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Digitization, Automation, Network Externalities, and Effectiveness - Firm-level Evidence from Taiwan

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Abstract

This study utilizes constructed firm-level panel data encompassing Taiwanese manufacturing firms from 1999, 2000, and 2002. We endeavor to examine the relationship between the adoption of digital and automated technologies by applying the seemingly unrelated bivariate probit model. Furthermore, digital capital possesses a distinctive characteristic that sets it apart from traditional inputs-it has the potential to generate significant economic externalities. Consequently, in addition to incorporating the relationship between the adoption of digital and automated technologies into our model, this study also investigates the e-commerce externalities within and between industries.

Keywords: *Automatic, Digital, Externalities, Productivity, Seemingly unrelated bivariate probit model.*

INTRODUCTION

As part of the tools for fostering competitiveness in organizations and promoting the use of information and communication technologies (ICT), digital commerce, or e-commerce, has emerged in the new millennium. This form of trade has witnessed steady growth over time, with more organizations establishing these communication channels with customers to enhance their trade relationships. E-commerce, in general, is reshaping the nature of global trade. However, this transformation is occurring at varying paces in different regions around the world (Villa et al., 2018). Currently, its most significant impact is observed in Asia, the USA, and Northern Europe (Awiagah et al., 2016; Pappas et al., 2017). In 2020, the global Business-to-Business e-commerce market reached a value of USD 6.64 trillion, and it is projected to grow at a compound annual growth rate (CAGR) of 18.7% from 2021 to 2028. The COVID-19 pandemic has driven a shift in consumer preferences towards online shopping, creating opportunities for further expansion in this sector.

The B2B e-commerce landscape has undergone significant changes due to increased order volumes, shifts in consumer behavior, supply chain disruptions, and the closure of physical stores. While retail sales experienced a decline in 2020, e-commerce sales surged. Many B2B businesses have pivoted their focus towards establishing a stronger online presence. On a global scale, the market exhibits a high degree of fragmentation, with a mix of small, medium, and large enterprises transitioning to digital platforms. The pandemic has prompted a substantial shift, as numerous businesses have turned to online platforms as an alternative means to meet customer demands. In the long term, the COVID-19 pandemic is expected to continue influencing the way organizations conduct business, with online commerce becoming the primary strategy for most B2B vendors. Notable global players in this arena include Walmart, Amazon.com, Inc., ChinaAseanTrade.com, Flipkart.com, and Alibaba. Collaborations and partnerships will facilitate local vendors in expanding into global markets more swiftly.[2]

In the 1990s, Taiwanese manufacturing firms encountered a dilemma characterized by a shortage of entry-level labor and technological human capital, compounded by challenges in acquiring land due to increased environmental protection awareness. To sustain their competitive edge, companies in certain industries opted to relocate their operations from Taiwan to Southeast Asia and/or mainland China. Meanwhile, those in other industries that remained in Taiwan embarked on a path of technological and manufacturing process enhancements. Consequently, innovative automation equipment and techniques emerged as pivotal focal points for firms to invest in.

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According to Liu et al., (2013), Taiwan serves as an exceptional case for investigating the relationship between e-commerce and productivity for the following three key reasons. First, Taiwan not only played a pivotal role in the manufacturing of information and communication technology (ICT) products in the late 1990s but also achieved a high adoption rate of e-commerce. In 1998, Taiwanese firms held a dominant cumulative global market share, with 58% for computer monitors, nearly 40% for notebook PCs, 61% for motherboards, 69% for desktop scanners, 65% for computer keyboards, and 60% for mouse devices (Chung, 1997). Given that e-commerce can be viewed as a new technology or a process innovation, it raises the intriguing question of whether e-commerce adoption truly enhances firms' productivity in Taiwan. Second, Taiwan offers access to a unique dataset obtained from government surveys, which includes information on the volume of e-commerce transactions. It's worth noting that digital technology applications extend beyond just Internet usage. Taiwanese firms utilize email, digital data interchange (EDI), and the Internet to communicate with their upstream and downstream partners. While other digital technologies might also influence firm productivity, this study concentrates on e-commerce technology, aligning with existing literature. Consequently, the conventional approach of using a binary variable for Internet usage in prior studies may not adequately capture the dynamic landscape of firms involved in e-commerce investments. This study, therefore, employs an alternative measure of e-commerce as a proxy for empirical estimations. Third, Taiwanese firms have carved out niche positions through vertical disintegration within global production networks, particularly in high-tech industries (Chen, 2002). Taiwan's major sectors are marked by their vertical disintegration and their pursuit of original equipment (design) manufacturing (OEM/ODM) contracts for brand firms (Chen, 2004). This suggests that information technology, including e-commerce, facilitates Taiwanese firms' participation in global production networks and potentially enhances productivity.

Lucking-Reiley and Spulber (2001) have emphasized that B2B (business-to-business) e-commerce has introduced significant efficiencies through automation and transactions. This enables companies to leverage transaction-generated data for the automatic updating of their inventory, production, and accounting records. This is achieved by integrating their transactions with software designed to manage all aspects of the firm, including sales, procurement, and operations. In a study by Alderete (2019), the relationship between the extent of digital commerce and the performance of small and medium-sized enterprises (SMEs) was explored, representing a burgeoning area of research that warrants further investigation. The results obtained indicate that firms with more advanced websites capable of conducting e-commerce operations achieve higher sales compared to SMEs with rudimentary or no online presence. The advent of B2C (business-to-consumer) e-commerce in the past decade has ushered in transformative changes in the way warehouses fulfill online orders. This includes handling a wide range of product assortments, managing variable workloads, and meeting extremely tight delivery schedules (Ponis et al., 2020).

E-commerce has experienced significant growth in recent years. While prior literature has examined the factors contributing to the adoption of e-commerce, limited attention has been given to its impact on both profitability and revenue (Lorca, 2019). Some economists have argued that the IT (information technology) revolution does not necessarily lead to increased productivity, and higher IT investment does not always correlate with improved productivity. Solow (1987) termed this phenomenon the "Productivity Paradox" (Liu et al., 2014). For instance, Lorca (2019) conducted a study using data from the Spanish Survey on Business Strategies (ESEE) over an eight-year period (2008-2015). The study analyzed 2,544 Spanish companies operating in the manufacturing sector. The results indicate that neither business-to-business (B2B) nor business-to-consumer (B2C) e-commerce appears to have an influence on revenue growth. This suggests the possibility of a substitution effect between sales through physical channels and e-commerce sales.

Furthermore, Svobodová and Rajchlová (2020) conducted a study involving a sample of 89 e-commerce businesses specializing in online digitals sales. The research revealed that most e-commerce businesses employ a well-rounded e-commerce strategy based on the factors related to online shopping behavior, which may not align with the rapidly evolving landscape of e-commerce. The study identified fifteen factors that significantly influence customers in their choices and purchases of digitals online. It was also observed that the strategic decisions of e-commerce businesses are influenced by factors related to online shopping behavior. Lastly, the research indicated that the current well-rounded e-commerce strategy adopted by e-commerce businesses does not necessarily align with a conservative financial strategy.

Scholars and experts widely believe that Artificial Intelligence (AI) will play a pivotal role in driving innovation in the years to come. A crucial aspect of this belief pertains to understanding the impact of AI technologies on productivity. Historical observations of disruptive innovations, such as the industrial revolution and the mechanization of agriculture, suggest that automating existing tasks has led to remarkable increases in productivity (Acemoglu and Restrepo, 2019). Electrical automation technology is a comprehensive approach that integrates automation software and hardware to oversee electrical automation processes. It encompasses the utilization of computer technology, information technology, and control theory across various domains, substantially enhancing work efficiency, product quality, and overall safety in the production process. Consequently, the market for electrical automatic control systems continues to expand, providing a solid foundation for its growth. Niu et al., (2018) highlight that the development of electrical automation engineering control systems is fundamental to modern industrial progress in China, reflecting the rapid advancement of modern technology. The application of electrical automation technology not only enhances work efficiency but also reduces enterprise costs. In summary, the ongoing evolution of the social economy imposes higher demands on electrical automatic control systems. Currently, these systems are extensively used across various sectors in China, effectively promoting the development and advancement of the country's social economy.

It has been observed that automation significantly boosts employee productivity while also saving time. It has a notable impact on the workload of employees, effectively controlling errors and fraudulent activities, ultimately resulting in enhanced productivity. It is assumed that in the corporate sector, employees already contend with substantial workloads, and any further increase in workload tends to lead to diminished productivity (Camara et al., 2019). In recent years, businesses have gradually embraced information and communication technology (ICT) as they recognize its numerous advantages. Although the new ICT paradigm holds great promise for enhancing competitiveness, there remains a scarcity of empirical evidence regarding the relationship between ICT and the performance of small and medium-sized enterprises (SMEs) in developing countries, particularly concerning e-commerce adoption (Alderete, 2019).

According to the study and survey mentioned above, the application of digital technology encompasses both the supply and demand sides. For instance, companies integrate automation facilities with various IT functions, such as monitoring, data processing, computer control, and other digital technologies like CAD, CAM, and CNC. This suggests that the decision by firms to invest in automation and digital activities is influenced not only by industrial transitions and government policies but also by the interconnectedness of technological applications. For instance, as indicated by Sirvi et al., (2021), the role of e-commerce in customer engagement is closely tied to various factors, with technology and the internet playing pivotal roles. Moreover, the automation of technological tools in e-commerce plays a critical role in supporting customer engagement. However, empirical evidence regarding the relationship between the adoption of digital and automatic technology remains scarce. Most analyses of technology adoption relationships predominantly focus on automation, such as CNC/CCT (Wozniak 1984; Stonman and Kwon 1994; Camara et al., 2019), without considering other related technologies.

Given the past literature's limited consideration of the adoption of multiple technologies and the inconsistent research findings, there is a need to delve into the relationship between the adoption of multiple technologies and the significant increase in spending on automation and digital transactions in recent years. We contend that the Taiwanese authorities should place greater emphasis on internal technological resources to gain a deeper understanding of this dynamic. In this study, we utilize a newly constructed panel dataset encompassing Taiwanese manufacturing firms from 1999, 2000, and 2002 to investigate the interplay between the adoption of digital and automatic technologies. This is achieved through the application of the seemingly unrelated bivariate probit model. It is noteworthy that there is a scarcity of similar studies on this topic in newly industrializing economies (NIEs). These studies have neither simultaneously estimated the substitutive/complementary relationship between the adoption of digital and automatic technology nor employed firm-level panel data for such investigations (e.g., Muntean et al., 2016). Therefore, the insights derived from Taiwan's experience may serve as a valuable reference for other developing countries.

E-COMMERCE AND AUTOMATION ADOPTION IN TAIWAN

Table 1 provides a comprehensive overview of the technology and industry distribution of e-commerce adoption in 2002. When considering digital technologies, the most extensively adopted component is network construction, encompassing Internet, intranet, and extranet construction, with a remarkable penetration rate of 63.98%. Following closely, enterprise resource planning (ERP) and shop floor control systems (SFCS) occupy the second and third positions, boasting penetration rates of 59.02% and 37.79%, respectively. These figures underscore the widespread popularity and adoption of these three digital technologies throughout Taiwan's industrial landscape. Conversely, the adoption rates for customer relations management (CRM), supply chain management (SCM), and the e-marketplace all fall below the 17% mark in 2002.

Table 1 presents statistical data indicating that enterprises in Taiwan have extensively integrated digital technology into their operations. In addition to network construction, management, and enterprise resource planning (ERP), a significant number of them have interconnected their shop floor control systems (SFCS) with digital technology. As noted by Biag (2004), the automation of economic transactions is regarded as a major benefit of IT development. Digital data interchange (EDI) networks have successfully achieved this objective in specific sectors and for a limited number of companies, largely facilitated by the use of private networks (VAN) and the establishment of standardized communication protocols. The advent of the internet has introduced a new challenge, that of automating transactions among multiple economic entities.

Table 1. Investment of digital technologies in Taiwan (2002) (%).

Industry	Total	M&E	I&E	Chemical	Civil
Network construction	63.98	57.39	70.52	58.54	64.90
ERP	59.02	59.85	67.70	54.74	43.71
SFCS	37.79	31.28	35.11	42.28	47.02
PDM	32.48	35.71	36.59	25.47	27.48
EDI	27.91	30.54	32.44	22.22	21.19
ASP	21.00	20.44	21.04	18.70	24.50
CRM	16.27	15.27	17.48	15.45	15.89
SCM	15.58	19.21	17.33	10.84	12.58
E-marketplace	8.62	9.85	8.74	6.78	8.94

Table 2 provides a breakdown of the hardware and software automation equipment purchase ratios within the four categorized industries. These industries encompass (1) metal and engineering (M&E), (2) information and digitals (I&E), (3) chemical industries, and (4) civil industries. Upon examining the data in Table 2, it becomes evident that, with the exception of the metal and engineering sector, the purchase ratios have exhibited consistent annual growth across the other industries. Notably, the information and digitals industry has experienced a notably rapid increase in its purchase ratio, surpassing all others.

Table 3 reveals the adoption of communication methods, including email, digital data interchange (EDI), and the Internet, for interactions with both upstream and downstream partners in Taiwan. Notably, the penetration rate of the Internet experienced a substantial rise, surging from 39.39% in 2000 to 57.80% in 2002. Furthermore, it is intuitive that the information and digitals industries exhibit the highest adoption rates among various e-commerce technologies.

Table 2. Investment of automatic equipment (1998-2002) (%).

Industry	Total	M&E	I&E	Chemistry	Civil
1998	65.01	67.86	68.91	66.40	54.79
1999	65.27	68.06	70.98	64.78	54.44
2000	66.34	67.90	72.29	65.94	54.90
2001	70.82	64.72	81.70	63.58	61.43
2002	71.42	64.15	82.15	64.16	61.35

Table 3. Modes of communication between manufacturers and up and downstream partners.

Industry		Total	M & E	I & E	Chemical	Civil
2000	E-mail	92.47	90.77	95.77	92.73	89.14
2002	E-mail	91.76	87.72	96.39	89.16	89.40
2000	EDI	23.52	25.68	27.88	19.39	17.57
2002	EDI	24.73	25.93	25.41	25.30	20.63
2000	Internet	39.39	37.39	43.85	37.58	36.74
2002	Internet	57.80	57.31	61.07	53.49	55.59

Table 4 displays the results related to e-commerce adoption from a 2001–2002 survey conducted by the Ministry of Economic Affairs (MOEA), Taiwan. Despite the time-span being only 2 years, there has been a sharp increase in the various indicators of e-commerce. The amount (share) of procurement through e-mail increased from NT$169.9 billion (6.51%) in 2001 to NT$214 billion (7.39%) in 2002, an increase of NT$44.1 billion (0.9 percentage points). The amount (share) of procurement via the Internet increased more than 1.9-fold (1.7-fold) –that is, from NT$90.3 billion (3.46%) in 2001 to NT$174.1 billion (6.01%) in 2002. On the other hand, e-mail and the Internet began to play a new role as an important sales channel. The survey indicates that the amount (share) of e-mail sales reached NT$253.9 billion (5.97%) in 2001 and then slightly grew to NT$317.7 billion (6.81%) in 2002. Specifically, the amount (share) of Internet sales reached NT$274.7 billion (5.89%) in 2002, an increase of more than 31.12% (1%) from 2001.

Table 4. Procurement and sales through email and the internet in Taiwan (2001-2002).

Email	Procurement (NT$ billion)	Sales (NT$ billion)	Percentage of total procurement (%)	Percentage of total sales (%)
2001	169.9	253.9	6.51	5.97
2002	214.0	317.7	7.39	6.81
Internet	Procurement (NT$ billion)	Sales (NT$ billion)	Percentage of total procurement (%)	Percentage of total sales (%)
2001	90.3	209.5	3.46	4.93
2002	174.1	274.7	6.01	5.89

RESEARCH METHOD

Seemingly Unrelated Bivariate Probit Model

As each firm's decision to adopt a technology is interconnected with the decisions of others regarding technological adoption, we employ a seemingly unrelated bivariate probit model for estimation. This model aims to identify the determinants influencing the decisions to adopt automatic and/or digital technologies and explore the relationships among multiple technological adoptions

Let Y_{i1}^*represent the decision of digital technology adoption by a given firm i, which depends on a set of economic and industrial characteristics X_{i1}, as well as other unobserved variables ε_{i1}. This relationship can be expressed as

$$Y_{i1}^* = X_{i1}\beta + \varepsilon_{i1} \qquad (1)$$

$$Y_{i1} = 1 \text{ if } Y_{i1}^* > 0, 0 \text{ otherwise}$$

Similarly, Y_{i2}^* represents the decision of adopting automatic technology by a given firm i, which depends on a set of economic and industrial characteristics X_{i2}, as well as unobserved variables ξ_{i2}. The choice is once again represented as an observed binary outcome, as illustrated in Equation (2)

$$Y_{i2}^* = X_{i2}\beta + \xi_{i2} \qquad (2)$$

$$Y_{i2} = 1 \text{ if } Y_{i2}^* > 0, 0 \text{ otherwise}$$

Estimating the determinants of firm behavior separately may introduce bias since unmeasured variables can simultaneously influence both outcomes. To address this potential endogenous bias, simultaneous equations are employed. The random error terms, ε_{i1} and ξ_{i2}, are correlated and follow a normal distribution, such that $E[\varepsilon_{i1}] = E[\xi_{i2}] = 0$, $var[\varepsilon_{i1}] = var[\xi_{i2}] = 1$ and $cov[\varepsilon_{i1}, \xi_{i2}] = \rho$.

If a Wald Test indicates that variable ρ is statistically insignificant, it implies the absence of endogenous bias. In such a case, the two models can be independently estimated as binomial probits. However, if variable ρ exhibits statistical significance and the log-likelihood of the bivariate estimation is significantly lower than that of the joint binomial probit log-likelihood, it suggests that the processes Y_{i1} and Y_{i2} are indeed endogenous. The log-likelihood associated with the bivariate probit model is given by:

$$L = \Pi_{y1=0,\,y2=0}\Phi_2(-X_{y1i}\beta_{y1}, -X_{y2i}\beta_{y2}, \rho)\ \Pi_{y1=1,\,y2=1}\Phi_2(X_{y1i}\beta_{y1}, X_{y2i}\beta_{y2}, \rho)$$
$$\Pi_{y1=1,\,y2=0}\Phi_2(X_{y1i}\beta_{y1}, -X_{y2i}\beta_{y2}, -\rho)\ \Pi_{y1=0,\,y2=1}\Phi_2(-X_{y1i}, X_{y2i}\beta_{y2}, -\rho) \qquad (3)$$

Where, Φrepresents the standard univariate normal cumulative distribution, while$\Phi\Phi_2, \rho$ signifies the standard bivariate normal cumulative distribution with a correlation denoted as ρ. Equations (1) and (2) are jointly estimated through the maximum likelihood method

Function of Digital Technology Adoption

The functions can be represented as illustrated below, with particular attention to

$$DTADT_i^* = \alpha_0 + \alpha_1 \ln SIZE_i + \alpha_2 \ln RD_i + \alpha_3 \ln NETRA_i + \alpha_4 \ln NETER_i$$
$$+\alpha_5 \ln TFP_{t-1,i} + \alpha_6 IND_i + \alpha_7 TIM_i + \varepsilon_i \qquad (4)$$

And the observed decision is

$$DTADT_i = \begin{cases} 1, & if \quad DTADT_i^* > 0 \\ 0, & otherwise \end{cases} \qquad (5)$$

Where the (*DTADT*) is a dummy variable of the adoption of e-commerce, (*SIZE*) and (*RD*) indicate the firm size and R&D investment, respectively. Besides, we follow the work of Liu et al., (2013) to construct two types of e-commerce network externalities: intra-industry network externalities (*NETRA*) and inter-industry network externalities (*NETER*) based on the following definitions, respectively

$$NETRA_i = \sum_{j\neq i}^{N} w_i ECO_j\,, \quad w_i = DE_i + IE_i \qquad (6)$$
$$NETER_i = \sum_{k\neq l}^{M} w_l ECO_k\,, \quad w_l = DE_l + IE_l \qquad (7)$$

The intra-industry network externality (*NETRA*) represents the spillover effects stemming from the adoption of e-commerce by other firms within the same 4-digit industry as the focal firm. The strength of this spillover effect for firm i is contingent upon a weight (w_i), which is a composite of two distinct components: (1) the direct effect (*DE*), and (2) the indirect effect (*IE*). DE_i is defined as the ratio of firms engaged in e-commerce to the total number of firms operating within the 4-digit industry where firm *i* is situated. On the other hand, the indirect effect IE_i is quantified by the ratio of firm *i*'s digital technology application index to the aggregate digital technology application index of the 4-digit industry in which firm *i* operates. In this context, ECO_j represents the e-commerce stock of firm *j* within the same 4-digit industry as firm *i*.

The inter-industry network externality (NETER) signifies the spillover effects resulting from the e-commerce adoption by other industries within the same 2-digit industry where the firm is situated. In Equation (7), the term w_l represents the inter-industry weight of network externality for firm i. The direct effect, denoted as DE_l, is calculated as the ratio of firms engaged in e-commerce within the 4-digit industry (where firm i is located) to the total number of firms in the 2-digit industry. Meanwhile, the indirect effect, labeled as IE_l, is quantified by the ratio of the digital technology application index of the 4-digit industry l (in which firm i operates) to the total digital technology application index of the 2-digit industry. Notably, ECO_k represents the e-commerce stock of the 4-digit industry k within the same 2-digit industry as firm i. The (TFP) variable refers to total factor productivity, estimated with reference to the methodology presented in Ahmed (2009). (IND) and (TIM) denote industry and time dummy variables, respectively.

Function of Automatic Technology Adoption

The automatic technology adoption functions is

$$AUTADT_i^* = \beta_0 + \beta_1 \ln SIZE_i + \beta_2 \ln RD_i + \beta_3 \ln TFP_{t-1,i} + \beta_4 IND_i + \beta_5 TIME_i + \xi_i \quad (8)$$

And the observed decision is

$$AUTADT_i = \begin{cases} 1, & if \quad AUTADT_i^* > 0 \\ 0, & otherwise \end{cases} \quad (9)$$

Where the (AUTADT) is a dummy variable of the adoption of automation.

The Contribution of Multiple Technical Adoptions to Productivity

$$Y_{it} = a + \lambda_t + \gamma_1 CAP_{it} + \gamma_2 LAB_{it} + \gamma_e \sqrt{DT_{it}} + \gamma_a \sqrt{AUT_{it}} + \gamma_{ea} \sqrt{DT_{it}} \sqrt{AUT_{it}} + \nu_{it} \quad (10)$$

Where (Y), (CAP) and (LAB) represent the added value, capital and labor after taking the logarithm. (DT) and (AUT) represent the amount of e-commerce transactions and the amount of investment in automation equipment. Besides, in order to evaluate the impact of multiple technology adoptions decision on productivity, this study specifics three multiple technical adoptions dummies, i.e. firms adopt both technology (MT11), firms adopt just digital technology (MT10), and firms adopt just automation (MT01) in the specification of Equation (10) will also be discussed in our study.

Data Sources

Due to the absence of comprehensive data on e-commerce and related operational details for Taiwanese firms, this study integrates the automation and e-commerce survey data with the plant survey conducted by the Ministry of Economic Affairs (MOEA) in 1999, 2000, and 2002. This amalgamation aims to create a more comprehensive and cohesive database. Additionally, taking into account industry distribution and the temporal span, we construct a balanced panel dataset comprising 1,876 Taiwanese manufacturing firms for the survey period. Table 5 presents sample statistics for our key variables.

Table 5. Statistics on variables (After deflation) (NT$ Million).

Variable (Unit)	Name	Mean (S.E.)
Value added (Million)	*Y*	576.739 (2543.117)
Capital stock (Million)	*CAP*	1,538.458 (9,436.143)
Number of employees	*LAB*	177.186 (394.483)
Lagged Total factor productivity	$\log TFP_{t-1}$	0.636 (0.067)
Firm size (Number of employee)	*SCALE*	220.121 (455.668)
R&D (Million)	*RD*	38.786 (263.749)
E-commerce transaction (Million)	*DT*	132.274 (2450.291)
Automation investment (Million)	*AUT*	122.467 (1,214.529)
E-commerce network externalities (intra-industry) (Million)	*NETRA*	434.731 (1,434.990)
E-commerce network externalities (Inter-industry) (Million)	*NETER*	4,055.552 (1,3762.169)

Note: The numbers in parentheses are standard errors.

EMPIRICAL RESULTS

To explore the substitute/complementary relationship between the adoption of digital and automatic technology, we employ the seemingly unrelated bivariate probit model on the entire sample. The results of the estimated seemingly unrelated bivariate probit model are presented in Table 6. Notably, the two errors exhibit a strong correlation, statistically significant at 0.1359. The correlation of disturbances, denoted as ϱ, between the two models is positive and significant, indicating positive self-selection. This implies that unobserved factors influencing the decision to adopt digital technology are also likely to influence automatic technology adoption in the same direction. Consequently, there is evidence of interdependence in firms' decisions, suggesting a complementary relationship between the adoption of the two technologies. Thus, the findings from this survey provide some validation for our methodological choice in analyzing the relationships of multiple technical adoptions.

Table 6. Estimates of seemingly unrelated bivariate probit model.

Function

	DTADT		*AUTADT*	
Constant	-1.3025	(0.1633) ***	-0.6031	(0.1150) ***
ln*SCALE*	0.1152	(0.0161) ***	0.1037	(0.0148) ***
ln*RD*	0.0231	(0.0039) ***	0.0243	(0.0036) ***
ln*NETRA*	0.6153	(0.0170) ***		
ln*NETER*	-0.6008	(0.0150) ***		
logTFP_{t-1}	0.7925	(0.3011) ***	0.3502	(0.2413) *
IND1	0.0806	(0.0704)	0.1347	(0.0307) ***
IND2	-0.0401	(0.0376)	0.2110	(0.0325) ***
IND3	0.0215	(0.0432)	0.0632	(0.0315) *
TIME2000	0.0378	(0.0493)	0.1435	(0.0381) ***
TIME2001	-0.0175	(0.0496)	0.0211	(0.0365)
TIME2002	0.1338	(0.0462) ***	-0.0107	(0.0357)
ρ	0.1359 (0.0176) ***			
Log likelihood	-7635.3638			
No. of Observations	7,504			

Note: 1. The numbers in parentheses are standard errors. 2. Terms ***, **, and * represent the 1%, 5%, and 10% significance levels, respectively. 3. *LR* test of ρ =0: chi2 (1) =38.74, Prob > chi2 = 0.0000.

In order to realize under the complementary relationship of multiple technical adoptions, firms invest in both technologies and firm's adoption decisions whether have different contribution to productivity. Equation (10) is estimated and the results are shown in Table 7. The second column of Table 7 presents that the sign of ($\sqrt{\text{ET}}$), ($\sqrt{\text{AUT}}$) appears as expected, and has a significant and positive impact on the level of productivity. Between them, the variable ($\sqrt{\text{ET}}$) has the greatest effect on productivity improvement. This provides evidence that Taiwanese firms that invest more in digital technology tend to perform better in terms of productivity, and there is considerable room for productivity to be enhanced especially, by Taiwanese non digital technology adoption firms investing in digitals-related activities to create a better e-commerce environment. *This result is* proved by the findings *of* Konings and Roodhooft (2002), Litan and Rivlin (2001), Goss (2001), Alderete (2019) and Ponis et al., (2020). Goss suggest that job-related Internet usage had a positive and statistically significant impact on productivity growth of roughly 0.25% per year. The firms adopt multiple technologies and only one digital technology would have more effective in productivity improvement than those who only have automatic technology.

Table 7. Estimates of the production function.

	Coefficients	**Standard Errors**
Constant	-3.5011	(0.0878) ***
CAP	0.1524	(0.0577) ***
LAB	0.6491	(0.0320) ***
$\sqrt{\text{DT}}$	0.1216	(0.0579) ***
$\sqrt{AUT}$	0.0002	(0.0001) *
$\sqrt{\text{DT}} * \sqrt{AUT}$	-0.0002	(0.0002)
MT10	0.2365	(0.1235) **
MT01	-0.0029	(0.0612)
MT11	0.2101	(0.1123) **
R^2: within	0.2675	
R^2: between	0.8511	
R^2: overall	0.8237	
No. of Obs	7,504	

Note: 1. The numbers in parentheses are standard errors. 2. Terms ***, **, and * represent the 1%, 5%, and 10% significance levels, respectively.

CONCLUSION

Empirical findings indicate a complementary relationship between the adoption decisions of digital and automatic technologies. Firms exhibiting larger size, higher productivity, and greater innovation tendencies are more inclined to adopt multiple technologies. The significantly positive outcomes associated with intra-industry network externalities suggest that firms adopt digital technology not merely in response to competitive pressure but also due to cooperative requirements within related industries. Consequently, the adoption of multiple technologies plays a pivotal role in enhancing firms' productivity. Our empirical results offer valuable insights for other developing countries. Looking ahead, with the anticipation of more detailed data availability, we aim to delve into a nuanced discussion on the breakdown of e-commerce transactions into categories such as pure investment, sales, and purchases. Additionally, we aspire to explore the intricate relationships between knowledge or artificial intelligence capital and spillover variables. The intersection of e-commerce with financial technology, artificial intelligence, and third-party payment stands as an intriguing avenue for future investigation. If the available information is fully harnessed, it warrants in-depth exploration in subsequent studies.

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