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HOW DOES 5G TECHNOLOGY DEPLOYMENT IMPACT E-TURNOVER IN SMES?

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Abstract. This study analyzes the impact of 5G technology on the electronic turnover (e-turnover) of SMEs in 26 EU Member States between 2020 and 2023, using the ENET methodology. It examines key digitalization drivers: 5G coverage, 5G spectrum, ICT specialists, and very high-capacity networks (VHCN). The results show that 5G coverage has a strong positive effect on e-turnover, particularly in countries with lower regulatory constraints, where implementation flexibility enhances connectivity and performance. Similarly, 5G spectrum allocation improves operational efficiency, but this effect weakens under stricter regulation, suggesting that rigid frameworks may hinder potential benefits. An unexpected finding is the negative relationship between ICT specialists and e-turnover, likely due to high integration costs in small firms. Although the impact lessens in regulated environments, it remains significant, indicating the need for SMEs to adopt cost-effective strategies such as upskilling or outsourcing. Granger causality analysis confirms a one-way influence from ICT specialists to e-turnover. The most substantial positive effect is linked to VHCN, especially in regulated settings, where fast and reliable data transmission drives innovation and revenue through advanced digital services. These results highlight the importance of coordinated 5G and VHCN strategies and strategic digital investment for SME competitiveness in the digital economy.

Keywords: SMEs, 5G, 5G coverage, 5G spectrum, ICT specialist, VHCN, e-turnover.

JEL Classification: L86, O33, C33, M15, L96.

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1. Introduction

Small and Medium Enterprises (SMEs) represent the majority of businesses and play a vital role in economic development (Beisengaliyev et al., 2018; Rotar et al., 2019; Taiwo et al., 2012). Even during crises, they contribute to employment and stability (Rotar et al., 2019). However, SMEs face financial and informational constraints in adopting new technologies (Taiwo et al., 2012). The COVID-19 pandemic accelerated digitalization, making technology adoption essential for survival (Papadopoulos et al., 2020). 5G integration is linked to improved performance and competitiveness (Eller et al., 2020; Guo et al., 2020). Key enablers include IT infrastructure, employee skills, and strategic orientation. Still, SMEs struggle with high implementation costs, lack of infrastructure, and limited expertise (Fitriasari, 2020;

Ievdokymov et al., 2023; Smith, 2024). Addressing these challenges through targeted digital strategies is crucial. 5G offers transformative potential for SMEs by enhancing connectivity, efficiency, and market access, but successful adoption depends on overcoming structural and capacity-related barriers.

Chinakidzwa and Phiri (2020, p. 746) finds that digital market innovation positively affects SMEs' performance in terms of sales growth, market share, and profitability. However, digital transformation poses challenges, including financial constraints, organizational inertia, regulatory barriers, and a lack of digital skills (Stentoft et al., 2021). These issues must be addressed when designing effective digital strategies. The emergence of 5G, since 2019, offers significant potential for SMEs, yet its impact remains underexplored in academic literature. This gap is critical, given SMEs' contribution to economic growth and innovation. Without empirical insights into 5G's influence on operations and financial performance, SMEs face uncertainty in strategic planning. Moreover, policymakers lack evidence to develop targeted support mechanisms. Addressing this gap is vital for guiding SMEs in their digital transition. This study contributes by offering one of the first comprehensive analyses of the link between 5G adoption and SME performance, advancing theoretical understanding and informing practical interventions.

This study examines how 5G coverage, 5G spectrum, ICT specialists, and VHCN access influence SMEs' e-turnover. Understanding these factors helps managers adopt digital tools to boost efficiency and competitiveness. The research offers both academic value and practical guidance for SMEs aiming to adapt in a digital economy. By addressing literature gaps, it builds a clear, relevant research narrative and supports strategic decision-making in technology adoption and workforce development.

In accordance with the aim of the paper, we have formulated some essential re-search questions to explore and highlight the relationship between the analyzed variables:

RQ1: *How does 5G coverage influence the financial performance and e-turnover of SMEs in European Union Member States?*

RQ2: *To what extent does the 5G spectrum contribute to improving the operational efficiency of SMEs and maintaining competitive advantages?*

RQ3: *What is the role of ICT specialists in facilitating the transition of SMEs to the use of very high connectivity networks* (*VHCN*) *and their impact on e-turnover?*

RQ4: *What strategies can SMEs adopt to maximize the benefits of 5G technology and VHCN networks in the context of the digital market?*

This study is structured as follows: Section 2 reviews relevant literature and identifies research gaps. Section 3 outlines the data and methodology, while Section 4 presents and analyzes findings. The final Section concludes with key insights and recommendations. By addressing existing gaps, the study contributes to understanding 5G's impact on SMEs and supports business leaders and policymakers in promoting digital transformation and enhancing SME competitiveness in a technology-driven economy.

2. Literature review

The 5G technology has emerged as a key enabler of organizational innovation and efficiency (Jiang & Xu, 2024; Khujamatov et al., 2020; Patel et al., 2022). It enhances manufacturing capabilities (Jiang & Xu, 2024) and improves connectivity, though it faces challenges such as high costs, limited coverage, and technological risks (Okoh & Oko, 2024; Patel et al., 2022). Government support for infrastructure and spectrum allocation remains essential (Patel et al., 2022, p. 117). Its industrial relevance is further underlined by Wang et al. (2015), Ancans et al. (2017), and Oughton et al. (2019, p. 50), who emphasize performance gains and strategic planning. The adoption of 5G technology enhances e-commerce performance, increasing e-turnover by boosting online sales and advertising efficiency (Kshetri, 2021, p. 73). It improves logistics and the value chain (Rejeb & Keogh, 2021) and enables real-time consumer insights for targeted marketing (Gisca, 2024; Nesse et al., 2024). Si (2021) links higher purchase intention to improved platform quality through 5G. The technology supports smooth operations and behavioral tracking. Rao and Prasad (2018) highlight 5G's role in Industry 4.0, fostering innovation and job creation. Tian (2020) argues that 5G provides "more outstanding development space" for e-commerce.

Digitalization increases demand for ICT professionals, especially in e-commerce (Bănescu et al., 2022). However, ICT skill gaps hinder SME adoption of digital models (Kapurubandara & Lawson, 2006; Tikhvinskiy & Umanskiy, 2024). ICT capabilities support internationalization (Hagsten & Kotnik, 2017) and require combined technical-sales expertise (Kock, 2015). Román-Bermeo and Vilema-Escudero (2023) show ICT's impact on sales during the pandemic, especially through female professionals. ICT infrastructure boosts Eastern Europe's economic growth (Dubyna et al., 2022). VHCN, promoted by the EU (European Commission, 2024), accelerates digitalization and innovation (De Rojas et al., 2023) and supports SDG performance (Imran et al., 2022).

Ejdys and Soler (2023) emphasized that social acceptance significantly affects 5G implementation. Their research in Poland revealed that frequent internet users exhibit more favorable attitudes towards 5G. Such acceptance is crucial, as public perception directly influences the rate at which businesses adopt new technologies, potentially impacting SMEs' digital turnover.

Li and Zhang (2024) identify health concerns and digital activism as barriers to 5G adoption in China, potentially affecting SMEs' digital strategies. Martín et al. (2019) highlight financially viable 5G use-cases, offering SMEs insights into cost-effective applications. Golovanova et al. (2019) find the single wholesale network model economically inefficient, suggesting infrastructure-sharing as a better alternative. Koutroumpis et al. (2023) confirm the benefits of network-sharing for reducing costs and enhancing coverage, thus supporting broader SME access to 5G and fostering increased e-turnover through more affordable digital infrastructure.

Adamauskas and Krušinskas (2016, 2017) show that financial constraints delay 5G adoption in SMEs, affecting competitiveness and e-turnover. Geopolitical tensions also play a role: Maurício et al. (2021) highlight Brazil's position between China and the USA, while Walter and Trampusch (2024) analyze the impact of Huawei bans, noting political interests shape 5G access. Such dynamics may increase costs or delays for SMEs. Additionally, Bukhari and Mérida (2024) discuss aviation-related 5G interference, underscoring regulatory challenges. Addressing financial, geopolitical, and regulatory barriers is vital for SMEs to fully benefit from 5G in e-commerce contexts.

Walter and Trampusch (2024) further showed that policies like the Huawei ban across the US, UK, and Germany illustrate economic statecraft influenced by political economy factors. SMEs must navigate these complex regulatory environments, which directly affects their operational costs and speed of adoption.

Savulescu et al. (2019) argued that 5G fosters digital competencies essential for thriving in the digital economy. SMEs need significant training and skill development to effectively leverage 5G technology, directly influencing their productivity, operational efficiency, and e-turnover.

Azic et al. (2024) described FCC economists' initiatives in promoting 5G infrastructure to bridge digital divides, especially for rural connectivity. SMEs located in rural areas stand to benefit significantly from improved digital infrastructure through reduced costs and increased online transactions.

Mishra and Tripathi (2020) and Kalenyuk et al. (2023) identified how IoT platforms and smart city investments, enhanced by 5G, provide SMEs opportunities to improve operational efficiencies, innovate management systems, and stimulate sustainable economic growth, potentially boosting e-turnover.

Walter and Trampusch (2024) analyzed economic statecraft surrounding Huawei's 5G bans and found varied domestic responses to these bans. Such decisions impact SMEs by influencing their choices.

Qin et al. (2023) identified the implications of advanced network technologies, including 5G, on e-commerce and cybersecurity. SMEs engaging in e-commerce could face increased risks and legal responsibilities with network advancements, affecting consumer trust and potentially influencing e-turnover.

The EU's Digital Economy and Society Index (DESI) tracks digitalization across member states, including skills, infrastructure, and business digitalization. VHCN and 5G are key components supporting public and private sector connectivity. E-commerce reached $5.78 trillion in 2023, driven by robust digital infrastructure (Statista, n.d.). However, only 55% of EU SMEs had basic digitalization in 2021 (Coban, 2023), revealing a gap compared to larger firms. This underscores the potential for SMEs to adopt digital tools and expand customer reach. To enhance competitiveness, increased investment in infrastructure and workforce training remains crucial (Jafor et al., 2024).

Recent literature confirms that 5G and Very High-Capacity Networks (VHCN) drive digital progress, improving efficiency and innovation across sectors (Jiang & Xu, 2024; Khujamatov et al., 2020; Patel et al., 2022). However, challenges persist, including high costs, technological risks, and limited coverage. Spectrum allocation and infrastructure are essential for 5G's success (Khujamatov et al., 2020; Patel et al., 2022; Wang et al., 2015). Jiang and Xu (2024) highlight 5G's role in manufacturing innovation, while Patel et al. (2022) emphasize its dual impact. Kshetri (2021) shows 5G enhances e-commerce through speed and reliability. Bănescu et al. (2022) underline rising ICT workforce demands. Imran et al. (2022) demonstrate VHCN's role in sustainable development. Oughton et al. (2019) reveal 5G's superior user capacity. These findings support using 5G coverage, 5G spectrum, ICT specialists, and VHCN as multidimensional indicators of digital infrastructure and human capital, crucial for SMEs' competitiveness and 5G-driven transformation.

Despite growing interest in 5G, current literature lacks detailed analysis of its impact on SMEs across sectors and regions. Long-term effects on economic performance, competitiveness, job creation, and innovation remain underexplored (Kshetri, 2021; Oughton et al. 2019;; Rejeb & Keogh, 2021; Si, 2021; Rao, 2018; Tian, 2020). While prior studies discuss general benefits and challenges, more granular research is needed. This study addresses these gaps by examining how 5G influences SMEs through variables such as 5G coverage, 5G spectrum allocation, ICT specialist availability, and VHCN deployment. The research further assesses the impact of these factors on SMEs' e-commerce turnover. By integrating technical infrastructure indicators with financial performance metrics, the study offers a comprehensive view of how 5G adoption affects SME innovation and competitiveness. These findings aim to support evidence-based decision-making for both policymakers and business leaders, contributing to the strategic development of the digital economy.

3. Data and methodology

3.1. Data

To assess the impact of 5G technology on SMEs' e-commerce turnover (e-turnover), we constructed a panel dataset covering 26 EU member states from 2020 to 2023. This period corresponds to the early phase of 5G deployment across the EU, making it relevant for analyzing its initial economic effects. Earlier data were either unavailable or insufficient due to the recent introduction of 5G around 2019–2020. Luxembourg was excluded due to the confidentiality of e-turnover data. While this slightly limits generalizability – particularly for small, highly digital economies – the effect is minimal given Luxembourg's small economic weight relative to the EU aggregate.

Our analysis uses four key indicators (Table 1): 5G coverage and 5G spectrum, essential to assess network deployment and spectrum readiness; VHCN (Very High-Capacity Network) coverage, which captures the fixed broadband infrastructure (e.g., FTTH and FTTB); and the number of ICT specialists, reflecting the human capital dimension. While VHCN and 5G infrastructure may appear overlapping, they capture distinct elements: 5G spectrum reflects wireless readiness, while VHCN shows fixed-line capacity vital for reliable, high-speed business connectivity – particularly for SMEs.

The data were sourced from the European Commission's Digital Decade DESI visualization tool (European Commission, n.d.), a recognized and standardized resource collecting data from national statistical offices and EU-level entities. DESI provides consistent, high-quality indicators on digital infrastructure, ICT workforce, and e-commerce activity, widely used in both research and policymaking.

The selected indicators align with three key dimensions of the 5G ecosystem. 5G coverage and spectrum allocation reflect Infrastructure Availability, enabling high-speed wireless access. VHCN represents Complementary Infrastructure, supporting mobile 5G through fixed broadband networks. ICT specialists indicate the Human Capital required to adopt, manage, and integrate digital technologies. These indicators are not purely technical; they capture broader institutional, infrastructural, and workforce capacities essential to SMEs' digital transformation and economic performance.

By linking these dimensions, our analysis provides a multidimensional framework to evaluate how 5G technology and related factors contribute to SMEs' e-turnover. This approach allows for a comprehensive assessment of both external enabling conditions and internal capabilities necessary for successful digitalization in the SME sector.

Table 1 provides definitions and units of measure for each variable used in the analysis. For example, 5G coverage is expressed as the percentage of households within the range of at least one 5G network, with values ranging from 0% to 100% across the dataset. The ICT Specialist variable varies significantly between countries, from as low as 11.2 thousand to over 2,000 thousand, indicating a strong disparity in human capital across EU member states.

The 5G coverage indicator measures the percentage of households within the range of at least one 5G network, offering key insights into the adoption of advanced mobile technology. This metric is vital for understanding how 5G supports digital innovation and services. Between 2020 and 2023, most EU countries saw substantial growth in 5G coverage. Austria rose from 50% to over 96%, and Germany from 17.8% to 98.1%. In contrast, some countries had little or no coverage in 2020 – Belgium stood at 4.4%, while Bulgaria, Cyprus, Greece, and Romania had none. By 2022, Cyprus, Denmark, and Italy had reached full coverage. In

2023, Cyprus, Denmark, Malta, and the Netherlands achieved 100%. Others, like Belgium and Romania, progressed more slowly, reaching only 40.35% and 32.75% respectively. These figures reveal a rapid but uneven rollout across the EU, with early adopters achieving faster results and others still catching up in implementing 5G infrastructure.

Table 1. Variables characteristics (source: own processing, 2024)

Indicator	Variable type	Definition	Unit of measure
5G coverage	Explicative	Percentage of households with coverage by at least one 5G mobile network	Percentage of households
5G spectrum	Explicative	The amount of spectrum assigned and ready for 5G use within the so-called 5G pioneer bands. These bands are 700 MHz (703–733 MHz and 758–788 MHz), 3.6 GHz (3400–3800 MHz) and 26 GHz (1000 MHz within 24250–27500 MHz).	Percentage of harmonized spectrum assigned
ICT specialist	Explicative	Employed ICT specialists. Broad definition based on the ISCO-08 classification and including jobs like ICT service managers, ICT professionals, ICT technicians, ICT installers and servicers.	Thousands of individuals
Fixed Very High-Capacity Network (VHCN) coverage	Explicative	Percentage of households covered by any fixed VHCN. The technologies considered are FTTH and FTTB for 2017–2018 and FTTH, FTTB and Cable DOCSIS 3.1 for 2019 onwards.	Percentage of households
E-turnover	Dependent	SMEs total turnover from e-commerce	Percentage of turnover

The 26 GHz band has been identified to help deliver 5G services to people and businesses. It measures a country's readiness to support high-speed, low-latency connectivity. From 2020 to 2023, spectrum allocation increased across Europe, with countries like Germany, Denmark, and Greece maximizing early, while Belgium and Bulgaria showed delayed but notable progress. Poland and Romania maintained low allocations, signaling potential implementation challenges.

The ICT specialist indicator tracks the number of professionals in the digital workforce under ISCO-08 classifications. It highlights a country's capacity to sustain digital transformation. Most EU countries experienced growth in ICT personnel from 2020 to 2023. Spain increased from 742.8 to 935.9 thousand specialists, Italy from 817 to 970.3, while Germany exceeded 2,000. Smaller states like Cyprus, Malta, and Latvia showed gradual increases, but Slovenia and Slovakia remained stable at lower levels, reflecting difficulties in scaling digital human capital.

The VHCN indicator measures household coverage with high-speed fixed networks like FTTH, FTTB, and DOCSIS 3.1, reflecting digital infrastructure readiness. High VHCN coverage supports economic growth, digital services, and social inclusion. From 2020 to 2023, countries like Denmark, Latvia, and Malta reached full coverage, while Belgium improved significantly – from 67.5% to 95.95%. Austria also progressed, but Slovakia and Bulgaria showed slower growth, indicating infrastructural or policy challenges.

The e-turnover indicator reflects the share of SME revenue from e-commerce, revealing digital adoption levels. Higher e-turnover suggests better integration of digital strategies. Ireland consistently reported high values (26.9% in 2020), while Cyprus and Greece showed low, fluctuating levels. Belgium and Lithuania demonstrated notable increases, while Austria and Denmark experienced slight declines, possibly due to market saturation. These trends highlight uneven digital transformation across the EU, with national policies and market dynamics influencing SME engagement in e-commerce and broader digital economic participation.

3.2. Methodology

The analysis of the data in this study follows a structured approach aimed at un-covering the relationships and potential causal linkages among the variables of interest. The methodology is divided into five main steps: analysis of descriptive statistics, analysis of the correlation matrix, Ordinary Least Squares (OLS) estimation, Elastic Net (ENET) estimation, and the Granger causality test. Each step is designed to progressively build an understanding of the data and the underlying dynamics.

The first step involves the computation and interpretation of descriptive statistics for each variable in the dataset. This includes measures such as the mean, median, standard deviation, minimum, and maximum values (Kaur et al., 2018). The purpose of this analysis is to gain an initial understanding of the data distribution, central tendency, and variability, as well as to identify any potential outliers or anomalies (Marshall & Jonker, 2010). This step is crucial in ensuring the quality of the data and preparing it for subsequent analyses.

Following the descriptive analysis, a correlation matrix is constructed to examine the pairwise relationships between the variables. This matrix provides insight into the strength and direction (positive or negative) of linear relationships between the variables (Dziuban & Shirkey, 1974). By identifying significant correlations, this step helps in understanding which variables may be closely related and could potentially influence each other. It also serves as a preliminary step in identifying multicollinearity issues that may affect the reliability of regression analyses (Higham, 2002).

The third step involves conducting an Ordinary Least Squares (OLS) regression analysis. OLS estimation is a linear regression technique used to model the relationship between the dependent variable and one or more independent variables by minimizing the sum of the squared differences between observed and predicted values (Pace & Gilley, 1998). This method provides coefficients that quantify the effect of each independent variable on the dependent variable. The significance of these coefficients is tested to identify which variables have a statistically significant impact on the outcome of interest. OLS is a fundamental step in understanding the basic relationships within the dataset (Francq & Govaerts, 1998).

After the OLS estimation, an Elastic Net (ENET) regression is conducted. ENET is a regularization technique that combines the penalties of both Lasso and Ridge regression, taking the following equation form Friedman et al. (2010):

$$J = \frac{1}{2m}\sum_{i=1}^{m}\left(y_i - \beta_0 - \sum_{j=1}^{p} x_{ij}\beta_j\right)^2 + \lambda\left[\frac{(1-\alpha)}{2}\sum_{j=1}^{p}\beta_j^2 + \alpha\sum_{j=1}^{p}\left|\beta_j\right|\right], \quad (1)$$

with m samples and p predictors, the target variable for the i-th sample is denoted as y_i, and x_{ij} represents the value of the j-th predictor for the i-th sample. The relationship between the predictors and the target variable is modeled using a set of coefficients β_j, where each β_j is associated with the corresponding j-th predictor. Additionally, β_0 is the intercept term, representing the baseline value when all predictors are equal to zero. Lambda (λ) is a critical parameter known as the regularization parameter. Its primary role is to control the complexity of the model and prevent overfitting by applying a penalty to the size of the regression coefficients. Specifically, higher values of lambda increase the penalty, causing coefficients to shrink toward zero and reducing the model complexity. Conversely, lower values of lambda result in smaller penalties, allowing coefficients to take larger values and thus creating a more complex model. Selecting an optimal lambda value involves finding a balance: too large a lambda can overly simplify the model, missing important predictors, while too small a lambda might lead to an overly complex model that captures noise in the data rather than meaningful patterns (Zou & Hastie, 2005).

This framework describes the general linear regression model. This method is particularly useful when dealing with datasets that may have multicollinearity or when the number of predictors is large relative to the number of observations (Zou & Hastie, 2005). ENET helps in feature selection by shrinking some coefficients to zero, effectively eliminating irrelevant variables, while also handling correlated predictors better than Lasso or Ridge alone. This step refines the model by selecting the most important predictors and providing more robust estimates (Liang et al., 2022). The ENET regression is utilized alongside to OLS primarily due to potential issues of multicollinearity among predictors in our dataset. Multicollinearity, a common challenge when dealing with related explanatory variables (such as 5G coverage, 5G spectrum allocation, VHCN infrastructure, and the number of ICT specialists), can lead to inflated variances in coefficient estimates and instability in OLS regression outcomes. ENET regression effectively addresses this by combining both L1 (Lasso) and L2 (Ridge) regularization techniques. Lasso assists in variable selection by reducing some coefficients to zero, thus identifying the most impactful variables, while Ridge helps stabilize coefficient estimates in the presence of correlated variables. By employing ENET after an initial OLS analysis, we validated and refined our findings, ensuring robustness and greater accuracy of our model.

The final step involves conducting a Granger causality test (Shojaie & Fox, 2022) to explore the directional relationship between variables. The Granger causality test is a statistical hypothesis test used to determine whether one time series can predict another time series (Grassmann, 2020). Specifically, it tests whether past values of one variable can improve the prediction of another variable beyond what is possible using only the past values of the latter. This test is crucial in establishing potential causal links between variables, providing deeper insights into the temporal dynamics and possible cause-and-effect relationships (Molnár & Csiszarik-Kocsir, 2023).

4. Results and discussions

To establish a thorough basis for the upcoming analysis, the descriptive statistics for variables such as E_TURNOVER, 5G COVERAGE, 5G SPECTRUM, ICT SPECIALIST, and VHCN have been carefully computed and are summarized in Table 2. The Table 2 shows that the average e-turnover (percentage of e-commerce revenue) among SMEs is 11.02%, with a maximum of 26.9% and a minimum of 0%. The 5G coverage ranges from 0% to 100%, with a mean of 54.8%. The 5G spectrum assigned has a mean of 62.33%, reaching full allocation (100%) in some countries. The number of ICT specialists varies significantly, with a mean of 351.06 thousand, a median of 189.75, and a highly skewed distribution (skewness = 2.25). VHCN coverage is relatively high, with a mean of 71.77% and values ranging from 10.17% to full coverage (100%).

Table 2. Descriptive statistics of the data (source: own processing, 2024)

	E_TURNOVER	5G COVERAGE	5G SPECTRUM	ICT SPECIALIST	VHCN
Mean	11.02019	54.80046	62.33040	351.0596	71.77306
Median	10.90000	65.01047	65.83333	189.7500	74.07166
Maximum	26.90000	100.0000	100.0000	2114.000	100.0000
Minimum	0.000000	0.000000	0.000000	11.20000	10.17028
Std. Dev.	5.461398	37.26801	31.23430	461.0973	19.39134
Skewness	0.249859	–0.249895	–0.437433	2.251070	–0.758080
Kurtosis	3.134419	1.481307	2.192584	7.989729	3.348832
Jarque-Bera	1.160407	11.07694	6.141680	195.7222	10.48852
Probability	0.559784	0.003933	0.046382	0.000000	0.005278
Sum	1146.100	5699.248	6482.361	36510.20	7464.398
Sum Sq. Dev.	3072.168	143057.1	100484.9	21898902	38730.46

The mean values indicate average levels, with E_TURNOVER (11.02), 5G COVERAGE (54.80), 5G SPECTRUM (62.33), and VHCN (71.77) showing moderate to high averages. ICT SPECIALIST has a notably high mean (351.06), indicating significant variability in the number of ICT specialists. The median values are close to the means for most variables, suggesting relatively symmetric distributions except for ICT SPECIALIST, where the median (189.75) is much lower than the mean, indicating a right-skewed distribution. Skewness values indicate that E_TURNOVER and ICT SPECIALIST are positively skewed, with ICT SPECIALIST being highly skewed (2.25), while 5G COVERAGE, 5G SPECTRUM, and VHCN are negatively skewed, showing a concentration of higher values. Kurtosis reveals that ICT SPECIALIST has a leptokurtic distribution (7.99), indicating heavy tails and outliers, whereas other variables have kurtosis values near or below 3, indicating distributions that are more normal or flatter. The Jarque-Bera test indicates that E_TURNOVER does not significantly deviate from normality, while 5G COVERAGE, 5G SPECTRUM, ICT SPECIALIST, and VHCN do, particularly ICT SPE-CIALIST (with a probability of 0.000), confirming its deviation from a normal distribution. These variables exhibit different patterns of distribution, with ICT SPECIALIST being an outlier in terms of variability and distribution shape.

The correlation matrix presented in Table 3 provides insights into the linear relationships between the variables E_TURNOVER, 5G COVERAGE, 5G SPECTRUM, ICT SPECIALIST, and VHCN. E-turnover has a statistically significant positive correlation with VHCN ($r = 0.226$, $p = 0.0209$), indicating that high-capacity fixed networks are associated with increased digital turnover. The correlation between 5G coverage and e-turnover is weak and not statistically significant ($r = 0.135$, $p = 0.1715$). Similar weak correlations are observed with 5G spectrum ($r = 0.027$, $p = 0.7851$) and ICT specialists ($r = –0.0108$, $p = 0.9135$).

Overall, E_TURNOVER has a limited but statistically significant positive relationship with VHCN, suggesting that electronic turnover may be linked to the extent of Very High-Capacity Networks. The relationships with 5G COVERAGE, 5G SPECTRUM, and ICT SPECIALIST are weak and not significant, indicating that E_TURNOVER does not have a strong or reliable association with these variables.

These findings highlight that while electronic turnover shows a significant, albeit modest, association with Very High-Capacity Networks, it does not demonstrate a strong or reliable connection with 5G coverage, spectrum allocation, or the presence of ICT specialists. This suggests that the influence of electronic turnover on network infrastructure may be more pronounced in the context of Very High-Capacity Networks rather than in broader measures of 5G infrastructure or human resources related to ICT.

Table 3. Correlation matrix (source: own processing, 2024)

Correlation					
Probability	E_TURNOVER	5G COVERAGE	5G SPECTRUM	ICT SPECIALIST	VHCN
E_TURNOVER	1.000000				
	–				
5G COVERAGE	0.135090	1.000000			
	0.1715	–			
5G SPECTRUM	0.027056	0.362987	1.000000		
	0.7851	0.0002	–		
ICT SPECIALIST	–0.010778	0.202262	0.157151	1.000000	
	0.9135	0.0395	0.1111	–	
VHCN	0.226196	0.220089	–0.231034	0.030860	1.000000
	0.0209	0.0248	0.0183	0.7558	–

Table 4 displays the results of the OLS regression. Among the explanatory variables, only VHCN shows a statistically significant and positive effect on E-Turnover (β = 0.0634, p = 0.0363), indicating that better VHCN infrastructure is associated with higher e-commerce turnover. The coefficients for 5G Coverage (β = 0.0106, p = 0.5195), 5G Spectrum (β = 0.0104, p = 0.5959), and ICT Specialists (β = –0.00049, p = 0.6769) are not statistically significant, suggesting limited direct influence. The OLS results reveal that among the variables examined, only VHCN has a statistically significant impact on E_TURNOVER. The positive coefficient for VHCN indicates that greater investment in Very High-Capacity Networks is associated with higher electronic turnover. In contrast, 5G COVERAGE, 5G SPECTRUM, and ICT SPECIALIST do not show statistically significant effects on electronic turnover, suggesting that these factors may not be critical drivers of variations in electronic turnover within the context of this model.

The model's limited explanatory power, as indicated by the low R-squared and Adjusted R-squared values, suggests that other unobserved factors may be influencing e-turnover. Additionally, the indication of potential serial correlation in the residuals points to possible issues with the model specification that may need to be addressed in future analyses.

Table 5 shows the Elastic Net regression results at the optimal regularization level (λ = 357.4), selected via 5-fold cross-validation. At this lambda, 5G Coverage has a positive coefficient (β = 0.01295), as does VHCN (β = 0.03059), indicating a strong contribution to e-turnover. In contrast, ICT Specialists still present a negative effect (β = –0.00041), reinforcing earlier findings from the OLS model. 5G Spectrum has a smaller positive effect (β = 0.00328). The intercept (C = 8.06) suggests a baseline e-turnover of approximately 8.05% when other variables are zero. The results of the Elastic Net analysis provide essential insights into the influence of variables on E_TURNOVER, with significant observations depending on the level of regularization applied. Firstly, all the variables analyzed retain coefficients significantly different from zero across all levels of lambda, suggesting that each variable has some impact on E_TURNOVER. This indicates that, although the magnitude of the effects may vary, none of the variables is irrelevant in our model.

Table 4. OLS estimation results (source: own processing, 2024)

Dependent Variable: E_TURNOVER				
Method: Panel Least Squares				
Sample: 2020 2023				
Periods included: 4				
Cross-sections included: 26				
Total panel (balanced) observations: 104				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
5G COVERAGE	0.010609	0.016411	0.646455	0.5195
5G SPECTRUM	0.010382	0.019514	0.532040	0.5959
ICT SPECIALIST	–0.000494	0.001182	–0.417916	0.6769
VHCN	0.063445	0.029900	2.121883	0.0363
C	5.411494	2.591871	2.087871	0.0394
R-squared	0.062790	Mean dependent var		11.02019
Adjusted R-squared	0.024923	S.D. dependent var		5.461398
S.E. of regression	5.392911	Akaike info criterion		6.254931
Sum squared resid	2879.266	Schwarz criterion		6.382065
Log likelihood	–320.2564	Hannan-Quinn criter		6.306436
F-statistic	1.658174	Durbin-Watson stat		0.309282
Prob(F-statistic)	0.165793			

Table 5. ENET estimation results (source: own processing, 2024)

Dependent Variable: E_TURNOVER			
Method: Elastic Net Regularization			
Sample: 2020 2023			
Included observations: 104			
Penalty type: Elastic Net (alpha = 0)			
Lambda at minimum error: 357.4			
Regressor transformation: None			
Cross-validation method: K-Fold (number of folds = 5), rng = kn, seed = 889984332			
Selection measure: Mean Squared Error			
	(minimum)	(+ 1 SE)	(+ 2 SE)
Lambda	357.4	2.832e+04	2.832e+04
Variable		Coefficients	
5G COVERAGE	0.012951	0.000925	0.000925
5G SPECTRUM	0.003281	0.000157	0.000157
ICT SPECIALIST	–0.000413	–0.000128	–0.000128
VHCN	0.030588	0.000824	0.000824
C	8.055592	10.94563	10.94563
d.f.	4	4	4
L1 Norm	8.102825	10.94767	10.94767
R-squared	0.050802	0.003166	0.003166

At low levels of lambda, 5G COVERAGE has the most substantial positive impact on E_TURNOVER, highlighting its importance in driving electronic turnover. This finding aligns with existing literature (Oughton et al., 2019), which recognizes the importance of extensive coverage in facilitating access to advanced digital services and applications. This positive impact can be explained by the fact that broader coverage facilitates greater access to 5G-based services, which may include advanced electronic applications and services. This, in turn, increases demand for digital products and services. Additionally, extensive coverage encourages the development of new solutions and applications that require fast and high-quality connectivity, potentially leading to increased revenue from these applications. However, as lambda increases, the influence of 5G COVERAGE diminishes, and VHCN becomes the variable with the most significant positive impact. Thus, VHCN becomes more influential in modeling E_TURNOVER under stricter regularization conditions, with results consistent with earlier studies (de Rojas, et al., 2023; Imran et al., 2022). Very High-Capacity Networks (VHCN) enhance operational efficiency and enable rapid data transfer, facilitating the development and use of high-capacity applications that can generate additional revenue. Moreover, investments in VHCN infrastructure can attract companies and developers who create innovative solutions based on these networks, thereby contributing to the growth of E_TURNOVER. However, translating these benefits into actionable strategies requires further elaboration. Practically, SMEs can leverage the benefits of VHCN by investing strategically in digital infrastructures, such as cloud-based platforms and advanced data analytics systems, to optimize operational processes and enhance customer interactions. Policymakers should thus prioritize investments that expand high-capacity digital infrastructure, focusing particularly on underserved areas to ensure equitable digital access and to foster a conducive environment for SME growth and innovation. Such targeted investments can significantly enhance SMEs' competitive positioning within the digital economy (Jafor et al., 2024).

Regarding 5G SPECTRUM, although this variable continues to have a positive effect, its impact decreases significantly as lambda increases, similar to results found in previous studies (Ancans et al., 2017; Patel et al., 2022; Wang, et al., 2015). This indicates that, under more severe regularization, 5G SPECTRUM becomes less relevant compared to other variables. A larger spectrum allows for the management of more simultaneous connections and faster data transfer speeds, improving user experience and supporting the development of more sophisticated electronic services and products. Furthermore, emerging technologies that require broadbad, such as the Internet of Things (IoT) and Augmented Reality (AR), are better developed with an expanded 5G spectrum, thus contributing to revenue growth in these areas.

In contrast, ICT SPECIALIST presents a negative coefficient, reflecting an adverse im-pact on E_TURNOVER, which contrasts with some previous hypotheses and findings (Dubyna et al., 2022; Hagsten & Kotnik, 2017; Kapurubandara & Lawson, 2006; Román-Bermeo & Vilema-Escudero, 2023;). The negative impact of ICT SPECIALIST decreases as lambda increases but remains significant even at high levels of regularization. This suggests that, although the negative effect is attenuated, ICT SPECIALIST continues to negatively influence E_TURNOVER. The negative influence of ICT SPECIALIST on E_TURNOVER may result from the high costs associated with hiring and maintaining these specialists, technical complexity, integration challenges, and possible overinvestment in technology. Also insufficient or inappropriate training of ICT specialists could hinder their effectiveness within SMEs, especially if training does not adequately match the evolving technological needs of businesses (Stentoft et al., 2021). Additionally, a potential misalignment between the specific technological requirements of SMEs and the expertise of employed ICT specialists might negatively impact productivity, indicating that SMEs may not fully capitalize on their ICT investments (Kock, 2015; Román-Bermeo & Vilema-Escudero, 2023). Another plausible explanation is overinvestment in advanced technology or highly specialized personnel, which could create inefficiencies or resource misallocation, ultimately affecting financial performance negatively (Dubyna et al., 2022). Expanding on these points enriches our understanding and aligns our interpretations more closely with current scholarly debates.

These results underscore that the Elastic Net analysis allowed us to uncover different effects compared to the OLS model. While VHCN proves to be the most influential variable at the highest level of lambda, we observe that all variables maintain a significant impact on the dependent variable E_TURNOVER. This finding highlights the importance of each variable in modeling electronic turnover, emphasizing their relevance within a context of variable regularization. Thus, for a comprehensive and accurate evaluation, it is crucial to consider the effects of variables in the specific context of the applied regularization.

Table 6 presents the evolution of the Elastic Net model's performance across different lambda values. At $\lambda = 357.36$ (row 48), the model achieves the optimal balance between complexity and fit, with an R-squared of 0.0508 and the lowest AIC (1.0261). As lambda decreases, the L1 norm (sum of absolute values of coefficients) increases, indicating less penalization and more model complexity. Conversely, very high lambda values (e.g., $\lambda > 28{,}000$) lead to oversimplified models with low explanatory power ($R^2 \approx 0.003$). This summary path validates the choice of the selected lambda by minimizing overfitting while retaining predictive power.

Table 6. Summary path (source: own processing, 2024)

	Lambda	d.f.	L1Norm	R-squared	AIC
1	28320.47	4	10.94767	0.003166	1.073757
2	25804.56	4	10.93764	0.003446	1.073477
...					
47	392.2063	4	8.218464	0.049694	1.027230
48	357.3638	4	8.102825	0.050802	1.026121
49	325.6166	4	7.984411	0.051881	1.025042
...					
99	3.108168	4	5.545745	0.062786	1.014137
100	2.832047	4	5.541400	0.062787	1.014136

Figure 1 illustrates the evolution of model coefficients under varying degrees of regularization (lambda). At low lambda values (e.g., $\lambda \approx 357.4$), 5G Coverage ($\beta = 0.01295$) and VHCN ($\beta = 0.03059$) show the highest positive influence on E-Turnover. As lambda increases toward the maximum tested values (e.g., $\lambda > 28{,}000$), their influence decreases, with coefficients shrinking toward zero. ICT Specialist has a consistent negative effect (e.g., $\beta = -0.00041$), which remains even as lambda increases, suggesting a potential cost inefficiency in this variable's influence. As indicated by the model's results, both 5G COVERAGE and VHCN seem to have the most significant impact at lower lambda values, but their influence diminishes rapidly with increased regularization. However, VHCN maintains a relatively consistent coefficient, suggesting that it may be a more robust predictor even under high regularization conditions. SPECIALIST has a negative impact on E_TURNOVER at lower levels of regularization, but this effect decreases as lambda increases. This behaviour is typical in Elastic Net regression, where regularization helps to mitigate overfitting by shrinking less important or more collinear predictors.

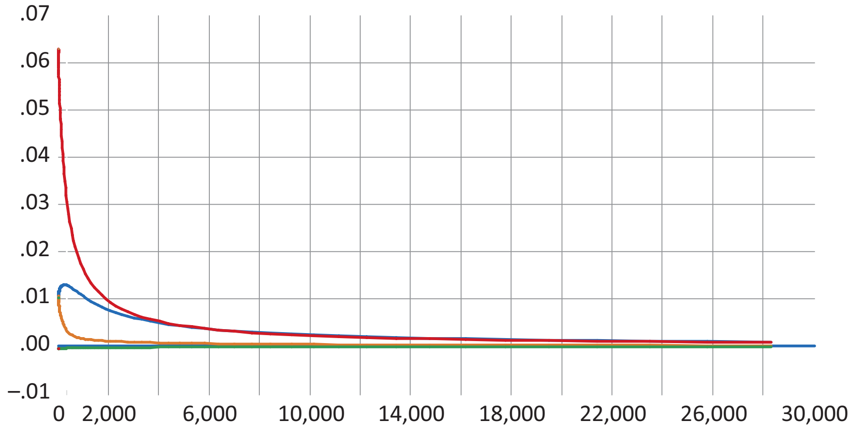

Figure 1. Coefficient evolution (source: own processing)

The graph presented in Figure 2 highlights the importance of choosing an appropriate lambda value in the Elastic Net model. The training error increases with lambda, reflecting the reduction in model complexity, while the test error decreases to a point before increasing again, signalling the transition from overfitting to underfitting. The optimal lambda is where the test error is minimized, ensuring the best predictive performance with the least overfitting or underfitting.

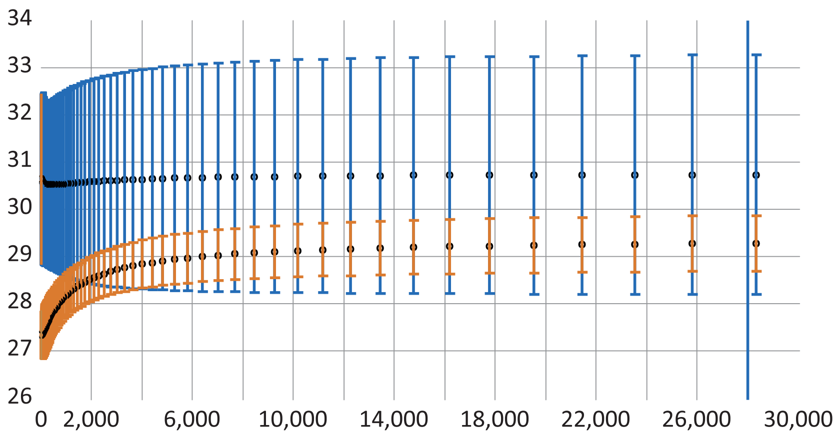

Figure 2. Evolution of training and testing errors across lambda values (source: own processing)

Figure 2 demonstrates the typical U-shaped behavior of regularization models. The training error increases steadily with lambda due to stronger penalization, while test error initially decreases – reaching its minimum at $\lambda \approx 357.4$ – before rising again. This validates the choice of optimal lambda and indicates that model complexity is best balanced at this point, maximizing predictive performance without overfitting.

The Granger causality analysis revealed both bidirectional and unidirectional relationships between the variables, providing a detailed understanding of their impact on E_TURNOVER. Specifically, a significant reciprocal causal relationship was identified between 5G COVERAGE and E_TURNOVER, indicating that these two variables mutually influence each other. Improvements in 5G coverage can stimulate the growth of electronic commerce, while success in electronic commerce can motivate the expansion and development of 5G networks, thereby creating a virtuous cycle of interaction.

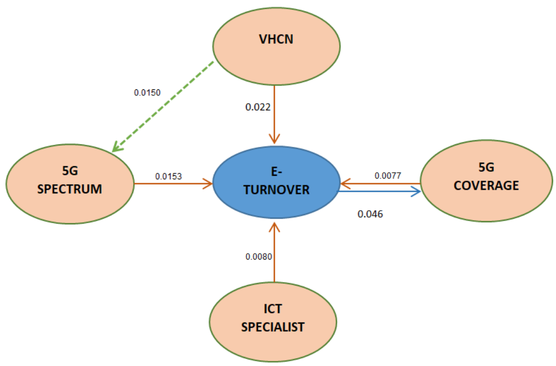

Figure 3. Granger causality test results (source: own processing)

In contrast, the remaining relationships observed in the Granger causality test are unidirectional, indicating an influence from 5G SPECTRUM, ICT SPECIALIST, and VHCN towards E_TURNOVER (see Figure 3).These unidirectional relationships suggest that the variables 5G SPECTRUM, ICT SPECIALIST, and VHCN have a significant impact on electronic turnover without being significantly influenced by its fluctuations. Specifically, 5G SPECTRUM, ICT SPECIALIST, and VHCN contribute to the enhancement and expansion of technological infrastructure and services, which in turn drives the growth of E_TURNOVER. Although Bănescu et al. (2022) concluded that the number of ICT specialists increases with the development of electronic commerce, our Granger causality test revealed a unidirectional relationship, from ICT specialists to e-turnover, and not the other way around. This underscores the essential role of these variables in the development and success of electronic commerce, highlighting the fact that financial performance does not directly influence technological decisions regarding these variables.

5. Conclusions

Our study provides important insights into how 5G technology influences e-turnover in SMEs, addressing aspects that have not been sufficiently explored in the existing literature. Based on current knowledge, which highlights the transformative potential of 5G technology and Very High-Capacity Networks (VHCN) for digital progress and organizational innovation, our research fills critical gaps by specifically analysing their impact on Small and Medium-Sized Enterprises (SMEs) in European Union member states.

As a response to RQ1, our analysis revealed that 5G coverage has a significant positive impact on e-turnover, particularly at lower levels of regularization. In response to RQ2, we found that the 5G spectrum significantly contributes to improving operational efficiency, though its impact diminishes as the level of regulation increases, suggesting that flexibility in regulatory frameworks may be beneficial for SMEs to fully capitalize on the potential of 5G.

A notable aspect of our study, which addresses RQ3, regarding the impact of ICT specialists, is that the presence of ICT specialists appears to have a negative impact on turnover. This negative effect may result from high costs and integration challenges associated with these specialists. Although the magnitude of this negative impact de-creases with higher regularization, it remains significant, suggesting that SMEs need to carefully balance investments in ICT talent with other technological needs. Although the magnitude of this negative impact decreases with stricter regulations, it remains significant, indicating that SMEs need to adopt a strategic approach in balancing the costs of ICT talent with their technological investments. A potential solution could be to focus on upskilling existing employees or leveraging flexible staffing models, such as outsourcing or part-time ICT specialists, to manage costs more efficiently. Moreover, while Bănescu et al. (2022) found that the number of ICT specialists rises with the expansion of electronic commerce, our Granger causality test identified a one-way causal relationship from ICT specialists to e-turnover, rather than the reverse. These findings emphasize the need for further in-depth studies to explore and clarify this relationship and its broader implications. Very High-Capacity Networks (VHCN) showed the most substantial positive impact on e-turnover at higher levels of regularization.

The answer to the last research question is that VHCN improves operational efficiency and enables rapid data transfer, making it a critical factor for generating revenue through high-capacity applications and innovative solutions.

In response to RQ4, we found that VHCN plays a critical role in improving operational efficiency by enabling rapid data transfer. This makes VHCN a crucial factor for revenue generation through high-capacity applications and innovative digital solutions, particularly in sectors and regions with higher levels of regulation.

Based on these results, we recommend prioritizing the expansion of 5G coverage and the development of VHCN infrastructure. Governments should allocate adequate resources to improve coverage and develop high-capacity networks to support SME growth. Governments should focus on targeted investments in underserved regions and collaborate with private-sector players to enhance 5G coverage and develop VHCN infrastructure, ensuring that SMEs can access these technologies without significant barriers.

Additionally, spectrum allocation policies should balance current and future needs of emerging technologies. Spectrum allocation policies should be flexible, providing sufficient bandwidth for both current technologies and future demands. Policymakers should prioritize efficient spectrum use to support the scalability of 5G and VHCN infrastructures, ensuring long-term economic benefits.

To maximize the benefits of 5G technology and VHCN, SMEs should invest in expanding digital infrastructure and focus on utilizing high-capacity applications. Strategic investments in VHCN infrastructure can significantly boost revenue growth, while optimizing 5G coverage can enhance service access and customer engagement. SMEs should strategically invest in both 5G coverage and VHCN to enhance operational efficiency and service delivery. They should also focus on integrating high-capacity applications to drive revenue growth. Furthermore, SMEs can explore partnerships with technology providers to ease the costs of initial investment in digital infrastructure. Despite offering valuable insights into the relationship between 5G technology deployment and e-turnover in SMEs across the European Union, this study has several limitations that should be acknowledged. First, the research relies on data from a relatively short time frame (2020–2023), which captures only the early stages of

5G implementation. As such, the long-term effects of 5G and VHCN infrastructure on SMEs remain unexplored. Additionally, the use of aggregated national-level data may mask important regional or sectoral differences in digital adoption, infrastructure development, and SME behavior, which could limit the generalizability of the findings. Furthermore, the exclusion of Luxembourg due to data confidentiality may have slightly reduced the completeness of the dataset, particularly when analyzing small economies with unique digital dynamics.

Another limitation concerns the methodological constraints associated with the use of panel data and the applied econometric techniques. While the Elastic Net model improves robustness in the presence of multicollinearity, it may still underperform in capturing complex nonlinear relationships or unobserved heterogeneity across countries. The relatively low R-squared values suggest that important explanatory variables may be missing from the model, such as SME size, sector-specific technological readiness, or regulatory complexity at the national level. Future research should aim to include more granular firm-level data and incorporate qualitative dimensions such as managerial attitudes toward technology or firm-level innovation practices to build a more comprehensive understanding of the impact of 5G on SME performance. These findings also suggest new research directions. Future research should explore the long-term effects of 5G and VHCN on SMEs, considering differences across industrial sectors, geographical regions, and varying regulatory environments. This will help determine the most effective implementation strategies for different contexts. Furthermore, exploring the nuanced role of ICT specialists in the context of high-connectivity networks could provide deeper insights into balancing investments in technology and human resources. Investigating the evolving role of ICT specialists in high-connectivity environments, particularly regarding the integration of 5G and VHCN technologies, could offer valuable insights into optimizing the interplay between human resources and digital infrastructure.

In conclusion, while 5G technology and VHCN offer transformative potential for SMEs, a balanced approach that considers coverage, spectrum, and infrastructure investments is essential for optimizing e-turnover and maintaining competitive advantages in the digital market. Policymakers should prioritize flexible regulatory frameworks and strategic investments in digital infrastructure to maximize the benefits of these technologies, while SMEs should adopt a strategic approach to balance technological investments with human resource management.

Author contributions

Conceptualization, G. B. and N. M. D.; methodology, N. M. D.; software, N. M. D.; validation, S. V. and G. B.; formal analysis, S. P.; investigation, G. B.; resources, N. M. D.; data curation, S. P.; writing – original draft preparation, D. C.; writing – review and editing, D. C.; visualization, D. C.; supervision, G. B.; project administration, N. M. D. All authors have read and agreed to the published version of the manuscript.

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