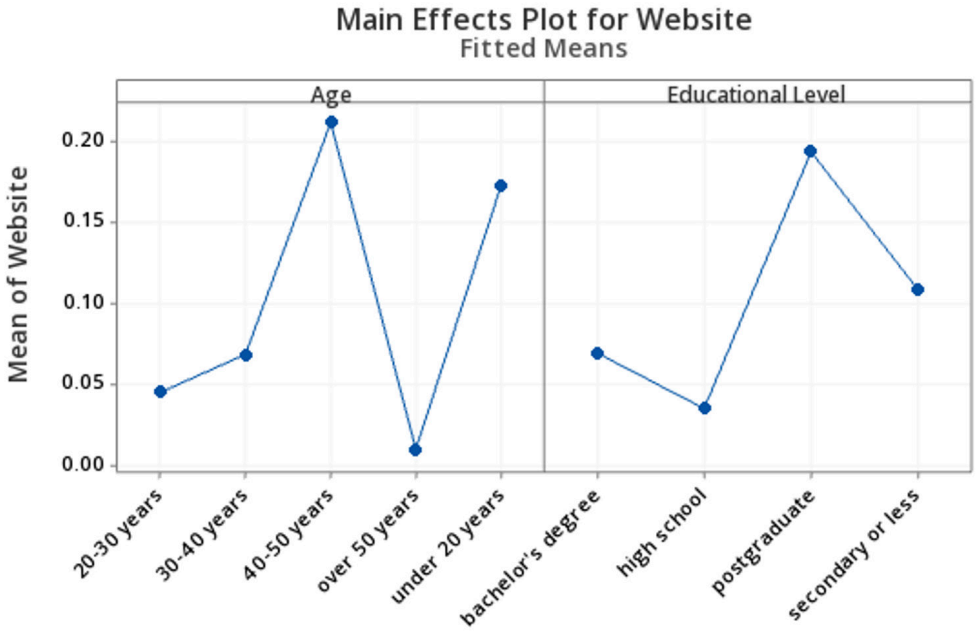

Figure 9. Main effect plot: website vs. age and educational level.

3.2.4. Prediction of VVC Adoption by MSEs

To provide greater methodological clarity, a brief overview of the machine learning techniques employed is included here. Logistic Regression is a linear model commonly used for binary classification tasks. K-Nearest Neighbors (KNN) classifies new observations based on their similarity to nearby cases in the dataset. Support Vector Machines (SVMs) aim to find the optimal boundary that separates classes. Random Forest and Gradient Boosting are ensemble methods that combine multiple decision trees to improve prediction accuracy and reduce overfitting. Finally, neural networks are flexible models capable of capturing non-linear relationships in the data. These techniques were selected because they represent a balance of interpretability, robustness, and predictive power in classification problems.

In this section, we detail the implementation of machine learning techniques to evaluate whether it is possible to predict, based on certain managerial features, their willingness to adopt a VVC. To address this, we first analyze the dataset obtained from the survey using visualizations, descriptive statistics, and a correlation matrix. It is important to note that the dataset is unbalanced, and since this is a binary classification problem, the F1 score is the most suitable metric for evaluating the performance of the tested models.

A pipeline was used using scikit-learn [74], in order to evaluate if the use of machine learning has value to predict if a manager adopts a VVC, and a set of baseline models was used. Scikit-learn uses a dummy classifier with some easy strategies to generate predictions. The most frequent strategy always predicts the most frequent class from the training set. The stratified strategy generates predictions while respecting the class distribution of the training set. The uniform strategy makes random predictions for each class with a uniform distribution. Finally, the constant strategy always predicts a specific class, which must be defined beforehand, in our case, the constant value of 1 in change label prediction.

The machine learning (ML) models used included Logistic Regression, K-Nearest Neighbors, Support Vector Machine, Random Forest, Gradient Boosting, and a neural network. Stratified random sampling was applied due to the unbalanced dataset, with an 80% training and 20% validation split. Cross-validation was performed using five folds. Finally, hyperparameter optimization was conducted using Optuna [75].

The results shown in Figure 10 show the F1 Score values for both the training and validation sets across different models, including the Dummy classifiers and ML algorithms. In general, the baseline models exhibit consistently high performance in both the training and validation sets, with an F1 Score close to 0.77 and a low standard error. This suggests that these models are consistent, as they rely on trivial predictions. However, more sophisticated models, such as Logistic Regression, K-Nearest Neighbors, Random Forest, and neural networks, achieve similar or slightly better validation results. Notably, Random Forest stands out with a validation F1 Score of 0.79, indicating superior generalization performance compared to other algorithms. In summary, perhaps Random Forest appears to be the most robust option, offering a good balance between a strong validation F1 Score and a moderate standard error; some dummy models maintain good F1 Scores, and it is thus concluded that, at least for this dataset generated, the use of ML models does not notably increase the performance metric (F1 Score).

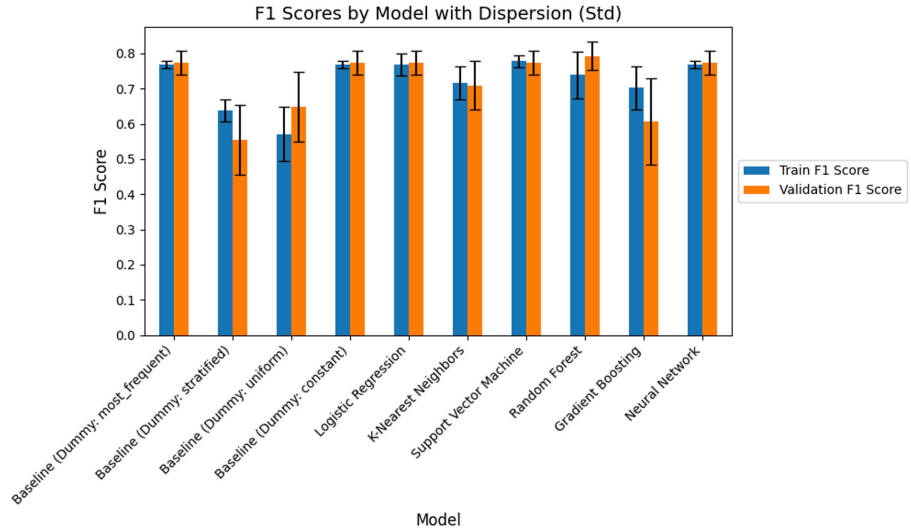

Figure 10. Results of the ML models and the baselines.

4. Results and Discussion

Regarding the first research question (RQ1), which explores whether grocery stores in Mexico possess the technological capabilities necessary to implement Virtual Value Chains (VVCs) with suppliers and customers, the analysis of the collected data indicates that they do not. Between 60.43% and 67.44% of stores only have access to a mobile phone, and between 53.42% and 67.4% still record sales manually in notebooks, lacking clear insight into their inventory levels. Only 18.43% to 30.77% of stores use an inventory system, which makes it currently unfeasible to implement a demand forecasting system that would enable timely orders from suppliers.

Between 50.12% and 64.31% receive products directly from suppliers; however, these deliveries mostly consist of beverages and soft drinks, which account for only 17.39% of their top-selling items. In contrast, their best-selling products, perishables (32.3%), are typically self-procured and transported in store-owned vehicles. Additionally, while 54.03% to 73.03% of stores have card payment terminals, only 31.2% accept electronic transfers.

The analysis revealed that most grocery stores lack the technological infrastructure needed to implement a Virtual Value Chain. A majority of businesses rely on mobile phones and manual sales recording, with only a small portion using inventory systems or accepting digital payments beyond card terminals. This limited technological maturity constrains both data generation (input) and information dissemination (output), two critical stages in the VVC model.

The findings align with global challenges in digitalizing small retailers, particularly in logistics and infrastructure [76]. However, the widespread access to mobile phones presents a viable entry point for digital integration. Designing a user-friendly mobile app, complemented by digital skills training (between 83.92% and 92.85% of managers have never received any), could enable store managers to initiate VVC processes incrementally, starting with inventory tracking and supplier communication. As Heeks [11] points out, MSEs only require access to a mobile device to benefit effectively from ICT4D initiatives.

Despite these technological gaps, most micro-stores have been operating for more than five years (60.96%), indicating strong market resilience. While large grocery chains dominate urban areas, small stores remain competitive due to their flexibility: they sell individual items, offer fresh and less-processed goods, remain open late, and are located in convenient neighborhoods, factors that continue to attract customers. Future analyses will examine the drivers that lead customers to prefer small stores over larger chains.

Regarding the second research question (RQ2), the results suggest that the age and education of store managers are significant determinants of digital tool adoption. Younger and more educated managers are more likely to use digital platforms and engage with external systems (e.g., delivery apps, websites), thus enabling data flow across the value chain. In contrast, resistance among older managers, often due to a lack of training or fear of technology, creates informational bottlenecks.

These behavioral barriers inhibit the input–mediation–output cycle of the VVC. Without reliable digital data (input), insight generation (mediation) and online customer/supplier interaction (output) are severely limited. These insights reinforce existing ICT4D literature that highlights the critical role of local agency, digital literacy, and managerial mindset [11,13].

These findings are consistent with Weyer [61], who argues that beyond resource scarcity, managerial mindset plays a critical role in determining which technologies are adopted and how effectively they are integrated into the value chain. In the context of Mexican MSEs, a limited technological mindset hinders the transformation of traditional supply chain operations into digital flows of information and value, the essence of the VVC concept.

Finally, regarding the third research question (RQ3), machine learning models applied to predict a manager's likelihood of adopting digital tools yielded inconclusive results. The lack of predictive power suggests that additional variables, such as managerial attitudes, trust in digital systems, or prior exposure, may be necessary for accurate modeling. This reinforces the complexity of behavioral dynamics in ICT adoption and indicates the need for more qualitative or mixed-methods approaches in future studies, exploring dimensionality reduction techniques or feature-label discrimination using covariance analysis to enhance data quality and model performance.

5. Conclusions

This research demonstrates that while grocery MSEs in Mexico exhibit operational resilience and social embeddedness, their potential for digital development through the VVC remains largely untapped. Despite some progress in payment technologies, there is a substantial gap in digitalizing supply chain operations, particularly in the areas of inventory management, supplier coordination, and data-driven decision-making like demand forecasting.

Our findings suggest that education and training are pivotal for enabling the VVC in microenterprise contexts. A mobile-based application, combined with capacity-building programs (over 80% of store managers have never received any form of technology training), could empower MSEs to engage more actively in digital value networks. Additionally, community-based logistics models, such as shared delivery services or app-enabled cooperatives, may offer scalable solutions in low-resource environments [77,78]. These alternatives align with the four key characteristics of ICT4D proposed by Heeks [11]: readiness, availability, sustainability (uptake), and impact.

This study contributes to ICT4D discourse by illustrating how VVC theory can be operationalized in the context of urban retail microenterprises in Mexico. It highlights the dual importance of technological enablers and behavioral readiness, bridging the gap between macro-level ICT policy and micro-level business practice.

Limitations of the Study and Future Research

The study is limited in geographic scope and does not incorporate consumer perspectives directly. Future work should explore how consumer trust, digital behavior, and generational preferences shape the success of digitalization strategies. Factors such as personalized service, proximity, and product flexibility appear to contribute to their sustained relevance [79].

Additionally, the sampling relied on surveys distributed by undergraduate students to nearby grocery stores, which introduces a convenience component. Out of 233 surveys distributed, 187 valid responses were obtained (a non-response rate of 19.7%). While this dataset provides valuable insights, the findings should be interpreted with caution and cannot be generalized to the more than 1,000,000 grocery stores that exist nationwide. Future studies should aim to apply stricter random sampling methods across a wider geographical scope.

Another limitation of this study is that the survey instrument did not incorporate items related to policy and regulatory changes, which can play a significant role in shaping MSEs' supply chains. While the present research prioritized operational and technological readiness, future work should integrate institutional and regulatory dimensions to provide a more comprehensive understanding of the factors influencing VVC adoption.

Although this study employed machine learning techniques to explore managers' willingness to adopt digital tools, the predictive power of the models was limited and yielded inconclusive results. This indicates that additional variables, such as managerial attitudes, trust in digital systems, or prior exposure to technology, may be required to improve accuracy. Furthermore, while Artificial Intelligence (AI) was not fully implemented in this study, we recognize its potential as a smart tool for future research. AI techniques could support dimensionality reduction, feature-label discrimination, and advanced behavioral modeling to enhance the analysis of Virtual Value Chain adoption. Future studies should explore these avenues to complement mixed methods approaches and strengthen predictive insights.

While technology and digital services play a crucial role in shaping consumer experiences and offer retailers the potential to enrich in-store engagement [80], a deeper understanding of consumer preferences remains essential. In some cases, habitual shopping practices and age-related factors prevent customers from feeling comfortable with alternatives to face-to-face purchasing [81].

Ultimately, this research reinforces the idea that development through ICT is not solely a matter of infrastructure, but of human capability, strategic design, and context-aware innovation. In the case of grocery MSEs, ICT does not inherently lead to development; however, when it is used to strengthen operations through the VVC, it can effectively support their growth. Importantly, complex technologies are not always required; access to a mobile phone, combined with proper training, can be sufficient to initiate meaningful digital engagement.

Author Contributions: Conceptualization, E.S.H.-G. and S.D.; methodology, A.I.R.M., J.E.G.-R. and E.S.H.-G.; software, A.I.R.M., J.E.G.-R. and E.S.H.-G.; validation, A.I.R.M.; formal analysis, E.S.H.-G.; investigation, E.S.H.-G.; data curation, E.S.H.-G., J.E.G.-R. and S.D.; writing—original draft preparation, E.S.H.-G. and J.E.G.-R. writing—review and editing methodology, A.I.R.M. and E.S.H.-G.; visualization, E.S.H.-G.; supervision, E.S.H.-G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data are available at the repository https://doi.org/10.6084/m9.figshare.25977001.v1 [65] and can be requested from the corresponding author when necessary.

Acknowledgments: We would like to thank Andrés Tellez for his valuable comments.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Questions included in the survey.

Area	Question
Profile	What is the name of your business? How many personnel have you employed? Please provide your working hours per day. How much can your business earn monthly?
Managerial characteristics	Please provide your full name. Please select your gender, age, and highest level of education. Are you interested in making some changes in your business? If so, how long does it take for you to get familiar with these changes
Personnel management	Do your personnel collaborate with each other during work? How long does it take for your personnel to adapt to a new condition or a new decision in your business? How long does it take for your personnel to learn and apply new ways of doing operations? Are your personnel act as a part of your business with others?
Company infrastructure	How do you manage space in your shelves? Do you have a specific place for loading/unloading? Which types of vehicles do you prefer when transporting your products?
Procurement	Which products are sold more than others? How much space do your stocks occupy in your store? Do you know the average sales number for the next periods? Do you inform your suppliers about your orders? /If so, in which way?
ICT4D	Do you have a convenient internet connection in your store? Do you have an IT/paper-based system to monitor your sales and inventory? Which devices do you use to track your orders?
E-commerce	Do you receive electronic payments from customers? Do you have a website to introduce your business or to sell your products online? Do you sell your products via Facebook, WA, or other social media channels? Do you receive orders via phone calls? Do you sell your products via digital marketplaces (e.g., Mercado Libre, Amazon, etc.)?
Challenges to introducing technology	Do you receive any financial/technical/educational support from the government? Do you need external support to engage with digitalization and political changes? Do you distribute products provided by NGOs?

References

1. Tarmidi, L.T. Strategies for HRM of SMEs in Indonesia. Human Resource Management Symposium on SMEs. 1999. Available online: https://www.apec.org/docs/default-source/Publications/1999/10/Human-Resource-Management-Symposium-on-Small-and-Medium-Enterprises-SMEs-Volume-1-and-Volume-2-1999/TOC/Volume-2.pdf#page=5 (accessed on 26 March 2025).
2. Ministry of Economy in Mexico. Acuerdo por el que se Establece la Estratificación de las Micro, Pequeñas y Medianas Empresas. 2009. Available online: https://www.economia.gob.mx/files/marco_normativo/A539.pdf (accessed on 19 February 2025).
3. Marett, K.; Niu, Z.; Barnett, T.R. Professionalizing the information security of family firms: A family essence perspective. *J. Small Bus. Manag.* **2020**, *58*, 390–408. [CrossRef]
4. Saavedra, M.L.; Hernández, Y. Caracterización e importancia de las MIPYMES en Latinoamérica: Un estudio comparativo. *Actual. Contab. Faces* **2008**, *11*, 122–134.
5. OECD. *Latin American Economic Outlook 2013: SME Policies for Structural Change*; OECD Publications: Paris, France, 2012.
6. Leading Short-Term Digital Strategies from Small and Medium-Sized Enterprises (SMEs) to Get Through the COVID-19 Crisis in Mexico in 2020, by Type of Company [Graph], Statista. Available online: https://www.statista.com/statistics/1176417/short-term-digital-strategies-small-medium-enterprises-coronavirus/ (accessed on 3 July 2024).
7. Cash Flow Challenge in Mexico, Mexico Business. Available online: https://mexicobusiness.news/finance/news/cash-flow-challenge-mexico (accessed on 9 July 2024).
8. Velázquez-Martínez, J.C.; Tayaksi, C. Supply chain management for micro and small firms in Latin America. In *Supply Chain Management and Logistics in Emerging Markets: Selected Papers from the 2018 MIT SCALE Latin America Conference*; Emerald Publishing Limited.: Leeds, UK, 2020; pp. 197–214. [CrossRef]
9. Chacko, J.G.; Harris, G. Information and communication technology and small, medium, and micro enterprises in Asia-Pacific—Size does matter. *Inf. Technol. Dev.* **2006**, *12*, 175–177. [CrossRef]
10. Andaregie, A.; Astatkie, T. Determinants of technology adoption by micro and small enterprises (MSEs) in Awi Zone, Northwest Ethiopia. *Afr. J. Sci. Technol. Innov. Dev.* **2022**, *14*, 997–1006. [CrossRef]
11. Heeks, R. Do information and communication technologies (ICTs) contribute to development? *J. Int. Dev.* **2010**, *22*, 625–640. [CrossRef]
12. Avgerou, C. Theoretical framing of ICT4D research. *Inf. Technol. Int. Dev.* **2017**, *13*, 52–64. [CrossRef]
13. Walsham, G. ICT4D research: Reflections on history and future agenda. *Inf. Technol. Dev.* **2017**, *23*, 18–41. [CrossRef]
14. Duncombe, R. Using the livelihoods framework to analyze ICT applications for poverty reduction through microenterprise. *Inf. Technol. Int. Dev.* **2006**, *3*, 81–100. [CrossRef]
15. Donner, J. Microentrepreneurs and mobiles: An exploration of the uses of mobile phones by small business owners in Rwanda. *Inf. Technol. Int. Dev.* **2004**, *2*, 1–21. [CrossRef]
16. AlBar, A.M.; Hoque, R. Factors affecting the adoption of information and communication technology in small and medium enterprises: A perspective from rural Saudi Arabia. *Inf. Technol. Dev.* **2019**, *25*, 715–738. [CrossRef]
17. Weiber, R.; Kollmann, T. Competitive advantages in virtual markets-perspectives of 'information-based marketing' in cyberspace. *Eur. J. Mark.* **1998**, *32*, 603–615. [CrossRef]
18. Thapa, D.; Sæbø, Ø. Participation in ICT development interventions: Who and how? *Electron. J. Inf. Syst. Dev. Ctries.* **2016**, *75*, 1–14. [CrossRef]
19. Bag, S.; Pretorius, J.H.C. Relationships between industry 4.0, sustainable manufacturing and circular economy: Proposal of a research framework. *Int. J. Organ. Anal.* **2022**, *30*, 864–898. [CrossRef]
20. Culot, G.; Orzes, G.; Sartor, M.; Nassimbeni, G. The future of manufacturing: A Delphi-based scenario analysis on Industry 4.0. *Technol. Forecast. Soc. Change* **2020**, *157*, 120092. [CrossRef] [PubMed]
21. Abagissa, J. The assessment of micro and small enterprises performance and challenges in Addis Ababa, Ethiopia. *Int. J. Appl. Econ. Financ. Account.* **2021**, *9*, 8–18. [CrossRef]
22. Chen, C.-L.; Lin, Y.-C.; Chen, W.-H.; Chao, C.-F.; Pandia, H. Role of government to enhance digital transformation in small service business. *Sustainability* **2021**, *13*, 1028. [CrossRef]
23. Ozols, A.; Avotins, V. Regional centre development management factors: Case study of Liepaja. In Proceedings of the 20th International Scientific Conference Engineering or Rural Development Proceedings, Jelgava, Latvia, 26–28 May 2021; Latvia University of Life Sciences and Technologies, Faculty of Engineering: Jelgava, Latvia, 2021.
24. Agrawal, P.; Narain, R. Analysis of enablers for the digitalization of supply chain using an interpretive structural modelling approach. *Int. J. Prod. Perform. Manag.* **2023**, *72*, 410–439. [CrossRef]
25. Chatterjee, S.; Chaudhuri, R.; Shah, M.; Maheshwari, P. Big data driven innovation for sustaining SME supply chain operationm in post COVID-19 scenario: Moderating role of SME technology leadership. *Comput. Ind. Eng.* **2022**, *168*, 108058. [CrossRef]
26. Trinugroho, I.; Pamungkas, P.; Wiwoho, J.; Damayanti, S.M.; Pramono, T. Adoption of digital technologies for micro and small business in Indonesia. *Finance Res. Lett.* **2022**, *45*, 102156. [CrossRef]

27. Mikhaylova, A.; Sakulyeva, T.; Shcherbina, T.; Levoshich, N.; Truntsevsky, Y. Impact of digitalization on the efficiency of supply chain management in the digital economy. *Int. J. Enterp. Inf. Syst.* **2021**, *17*, 34–46. [CrossRef]
28. García-Salirrosas, E.E.; Acevedo-Duque, Á.; Chaves, V.M.; Henao, P.A.M.; Molano, J.C.O. Purchase intention and satisfaction of online shop users in developing countries during the COVID-19 pandemic. *Sustainability* **2022**, *14*, 6302. [CrossRef]
29. Garay-Rondero, C.L.; Martinez-Flores, J.L.; Smith, N.R.; Caballero Morales, S.O.; Aldrette-Malacara, A. Digital supply chain model in Industry 4.0. *J. Manuf. Technol. Manag.* **2019**, *31*, 887–933. [CrossRef]
30. Tanoira, F.G.B.; Valencia, R.A.S. Knowledge management entrepreneurial competencies and organizational development in micro and small enterprises in rural regions in the state of Yucatan, Mexico. *Eur. Sci. J.* **2014**, *10*, 177–193.
31. Aguilar, O.; Posada, R.; Peña, N. *La Micro y Pequeña Empresa Como Objeto de Estudio*; Caso San Juan del Río: Querétaro, Mexico, 2015.
32. Hernández-Gracia, T.J.; Duana-Avila, D. Discourse on Entrepreneurial Orientation in Hidalgo State, Mexico. *Sustainability* **2022**, *14*, 3205. [CrossRef]
33. Vidal Olivares, J.; Barbero, M.I. Latin American small and medium-sized enterprises: A historical perspective. *J. Evol. Stud. Bus.* **2022**, *7*, 1–12. [CrossRef]
34. Ramírez-Angulo, N.; Mungaray-Lagarda, A.; Aguilar-Barceló, J.G.; Flores-Anaya, Y. Microemprendimientos como instrumento de combate a la pobreza: Una evaluación social para el caso mexicano. *Innovar* **2017**, *27*, 63–74. [CrossRef]
35. Autio, E. 'Atomistic' and 'systemic' approaches to research on new, technology-based firms: A literature study. *Small Bus. Econ.* **1997**, *9*, 195–209. [CrossRef]
36. Fariselli, P.; Oughton, C.; Picory, C.; Sugden, R. Electronic commerce and the future for SMEs in a global marketplace: Networking and public policies. *Small Bus. Econ.* **1999**, *12*, 261–275. [CrossRef]
37. Zhu, L. Optimization and Simulation for E-Commerce Supply Chain in the Internet of Things Environment. *Complexity* **2020**, *2020*, 8821128. [CrossRef]
38. Graham, G.; Hardaker, G. Supply-chain management across the Internet. *Int. J. Phys. Distrib. Logist. Manag.* **2000**, *30*, 286–295. [CrossRef]
39. Corso, M.; Martini, A.; Pellegrini, L.; Paolucci, E. Technological and organizational tools for knowledge management: In search of configurations. *Small Bus. Econ.* **2003**, *21*, 397–408. [CrossRef]
40. Hongmei, W.; Jincheng, F. Research on virtual value chain model of smart travel agency under the background of digital media. In Proceedings of the 2021 2nd Artificial Intelligence and Complex Systems Conference, Hangzhou, China, 26–28 June 2021; ACM: New York, NY, USA, 2021.
41. Ramantoko, G.; Fatimah, L.V.; Pratiwi, S.C.; Kinasih, K. Measuring Digital Capability Maturity: Case of Small-Medium Kampong-Digital Companies in Bandung. *Pertanika J. Soc. Sci. Humanit.* **2018**, *26*, 215–230.
42. Piscitello, L.; Sgobbi, F. Globalisation, E-business and SMEs: Evidence from the Italian district of Prato. *Small Bus. Econ.* **2004**, *22*, 333–347. [CrossRef]
43. Ariffin, A.S.; Hashom, H.; Abas, Z.; Ali, A.H.M.; Ramli, M.F. Empowering Kedah as the northern national hub for sustainable beef-cattle supply chain and production. *E3S Web of Conferences* **2021**, *316*, 01007. [CrossRef]
44. Fromhold-Eisebith, M.; Marschall, P.; Peters, R.; Thomes, P. Torn between Digitized Future and Context Dependent Past—How Implementing 'Industry 4.0' Production Technologies Could Transform the German Textile Industry. *Technol. Forecast. Soc. Chang.* **2021**, *166*, 120620. [CrossRef]
45. Gyenge, B.; Máté, Z.; Vida, I.; Bilan, Y.; Vasa, L. A new strategic marketing management model for the specificities of E-commerce in the supply chain. *J. Theor. Appl. Electron. Commer. Res.* **2021**, *16*, 1136–1149. [CrossRef]
46. Hermawan, I.; Hindrawati, G.; Amid, J.; Suwondo, A. Designing internet shopping mall in the customer behavior perspective. *Conf. Ser.* **2021**, *3*, 537–551. [CrossRef]
47. Hu, K.; Xu, X.; Qu, A. The psychology of virtual queue: When waiting feels less like waiting. Vanderbilt Owen Graduate School of Management Research Paper Forthcoming. 2021. Available online: https://ssrn.com/abstract=3933040 (accessed on 20 March 2025).
48. Taherinia, M.; Nawaser, K.; Shariatnejad, A.; Saedi, A.; Moshtaghi, M. The evolution of the e-business value cycle through value co-creation during the COVID-19 pandemic: An empirical study from Iran. *J. Asian Financ. Econ. Bus.* **2021**, *8*, 19–28.
49. Zumstein, D.; Oswald, C.; Brauer, C. *Online Retailer Survey 2021: Empirical Findings on the E-Commerce Boom in Switzerland and Austria*; ZHAW Zurich University of Applied Sciences: Winterthur, Switzerland, 2021.
50. Liu, Y.; Zhang, J.Z.; Jasimuddin, S.; Babai, M.Z. Exploring servitization and digital transformation of manufacturing enterprises: Evidence from an industrial internet platform in China. *Int. J. Prod. Res.* **2024**, *62*, 2812–2831. [CrossRef]
51. Eng, T.Y.; Mohsen, K.; Wu, L.C. Wireless information technology competency and transformational leadership in supply chain management: Implications for innovative capability. *Inf. Technol. People* **2023**, *36*, 969–995. [CrossRef]
52. Omoruyi, O.; Makaleng, M.S.M. SMEs COVID-19 supply chain resilience strategies in South Africa. *J. Contemp. Manag.* **2022**, *19*, 299–319. [CrossRef]

53. Sharma, M.; Raut, R.D.; Sehrawat, R.; Ishizaka, A. Digitalisation of manufacturing operations: The influential role of organisational, social, environmental, and technological impediments. *Expert Syst. Appl.* **2023**, *211*, 118501. [CrossRef]
54. Berrone, P.; Gertel, H.; Giuliodori, R.; Bernard, L.; Meiners, E. Determinants of performance in microenterprises: Preliminary evidence from Argentina. *J. Small Bus. Manag.* **2014**, *52*, 477–500. [CrossRef]
55. Gupta, S.; Ramachandran, D. Emerging market retail: Transitioning from product-centric to a customer-centric approach. *J. Retail.* **2021**, *97*, 597–620. [CrossRef]
56. Hwang, W.-S.; Kim, H.-S. Does the adoption of emerging technologies improve technical efficiency? Evidence from Korean manufacturing SMEs. *Small Bus. Econ.* **2022**, *59*, 627–643. [CrossRef] [PubMed]
57. Roth, A.; Rosenzweig, E. Advancing empirical science in operations management research: A clarion call to action. *Manuf. Serv. Oper. Manag. M SOM* **2020**, *22*, 179–190. [CrossRef]
58. Sharma, N.; Dutta, N. Omnichannel retailing: Exploring future research avenues in retail marketing and distribution management. *Int. J. Retail. Distrib. Manag.* **2023**, *51*, 894–919. [CrossRef]
59. Ciacci, A.; Penco, L. Business model innovation: Harnessing big data analytics and digital transformation in hostile environments. *J. Small Bus. Enterp. Dev.* **2024**, *31*, 22–46. [CrossRef]
60. Matalamäki, M.J.; Joensuu-Salo, S. Digitalization and strategic flexibility—A recipe for business growth. *J. Small Bus. Enterp. Dev.* **2022**, *29*, 380–401. [CrossRef]
61. Weyer, J.; Tiberius, V.; Bican, P.; Kraus, S. Digitizing grocery retailing: The role of emerging technologies in the value chain. *Int. J. Innov. Technol. Manag.* **2020**, *17*, 2050058. [CrossRef]
62. Bierganz, M. Delivering Virtual Value: The Role of Virtual Value Creation in e-Grocery Business Models and Resulting Implications for Today's Grocery Retail Firms. Ph.D. Dissertation, Universidad Católica Portuguesa, Lisbon, Portugal, 2021.
63. Sampieri, R.H. *Metodología de la Investigación: Las Rutas Cuantitativa, Cualitativa y Mixta*; McGraw-Hill: México City, Mexico, 2018.
64. INEGI: National Directory of Economic Units. Directorio Estadístico Nacional de Unidades Económicas. 2024. Available online: https://www.inegi.org.mx/app/mapa/denue/default.aspx (accessed on 9 July 2024).
65. Gurdur, D.; Ei-Khoury, J.; Torngren, M. Digitalizing Swedish industry: What is next? Data analytics readiness assessment of Swedish industry, according to survey results. *Comput. Ind.* **2019**, *105*, 153–163.
66. Peutz, M.M.; Post, G. A Shared Digital Twinning Facility for SMEs. In Proceedings of the XXXIII ISPIM Innovation Conference "Innovating in a Digital World", Copenhagen, Denmark, 5–8 June 2022; ISPIM: Manchester, UK, 2022; pp. 1–11.
67. Merchán, D.; Arora, J.; Pachon, J.; Konduri, K.; Winkenbach, M.; Parks, S.; Noszek, J. 2021 Amazon Last Mile Routing Research Challenge: Data set. *Transp. Sci.* **2022**, *58*, 8–11. [CrossRef]
68. Elkhouly, P.R.O.; Elsayed, S.M.; Hamid, R.M. Effect of Artificial Intelligence on End-to-End Customer Centric. *Bus. Model* **2022**, *13*, 121–142.
69. Naimi-Sadigh, A.; Asgari, T.; Rabiei, M. Digital transformation in the value chain disruption of banking services. *J. Knowl. Econ.* **2022**, *13*, 1212–1242. [CrossRef]
70. Winkler, M.; Moltenbrey, F.; Tilebein, M. Business Model Scenarios for Digital Textile Microfactories. *Conf. Prod. Syst. Logist. CPSL* **2022**, 574–582. [CrossRef]
71. Wasan, P.; Kumar, A.; Luthra, S. How can banks and finance companies incorporate value chain factors in their risk management strategy? The case of agro-food firms. *Bus. Strat. Environ.* **2023**, *32*, 858–877. [CrossRef]
72. Hernández-Gress, E.S.; Ramírez-Mejia, A.I. Virtual value chains in Micro and Small Enterprises: An evidence for grocery stores in Mexico. *Figshare J. Contrib.* **2024**. [CrossRef]
73. Devore, J. *Probability and Statistics for Engineering and the Sciences*, 9th ed.; CENGAGE Learning: Boston, MA, USA, 2019. Available online: https://cdn.prexams.com/9441/Devore (accessed on 8 June 2024).
74. Pedregosa, F.; Varoquaux, G.; Gramfort, A.; Michel, V.; Thirion, B.; Grisel, O.; Duchesnay, É. Scikit-learn: Machine Learning in Python. *J. Mach. Learn. Res.* **2011**, *12*, 2825–2830.
75. Akiba, T.; Shotaro, S.; Toshihiko, Y.; Takeru, O.; Koyama, M. Optuna: A Next-generation Hyperparameter Optimization Framework. In Proceedings of the 25th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, Anchorage, AK, USA, 4–8 August 2019.
76. Piroth, P.; Rüger-Muck, E.; Bruwer, J. Digitalisation in grocery retailing in Germany: An exploratory study. *Int. Rev. Retail. Distrib. Consum. Res.* **2020**, *30*, 479–497. [CrossRef]
77. Escamilla, R.; Fransoo, J.C.; Tang, C.S. Improving agility, adaptability, alignment, accessibility, and affordability in nanostore supply chains. *Prod. Oper. Manag.* **2021**, *30*, 676–688. [CrossRef]
78. Yang, Y.; Kobbacy, Y.; Onofrei, G.; Nguyen, H. Entrepreneurial strategies for coping with supply chain disruptions in the grocery-retail sector. *J. Small Bus. Enterp. Dev.* **2022**, *30*, 213–233. [CrossRef]
79. Duh, H.I.; Pwaka, O. Grocery retailer's brand performances from brand personalities and marketing offerings. *Int. J. Retail. Distrib. Manag.* **2023**, *51*, 101–122. [CrossRef]

80. Berg, H.; Nilsson, E.; Liljedal, K.T. Consumer-facing technology in retailing: How technology shapes customer experience in physical and digital stores. *Int. Rev. Retail. Distrib. Consum. Res.* **2024**, *34*, 123–127. [CrossRef]
81. Stenius, M.; Eriksson, N. What can we learn from non-adopters of online grocery shopping? Insights from Finland. *Int. Rev. Retail. Distrib. Consum. Res.* **2024**, *35*, 480–499. [CrossRef]