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A Survival Analysis to Explore the Determinants of Digitalization in Egyptian Business Enterprises

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Abstract

This study investigates the determinants of digitalization among Egyptian enterprises, conceptualizing it as a multi-stage, time-dependent process rather than a monolithic event. Utilizing the 2022 Survey of Enterprise Digitization in Egypt (SEDE), we employ a novel methodological framework that compares semi-parametric Cox Proportional Hazards models with advanced machine learning techniques as Survival XGBoost, Random Survival Forest, and Survival SVM to analyze the time-to-adoption of high-speed internet, online payments, and company websites. The findings reveal that the drivers of digitalization are highly stage-specific: owner education and digital skills are paramount for initial infrastructure adoption, while gender diversity and R&D investment become critical for advanced e-commerce functions as building website. An Andersen-Gill recurrent events model further confirms that prior digital milestones significantly influence subsequent adoption hazards. The results challenge the uniform application of digitalization policies, highlighting the need for targeted, stage-specific interventions. This research provides a critical evidence base for policymakers and fills a significant gap in the literature on digital transformation in developing economies.

1. Introduction :-

There is no doubt that the digital divide exists globally and particularly in the view of stark disparities between regions, when it comes to discerning the determinant of digitalization for private and public business enterprises . Grigorescu et al. (2021) has proven that digitization of enterprises is positively correlated with welfare of countries especially in Eastern Europe. In a nutshell, the determinants of digitization for an enterprise pivot on three main pillars as per the World Digital Competitiveness Report (2024) generated by the IMD World competitiveness. The first pillar is devoted to the knowledge of digital literacy to include training, education , gender and managerial based digital access and presence of digital skills and other demographics. The second pillar delves into the technology related factors enabling the development of digitalization to cover access to high speed and broadband connections, enterprise size of online transactions for sales, exports , imports , regional development, access to e-payment services, enterprise expenditure on R&D and finally competitors' share in digitalized services . This comes in addition to technological challenges facing digital agility related to installation costs and procedures, power outages, interruptions in online services. Finally, the third pillar known by business readiness to digitalize, dwelling onto the usage of social media, smart phone applications and devices in the daily operations for business purposes and the provision of cyber security measures and regulatory framework to protect against privacy.

The World Digital Competitiveness Report (2024) discloses that North America , Canada and some of the Nordic countries sustain an internet penetration rate of around 95-98%, besides 80% of North America's population are privileged by 5G coverage , meanwhile, sub-Saharan Africa remains to be one of the least covered and digitally unprepared regions barely reaching a 40% internet penetration and holding the highest possible barriers related to data connection costs, low speed broadband, insufficient investments in electrical grids and infrastructure investments and discrepancies in fiber optics installations . For this very reason, Sustainable development Goals endorse a road map to support countries with an underscored digital connectivity as per the 9th SDG titled as "industry, innovation and infrastructure". In fact, the 9th SDG had targeted that by 2020, less developed countries should witness a significant increase in their access to information and communications technology and strive to provide universal and affordable access to the Internet and since then it became the pursuit of many countries and one of them is Egypt. Egypt since then had worked in providing accessible internet with hopes of encouraging the digitization of both the public and private enterprises particularly SMEs.

Hence this research aims to narrow the conceptual and methodological gap which identify the determinants of enterprises digitalization in Egypt. First, it conceptually, assesses the importance of digitalization theories and considers the overarching nexus between economic, governance and acceptance of technology theories featured via Technology Organization and Environmental (TOE) framework, Diffusion of Innovation theory (DOI) and Unified Theory of Acceptance and Use of Technology (UTAUT) model all shedding light on the determinants of digitization in enterprises and it as well as for Egyptian enterprises based on the knowledge, technological readiness and digital business agility indicators. (Andersen et al.,2022;Belle, 2019; Cavalcanti et al., 2022;Eller et al., 2020;Fu &Lee, 2020; Lutfi et al., 2022;Nguyen et al.,2022;Qi et al.,2023;Ta &Lin, 2023; Van Dyk & Van; Zaki, 2023). This comes in the light of the fact that Egypt ranks in 58th position out of 64 countries at the middle lower tier for the digital competitiveness report in 2023. Second, the rest of literature compares the digital divide across regions and finally provides an overview of empirical studies employing a plethora of causal and semiparametric modelling approaches (Alraja et al.,2021; Díaz-Arancibia et al.,2024; Marcysiak & Pleskacz, 2021; Oh et al., 2022;Shahadat et al., 2023;Sheikh Mokhtar & Mahomed ,2025; Zaki, 2023; Zhu & Luo, 2023)

Hence this study focuses on three main objectives, as it first addresses what is meant by the digitization of an enterprise. Second, it captures either through the theoretical and methodological literature the characteristics of digitalizing Egyptian enterprises surveyed in SEDE 2022. Finally, it seeks to identify the survival analysis algorithm which performed better. The main contribution of the study stands out through the methodological approach conducting a semi-parametric survival analysis to identify factors impacting the time till enterprises access high speed internet, having online transactions and launching website through the Cox proportional Hazard model. Then, the analysis is extended to include comparative machine learning algorithms like the Survival XGBoost, Random Survival Forest and the survival support vector machine algorithms. To the very best knowledge of the researchers only a few other studies apply semi-parametric analysis juxtapositioned to other XG-Boost feature selection models to study the determinants of digitalization in enterprises. The previous studies main findings where concentrated in China and none has been replicated in Egypt. (Chen et al., 2024;Ren & Wang, 2023; Tang & Wei, 2023). In addition, the study presented an Andersen Gill Model for dealing with the digitization process as a recurrent survival model that occurs on multiple of procedures that may affect the hazard of one another.

Finally, the main results indicate to certain determinants had high importance in predicting high speed internet as knowledge presented in digital skills and education of owners, along with the cost accompanying the access to internet. In addition, the region where the enterprise operates along with its importing strategy are all important features in predicting the time till company would access high speed internet. Similarly, the same variables were paramount in predicting online payments along with the industry and gender of the enterprise owner and the rest of the findings will be addressed in the discussion section. After the introduction, the paper delves into the literature followed by the methodology, main findings, discussion, policy implications and conclusion.

2. Literature review:

2.1 Theoretical Foundation: The overarching nexus between economic, governance and acceptance of technology theories

The literature realm extends to include the overarching nexus between economic, governance and acceptance of technology theories supporting the determinants of digitization in enterprises. The first strand of the literature which addresses the economic nexus is annexed back then to the endogenous growth theories motivated by Romer (1994), enterprises achieving higher market size, economies of scale through higher size of daily online and e-commerce exports, imports and outsourcing transactions attain higher knowledge and technology transfer rates and particularly reach higher levels of innovation. These studies advocate that digitization is a significant and visible byproduct of the accelerated performance of firms which trade (Ye & Tong, 2022). The endogenous growth models in the economy and their applications in the literature adopt the concept of how digital technologies platforms applied across firms along with human capital skills eventually lead to enhanced productivity and support financial transactions across the space. In addition, new generations of endogenous growth models in the economy perceive the "knowledge Economy pyramid" model; as the one reinforcing that the digitalization process into a accumulative change and it manages knowledge particularly intellectual knowledge, which is a pivot to support accelerating growth and competition between sectors and within enterprises and increases value added in the production flow(Chukwuemeka Ogugua,, 2024; Puaschunder, 2023;Serban, 2020). The second nexus moves into the governance and role of institutional factors in affecting the digitalization process in enterprises and they have been re-defined in most of the literature sources as the set of regulations , policies, training initiatives, information infrastructure and funding which boost the performance of enterprises to adopt digital technologies (DT). It is with certainty that governance vary based on the regional development and size of the firm, as SMEs cannot compete with larger enterprises which signals to an extra support mechanism provided to SMEs. (Fu & Li, 2023; Zhang & Ma, 2022; Nguyen, 2022). In parallel a considerable strand of literature considers the governance pillar and its efforts towards empowering enterprises of various sizes and across a regional scale. (Qi el al.,2023;Ta & Lin, 2023;Van Dyk & Van Belle, 2019)

Next nexus in the literature discusses in a nutshell the complementarity between the technology acceptance models in laying the theoretical foundation for various determinants of digitalization across enterprises of various sizes . It starts with the Technology -Organization – Environment framework (TOE) which takes a wholistic perspective on the three overlapping factors of technological, organizational and environmental context for enterprises. First the technological factor zooms into the enterprise's internal orientation , relative advantage and compatibility of digitalization complemented by the external surroundings prompting the

preparedness to adopt technology. In parallel to the technological factors, the organizational factors delve into the enterprises' demographic and control variables to include structure, size, ownership, resources, management hierarchy , employees' communication channels, whereas the environmental factors are relevant to market structure, competitors, and regulations. (Fu &Lee, 2020; Lutfi et al., 2022;Nguyen et al.,2022;Qi et al.,2023;Ta &Lin, 2023; Van Dyk & Van Belle, 2019). Another strand of literature favors the Diffusion of Innovation theory (DOI),which originates from the information systems research and focuses on explaining the factors pushing forward the adoption of innovation across distinctive organizations particularly the perceived usefulness (Zhu et al. 2006). DOI taps into a number of common advantages to the TOE framework pertaining to digital transformation, relative advantage, compatibility, complexity of adoption in enterprises, employees' skills, however, it sought security concerns as barrier to its adoption in case of enterprises more than for SMEs (Bitsanis & Ponis, 2022; Jamal, 2023; Oh et al.,2022;Lutfi et al., 2022; Zulu et al., 2023). A third strand of the literature deals with the Acceptance Model (TAMs) developed by Davis (1989) which is oriented towards application of new recent technologies and conceptually it arrives to the aggregate role of investments, acceptance and adaptability associated to technology. In most of the studies, this model addresses factors related to AI driven analytical cloud computing solutions, website and platform launches , online payment channels to enable digital transactions and presence of high-speed internet access, smart phones and social media applications which prompt enterprises profit, sales, operational efficiency, and shows it adaptability and agility to use digital tools. The case of how Malaysian SMEs can adopt cloud computing solutions to improve their data management is based on the TAMs model. (Nguyen et al, 2002; Sheikh Mokhtar & Mahomed, 2025).

Finally, Unified Theory of Acceptance and Use of Technology (UTAUT) model encapsulates all the above models combining both technology acceptance theories with the diffusion of innovation to practically affect the intention of usage and actual usage targeted for employees in SMEs and enterprises. (Alsyouf & Ishak, 2018; Venkatesh, et al.,2011). It solely postulates several factors presenting performance ,effort expectancy, facilitating conditions and social influence as determinants of technology adoption decisions with a particular distinction between factors affecting SMEs versus large sized enterprises. The UTAUT model further captures the forthcoming barriers facing enterprises when transforming to a digital environment. Finally, this strand of the literature advocates the adoption of technology driven growth models with AI applications introduce a network of learning if employees' capabilities and skills in firms are upgraded and a full-fledged ecosystem of human machine compatibility is achieved and is complemented with the formulation of the suitable institutional laws , policy and incentive-based frameworks (Andersen et al.,2022; Cavalcanti et al., 2022;Eller et al., 2020)

2.2 Digital Divide existing between Enterprises Across Regions

There is no doubt that inspecting the capability and digital divide by Amartya Sen (1993) is of paramount importance, as it taps into the regional disparities of digital literacy and adds to it institutional barriers, which prevent equality of access to internet services in businesses. A contrast in the literature is sparked concerning some of the additional barriers that might face enterprises in developing regions transforming into a more digitally enabled business ecosystem compared to developed ones. In addition to the normal control factors of socioeconomic, digital literacy, infrastructural preparedness, moderate industrialization and lower rate of knowhow transfer in developing compared to developing regions, the mainstream thought in the literature support the instrumental role of cultural factors and their role in

shaping the digital transformation of enterprises. It is particularly imperative to consider the cultural behavioral patterns across enterprises and how it affects the application digitalization, when it boils down to power distance, individualism versus collectivism , community norms and practices and resistance to change which might affect the speed and smooth transition and decision towards a digitally enhanced operations in enterprises (Alraja et al.,2021; Díaz-Arancibia et al.,2024; Marcysiak & Pleskacz, 2021;Shahadat et al., 2023). On one hand , some of the studies take into account 38 developed countries and recognizes their collective efforts towards digitalization are pivoted on a number of exogenous and endogenous determinants which are predominantly the related to online service index (OSI), ICT development Index(IDI), E-Government Development Index (EGDI), Telecommunication Infrastructure index (TII) and finally, Human Capital Index (HCI), however, they confirm that it is a matter of time until the investments in digitalization show their resonant returns on the enterprises adopting them (Rasskazova & Yurgenson,2021). On the other hand, a study designed for a comparative group of developing countries mainly sheds light on the financial constraints, technological and digital literacy deficits, infrastructural deficiencies together with cultural disparities stifle the smooth transition toward digitalized operations in enterprises particularly for SMEs. (Díaz-Arancibia et al.,2024)

2.3 Previous Empirical Studies for the Determinants of Digitalization in Enterprises

As much as there is an obvious scarcity in the empirical research which considers the phenomenon of enterprise digitization in Egypt, many of the empirical research rely on the Economic Research Forum (ERF) Survey dataset of the Enterprise Digitization in Egypt (SEDE) for (2022). Some studies have compared Egypt across to other countries in the region using a plethora of statistical, dimension reduction techniques depending on Principal Component Analysis (PCA), factor analysis and regression analysis such as probit models to identify the characteristics influencing digitalization in Egypt, Jordan and Morocco (Sheikh Mokhtar & Mahomed ,2025, Oh et al., 2022; Zaki, 2023; Zhu & Luo, 2023).Another realm of the methodologies employ the structural equation modelling approach through qualitative data collected via surveys as in the case of Vietnamese SMEs using determinants of TOEs' model to reflect on Technological, Organizational and Environmental variables. In parallel. A second study applies on the UTAT framework considering factors for SMEs in the Czech Republic and third study reinforces the overlap between both DOI and TOE model in the selection of factors relying on organizational readiness, training, competitive structure, sector activity and e-commerce inflows and outflows for Jordanian SMEs (Kwarteng et al., 2022; Lutfi et al., 2022; Nguyen et al.,2025). Finally, to the very best of our knowledge there is still a considerable gap in the literature for the use of classical multiple linear regression model and LASSO models to test the causal relationship driving technical, organizational and environmental variables towards the enterprise digital transformation, as in the case of Chen et al., (2024) for Chinese enterprises.

In fact, the case of Egyptian enterprises extracted from the dataset of the Enterprise Digitization in Egypt (SEDE) year 2022 collects information about enterprises and their employees' gender, digital literacy, skills, region, sector, location, different digitization practises like obtaining high speed internet access, developing website, accepting online payments and social media usage. The dataset includes 765 enterprises in Egypt. Zaki (2023) was one of the studies which compared the results of the survey in Egypt to that of Jordan. The study explores the characteristics influencing digitalization in Egypt and Jordan. In both countries, having an owner with a university education significantly increases the likelihood of adopting digital tools, with this effect being stronger in Egypt. Women owners in Egypt are more likely to

digitalize their firms, whereas this gender influence is not significant in Jordan. Firms in the service sector and those investing in R&D show higher digital adoption in both countries. However, smaller and medium-sized enterprises face more obstacles, such as legal and infrastructure issues, which hinder their digitalization process more in Egypt. Overall, Egypt exhibits a slightly higher association between owner characteristics (education and gender) and digital adoption compared to Jordan, reflecting different levels of digitalization progress influenced by institutional and infrastructural factors. Zaki (2023) utilizes Probit models (a type of binary choice model) to examine the likelihood of firms adopting various digital tools and platforms.

Additionally, robustness checks with linear probability models are conducted to validate the findings. To measure the intensity of digitalization, the study constructs an index using principal component analysis (PCA), where higher values indicate more digitalized firms. The analysis accounts for various firm-level characteristics (such as owner education, gender, sector, and size) and country-specific factors, emphasizing associations rather than causal relationships. All regressions incorporate weighting procedures to ensure representativeness of the survey data. Zhu & Luo (2023) is the other recent study examine how digitalization influences firm performance in Egypt, Jordan, and Morocco, based on surveys from 2022. It finds that digital adoption, especially in e-commerce, is relatively low in Egypt compared to Jordan and Morocco. While firms in Egypt face significant challenges such as infrastructure gaps and limited digital skills compared to firms in Jordan and Morocco which are generally more advanced in digital tools and e-commerce activities. Overall, Egypt lags the other two countries in digital integration, which impacts its economic competitiveness and growth potential. The analysis uses econometric models, particularly probit models, to identify factors influencing firms' participation in e-commerce. These models relate the likelihood of e-commerce adoption to various firm characteristics and controlled for potential biases, allowing for the causal inference about digitalization's impact on firm performance.

Finally, there exists even a wider gap for use of alternative AI models such as machine learning, random forest and XG-boost as an ensemble learning approach based on a decision tree and used to interpret the feature importance dimensions of factors affecting the digitalization of solely Chinese enterprises and no further studies have been identified (Chen et al., 2024;Ren & Wang, 2023; Tang & Wei, 2023).In fact, the dataset employed is the Survey of the Enterprise Digitization in Egypt (SEDE) year 2022 collects information about 765 enterprises in Egypt as mentioned earlier is comprehensive enough to represent a very fertile soil for conducting analysis using the extended Cox Proportional Hazards model for survival analysis and for robustness the machine learning-based Survival XG-Boost, and Survival Support Vector Regression is eligible to be adopted. Accordingly, the next section will introduce the model's variables description and data collection, methodological approach and calibration.

3. The Model's Selected Variables:

3.1 Digital Knowledge and Literacy Management versus Employees

Digital knowledge involves the difference or congruence between the technical skills, level of digital literacy, and conception of digital technologies between management and employees of various organizational levels. These variable measures the discrepancy between employees' skills and how they can benefit, learn and use digital technologies in their jobs. On the one hand, a lower knowledge gap is usually a positive sign towards effective internal communication, the successful use of technology, and eventually the digital transformation

process is easier. Organizations in which the management is much more digitally savvy compared to employees might face difficulties of technology adoption, as frontline workers will struggle with adopting systems, they are not entirely familiar with. On the other hand, in cases under the opposite narrative, when employees have acquired digital skills and management lacks them, the strategic decision making in relation to making investments in technology may not be well-informed. This variable can be frequently quantified based on surveys of digital competencies or the rate of training completion or proficiency of exams tested in the organization (Handrich & Otterbach, 2024; Karim & Khan, 2024; Rizvi et al. 2024).

3.2 Regions

Regions as a variable is used to capture the geographical location or territorial dividend within which the business is based taking into consideration that different geographical areas have remarkably different digital adoption patterns. This variable takes into consideration the spatial disparity in infrastructure accessibility, internet accessibility, regulatory conditions, cultural orientations towards technology and availability of digital resources. These regional differences can happen on several fronts; international (developed and developing nations), national (urban and rural), or subnational (coastal and inland, metropolitan and provincial areas). Regional conditions also impact the adoption of digital through metrics like the quality of telecommunication infrastructure, provision of technical support services, the closeness to technological centers, local government digitization programs, and the use of digital payment system. Researchers generally group this variable in terms of administrative borders, level of economic development, or metrics of infrastructure that can denote how digitalization can vary across geographical regions (Kolotouchkina et al. 2022; Salemink et al. 2017;Weinstein & Dewbury 2025).

3.3 Ownership by Gender and Proportion of Women Employed

This variable analyzes the connection between the gender composition of the business ownership and gender diversity in the workplace based on the measure of whether the business owner is a male or female. It takes into consideration the percentage of the workforce on a gender-based classification. It is also proposed that gender dynamics play a critical role in determining the digital adoption patterns with female-owned businesses potentially facing various challenges and opportunities towards the access to digital technologies. Those challenges include unequal access to capital, networks, and training. The gender inclusiveness in enterprises is shown by the percentage of women qualified to work, and this could be tied to various organizational cultures and decision-making, as far as adoption of technology is concerned. This twofold measure also includes the gender representation of leadership, as well as the workforce composition. This is precisely since gender diversity across various levels of the organization can affect technology adoption, the strategy of its implementation, and the perceived benefits of digitization. The variable is normally quantified by the self-reported ownership data and job statistics presenting the gender composition of employees (Al Omoush, 2024; Ergün et al. 2025; Kumra & Kumar, 2025; Salamzadeh et al. 2024).

3.4 Engaging in Imports/Exports (Trade Activity)

Trade activity can be defined as the involvement of a business in the international exchange system through importing and sourcing of raw materials, goods, or services by the foreign suppliers and parallel exporting of products and services to foreign markets. This variable includes the level of international business involvement and cross-border business activity.

Companies that engage in import and export operations are also subject to higher pressure and purpose to implement digital technology since international trade involves the need of a high level of logistics coordination, customs documentation, processing international payments, supply chain management, time zone, and language communication. Electronic data exchange (EDI), web-based markets, online payment system as well as software in supply chain management become almost necessary to handle the intricacy of global transactions. This variable is commonly recorded in two manners, first as a dichotomous value (whether the firm is involved in any trade activity or not). Second recorded as a continuous value to indicate to the proportion of revenues resulting from international operations or to how many times the firm has conducted trade across the borders (Añón Higón & Bonvin, 2024; Mirzaye Shirkoohi & Mohiuddin, 2025).

3.5 Investing in Research and Development (R&D)

Investment in research and development is the financial and human capital which a given firm has committed itself to the systematic creativity work to enhance knowledge and to create new applications, products, processes or services. This variable is the measure of innovation orientation and the progressive strategic position of an organization. Companies that invest in R&D are more likely to have a higher tendency to adopt digitalization as innovative activities become increasingly based on digital tools in data analysis, simulations, prototyping, collaboration and knowledge management. R&D investments is an indication of a firm determined to remain competitive through their technological development and willingness to invest in activities that have precise returns. Active R&D adopters in enterprises also have employees who are more technologically skilled and open to technological change. This variable is also often measured, either as a percentage of total revenues, presence of specialized R&D staff, or a binary measure of whether the firm has adopted R&D activities or not (Sun et al. 2025).

3.6 The Presence of Competitors

Presence of competitors signals to the intensity of competition in the market and it is a measure of the number and the strength of the business competitors who provide similar products or services to compete in the same segment. This variable reflects the competitive intensity which could either promote or discourage digital adoption, since companies are pursuing strategic benefits. Digital technologies can be used in most competitive markets to help businesses differentiate, enhance efficiency, lower costs, capitalize on customers' experiences, or react to digital efforts of their competitors (competitive mimicry). The competitive environment may generate push factors which represent the fear of losing market share to digitally developed competitors versus pull factors which are the opportunities to acquire the advantage due to the early adoption of digitalization. In certain circumstances, however, excessive rivalry can limit the number of resources that can be invested in digitalization. This variable is usually rated in the market concentration indices, direct competitors reported by business owners, competitiveness ranks on Likert scales, or types of market structure (monopoly, oligopoly, perfect competition) (Rietveld & Schilling, 2021;Wang & Han, 2023; Yu et al. 2024 Valta & Frésard, 2012).

3.7 Cost of Digitization

Digitization cost refers to all monetary spending involved in adopting and implementing of digital technologies in an organization, both the amount of monetary investments at the start up and recurrent operational costs. This variable is a measure of the economic impediment or

facilitator of digital transformation such as hardware (computers, servers, networking devices) and software costs (licenses and subscriptions), web development costs, digital infrastructure (internet, cloud solutions) . It includes as measurement as well building capacity, and training, support and maintenance, cybersecurity, and possible disruption of a business in the process of transition. The real cost of digitization is a decisive element for its adoption especially among SMEs of limited funds (Brodny & Tutak, 2022; Faiz et al. 2024;Klein & Todesco, 2021; Taiminen & Karjaluoto, 2015).

4.Methodological Approach, Main Results and Findings

4.1 Models' Definition

The dataset employs the Survey of the Enterprise Digitization in Egypt (SEDE) for year 2022 and it collects information about enterprises and their employees' gender, digital literacy, skills, region, sector, location, different digitization practises like obtaining high speed internet access, developing website, accepting online payments and social media usage. The dataset includes 765 enterprises in Egypt. Some of these companies have witnessed the digitization process while others did not. In this study, the digitization process will be measured by three survival variables the access of high-speed internet, having a website and starting the online transactions. If companies decide not to use high speed internet, or website or online transactions till end of 2022, they would have believed to be censored. The time will be calculated from the moment the company was established till the high-speed internet access is used. The dataset includes many quantitative and qualitative variables, however, only few variables would be considered as determinants of the digitization.

The objective of the model is to identify the determinants that affect the time till company uses high speed internet taking into consideration that some companies are censored. Thus, a survival analysis approach should be implemented, and three techniques would be compared. Those techniques are the the semi-parametric Cox Proportional Hazards model, the machine learning-based Survival XGBoost, Survival Random Forest and Survival Support Vector Regression. The Cox Proportional Hazards (Cox-PH) model serves as a statistical approach, modelling the hazard function as

$$h(t; X) = e^{\beta' X} h_0(t),$$

where $h_0(t)$ is baseline hazard, X is covariates, β is vector of coefficients.

This formulation allows the estimation for how covariates influence the probability of internet adoption while making minimal assumptions about the baseline hazard. The model's two key assumptions are the proportional hazards assumption and linear covariate effects. In case of proportional hazard assumption violation, an extension for the Cox-PH model would be used such as time-dependent covariates or stratified models (Collett. 2023).

Three machine learning algorithms have been proposed due to their ability to deal with further complexities of dataset. The survival XGBoost is then employed to capture potential non-linear relationships and the complex interactions among the predictors. This gradient-boosted tree algorithm has been adapted for survival analysis through specialized loss functions that properly handles censored observations (Bojer & Meldgaard, 2021). Secondly the survival random forest, is also a tree algorithm built on bagging ensemble machine learning algorithm. This method entails the creation of a collection of decision trees, each independently grown on

bootstrapped samples derived from the training data (Baralou et al., 2023). Lastly, Survival Support Vector Regression (SSVR) as the third analytical approach. SSVR extends traditional support vector machines to survival data by employing a ranking-based objective function that accounts for censoring. This method is particularly valuable when the relationship between predictors and survival times may be nonlinear but can be captured through appropriate kernel functions (Goli et al. 2016). During the model evaluation process, the concordance censored index (C-index) will be employed to measure predictive discrimination (Mayr & Schmid, 2014). This helps in showing the performance of each algorithm and determine which is the best to investigate the effect of the determinants on digitization of companies in Egypt.

Another model suggested is the Andersen Gill (AG) model to deal with recurrent survival phenomenon. AG model holds fundamental importance in recurrent event analysis as it provides a powerful and natural extension of the Cox proportional hazards model to handle multiple events per subject. Its key strength lies in treating each recurrence as a new observation within the same counting process framework, effectively using the entire event history of a subject to explain the correlation between their events. By structuring data into multiple risk intervals, the AG model leverages the robust machinery of Cox regression, making it computationally efficient and straightforward to implement by clustering the individuals (Andersen & Gill, 1982).

4.2 Models Main Findings

Table (I): Descriptive Statistics for the quantitative variables in the study

		Variable	Share of total cost of internet	share of imports	share of exports	% of women in sample
High Speed Internet	Event	Mean	325.5109	11.2913	25.6913	0.201866
		STDEV	459.2682	93.29094	131.3311	0.25706
	Censored	Mean	557.1833	10.8	28.72787	0.086431
		STDEV	491.6164	98.86921	159.8555	0.18311
Online Pay	Event	Mean	310.8018	12.08108	47.22973	0.242913
		STDEV	453.0659	95.11675	185.9182	0.269055
	Censored	Mean	383.1141	10.69245	18.59116	0.120245
		STDEV	478.1215	95.72712	120.8715	0.213034
Website	Event	Mean	347.8502	18.90283	39.87854	0.250722
		STDEV	467.8284	126.4217	165.8259	0.266728
	Censored	Mean	356.2161	7.372587	20.71429	0.110601
		STDEV	469.9594	76.33444	130.9157	0.207137

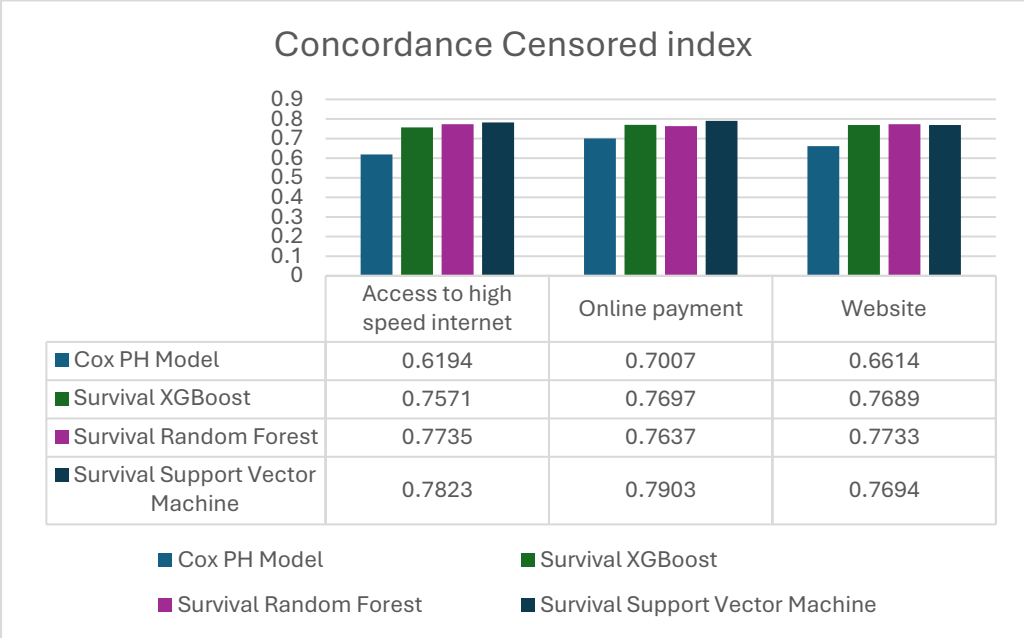
Authors original model and elaboration

The descriptive statistics reveal clear profiles differentiating firms that have adopted key digital technologies from those that have not. A consistent and robust demographic pattern emerges concerning workforce composition. Across all three technology categories; high-speed internet, online payment systems, and websites, firms that completed a digitization event exhibit a substantially higher mean percentage of female employees compared to their non-digitizing counterparts. This suggests a strong positive correlation between gender diversity and the propensity for technological adoption, implying that firms with a greater share of women may be more innovative or receptive to digital transformation. In terms of market

orientation, digitizing firms are demonstrably more engaged in the global economy. The data indicates that the mean share of exports is consistently and significantly larger for event firms than for censored firms. This trend is most pronounced for adopters of online payment systems, whose mean export share is over double that of non-adopters. This finding strongly supports the hypothesis that integration into global value chains is a key characteristic of digitally advanced firms, potentially since digital tools facilitate international trade and e-commerce activities.

The financial commitment to digital infrastructure, however, presents a more nuanced picture. For the specific adoption of high-speed internet, censored firms unexpectedly report a higher mean share of total internet costs, which may indicate that prior, potentially inefficient expenditure does not necessarily lead to formal adoption. In contrast, for the adoption of online payment systems and websites, the event firms show comparable or higher mean costs, aligning with the expectation that investment accompanies adoption. The considerable standard deviations across all financial variables highlight significant heterogeneity within each group, suggesting that while broad trends are evident, firm-level factors play a critical role in the digitization process.

Figure (I): Bar chart for concordance censored index for each algorithm for the three dependent variables



	Access to high speed internet	Online payment	Website
Cox PH Model	0.6194	0.7007	0.6614
Survival XGBoost	0.7571	0.7697	0.7689
Survival Random Forest	0.7735	0.7637	0.7733
Survival Support Vector Machine	0.7823	0.7903	0.7694

Authors original model and elaboration

As observed in figure I, the machine learning algorithms showed better performance in terms of concordance censored index. It seems that the survival support vector machine which is conducted through the Fast Kernel Survival Support Vector machine command in python is understandably performing better than the rest in terms of predicting time till having access to high-speed internet or online payments and transactions. Regarding predicting time till having a website, it seems that the survival random forest was outperforming the rest due to the presence of the interactions between the variables to predict the time.

Table (II): Ranking of features in the machine learning algorithm with highest concordance censored index for each dependent variable

Rank	High Speed Internet Access	Online Payment	Website
1	Digital Skills in appointing managerial staff	Digital Skills in appointing managerial staff	% of women as employees
2	Digital skills in appointing employees	Region	Financial cost
3	Education of the owner	Gender of owner	Digital skills in appointing employees
4	Imports	Digital skills in employees	Education of the owner
5	Financial cost	Education of the owner	Region
6	Region	Exports and Imports	Research and development
7	-	Industry	Digital Skills in appointing managerial staff

Authors original model and elaboration

It is observed from table II, that the digital skills in appointing managerial staff have the highest importance in terms of permutation score in predicting the survival time of having high access speed of internet and having started online payment. Regarding high-speed internet, other important features are related to having digital skills in appointing employees, the education of the owner and whether or not the company imports as part of its activities. The financial cost and the regions are also contributing factors. Regarding online payments, the region, gender of the owner and the industry of the company and its activities concerning importing and exporting they happen to be the most important features in predicting time till transferring to online payments. In addition, the education of the owner and digital skills of their employees show a highly important score.

Lastly, having a website is a crucial step in digitization of companies. It is affected by multiple factors. The most important feature that predicts the websites launch timing is gender; namely the percentage of women in the workforce of the company. In addition, the financial costs attributed to accessing high speed internet. The following feature in importance is the education of the owner, the managerial staff and the employees mainly their acquisition of digital skills. In addition, investing in R &D is an important feature in understanding the launch of website. Since the feature of investing in the last 3 years play the role of the proxy to understanding how companies observe the investment in R &D.

These results are based on the machine learning algorithms previously mentioned. As it is apparent, all those models deal with the survival event as if it is a univariate case. While, this assumption helps in understanding how every dependent variable can be affected independently by different features. It still does not take into consideration the fact that, each of these actions namely, having high speed internet, online payment and websites, are all steps towards digitization of an enterprise and the occurrence of one of them may influence the hazard of the others. Therefore, using recurrent survival analysis models can provide deeper insights while taking these assumptions into consideration.

Table (III): Andersen Gill Model hazard ratio of the recurrent survival models

_t	Haz. ratio	std. err.	Z	P>z	[95% conf.	interval]
Event type						
Transaction	0.3718	0.031522	-11.67	0	0.314879	0.439011
Website	0.455903	0.039568	-9.05	0	0.384589	0.54044
Share of women	2.007943	0.555312	2.52	0.012	1.167737	3.45269
industry						
Services	1.018771	0.122405	0.15	0.877	0.805016	1.289284
Research and Development						
No	1.065693	0.134167	0.51	0.613	0.832662	1.363939
Exports	-0.05506	0.024719	-2.23	0.026	-0.10351	-0.00661
Imports	-0.01232	0.003433	-3.59	0	-0.01905	-0.00559
Digital Skills in appointing managerial staff						
No	0.520461	0.077698	-4.37	0	0.388432	0.697366
Digital skills in appointing employees						
No	0.792459	0.108174	-1.7	0.088	0.606435	1.035547
Share of total Cost	0.999156	0.000143	-5.9	0	0.998876	0.999436
Gender of Owner						
Female	1.441437	0.30646	1.72	0.085	0.95022	2.186588
Model evaluation						
PH assumption test statistic	15.38		*Significance level*		0.1657	
Chi-square	46.129		*Prob > chi2*		0	
Pseudo r-squared	0.293		Mean dependent var		19.795	
Akaike crit. (AIC)	110.433		*Bayesian crit. (BIC)*		130.059	
Harrell's C	0.7101		*Somer's D*		0.4202	

Authors original model and elaboration

This is an Andersen-Gill (AG) recurrent event model analyzing the time to digital adoption in companies. Digital adoption is defined as achieving any of three milestones which are website creation, online payments/transaction capability and having High-speed internet access. Each milestone is independent and can be done in various orders. However, the adoption of one method can be related to the hazard of employing another. Companies which do not reach a certain point to adopt any technology are considered right-censored. The model takes into consideration the firms as clusters that can face multiple risks. The model is found to be significant at 99% confidence level. The proportional hazard assumption is not violated at 0.05 level of significance after stratifying regions and education of owner. The model had a moderate explanatory power of 29.3%. In addition, it had high concordance censored index of 71%. Overall, the model performs well and can be used for further prediction of the survival of the company till it gets digitalized.

Adopting the online payment shows a 63% lower hazard of experiencing having access to high speed internet at 99% confidence level. While having a website showed 54% lower hazard ratio compared to high speed internet at 99% confidence level. Each percentage point increase in female employees doubles the hazard rate of digital adoption. This suggests enterprises with more gender diversity adopt digital technologies much faster. This also comes in line with governance and owner gender relation with the adoption of digitization in enterprises. The organization with female owners had higher hazard by 44% of digitization compared to those of males at 90% confidence level.

Regarding the educational variable, it seems that having digital skills have a significant impact on predicting time till digital adoption of organizations. At 99% confidence level, having no digital skills for managerial staff results in lower hazard of digitization by 48%. While on the other hand, having no digital skills in employees shows lower hazard by 21%. Thus, having digital skills is a necessity in a seamless digitization for organizations. R &D investments in these years, shows no significant relation to the time till digitization at 0.1 level of significance. This may be explained due to the occurrence of digitization in most companies during earlier years and upon comparing the different digitization adoptions it had a more significant role in determining the time till adoption.

Regarding the economic and financial aspect, it is observed that the share of cost had a significant negative impact on the time till digitization. Every increase in cost by 1 unit, causes a decrease in hazard by 1% at 90% confidence level. The industry type shows no significant impact on digitization timing. At 0.1 level of significance and 95% confidence level, each unit increase in exports is associated with a 5.4% decrease in adoption hazard. Companies heavily focused on exports may be slower to adopt domestic-facing digital tools. Similarly, import-focused companies show slightly slower digital adoption rates at 95% confidence level. So having trade in the enterprise's activities, results in negative significant impact on digital adoption at 0.05 level of significance. Therefore, there are different determinants that affect digitization of enterprises.

4.3 Main Discussion and Policy Implications

The results of the paper are consistent with and complementary to the already available literature on the topic of enterprise digitalization in developing economies and provide original methodological perspectives in the Egyptian setting. Past empirical studies by Zaki (2023) and Zhu and Luo (2023) have proven that the owner characteristics and especially the level of education and gender are important in adopting digitalization in Egyptian enterprises. Egypt shows a higher correlation between these demographic variables with digitalization than other regional counterparts such as Jordan and Morocco. These results are supported in the present study with more use of methods of survival analysis, which indicates that owner education and gender are still decisive factors of time spent before access to high speed internet by enterprises. Nonetheless, the study goes further than the binary adoption results, as it seeks to establish the time aspect of digital transformation, making the point that some owner traits fast-track the adoption of the internet, but they do not necessarily affect other digitalization indicators like the development of websites or the initiation of online transactions. This subtle insight implies that digitalization is not a totally smooth process but a series of various stages of technology adoption, which is sensitive to various organizational and environmental conditions.

The relevance of the theoretical frameworks used in the present study, specifically, the TOE, DOI, and UTAUT models, prove their applicability in the current context, where numerous

studies of SMEs in Vietnamese, Jordanian, and Malaysian contexts are currently examined (Nguyen et al., 2022; Lutfi et al., 2022; Sheikh Mokhtar & Mahomed, 2025). The technological, organizational and environmental environment that is singled out in these models is appropriate in understanding the multidimensional aspect of the digital transformation with technological aspects such as size of an enterprise and capability of online transaction, organizational aspects such as structure and management hierarchy and environmental aspects such as market competition and regulatory frameworks. The initial results indicate a regional imbalance in internet access timeline, which is in line with the digital divide literature that emphasizes the geographical location, the quality of infrastructure, and the local government digitization initiatives as the source of spatial inequality in usage of new technologies (Kolotouchkina et al., 2022;Salemink et al., 2017). Also, the great effect of digital skills and knowledge on the timing of online transactions confirms the endogenous growth theory views, which hold that knowledge buildup and innovation orientation are the cornerstones of technological progress and competitive edge in digitally transforming enterprises.

From the methodological perspective, the research design fills a critical gap in the existing research by introducing semi-parametric methods of survival analysis and machine learning algorithms, which is not commonly used in digitalization research beyond China (Chen et al., 2024; Ren and Wang, 2023; Tang and Wei, 2023). Although previous studies on the subject of enterprises in Egypt were based mainly on probit models and principal component analysis to determine the determinants of digitalization, the present study utilizes Cox Proportional Hazards models, Survival XGBoost, Random Survival Forest, and Survival Support Vector Regression to determine the relationships and intricate-level interactions between the predictors and the outcome. The relative evaluation of these four previous models of analysis based on the evaluation of concordance indices provides useful suggestions to future researchers interested in the time-to-event outcomes in the context of digitalization. Furthermore, the capacity of machine learning models to address censored observations, i.e. those enterprises that were not ready to embrace some technologies as of 2022, is a major advancement in comparison to the traditional regression models which find it difficult to deal with data which is not fully adopted. In addition, the survival analysis took into consideration another perspective which considers the digitization process as a recurrent one that can occur with any step of digitization and can affect the hazard of the occurrence of other technological adoption.

The difference in the effects of determinants in different digitalization processes that were determined in this study are significant implications to theory and practice. There are interactions between those determinants, thus resulting in machine learning algorithms playing a more significant role in predicting time till digitization for each event. Certain determinants had high importance in predicting high speed internet as knowledge presented in digital skills and education of owners, along with the cost accompanying the access to internet. In addition, the region where the enterprise operates along with its importing strategy were all important features in predicting the time till company would access high speed internet. Similarly, the same variables were paramount in predicting online payments along with the industry and gender of the enterprise owner. This highlights that online transactions may be affected by gender diversity similar to the launch of the website. The features which are considered important in predicting time till launch of website are the gender diversity, financial costs, knowledge along with the R&D. This heterogeneity disputes the implicit assumption made in much of the literature that digitalization is a monolithic phenomenon, and is impacted by a uniform set of factors, and thus it is monolithic. Rather, the findings imply that policymakers

and business leaders should embrace specific interventions to fit certain goals of digitalization, such as infrastructure development and digital literacy initiatives to speed up the use of the internet, and innovation ecosystems and R&D support to enable e-commerce functions. These insights are further investigated with the recurrent model. It shows that each digitization procedure affects negatively the hazard of taking another step and continuing in the digitization phase. In addition, it shows how the time till digitization is affected by gender diversity, knowledge and digital literacy, financial cost and the trading activities of the enterprise. Thus, it provides further evidence to the earlier results. In a nutshell this study captures a set of policy implications with respect to business enterprises policy makers and academia in the following manner,

First: This realization that female owners affect the timing of digitalization implies that there may be specific obstacles to digitalization facing women-owned businesses, possibly including unequal access to finance, business connections, or technical education. As per 5th SDG Gender equality overlapping with 9th SDG titled as "industry, innovation and infrastructure, the implications would require more gender-sensitive policy related tools and incentives to support women-specific entrepreneurial initiatives, access to finance , mentorship and technical support programs enabling their efforts to attain a steadfast track towards digitalization of their enterprises.

Second: The close connection between the education's levels of the owner and the adoption of digitalization points out to the indispensable need to digital literacy and capacity-building initiatives tailored to the needs of business owners and top management calibers. Hence, elaborate training programs which include strategic digital transformation planning, technology investment analysis, cybersecurity awareness, and digital business model innovation developed by governments and business development bodies are imperative. As per the indicative results, enterprise size and sector should be differentiated in these programs since SMEs are prone to different challenges compared to large sized enterprises and need different types of support due to resource limitations, risk aversion, and lack of technical know-how.

Third: the disparity in digitalization between enterprises and their outcomes signals to the dire need of governmental institutions, regulatory bodies and industry associations to refrain from introducing digital support programs targeting a single size formula across all enterprises but to embrace stage-specific support, which the enterprises would receive, based on their current technological level of maturity and customized to their level of digital capability.

Fourth: trading companies must prioritize digital adoption by investing in core infrastructural tools such as corporate websites and online transactions. Given the strategic importance of both domestic and international operations, a focus on foundational digital tools is critical. To accelerate this transition, it is recommended that the Egyptian government introduce targeted incentives to encourage such investments.

Fifth: In businesses with a low adoption scale of digitalization, enterprises and who's still grappling with the adoption of basic internet infrastructure should focus on the combined effect of investing in a high-speed internet; particularly in less served areas where geographical inequalities are accelerating the adoption timeline. They should provide more options for online payment transactions and improve the features of a user-friendly accessible platform or websites.

Finally, according to this research findings, the enterprises that invest in developing the digital skills of the employees, bridge the management-employee knowledge gaps, and promote the cultures of innovations by enabling the knowledge having greater chances to survive the further stages of the digitalization. Peer learning can be enabled by business associations and chambers of commerce by establishing forums where early adopters of digital can exchange experiences, share challenges, and best practices with firms in the previous stages of transformation. This is possibly adopted through digitalization maturity benchmarking instruments, industry-specific roadmaps, or peer networks of learning to reduce the information asymmetry and exemplify firm gains in digital investments. Finally, this study is subject to certain limitations that present opportunities for future research. A primary limitation was the exclusion of recurrent survival machine learning algorithms; consequently, a key recommendation is the application of models such as recurrent neural networks to better capture temporal dependencies in the data. Furthermore, several potentially significant determinants, such as governmental incentives offered to enterprises, are not considered due to data unavailability. Future surveys should seek to incorporate these variables to enable a more comprehensive analysis.

5. Conclusion

The paper has effectively addressed the determinants of digitalization of business enterprises in Egypt by utilizing innovative developments in the methodology of survival analysis using a large-scale dataset of SEDE 2022 (n=765 enterprises, across business fields and regions). Using both Cox Proportional Hazards and extremely detailed machine learning models Survival XGBoost, Survival Random Forest and Survival Support Vector Regression, the study has shown that digitalization is not a homogeneous phenomenon but a highly multidimensional change, which has a number of stages, each of which is affected by various organizational, technological, and environmental factors. The results show that the owner related factors, including education level and the level of trade activity when to adopt the high-speed internet, other milestones of digitalization, like the development of websites, react differently to such determinants as R&D investments and the gender diversity in addition to the digital literacy and financial cost.

The study fills the gaps in the conceptual and methodological literature on analyzing the relation to enterprise digitalization in developing economies and the Middle Eastern and North African region specifically, where empirical research on the matter is limited. Combining the theoretical frameworks of the Technology-Organization-Environment (TOE) model, Diffusion of Innovation (DOI) theory, and Unified Theory of Acceptance and Use of Technology (UTAUT) with the use of the latest quantitative research techniques, the study offers a holistic approach to the analysis enabling the researchers to capture both the complexity and the time-related aspect of the digital transformation.

The four univariate survival analysis and the recurrent survival analysis methods, through the comparative evaluation, provide useful information on the algorithmic operation in terms of dealing with censored data and non-linear association, thus creating a blueprint of the methodology to be applied in future investigations of the time-to-event phenomenon in the digitalization setting. More so, the country-specific analysis of Egypt (ranked 58th among 64 countries in the 2023 Digital Competitiveness Report) brings important evidence of how enterprises in middle-lower tier digital economies adapt to technological changes and infrastructure limitations, regulatory pressures, and resource constraints, which are not necessarily the same as in the developed countries.

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