

Research article

Digital Transformation and Employment in Micro and Small Industries: Evaluating the Impact of E-Commerce Adoption in Indonesia

Muhammad Shalih*, Djoni Hartono

¹ Department of Economics, Faculty of Economics and Business, Universitas Indonesia, Depok, West Java, Indonesia

* Corresponding author email: m.shalih@bps.go.id

ABSTRACT

This study aims to evaluate the impact of e-commerce adoption on employment absorption in micro and small manufacturing enterprises (IMK) in Indonesia. Utilizing data from the 2022 Micro and Small Industry Survey conducted by Statistics Indonesia, the analysis employs a Propensity Score Matching approach to address the imbalance in characteristics between e-commerce adopters and non-adopters. The results indicate that e-commerce adoption is positively associated with an increase in the number of workers employed by adopting firms. Business characteristics such as the presence of professional workers, business legality, and firm age are found to significantly influence adoption. Sensitivity analysis also shows that the estimates are robust against potential hidden bias. These findings highlight the importance of policy interventions that promote e-commerce adoption among IMK as a strategic effort to enhance employment capacity. Policy implications drawn from this study emphasize the need for cost-effective digital training programs, improved digital literacy, accelerated business formalization, and sectoral as well as business-cycle-based approaches to maximize the impact of e-commerce on employment in the IMK sector. With the right and targeted interventions, digitalization in the IMK sector has the potential not only to increase labor absorption but also to contribute to more inclusive and sustainable economic growth.

ARTICLE INFO

Article history:

Received: August 12th, 2025
Revised: January 18th, 2026
Accepted: January 26th, 2026
Published: January 30th, 2026

Keywords:

E-commerce; Employment, IMK, Propensity score matching; Digital transformation

JEL classification:

E44
G10
G12
O16

Citation:

Shalih, M., & Hartono, D. (2025). Digital Transformation and Employment in Micro and Small Industries: Evaluating the Impact of E-Commerce Adoption in Indonesia. *Jurnal Ekonomi Pembangunan*, 23(2), 97-110. DOI: 10.29259/jep.v23i2.23441

Copyright © 2025 The Authors. Published by JEP is licensed under a CC BY-SA 4.0 International License

1. INTRODUCTION

The open unemployment rate (OUR) remains a formidable structural challenge in Indonesia. The COVID-19 pandemic further exposed the vulnerability of the domestic labor market, as the OUR surged from 5.28% in August 2019 to 7.07% in August 2020, before gradually declining to 6.49% by August 2021 (BPS, 2023). Throughout this crisis, the informal sector served as a critical economic buffer, with Micro and Small Industries (IMK) acting as a backbone for job creation. Within the manufacturing sector, particularly at the micro and small scale, these enterprises employed over 50% of the sectoral workforce in 2023 (BPS, 2023). Furthermore, the sector contributed approximately 18.98% to the national GDP in 2024. While digitalization studies frequently prioritize the service and trade sectors, the manufacturing industry is also facing intensified pressure to undergo digital transformation, especially in the wake of the pandemic. Within the IMK context, limited capital and simple organizational structures present significant barriers to digital technology adoption. Nevertheless, e-commerce has emerged as a viable solution to broaden market access, mitigate dependency on physical distribution channels, and ensure business continuity amidst mobility restrictions. Despite national internet penetration exceeding 78% in 2024, e-commerce adoption among Indonesian IMK reached only 27.74% in 2023 (BPS, 2024). This disparity highlights a substantial digital divide, which is particularly pronounced among microenterprises.

E-commerce facilitates direct engagement between small producers and end consumers, reducing reliance on intermediaries and enhancing business margins through improved distribution and promotional efficiency. Such digitalization is hypothesized to drive production expansion, thereby creating

additional demand for labor. However, the impact of e-commerce on employment is not inherently linear. On one hand, digital technologies may generate new roles in logistics and online services; on the other, digital efficiency may displace manual labor in traditional roles.

Evidence from previous studies remains mixed. In developed economies, such as the United States and South Korea, e-commerce expansion has been associated with job reductions in conventional retail sectors (Chava et al., 2024; and Chun et al., 2023). Conversely, in developing nations like Chile and Colombia, e-commerce adoption has been found to boost productivity and foster job creation, particularly within small-scale manufacturing (Pérez-Trujillo et al., 2024; and Rodríguez-Puello et al., 2022). In the Indonesian context, empirical studies explicitly examining the nexus between e-commerce adoption and employment absorption within the IMK sector remain scarce. Most domestic literature, such as Ausat & Peirisal (2021); and Harahap et al. (2022), has focused primarily on the impact of e-commerce on revenue, operational efficiency, or financial inclusion among MSMEs. Even studies addressing the manufacturing sector have often relied on aggregated units of analysis, such as Purnomo et al. (2021), rely on aggregated units of analysis (e.g., provinces), which fail to capture the nuanced micro-level dynamics at the enterprise level.

The impact of e-commerce on labor demand operates through two opposing channels (Bănescu et al., 2022). First, the expansion effect (a positive mechanism) occurs when e-commerce broadens market access and reduces transaction costs, leading to increased output. Bănescu et al. (2022) argue that e-commerce serves as a catalyst for creating new industrial sectors and fresh employment opportunities, particularly in specialized roles such as logistics and digital management, which can compensate for potential job losses in traditional sectors. In the short run, given the capital constraints of micro-enterprises, this growth necessitates additional labor input (Mankiw & Taylor, 2020). Conversely, a substitution effect (a negative mechanism) may arise if digital adoption enhances efficiency to the point of displacing manual tasks, often categorized as 'technological unemployment' (Bănescu et al., 2022; and Cirera et al., 2022). However, for labor-intensive IMKs in Indonesia characterized by simple structures, we hypothesize that the expansion effect dominates; the requirement to manage increased order volumes and logistics likely outweighs the labor-saving aspects of digitalization (Takeda et al., 2022).

The relationship between e-commerce adoption and labor demand in the Micro and Small Industry (IMK) sector can be analyzed through the lens of neoclassical production theory. In this framework, output (Y) is determined by the combination of two primary inputs, capital (K) and labor (L), traditionally formulated as $Y = f(K, L)$. In the short run, where capital tends to be fixed, any increase in output can typically only be achieved through an increase in labor input. Consequently, when production volumes rise in response to surging market demand facilitated by digital platforms, the demand for labor increases accordingly (Mankiw & Taylor, 2020).

This study to fill the existing literature gap by empirically evaluating the impact of e-commerce adoption on employment within Indonesian micro and small manufacturing enterprises. Methodologically, simple comparisons between adopters and non-adopters would yield biased results because technology adoption is not a random process; rather, it is driven by self-selection mechanisms. For instance, enterprises managed by younger, more risk-tolerant individuals or those with superior financial health are more predisposed to adopt e-commerce. Therefore, any observed differences in employment may reflect these pre-existing characteristics rather than the intrinsic impact of e-commerce. To mitigate this, the study utilizes Propensity Score Matching (PSM) to construct a counterfactual group of non-adopters that mirrors the observable characteristics of adopters. Specifically, the study seeks to answer the following question i.e. Does e-commerce adoption lead to a statistically significant increase in the workforce of micro and small manufacturing enterprises?. This method is chosen to estimate causal effects more accurately by addressing selection bias based on observable characteristics.

The primary contribution of this study lies in providing empirical evidence based on nationally representative microdata on the nexus between digital technology adoption and labor dynamics within labor-intensive sectors. Furthermore, the study employs a multidimensional conceptual framework that integrates firm characteristics, market conditions, economic factors, and human capital to analyze adoption behavior. Thus, the findings are expected to inform both academic inquiries and concrete policy implications for inclusive digitalization within Indonesia's micro and small manufacturing sectors. The scope of this study is limited to micro and small-scale manufacturing enterprises, focusing solely on labor quantity without assessing qualitative variables such as wages or job types. As a cross-sectional study reflecting post-

pandemic conditions in 2022, these findings provide an initial snapshot of digital transformation dynamics in the IMK sector, serving as a foundation for developing medium- and long-term policy interventions.

The remainder of this paper is organized as follows. Section 2 describes the data sourced from the 2022 Micro and Small Industry Survey and details the Propensity Score Matching (PSM) methodology. Section 3 presents the empirical results and discusses the causal impact of digital adoption on employment. Finally, Section 4 concludes the study with a summary of the findings, a discussion of the limitations inherent in cross-sectional post-pandemic data, and recommendations for medium-to-long-term policy interventions.

2. RESEARCH METHODS

2.1. Data Collection

This study utilizes microdata from the 2022 Micro and Small Industry (IMK) Survey conducted by BPS-Statistics Indonesia. This survey provides a comprehensive and standardized dataset regarding the characteristics of Indonesian manufacturing IMKs, including labor structure, legal status, financial conditions, and digital technology utilization. Although the data are cross-sectional, the Propensity Score Matching (PSM) framework is highly appropriate for estimating treatment effects, provided that observable confounders are strictly controlled. The year 2022 was specifically selected as it represents a critical post-pandemic recovery phase, during which digital transformation transitioned from a survival mechanism to a core business strategy. After rigorous data cleaning and the removal of observations with missing values, the final analytical sample consists of 90,358 enterprises (reduced from an initial 94,729), providing a robust basis for national-level inference. To ensure statistical stability and address the high skewness typically found in micro-enterprise financial data, variables such as total revenue and business expenditures were transformed into natural logarithms (ln). This transformation is essential to mitigate the influence of extreme outliers and stabilize variance, thereby ensuring that the regression estimates within the logit model are more robust and reliable (Wooldridge, 2015).

Table 1. The Description of Variables

Variables	Indicator	Scale	Unit
Dependent variable			
Treatment	• Total workers, including both paid and unpaid workers in the enterprise	Numeric	
Outcome	• Engages in marketing and sales via e-commerce	Categorical	1 = Yes; 0 = No
Independent variable			
Business Characteristics	• KBLI 2-digit classification	Categorical	1 = Yes; 0 = No
Economic Factors	• Business license	Categorical	1 = Yes; 0 = No
	• Year established	Numeric	
	• Enterprise scale	Categorical	1 = Small; 0 = Micro
	• Revenue	Numeric	
Market Characteristics	• Expenditure	Numeric	
	• Export activities	Categorical	1 = Yes; 0 = No
Human Resources	• Majority of customers from the local	Categorical	1 = Yes; 0 = No
	• Age of business owner/manager	Numeric	
	• Presence of professional workers	Categorical	1 = Yes; 0 = No

The primary variables analyzed in this study include the treatment variable, the outcome variable, and a set of control covariates. The treatment variable, e-commerce adoption, is defined as a binary indicator equal to 1 if the enterprise reports using digital platforms for marketing or sales, and 0 otherwise. The outcome variable is the total number of workers employed by the enterprise, which serves to measure overall labor absorption capacity and capture production expansion. To accurately estimate the impact of e-commerce on labor absorption, the study incorporates a set of covariates structured according to the conceptual framework by Pérez-Trujillo et al. (2024). First, in terms of firm characteristics, the variables include industrial subsector, enterprise scale (micro or small), year of establishment, and business license ownership. Industrial subsector controls for differences in

digitalization trends and labor intensity across industries (Alam et al., 2022), while enterprise scale distinguishes managerial and production capacity (OECD, 2019). Year of establishment reflects organizational age, which affects digital readiness newer firms are generally more responsive to new technologies (Cirera et al., 2022). Business license ownership captures formalization, which influences access to digital platforms and government support (Chen et al., 2025). Second, from an economic perspective, the log of business income and expenditure is used as a proxy for financial capacity, which, according to Zhang et al. (2023), is essential for adopting technology and expanding labor-intensive production. Third, market characteristics include export involvement and the proportion of customers from within the same province to reflect market orientation and coverage, which are relevant in the context of cross-regional e-commerce (Yin & Choi, 2021; and Takeda et al., 2022). Fourth, human capital factors include the age of the person in charge of the business and the presence of professional workers. As noted by Gherghina et al. (2021), human factors are key drivers of digital readiness in small businesses, while the presence of professional staff serves as a catalyst for implementing digital technologies and modern logistics systems (Alam & Murray, 2022).

2.2. Causal Inference using Propensity Score Matching

Propensity Score Matching (PSM), as developed by Rosenbaum & Rubin (1983), is applied in this study to mitigate selection bias in an observational setting where randomized treatment assignment is absent. Through the PSM framework, treated units (e-commerce adopters) are matched with untreated units (non-adopters) that exhibit similar probabilities of treatment participation based on observable characteristics. This matching process generates a statistically equivalent control group, thereby enabling a more credible estimation of causal effects. Following the procedure outlined by Caliendo & Kopeinig (2008), the estimation is conducted in two primary stages:

- Stage 1: the initial step involves estimating the propensity score, which represents the probability of an enterprise adopting e-commerce given its observable characteristics. To achieve this, a logit model is employed, formulated as follows:

$$P(D_i = 1|X_i) = \frac{e^{X_i\beta}}{1+e^{X_i\beta}} \quad (1)$$

In this equation, D_i is a binary indicator (1 if the enterprise adopts e-commerce, 0 otherwise); X_i is a vector of covariates categorized by financial capacity (ln revenue, ln expenditure); managerial age (owner's age); firm size (firm age), and market orientation (legality, professional workers).

The validity of the PSM estimates rests upon two core assumptions: conditional independence and common support. The first assumption implies that, once observed characteristics (X_i) are controlled for, treatment assignment is independent of the outcome. The second assumption ensures sufficient overlap in the distribution of propensity scores between the treated and control groups to facilitate valid matching.

- Stage 2: matching procedure and ATT Estimation Once common support is established and the matching is executed, a balance test is conducted to verify that the covariate distributions between the treatment and control groups are comparable. Upon achieving balance, the Average Treatment Effect on the Treated (ATT) is estimated. The ATT represents the average difference in outcomes between treated units and the counterfactual outcomes they would have experienced in the absence of treatment. It is calculated as the difference between the observed average outcome of the treated group and the estimated counterfactual outcome derived from matched control units, expressed formally as:

$$ATT = E[Y_1 - Y_0 | T = 1] \quad (2)$$

where, Y_1 is the observed outcome under treatment, and Y_0 is the unobserved counterfactual. Provided that the core assumptions are satisfied, the ATT produced via PSM serves as a credible causal estimate, offering a robust foundation for policy evaluation and evidence-based decision-making in public sector and development contexts.

2.3. Robustness test and Sensitivity Analysis

To ensure the validity of the estimation results, this study conducts extensive robustness checks by comparing ATT estimates across various matching algorithms. These include Nearest Neighbor Matching, Radius Caliper Matching, Kernel Matching (using the Epanechnikov function), and Local Linear Regression Matching. This multi-methodological approach follows established econometric practices to ensure that findings are not artifacts of a specific matching technique, thereby reinforcing internal validity in prior studies such as Black and Smith (2004); Baser (2006); and Pérez-Trujillo et al. (2024). The rationale for employing multiple matching algorithms is to strategically balance the trade-off between bias and variance, (1) Nearest Neighbor Matching provides a precise one-to-one comparison by pairing each adopter with its closest counterpart based on the propensity score; (2) Kernel and Local Linear Matching utilize a weighted average approach, incorporating more information from the control group to reduce variance and provide a smoother, more stable counterfactual; and (3) Radius Caliper Matching functions as a quality filter, ensuring that only matches within a predefined distance are included, which mitigates the risk of comparing dissimilar firms when a sufficiently close neighbor is unavailable. Furthermore, a sensitivity analysis is performed to assess the potential influence of hidden bias arising from unobserved variables. Using the Rosenbaum bounds method, the study examines the stability of the ATT estimates in the presence of hypothetical unobserved confounders. If the statistical significance of the results holds up to a Gamma value ($\gamma \geq 1.5$), the causal effect is deemed sufficiently robust. Conversely, high sensitivity to small changes in Gamma would necessitate caution in interpretation. Ultimately, this sensitivity analysis is essential for reinforcing the credibility of causal inference in PSM-based observational studies.

3. RESULTS AND DISCUSSION

3.1. Descriptive Analysis

Descriptive statistics reveal substantial disparities between Micro and Small Industry (IMK) enterprises that have adopted e-commerce and those that have not. On average, e-commerce adopters employ a larger workforce (2.73 workers) compared to non-adopters (2.06 workers), suggesting an inherently higher labor absorption capacity among digitally integrated firms. However, the high standard deviations observed in both groups underscore significant heterogeneity in enterprise scale across the sample. Demographic patterns also emerge, as business owners utilizing e-commerce are, on average, younger (44.21 years) than their non-adopting counterparts (48.62 years). This age differential suggests that digital literacy and a higher propensity for technological risk-taking among younger entrepreneurs may be critical drivers of adoption. With a total sample of 27,501 e-commerce users and 67,278 non-users, the dataset provides a robust empirical foundation for the subsequent causal analysis.

Table 2. Characteristics of IMK Based on E-Commerce Adoption for Numeric Variables

Variables	E-Commerce (n = 27,501)				Non E-Commerce (n = 67,278)			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Total workers	2.73	2.40	1.00	19	2.06	1.81	1.00	19.00
Year	2,010.87	9.43	1,900	2,022	2,007.14	11.70	1,902	2,022
Revenue	1.68×10^7	6.04×10^7	1.40×10^4	3.05×10^9	1.64×10^7	5.44×10^7	6.09×10^3	3.06×10^9
Expenditure	1.13×10^7	4.56×10^7	3.30×10^2	2.67×10^9	1.11×10^7	4.37×10^7	2.10×10^2	3.93×10^9
Age	44.21	10.12	15.00	99.00	48.62	11.39	14.00	99.00

Categorical analysis further clarifies these patterns. Interestingly, e-commerce adoption has penetrated even the smallest business units, with micro-enterprises accounting for 99.52% of adopters, a proportion nearly identical to that of non-adopters. This indicates the inclusive potential of digitalization at the micro-scale. However, significant differences appear regarding human capital and formalization: adopters are nearly three times more likely to employ professional workers (14.77% vs. 5.38%) and more likely to possess a formal business license (2.75% vs. 0.72%).

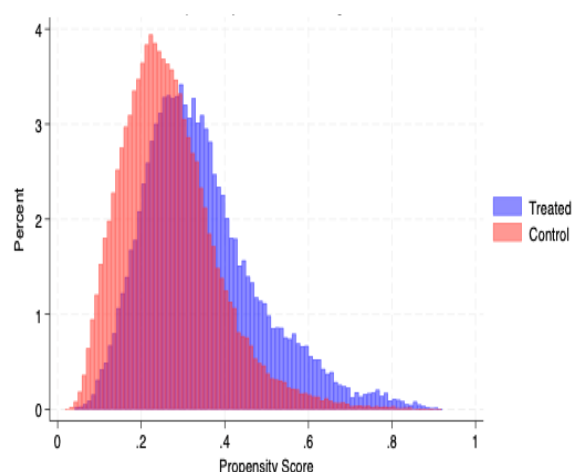
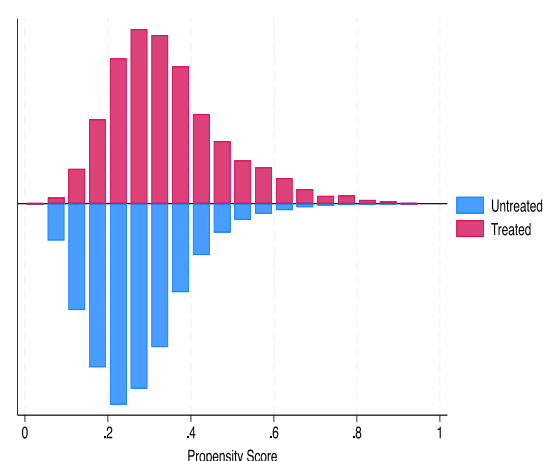
Table 3. Characteristics of IMK Based on E-Commerce Adoption for Categorical Variables

Variables	Category	E-Commerce		Non E-Commerce	
		Mean	SD	Mean	SD
Enterprise Scale	Micro	27,370	99.52	66,969	99.54
	Small	131	0.48	309	0.46
Presence of Professional Workers	Yes	4,061	14.77	3,619	5.38
	No	23,440	85.23	63,659	94.62
Majority of Customers from the local	Yes	26,910	97.85	65,780	97.77
	No	591	2.15	1,498	2.23
Business License	Yes	757	2,75	485	0,72
	No	26.744	97,25	66.793	99,28

Despite these digital advances, both groups remain heavily reliant on localized markets, with over 97% of enterprises reporting that the majority of their customers reside within the same province. This suggests that while e-commerce facilitates digital transformation, it has not yet fundamentally shifted the geographical market orientation of most IMK. These findings highlight a critical policy gap: digital adoption is advancing, yet it is not consistently accompanied by institutional formalization or expanded market reach.

3.2. Results of Propensity Score Matching

To ensure the validity of the Propensity Score Matching (PSM) results, the Common Support and Overlap assumptions were visually and statistically assessed. Figure 1 presents the distribution of propensity scores, revealing a substantial overlap between e-commerce adopters (treated) and non-adopters (control). While the control group is primarily concentrated in the lower propensity range (0.1–0.3), the treated group is more broadly dispersed across the mid-range (0.3–0.6).

**Figure 1.** Histogram of Propensity Score Distribution Between Treated and Control Groups**Figure 2.** Visualization of the Common Support Region Based on Propensity Scores

The visualization of the common support region in Figure 2 confirms that all treated observations fall within the distribution range of the control group. This indicates that every enterprise adopting e-commerce has a comparable "twin" in the non-adopting pool, satisfying the overlap condition required for high internal validity in the Average Treatment Effect on the Treated (ATT) estimation. With these assumptions met, the matching process proceeded to align the groups effectively, neutralizing the impact of observable confounding factors.

The first stage of the causal analysis involves estimating propensity scores using a logit model to determine the likelihood of e-commerce adoption based on observable firm characteristics. As presented in Table 4, several factors significantly influence the probability of adoption². The age of the business owner exhibits a negative and statistically significant effect ($p < 0.01$), reinforcing the premise that younger entrepreneurs possess higher digital literacy and a greater inclination toward technological integration.

Table 4. Results of Logistic Regression for Propensity Score Estimation

Variables	PSM	Variables	PSM
	Before		Before
Age of business owner	-0,027*** (0,001)	Tobacco industry	-0,467*** (0,066)
Enterprise scale	-0,024 (0,112)	Textile industry	-0,505*** (0,044)
Ln Revenue	-0,031 (0,015)	Apparel industry	-0,271*** (0,036)
Ln Expenditure	0,043*** (0,012)	Leather industry	0,276*** (0,055)
Year of operation	0,017*** (0,001)	Wood industry	-0,490*** (0,039)
Business license ownership	0,832*** (0,063)	Printing industry	0,837*** (0,054)
Majority of customers from the local	0,069 (0,051)	Chemical industry	-0,412*** (0,078)
Presence of professional workers	0,863*** (0,026)	Non-metallic mineral industry	-0,013 (0,039)
Export activity	-0,357 (0,672)	Metal product industry	0,368*** (0,040)
Food industry	-0,001 (0,032)	Furniture industry	0,472*** (0,041)
Beverage industry	-0,009 (0,043)	Other industry	0,155*** (0,046)

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Conversely, the year of establishment, business license ownership, and the presence of professional workers are positively associated with adoption, suggesting that operational experience, formalization, and human capital are primary catalysts for digitalization.

Table 5. Results of t-test for Mean Differences Before and After Matching

Variables	Matching		Variables	Matching	
	Before	After		Before	After
Age of business owner	4.410*** (0.079)	0.980*** (0.097)	Tobacco industry	-0.013*** (0.001)	0.002** (0.001)
Enterprise scale	0.000*** (0.000)	0.001 (0.001)	Textile industry	0.027*** (0.002)	0.004** (0.002)
Ln Revenue	0.044*** (0.011)	0.012 (0.014)	Apparel industry	0.028*** (0.002)	0.013*** (0.003)
Ln Expenditure	0.063*** (0.014)	0.024 (0.018)	Leather industry	-0.008*** (0.001)	0.001 (0.002)
Year of operation	3.730*** (0.079)	0.551*** (0.089)	Wood industry	0.060*** (0.002)	0.007*** (0.002)
Business license ownership	0.020*** (0.001)	0.011*** (0.001)	Printing industry	0.034*** (0.001)	0.019*** (0.002)
Majority of customers from the local	0.001*** (0.001)	0.001 (0.001)	Chemical industry	0.004*** (0.001)	0.001 (0.001)
Presence of professional workers	0.094*** (0.002)	0.046*** (0.003)	Non-metallic mineral industry	0.006*** (0.002)	0.003 (0.003)
Export activity	0.000*** (0.000)	0.000*** (0.000)	Metal product industry	0.028*** (0.002)	0.006*** (0.003)
Food industry	0.015*** (0.003)	0.005 (0.004)	Furniture industry	0.031*** (0.002)	0.010*** (0.002)
Beverage industry	0.012*** (0.002)	0.001 (0.002)	Other industry	0.008*** (0.001)	0.002 (0.002)

Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Sectoral analysis reveals that structural differences across industries shape technological readiness. Enterprises within the printing, furniture, leather, and metal goods subsectors demonstrate a higher propensity for e-commerce adoption. In contrast, firms in the textiles, apparel, wood, chemical, and tobacco industries display significantly lower adoption probabilities. These results justify the use of these variables as covariates to ensure a balanced comparison between treated and control units

The results of the logistic regression used for propensity score estimation are detailed in Table 4. The model demonstrates that various firm-level characteristics significantly influence the likelihood of e-commerce adoption. Beyond the previously noted impact of the owner's age, financial capacity, proxied by the logarithm of expenditure, shows a positive and significant association with digital integration. Furthermore, institutional factors, particularly business license ownership, significantly increase the probability of adoption, suggesting that formalized enterprises are better positioned to navigate digital marketplaces. The presence of professional workers also emerges as a robust predictor, highlighting the role of specialized human capital in facilitating the transition to digital sales channels.

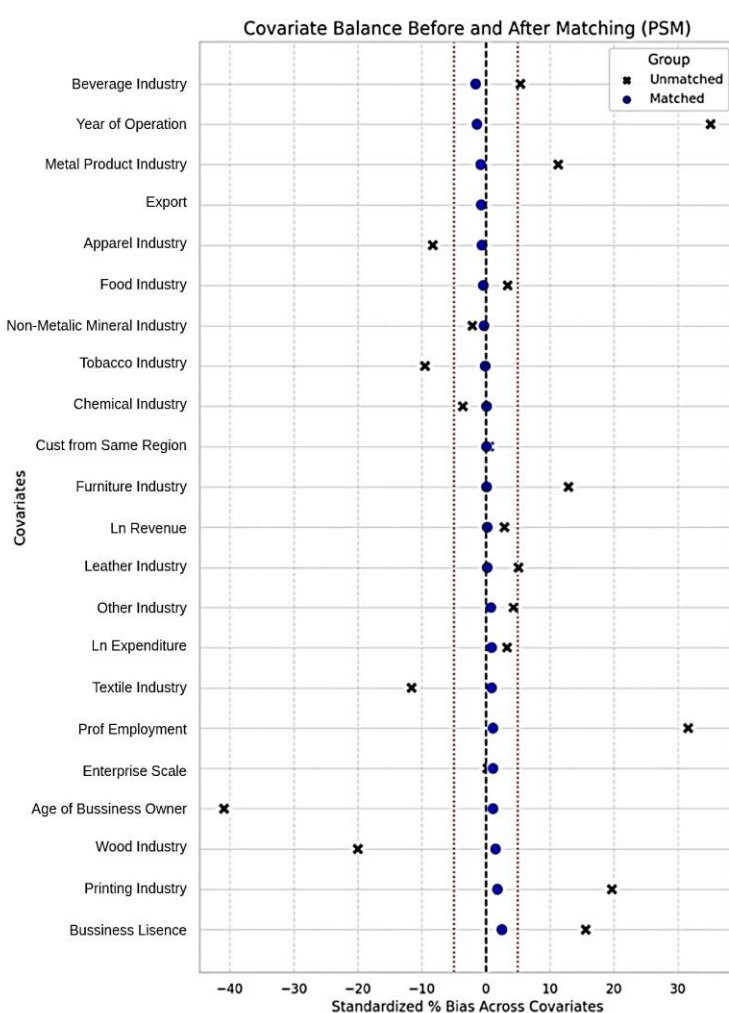


Figure 3. Covariate Balance Before and After Matching

To provide a clear visual assessment of the matching quality, Figure 3 illustrates the standardized percentage bias for each covariate both before and after the matching procedure. Prior to matching (indicated by the "Unmatched" dots), several variables exhibited a standardized bias exceeding the 20% threshold, particularly regarding managerial age and certain industrial subsectors. After matching (indicated by the "Matched" dots), the bias for nearly all covariates shifted significantly toward the zero-percent line, falling well within the acceptable $\pm 5\%$ range. This visual evidence confirms that the Propensity Score Matching successfully balanced the characteristics of e-commerce adopters and non-adopters, thereby neutralizing potential selection bias.

With a balanced counterfactual established, we estimate the Average Treatment Effect on the Treated (ATT) to quantify the causal impact of e-commerce adoption on employment. The results across multiple matching algorithms Nearest Neighbor, Radius Caliper, and Kernel Matching, are presented in Table 8. The findings are remarkably consistent: e-commerce adoption has a positive and statistically significant impact on labor absorption in the IMK sector ($p < 0.01$).

Table 6. The Result of Estimated Average Treatment Effect on the Treated

Variable	Sample	Treated	Control	Difference	S.E	t-Stat
Total Workers	Unmatched	2,7301	2,0557	0,6743	0,0143	47,15
	ATT	2,7301	2,1656	0,5644	0,0211	26,83

Specifically, the ATT estimates suggest that adopting e-commerce leads to an average increase of approximately 0.51 to 0.54 workers per enterprise. While this numerical increase may appear modest in absolute terms, it represents a substantial relative growth of approximately 25% compared to the control group's mean labor size. This finding strongly supports the "expansion effect" hypothesis: for Indonesian micro and small industries, the market-widening capabilities of e-commerce drive production increases that necessitate additional manual labor, far outweighing any potential labor-displacement effects from digital efficiency.

Furthermore, the heterogeneity analysis based on enterprise scale reveals differential impacts of e-commerce adoption on employment across micro and small enterprises (Table 7). Micro-enterprises experienced an average increase of 0.544 workers, equivalent to approximately a 27.2% rise relative to the sector's median of two workers per unit. In contrast, small enterprises recorded an average increase of 0.847 workers, corresponding to an 8.5% increase based on the median of ten workers. Thus, while the absolute effect is larger among small enterprises, the proportional impact is greater in micro-enterprises. This finding suggests that firms with more limited labor capacity are relatively more responsive to the integration of digital technologies.

Table 7. The Result of Estimated ATT by Enterprise Scale

Variable	ATT Result Total Workers	Variable	ATT Result Total Workers
Micro Scale Enterprise	0.544*** (0,283)	Small Scale Enterprise	0.847*** (0,211)

Note: Robust standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Within the broader literature framework, the findings of this study are consistent with those of Pérez-Trujillo et al. (2024) in Chile, which demonstrate that e-commerce adoption can increase employment by 36–37% in small and medium-sized enterprises. Their study also emphasizes that the positive impact of e-commerce is more pronounced among firms with moderate levels of online sales intensity and in sectors such as services and information.

3.3. Results of Robustness tests and Sensitivity Analysis

To ensure the reliability of the estimated treatment effects, a series of robustness checks were performed. As established in the previous section, the consistency of the Average Treatment Effect on the Treated (ATT) across Nearest Neighbor, Radius Caliper, and Kernel Matching algorithms, all yielding significant coefficients between 0.51 and 0.54, this indicates that the findings are not sensitive to the choice of matching technique. This stability reinforces the internal validity of the conclusion that e-commerce adoption facilitates labor absorption. Beyond algorithmic consistency, a sensitivity analysis was conducted using the Rosenbaum bounds (γ) method to address the potential for hidden bias from unobserved variables. In observational studies, the concern is that an unobserved factor (e.g., entrepreneurial motivation or innate digital aptitude) could simultaneously influence both the decision to adopt e-commerce and the level of employment, thereby biasing the ATT.

Table 8. The result of Estimated Average Treatment Effect on the Treated

Methods	ATT	Treated	Control	S.E.	t-Stat
<i>Nearest Neighbors (1)</i>	0.5644	2.7301	2.1656	0.0211	26.83
<i>Nearest Neighbors (5)</i>	0.5584	2.7301	2.1715	0.0176	31.61
<i>Nearest Neighbors (10)</i>	0.5511	2.7301	2.1791	0.0172	32.01
<i>Radius Caliper (0,05)</i>	0.5525	2.7301	2.1775	0.0167	33.05
<i>Radius Caliper (0,01)</i>	0.5464	2.7301	2.1836	0.0168	32.51
<i>Kernel Epanechnikov</i>	0.5515	2.7301	2.1785	0.0167	32.97
<i>Local Linear Regression</i>	0.5231	2.6588	2.1356	0.0161	32.35

Source: Authors' calculations

As detailed in Table 9, the sensitivity analysis reveals that the estimated impact of e-commerce on total workers remains statistically significant ($p < 0.01$) even as the level of hidden bias (γ) increases. The results remain robust up to a Gamma value of 1.5, suggesting that for the observed effect to be nullified, an unobserved covariate would have to increase the odds of e-commerce adoption by 50% while also being highly correlated with labor absorption.

Table 9. The result of Estimated Average Treatment Effect on the Treated

Gamma	Sig+	Sig-	T-hat+	T-hat-	CI+	CI-
1	0	0	0.5	0.5	0.5	0.5
1.1	0	0	0.5	0.5	0.5	0.5
1.2	0	0	0.5	0.5	0.5	0.5
1.3	0	0	2.70×10^7	0.5	2.70×10^7	0.5
1.4	0	0	2.70×10^7	0.5	2.70×10^7	0.5
1.5	0	0	-2.70×10^7	1	-2.70×10^7	1
1.6	2.40×10^{11}	0	-2.70×10^7	1	-2.70×10^7	1
1.7	0.004255	0	-2.70×10^7	1	-2.70×10^7	1

Given that the threshold of $\gamma \geq 1.5$ is widely considered a benchmark for robustness in social science research, these findings can be deemed resistant to potential confounding⁷. This provides a credible causal foundation for the study's primary argument: e-commerce adoption is a significant driver of job creation within Indonesia's micro and small manufacturing sectors.

3.4. Discussion

This section evaluates the empirical findings by interpreting their economic significance, situating them within the existing literature, and drawing policy-relevant implications. The discussion focuses on the mechanisms through which e-commerce adoption drives labor absorption in micro and small manufacturing enterprises (IMKs), explores how this effect varies across enterprise scales and sectors, and outlines the implications for digital transformation policies in developing economies like Indonesia.

The empirical results confirm that e-commerce adoption acts as a significant catalyst for labor demand within Indonesia's micro and small manufacturing sectors. The positive ATT suggests that the expansion effect where digital platforms broaden market reach and increase sales volumes effectively overrides the substitution effect where technology might otherwise displace manual labor. In the context of labor-intensive IMK with simple organizational structures, the increased operational complexity of managing online orders and logistics appears to require a larger workforce. Furthermore, the significant role of human capital (professional workers) and formalization (business licenses) in predicting adoption suggests that digitalization is most effective when paired with institutional support and skilled labor. These findings highlight that while e-commerce is a powerful tool for employment growth, its benefits are currently more concentrated among enterprises that have achieved a certain level of formal and human capital readiness.

The results of this study demonstrate that e-commerce adoption significantly increases labor absorption among micro and small manufacturing enterprises in Indonesia. The estimated Average Treatment Effect on the Treated (ATT) indicates an addition of approximately 0.56 workers per

enterprise. While this increase may appear modest at the firm level, its cumulative impact is substantial for small-scale industries; for instance, extrapolating these findings to a national scale of one million IMK adopters suggests the potential creation of over 500,000 new employment opportunities. This underscores that e-commerce does not merely enhance business efficiency but also serves as a vital engine for job creation in the informal and semi-formal sectors. This finding aligns with the landmark research by Hjort & Poulsen (2019), which provides causal evidence from developing regions showing that the expansion of digital infrastructure significantly increases employment rates. Their research suggests that in emerging economies, technology often complements rather than replaces labor, particularly when it opens access to previously unreachable markets. Similarly, such as Pérez-Trujillo et al. (2024) has found the positive impact observed here mirrors findings in other developing contexts, such as Chile and Colombia, where e-commerce has been found to boost productivity and foster job creation in small-scale manufacturing.

From a theoretical perspective, the positive relationship between e-commerce and employment confirms the dominance of the expansion effect over the substitution effect within the Indonesian IMK sector. According to neoclassical production theory, as digital platforms reduce transaction costs and broaden market access, the resulting surge in production volume necessitates additional labor inputs, particularly in short-run scenarios where capital remains fixed. In labor-intensive industries characterized by simple organizational structures, the labor required to manage increased order fulfillment, digital marketing, and logistics outweighs the labor-saving potential of digital automation.

The analysis further reveals that the propensity for e-commerce adoption is not uniform across the manufacturing landscape. Subsectors such as printing, furniture, and fabricated metal products exhibit higher digital adaptability, likely due to product complexity and the logistical advantages of online distribution. Conversely, sectors like tobacco, wood, and textiles show lower adoption rates, reflecting conventional market structures or technological limitations. These disparities indicate that a "one-size-fits-all" approach to digitalization is insufficient. Effective policies must prioritize strengthening key enabling factors, such as human capital development, business formalization, and localized technological infrastructure, to ensure that the benefits of the digital economy are inclusive and widespread across all industrial subsectors.

Interestingly, our analysis reveals that financial magnitude in terms of revenue does not show a statistically significant association with the probability of adoption. This aligns with the shifting dynamics of the post-pandemic digital landscape described by Takeda et al. (2022) they argue that digitalization has become a survival and growth strategy for MSMEs in Asia, driven more by managerial responsiveness and business formalization than by pre-existing financial scale. This suggests that the lowering costs of digital tools have made e-commerce more inclusive, allowing firms with smaller revenues to compete if they possess the necessary legal and human capital frameworks. It is important to distinguish that while these factors are identified as statistical associations in the logit model, the causal inference regarding job creation is strictly established through the PSM framework.

The analysis reveals that the impact of e-commerce on employment is significantly mediated by the "readiness" of the enterprise, particularly regarding human capital and formalization. The higher adoption rates among enterprises with professional workers and formal business licenses suggest that digital transformation is most effective when integrated into a structured business model. Furthermore, the age of the business owner emerged as a critical determinant. The negative correlation between owner age and e-commerce adoption reflects a generational digital divide. Younger entrepreneurs, often categorized as "digital natives," demonstrate a higher tolerance for technological risk and a greater ability to pivot toward online marketing strategies. This suggests that for older entrepreneurs, digital adoption is not merely a matter of access to technology but requires targeted digital literacy interventions to bridge the capability gap.

Importantly, the analysis distinguishes clearly between empirical evidence and its interpretation. While the Results section presents the causal estimates derived from the PSM framework, this Discussion section contextualizes those estimates within relevant economic theory and empirical literature. Such separation enhances the transparency of the empirical strategy and improves the clarity of the manuscript's contribution.

4. CONCLUSIONS

The empirical findings of this study provide robust evidence that e-commerce adoption is positively and significantly associated with increased labor absorption in Indonesia's Micro and Small Industry (IMK) sector. Extrapolating the estimated treatment effects to the national level suggests that widespread digital integration could potentially generate over 564,400 new employment opportunities. Furthermore, the analysis reveals that technological diffusion is not uniform across the manufacturing landscape; subsectors such as printing, furniture, and metal products exhibit higher adoption rates, indicating that digital transformation accelerates in industries characterized by greater structural and resource readiness. These results underscore the critical role of human capital and institutional preparedness in facilitating productive digitalization within the IMK sector. To validate the causal claims of this research, a sensitivity analysis using the Rosenbaum bounds method was conducted. The results confirm the robustness of the Average Treatment Effect on the Treated (ATT) estimates against potential hidden bias, with statistical significance persisting up to a Gamma value exceeding 1.5. This high threshold reinforces the credibility of the causal effect, establishing e-commerce adoption as a meaningful driver of job creation among micro and small manufacturing enterprises.

The study offers the following policy recommendations to strengthen the determinants of digital adoption and maximize its employment-generating potential. First, enhancing digital human capital through upgrading digital skills and literacy among both workers and business owners. Targeted technical training programs should be provided to entrepreneurs who demonstrate readiness for digital transition, while basic digital literacy initiatives should be directed toward micro-enterprises currently outside the digital ecosystem to ensure inclusive growth. Second, accelerating business formalization through streamlining and accelerating business license registration is essential. Formalization serves as a critical gateway for IMK to access formal digital marketplaces and financial services, thereby facilitating smoother digital integration. Third, life-cycle-tailored interventions through digitalization programs should be strategically designed to align with an enterprise's specific stage in its business life cycle. This ensures that support is appropriately matched to the firm's scale, experience, and capacity for expansion. Lastly, sector-specific strategic approaches through interventions should adopt a sectoral lens to address the unique needs of different industrial subsectors. For instance, sectors with high digital readiness (e.g., furniture and printing) may benefit most from strategies focused on expanding international market access, whereas other sectors may require foundational support to improve internal operational efficiency through basic digital tools. By adopting a nuanced, enterprise-centric, and sector-based approach, digital transformation policies can do more than just accelerate e-commerce adoption; they can serve as a catalyst for sustainable job creation and enhance the global competitiveness of Indonesia's small business sector in an increasingly digitalized economy.

Acknowledgment: This research was funded by the Indonesia Endowment Fund for Education (LPDP), Ministry of Finance of the Republic of Indonesia, through the LPDP Scholarship Program. We sincerely thank our academic advisors for their invaluable guidance and constructive feedback throughout the research process. Our gratitude also extends to the administrative staff for their assistance in managing research logistics and to those who contributed through proofreading and review, helping to enhance the clarity and quality of this manuscript. Lastly, we acknowledge the support of individuals and institutions that provided essential resources and materials, making this research possible.

Authors contribution: M.S. contributed to the conceptualization of the study, data collection, data analysis, and drafting of the manuscript. D.H. contributed to the research design and methodology, provided academic supervision, critically reviewed and revised the manuscript, and gave guidance on interpretation of results.

Conflict of interest: The authors declare no conflict of interest.

REFERENCES

- Alam, K., Ali, M. A., Erdiaw-Kwasie, M. O., Murray, P. A., & Wiesner, R. (2022). Digital Transformation among SMEs: Does Gender Matter?. *Sustainability*, 14(1), 535. <https://doi.org/10.3390/su14010535>
- Ausat, A. M. A., & Peirisal, T. (2021). Determinants of E-commerce Adoption on Business Performance: A

- Study of MSMEs in Malang City, Indonesia. *Jurnal Optimasi Sistem Industri*, 20(2), 104–114. <https://doi.org/10.25077/josi.v20.n2.p104-114.2021>
- Badan Pusat Statistik [BPS]. (2023). *Labour Force Situation in Indonesia August 2023*. Jakarta: Badan Pusat Statistik.
- Badan Pusat Statistik [BPS]. (2024). *Quarterly Gross Domestic Product of Indonesia 2020-2024*. Jakarta: Badan Pusat Statistik.
- Bănescu, C. E., Tițan, E., & Manea, D. (2022). The impact of e-commerce on the labor market. *Sustainability*, 14(9), 5086. <https://doi.org/10.3390/su14095086>
- Baser, O. (2006). Too Much Ado about Propensity Score Models? Comparing Methods of Propensity Score Matching. *Value in Health*, 9(6), 377-385. <https://doi.org/10.1111/j.1524-4733.2006.00130.x>
- Black, D. A., & Smith, J. A. (2004). How Robust is the Evidence on the Effects of College Quality? Evidence from Matching. *Journal of Econometrics*, 121(1-2), 99-124.. <https://doi.org/10.1016/j.jeconom.2003.10.006>
- Caliendo, M., & Kopeinig, S. (2008). Some practical guidance for the implementation of propensity score matching. *Journal of Economic Surveys*, 22(1), 31–72. <https://doi.org/10.1111/j.1467-6419.2007.00527.x>
- Chava, S., Oettl, A., Singh, M., & Zeng, L. (2024). Creative destruction? Impact of e-commerce on the retail sector. *Management Science*, 70(4), 2168–2187. <https://doi.org/10.1287/mnsc.2023.4795>
- Chen, S., Chao, X., Wang, C., & Xue, Z. (2025). Government Digital Product Procurement and Enterprise Digital Transformation. *China & World Economy*, 33(5), 139-166. <https://doi.org/10.1111/cwe.12605>
- Chun, H., Joo, H. H., Kang, J., & Lee, Y. (2023). E-commerce and Local Labor Markets: Is the “Retail Apocalypse” Near?. *Journal of Urban Economics*, 137, 103594.. <https://doi.org/10.1016/j.jue.2023.103594>
- Cirera, X., Comin, D., & Cruz, M. (2022). *Bridging the Technological Divide: Technology Adoption by Firms in Developing Countries*. World Bank Publications.
- Gherghina, Ș. C., Botezatu, M. A., & Simionescu, L. N. (2021). Exploring the Impact of Electronic Commerce on Employment Rate: Panel Data Evidence from European Union Countries. *Journal of Theoretical and Applied Electronic Commerce Research*, 16(7), 3157-3183. <https://doi.org/10.3390/jtaer16070172>
- Harahap, M. A., Sutrisno, S., Raharjo, I. B., Novianti, R., & Ausat, A. A. (2023). The Role of MSMEs in Improving the Economy in Ramadan. *Community Development Journal*, 4(2), 1907-1911.
- Hjort, J., & Poulsen, J. (2019). The Arrival of Fast Internet and Employment in Africa. *American Economic Review*, 109(3), 1032-1079. <https://doi.org/10.1257/aer.20161385>
- Mankiw, N. G., & Taylor, M. P. (2020). *Economics*. Cengage Learning EMEA.
- OECD. (2019). *SME and Entrepreneurship Outlook 2019*. OECD Publishing, Paris. <https://doi.org/10.1787/34907e9c-en>
- Pérez-Trujillo, M., Torrejón, C. A., & Calderón, M. L. (2024). Is E-commerce an Opportunity for Boosting Employment in Developing Countries? a study for the Chilean case. *Asia-Pacific Journal of Regional Science*, 8(4), 1077-1110. <https://doi.org/10.1007/s41685-024-00356-4>
- Purnomo, S. D., Adhitya, B., & Zumaeroh, Z. (2021). The Impact of the Digital Economy on the Income of Micro and Small Industries in Indonesia. *Jurnal Ekonomikawan*, 21(1), 85-95. <https://doi.org/10.30596/ekonomikawan.v21i1.6248>
- Rodríguez Puello, G., Sands Lambraño, Y., Méndez Rodríguez, A., & Castilla Castilla, L. (2022). The Impact of E-commerce on Productivity: Firm-level Evidence from Colombia. *Serie de Documentos de Trabajo IDEAS*, 1(1), 1-19. <https://doi.org/10.13140/RG.2.2.16661.19682>
- Rosenbaum, P. R., & Rubin, D. B. (1983). The Central Role of the Propensity Score in Observational Studies for Causal Effects. *Biometrika*, 70(1), 41-55. <https://doi.org/10.1093/biomet/70.1.41>
- Takeda, A., Truong, H. T., & Sonobe, T. (2022). The Impacts of the COVID-19 Pandemic on Micro, Small, and Medium Enterprises in Asia and Their Digitalization Responses. *Journal of Asian Economics*, 82, 101533. <https://doi.org/10.1016/j.asieco.2022.101533>
- Wooldridge, J. M. (2015). *Introductory Econometrics: A Modern Approach* (6th ed.). Cengage Learning.
- Yin, Z. H., & Choi, C. H. (2021). The Effects of China’s Cross-border E-commerce on its Exports: a Comparative Analysis of Goods and Services Trade. *Electronic Commerce Research*, 23(1), 443-474. <https://doi.org/10.1007/s10660-021-09483-y>
- Zhang, L., Chen, J., Liu, Z., & Hao, Z. (2023). Digital Inclusive Finance, Financing Constraints, and Technological Innovation of SMEs—Differences in the Effects of Financial Regulation and Government Subsidies. *Sustainability*, 15(9), 7144. <https://doi.org/10.3390/su15097144>

THIS PAGE INTENTIONALLY LEFT BLANK