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Application of Explainable Artificial Intelligence technique to model the predictors of South African SMMEs resilient performance during the Covid-19 pandemic

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ABSTRACT

Various studies have been carried out to establish the key drivers impacting small enterprise sustainable performance in developing countries. Despite many policy-oriented studies to uncover the factors influencing SME resilience in emerging markets, these firms continue to register high failure rate, which has been further exacerbated by the Covid-19 pandemic. Guided by a history of linear- and log-linear econometric model estimation that ignores potential network effects, our study extends the literature by implicating SMME resilience as a production network. Utilising data from both incubated and non-incubated SMMEs, marking a departure from traditional linear econometric models, radial basis function artificial neural network algorithm was invoked to establish the drivers of SMME resilience during Covid-19 regime. The study extends the literature by implicating eXplainable Artificial Intelligence (XAI) methods. Specifically, optimal SHapley Additive Explanations values (SHAP values) were computed to enhance the prediction output from the machine learning algorithm. The XAI analytics provide insightful findings on the key drivers which influenced the resilience of SMMEs during the Covid-19 pandemic. The importance of innovation through introduction of new products, company age and higher number of marketing mediums is confirmed however total assets, analytics, educational level and number of workers surfaced as a threat to these enterprises' sustainable performance. The study recommends that both the government and SMEs should leverage XAI to identify their heterogeneous attributes and inform intelligent decision-making which necessities their resilient performance.

Introduction

Research has shown that small business failure remains one of the perennial challenges faced by various countries especially developing ones (Msimango-Galawe and Hlatshwayo 2021). This was worsened by Covid-19 pandemic which did not only spur a heath crisis but a complex socio-economic challenge across the global community. For developing countries, the pandemic presented a deep-rooted quandary as not only small businesses but also some established entities tumbled, creating a complex challenge with entrenched knock-on effects onto other societal challenges like unemployment, poverty and inequality (DeTombe 2015). Since its outbreak in 2019, the Covid-19 pandemic has brought massive negative effects on various countries with a disastrous impact on human health. The lockdown restrictions such as social distancing and quarantines, imposed in many countries to limit the spread of

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the virus among people, adversely impacted the system of supply chains and slowed many countries' economic activities (Adam and Alarifi 2021).

Various studies agree that despite its impact on large enterprises, small businesses which are key drivers of local economic development, were severely affected by the pandemic. As argued by (Chen 2022), small firms which form a critical part of the economy were in general the hardest hit by the COVID-19 crisis. Under multiple pressures from tight logistics, stagnant production, declining demand, and declining cash-flows caused by the pandemic, operational activities, especially for SMEs have been significantly affected due to weaker risk management and thus poor resilient practices (Sun 2022). In South Africa, SMEs received substantial support aimed at assisting them achieve long term survival (Zhou 2022), especially during the Covid-19 outbreak. However, despite these interventions, these businesses failed en-masse, with only those with resilient practices surviving the harsh terrain.

This reality provoked another interesting question regarding the efficacy of various empirical studies which were used to inform policy during the outbreak as they informed interventions which had minimal impact in driving small firms' resilient performance. The non-linearity nature of the pandemic and the events which it triggered required techniques which can deal with such type of data. As such this study harnessed machine learning techniques, specifically Artificial Neural Networks (ANN) to model the resilient drivers of SMEs which survived the pandemic in South Africa. Due to their opaqueness, the study employed explainable AI (XAI) technique to identify feature importance and inform practical policy inferences not easily deductible from both traditional and machine learning predictive models' output.

Literature Review

This section discuss literature relating to SMMEs resilient performance with a major focus on the impact of Covid-19 on this sector.

SMMEs and the Covid-19 pandemic

The outbreak of the Covid-19 pandemic triggered panic across the globe, and this was marked by fear of death not only by humans but also businesses across different cycles (Adam 2021). While numerous policies were introduced by governments around the globe to combat the virus and to stimulate the economy, small firms were the major causalities, for example in South Africa, in 2020 it was predicted that around 55 000 SMEs will not survive the crisis thus shedding hundreds of thousands of jobs (GEN 22 On Sloane 2022). Some studies have noted that both internal and external initiatives that were adopted to drive resilient firm performance, especially on SMEs in developing economies, remain understudied (Chen 2022). This provides the current study with an entrenched impetus to identify and model the key predictors of SME performance during the pandemic.

The main agenda for this is two-fold, firstly the study findings will provide an adaptable template for both governments and businesses on how to deal with such kinds of crises. Secondly, this study propagates the adoption and use machine learning techniques which despite their flexibility and cutting-edge predictive accuracy have been hardly utilized in small business research thereby incentivizing future studies to utilize the same. In the next sections of this literature review, the study reviews the influence of methods such as social distancing and quarantines on SMEs during the pandemic, the types and impact of external support and the internal strategies that were adopted by SMEs to pivot and survive the pandemic. The production theoretic framework and the emergence of artificial intelligence techniques in small business research are also explored.

Importance of SMMEs in developing countries

Small businesses are becoming an increasingly influential factor towards economic growth across the world (Conradie & Lamprecht, 2018) and this is also noted in South Africa (Chimucheka, Dodd & Chinyamurindi, 2019). There is recognition that small businesses especially in emerging economies like South Africa have the potential to become leading global companies if developed and supported (Meyer & Peng, 2016; Pereira & Malik, 2017). Hence, there is need to focus on developing capabilities internally that will enhance not only their performance but also quests for sustainability. One way which this can be done is through developing efforts towards strategic resilience of these entities, and scholars argue that this can only be done when existing business functions are in sync as well.

Most developing countries have focused on Small and Medium Enterprises (SMEs) as a strong driver of economic growth and development (Gbandi & Amissah, 2014). However, sustainability remains integral due to the high failure rate in the SME sector, as close to half of SME startups fail within five years, especially in developing countries (Dalberg, 2011; Nikolić et al., 2019). Thus, it can be deduced that successful and sustainable SMEs require the right combination of essential contextual elements. Alraja, Imran, Khasab and Shah (2022) posit that sustainability of business operations have been severely affected by COVID-19 pandemic, with most entities taking this opportunity to reinvent themselves. However, this is not the case with SMEs which appear be hard-hit by the phenomenon and have become more vulnerable to this global crisis. With sustainability becoming an integral factor in enterprise operations in the current business environment, adopting operations to achieve long-term survival becomes an imperative (Mustafa & Abbas, 2021). This situation demands SMEs to develop coping tendencies which foster resilience.

SMME resilience

Organizational resilience, was a term coined by Meyer (1982), and describes the success of a business entity in anticipating, treatment and recovering from financial duress by means of their abilities, actions and behaviors (Iborra , Safon and Dolz, 2020; Buyl et al., 2017). Resilience therefore refers to the capacity which enables an organisation to cope effectively with unforeseen events, bounce back from crises, and even foster future success (Duchek, 2019). Several factors have influenced the interest of researchers and academics in organisational resilience. Linnenluecke, (2017) attributes the rising of natural disasters, conflicts, and political crisis states, institutional failures, economic recessions, and human errors as factors that have motivated researchers to examine the relevance of resilience. SMEs have faced a series of crises which have tested their resilience levels. The global financial crisis (GFC) (2008–2012) was a threatening and stressful external threat to business survival which caused financial and economic distress and reduced both the demand and financial availability of firms in an unexpected way (McGuinness et al., 2018). During this crisis, some SMEs demonstrated resilience and were able to survive and recover, others disappeared (up to 9% per year in Europe), while a good number did not recover. (EUROSTAT, 2018). The Covid- 19 pandemic brought yet another unrelenting stress factor for SMEs which required them to be agile and pivot or risk the imminent threat of failure and in the worst-case extinction.

Researchers have attempted to provide solutions for resilience of SMEs but there seems to be no consensus on their suggestions. Some advocate for organisational ambidexterity (Snehvrat et al. ,2018; Wilden et al. ,2018), while some suggest strategic consistency (Moss et al., 2014). Organisational ambidexterity has been defined as the ability to simultaneously undertake exploitation and exploration [O'Reilly and Tushman. 2008). This is an organisational capability which is difficult to achieve and may take a long time to develop in SMEs because exploration and exploitation compete for the same scarce resources. Thus SMEs' ambidexterity is rooted in the capabilities developed by the firm to sense, seize, and reconfigure resources in order to adapt to changes in the environment (Teece, 2007). Also in his recent submission, Teece (2020) states asserts that dynamic capabilities are essential for resilience because through sensing, firms continuously monitor their environment, prioritize focus areas, and identify new opportunities.

Moreover, seizing activities allows firms to act on opportunities and threats in a timely and effective manner. Through transforming or re-configuring, firms restructure themselves in order to create new products, services, markets or business models while others are abandoned. To this, Lengnick-Hall et al. (2011) affirm that resilience in business organizations looks beyond restoration as it describes the development of new capabilities to deal with disruptions and changing circumstances in the business environment. Thus, the capability to identify, recognize and seize business opportunities (Manfield & Newey, 2017) within challenging business environment is a desirable attribute in defining resilience of SMEs. The authors also posit that a turbulent business environment not only hold threats but also contain opportunities that need to be exploited (Hamel & Valikangas, 2003) to maintain firm continuity and success.

Iborra et al (2020) postulate that a combination of organizational ambidexterity and strategic consistency facilitate the resilience of SMEs. Ambidextrous SMEs are able to discern and appreciate the signals of change, disregard past explanations and challenge the status quo (O'Reilly and Tushman, 2008); and are also competent with regards sensing relevant opportunities and threats, particularly in rapidly shifting markets, to achieve resilience. Furthermore, ambidextrous SMEs can provide alternatives and make informed and quick decisions by seizing opportunities and being committed to innovation and experimentation that fosters resilience. Iborra et al (2020) also affirm that ambidexterity should be accompanied by strategic consistency which provides the essential stability to face adverse situations.

The study further argues that strategic consistency provides a sense of perseverance needed to achieve the stability that is required for resilience. Thus, the higher the "ambidexterity consistency", of SMEs, the more resilient they are. Hence the argument for business resilience is derived from a notion that SMEs need to be able to resist, respond and recover, when the environment surrounding their organisations alters. It can be argued that Covid-19 pandemic presented SMEs with unprecedented business challenges. However, these challenges came with a combination of both negative and positive facets that could have been changed into valuable opportunities for these enterprises if they had the required resilience. The greatest lesson for these entities as well as governments across the world is that fostering the sustainability of SMEs is key to economic growth and development.

The role of incubation support in driving SME resilience

The imperative to prevent the total demise of the SME sector due to unpredictable changes in the business environment is at the fore of academic and economic debates, as its raises concerns of sustainability of this important sector of the economy. Various measures have been practiced across the globe in a bid to avoid the demise of SMEs. The first form is financial assistance for these distressed entities. This comes in various forms such as postponing payments for utilities namely electricity, natural gas, water, phone and internet services, as well as postponement of rent payments for the building representing the registered office, and secondary offices of SMEs (Antonesscu, 2020).

The business incubation system is an important tool to implement and facilitate technological innovation and entrepreneurship development. These incubation systems may be public, or private or public-private partnership induced. An incubator is defined as an organization whose focus is to accelerate the growth and success of entrepreneurship, using a combination of resources and services to support business that can include a physical space, capital, coaching, common services and external networks (Morant & Soriano 2016; Franco, Haase and Rodini, 2020). The importance of business incubators is not only for the promotion of

entrepreneurship, but for development and technological innovation which fosters resilience of SMEs. (Mahmod et al, 2015). Business incubators are platforms where new ventures can be technically and financially supported. Hewit et al (2020) affirm that the role of incubators is rendering support services to start-ups, to overcome typical business challenges such as financial knowledge, rental space, human resources, access to markets and skills development. In essence, this takes the essence of mentoring with financial backing with the aim of improving the business environment and creating sustainable SMEs.

The business incubator model is based on research by Campell, Kendrick and Samuelson (1985), who emphasized four value-adds that a business incubator must possess. (Heit et al 2020). These are firstly, the ability to diagnose business needs; secondly the presence of a selection and monitoring of the services provided to these firms; thirdly investment of capital and the access to the working; and lastly a provision of a network. Thus, an effective business incubation system renders an important role in the nourishment of local, national, and regional economies by producing employment opportunities & development of SMEs.

Research & Methodology

Production Theoretic Framework

As has already been noted, the success of a small business depends on several factors, one of which is its production process. The production process refers to the transformation of inputs, such as labor, capital, and raw materials, into outputs, such as goods or services (Buyinza 2011; Bhatt 2014). To optimize the production process, it is important to understand the relationship between inputs and outputs, which can be described by a production function (Kajiji and Dash 2012). A production function is a mathematical relationship between inputs and outputs that reflects the technology of production (Kajiji and Dash 2013; Bhatt 2014). It can help small business owners either incubated or not to identify the optimal combination of inputs to maximize output and efficiency. Within the context of small business resilience, the production theoretic function lenses were adopted to model key drivers which sustained these enterprises' performance during the Covid-19 pandemic. The framework provides clarity regarding the strategies that resilient SMEs adopted to optimize input combinations and myriad input relationships to alter the output scale (Zhou, Dash and Kajiji 2021). Extant literature elaborates on the estimation models based on the Cobb-Douglas double log functional form. To achieve our main objective which was centered on modelling the resilience of SMEs in South Africa the study followed Kajiji and Dash (2013), to the map the functional relationship of SMEs output to their factor inputs during Covid-19, as per below:

$$f(x) = A\prod_{i=1}^{p} x_i^{\beta_i}, \beta_i > 0 \quad (1)$$

Based on Equation (1), A is an efficiency parameter, p is the total number of factors, $x_1, \dots, x_p$, are the features' quantities, and β_i feature I elasticity parameter.

The double-log function can be estimated as a linear relationship by taking a log transformation of the function,

$$\ln(y) = lnA + \sum_{i=1}^{p} \beta_i \ln(x_i), \beta_i > 0 \quad (2)$$

where the βi represent estimated model weights. Equation (2) requires all factor inputs to be strictly greater than zero. To ensure that this requirement is satisfied, the transformation of a modified zero-element argument is in the main achieved by replacing the observations which are less than zero with 1.0 so that $\ln(x) = 0$ (Moss 2000; Kajiji and Dash 2012)

Artificial Neural Network

Artificial Neural Networks (ANNs) provides a flexible and effective approach to non-linear statistical modeling. For this study, the enhanced Radial Basis Function Artificial Neural Network (K4-RANN) was harnessed to operationalize the production theoretic framework. The motivations for the adoption of this technique across various disciplines lies in its versatility in dealing with complex data structures by effectively addressing issues like outliers, multi-collinearity, and non-linearities (Merkel, Povinelli and Brown 2018; Zhou and Gumbo, 2021). Also compared to other techniques, ANNs are efficient in handling smaller datasets without compromising model predictive accuracy (Croda, Romero and Morales, 2019). As per Figure 3, ANNs employ a connectionist method to adapt computation to changes in the structure of the data for information processing.

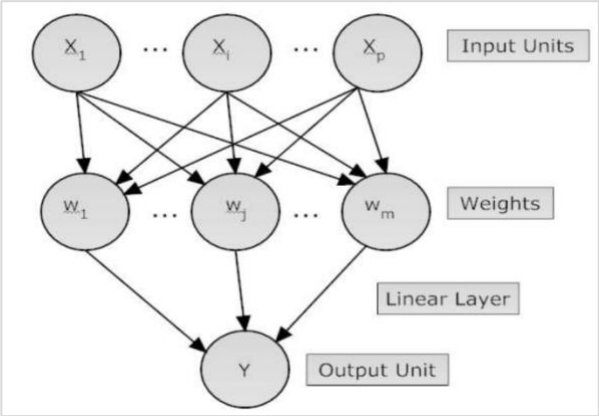

Figure 1: K4-RANN Flow Chart indicating the input, hidden, and the output layer; *Source:* Kajiji and Dash 2012.

As per Figure 1, each node in the hidden layer uses a radial basis function, $\sigma(r)$, as its nonlinear activation function. The learning function, which is supervised in this case, is stated as, $y = f(x)$ where y, the output vector, is a function of x, which is an input matrix, and the function can be stated as per Equation (3):

$$f(x) = \sum_{j=1}^{m} w_j h_j(x) \tag{3}$$

Where m is the number of basis functions, w is the vector of hidden units, w is the vector weight and $h(x)$ is the multiquadric activation function of the form, $\sqrt{1 + (\omega x)^2}$ (with ω being the shape parameter). As per Kajiji (2001) by adding a Tikhonov (1977) regularization parameter to the sum of squared errors (SSE), the augmented K4-RANN becomes a multiple objective algorithm. In essence, by including the regularisation parameter k, the K4-RANN algorithm minimises a cost function (C), defined as a modified SSE. In this case, as a weight decay parameter vector, k penalises mappings which fail to fit the data well and resultantly the algorithm mitigates any overfitting problems that may emanate from an ill-posed problem as per Equation (4):

$$C = \frac{argmin}{\lambda} \left(\sum_{t=1}^{T} \left(\hat{y}_t - f(x_t) \right)^2 + \sum_{j=1}^{m} \left(\lambda_j w_j^2 \right) \right) \tag{4}$$

where $f(x_t)$ is the model's prediction at w, and λ is the Tikhonov regularisation parameter that controls the compromise between the degree of smoothness of the solution and its closeness to the actual data. The $argmin$ function indicates the network solves for the λ that will minimise the deviations (error). The K4-RANN results in optimal weights that minimise error (SSE) while optimizing the accuracy of the predicted fit, owing to its ability to attack the twin evils the "curse" of dimensionality and inflated residual sum of squares (RSS) that tend to deter efficient ANN modeling.

Explainable Artificial Intelligence (XAI)

The use of AI in small businesses is not without its challenges. One of the main challenges is the lack of transparency and interpretability in AI models, which makes it difficult for companies to understand how the models arrived at their predictions. This is where explainable artificial intelligence (XAI) comes into play. XAI refers to the development of AI models that can provide clear and interpretable explanations of their predictions. This is important for small businesses as it allows them to understand how the models are making decisions and to identify any potential biases or limitations. In addition, XAI can help SME owners to make informed decisions by providing them with insights into the factors that drive their resilient business performance during the pandemic. To achieve this, SHAP (Shapley Additive exPlanations) are employed to interpret K4-RANN model output.

As such SHAP is harnessed to interpret the output of the K4-RANN model. SHAP is based on game theory and local explanations. SHAP provides a means to estimate the contribution of each feature to SME resilient performance. Consider a data set with P features and these are represented by a set $X = \{X^{(1)}, \ldots, X^{(p)}\}$. Assume an instance $x \in P$ then a model of v forecasts the target as $v(x)$. The contribution of each feature on $v(x)$, the model output is allocated based on their marginal contribution. To help allocate the contribution of each feature (based on various parameterizations the shapely value of $x^{(i)}$ can be derived as the average contribution of $x^{(i)}$ across all possible coalitions s, where s does not include i, $(S \subseteq D \backslash \{i\})$, the shapley values are computed by grouping the marginal conditional contributions in terms of coalitions (S) as per equation (5) below:

$$\overbrace{\phi_i(v)}^{i'sSHAP\ Value} = \underbrace{\sum_{S\subseteq D\setminus\{I\}} \frac{|S|!(|P|-|S|-1)!}{|P|!}}_{S's\ weight} \overbrace{(v(S\cup\{i\}) - v(S))}^{i's\ marginal\ Contribution} \quad (5)$$

SHAP is also used to study interaction effects, which occurs when the influence of one feature on the output depends on another feature. The interaction effects estimation requires an accurate attribution of the individual effect of the involved features. Shapley values are useful for estimating interaction effects for $i \neq j$ is computed as per Equation (6):

$$\phi_{i,j} = \sum_{S\subseteq(X\setminus\{i,j\})} \frac{||S||!\,(P-||S||-2)!}{2(N-1)!}\delta_{i,j}[S] \quad (6)$$

where $\delta_{i,j}[S] = v(S\cup\{i,j\} - v(S\cup\{i\}) - v(S\cup\{j\}) + v(S)$.

Utilizing the above XAI technique this paper proceeds to discuss the data that was used in to model SMME resilience during Covid-19.

Data

The panel data set covering all internal factors was accessed from a survey of SMEs across South Africa. The data set covered all the eight provinces from 604 participants for three years between 2019, 2020 and 2021, inclusive for a total observation of T= 1812. The current research employed an iterative process to identify and account for factor inputs as features of the neural network approach to model SME resilient performance. Multiple models will be executed and least Akaike Information Criterion (AIC) together with the mean squared error (MSE) scores will be used to identify the best model.

SME resilient performance

The objective of the model is to effectively model SME resilience during the pandemic, which is represented as the target variable referred to as SME performance. Despite the various and conflicting definitions of SME performance found in existing literature (Richard et al., 2009; Zhou 2021), we adopt the definition provided by Zhou and Gumbo (2021) and define performance as annual sales growth (over the three-year period, which was predominantly punctuated by a series of lockdowns and other trading restrictions). Annual sales ($Res\_perform$) were measured in rand value. For robustness purposes, total workers were also used to proxy resilient performance. The latter is also important as various governments took initiatives to support firms to sustain their pre-pandemic employment levels.

Independent feature definitions

The production of resilient SME performance is achieved through the efficient use of inputs, which are data features that are linked to the target feature of the study. The mapping determinants, of SME performance in this study include total assets, the gender of the company owner, the SME location (provincial region), the age of the company owner, the SME age, the number of total workers, incubation status, number of new products introduced over the study period, number of marketing mediums, registration type, and SME owner's qualifications, the age of the SME.

Total assets ($Assets$) were measured in rand value, the gender ($gender$) of the SME owner was indicated by 1 for male and 0 for female. Registration type (Reg_type) reflects whether the SMME is registered as a proprietary liability under the Companies Act, with 1 indicating a Pty registration type and 0 otherwise. Number of workers ($Workers$) captured the sum of both temporary and permanent workers. Owner's age (Own_Age) is the difference between the owner's birth year and the study period. Number of new products ($Products$) was measured by the total of product or services that were introduced by the company over the three-year period. SME age (SME_Age) is the difference between the company's start year and the study period. Inc indicated that the SME was under incubation whilst $NonInc$ proxied non-incubation participation. Marketing medium (Mkt_medium) captures the company's number of marketing platforms. Data analytics ($data\_analytics$) was captured by 1 for SMEs which conducted analytics and 0 otherwise. One hot encoding was utilized to transform the eight provinces (Loc) and qualifications ($Education$) into quantitative features for modeling purposes. All data for the features were log-transformed, except for the categorical variables.

SME Resilient Performance Predictive Model

Utilising Equation 3, the following SME-specific K4-RANN machine learning model to predict resilient SMEs performance was specified as per below. Specifically, the resilient performance model was executed as per Equation (7) established resilient performance drivers of SMEs, during the three years up to 2021. The models enabled the study to explore the potential heterogeneity among SMEs especially between the incubated and non-incubated cohorts.

$$ln(Res\_perform) = w_1(Assets) + w_2\big(Ln(workers)\big) + w_3\left(Ln\left(owner_{age}\right)\right) + w_4(Ln\,(SME\_age)) + w_5(Products) + w_6(Education) + w_7(mkt_{medium}) + w_8(Loc) + w_9\big(reg_{type}\big) + w_{10}\big(data_{analytics}\big) + w_{11}(gender) \quad (7)$$

Following previous studies, all continuous variables were scaled (Zhou and Gumbo 2021), the total observations were split into the training and test sets. The training set contained 33% of the total data points, and the latter was defined by the remaining observations. The shape parameter was set to 1.0, and the gaussian activation function was implemented for all neurons. Generalized cross-validation (GCV) error minimization rule, was active during model estimation. The WinORS System was used for the RBFN and concomitant SHAP analytics.

Model Results

The results from the K4-RANN model to map the key features which impacted the resilient performance of South African SMEs during the Covid-19 era. This is further accompanied by explainable AI, harnessing SHAP algorithmic analysis to further cast light on the reasons behind the features to help both practitioners and policymakers make informed decisions. Firstly, a feature map as per the figure below shows the relationships between input features and the target variable, with red indicating that the feature had a negative effect, whilst grey is indicative of positive effect on resilient performance.

Table 1 below shows the model weights based on Equation (7), for both sales and total workers. Based on the model assessment metrics which aligns with our research objectives, the model employing sales as the response feature serve as the reference. The model had the least AIC and MSE, it also had the best R-squared, which shows its striking predictive ability compared to Model 2.

Table 1: K4-RANN Weights

	Model: LogSales	**Model: LogWorkers**
LogCoAge	1.3893	-0.5014
Pty Reg	0.2618	1.0840
Food_Bev	0.2608	0.3194
Accomodation	0.4184	-1.3095
Female	-0.2891	-0.9250
Grad_Plus	-1.1867	0.7595
LogAge	-0.0960	0.3230
Incubated	0.3583	0.1908
LogAssets	-0.6198	-0.8704
Products	1.1921	-0.1978
Analytics	-1.7743	0.5550
Mkt_med	0.5195	-0.0209
LogWork	-0.5659	-
LogSales	-	0.5833
AIC	-386.39	-343.50
MSE	0.0267	0.0306
R^2	98.32%	77.02%

Source: Authors' Analysis

Based on model results, shows that firm age with an elasticity of 1.39, had a positive effect on the resilient performance of SMMEs. This feature compared to others had the highest positive impact on South African SMMEs' performance compared to other drivers. The finding implies that indeed, "with age comes wisdom", as older SMMEs were more resilient during the pandemic compared to their younger counterparts. However, this was not the case when number of workers proxied resilience, company age had a negative impact on the same. Interestingly formal (Pty) registration which had a weighting of 0.262, positively impacted the resilient performance of SMMEs for both models, this is contrary to previous studies (Zhou and Gumbo 2021, Zhou et al 2021) which found that this registration type negatively impacted performance. The reason for positive impact during the pandemic could be due to the fact that the South African government introduced various initiatives to assist formal registered SMMEs. These initiatives included, the Covid-19 Loan Guarantee Scheme, Debt Relief Finance Scheme, Business Growth/ Resilience Facility and the Tourism Relief Fund.

The results also indicated that for SMMEs operating in the Food and Beverage sub sectors performed better for both models, this contrasts with the Accommodation subsector, which was only positive for model 1 (sales) and negative for model 2 (workers). This was expected as many companies retrenched their staff as a means to cope with the pandemic. In both models, especially model 2, the female owned enterprises registered negative elasticities compared to their male owned counterparts, which is reflective of their inability to remain resilient during crises, in particular the Covid-19 pandemic. Surprisingly, in terms of sales performance, SMMEs which conducted analytics, owned by individuals with a post graduate qualification registered negative elasticities, thus implying

that higher levels of education were not that much important to navigate the uncertainty which was posed by the pandemic. This was however not the case for model 2 (workers), which connotes that educational level enhanced the SMMEs' ability to sustain higher levels of workers even in the peak of the pandemic. This finding was also related to the entrepreneur's age, which adversely impacted sales but positively affected firm employment. The study also revealed that being under the incubation support programme during the pandemic, enhanced SMMEs' resilience both in terms of sales and workforce.

Key to note was that SMMEs with high higher levels of assets were more susceptible to failure than those who were essentially "asset light". This finding was expected as many firms could not utilize their assets due to lockdown resections, however some of these assets still required servicing in terms of insurance and maintenance even though they were not generating any revenue at all. Interesting to note also was that companies which introduced new products or services during the pandemic registered resilient performance. The finding indicates that for every 10% increase in new product, sales grew by 119%. Another finding which was surprising is that of analytics, with those firms which conducted the same being less resilient (in terms of sales) compared to those which did not, however the relationship was reversed for model 2. On the other hand, as expected, utilization of increased number of marketing mediums improved the resilience of SMMEs in terms of sales, which however was not the case in the case of workers. Finally, number of workers negatively impacted SMMEs resilience prospects, whilst sales enhanced their likelihood to retain staff.

Explainable AI output

To further provide insights on the impact of various features on the performance of SMMEs SHAP values were used as they have been found to be both consistent and accurate. SHAP values offer great benefits for both practitioners and policy makers by providing two main advantages, firstly being that of global interpretability, which reveals the contribution of each feature to the target variable, and secondly, local interpretability, which indicates the features' contribution to each observation. The figures below show the SHAP values for row 14, which relates to a female owned incubated SMME operating in the accommodation sector.

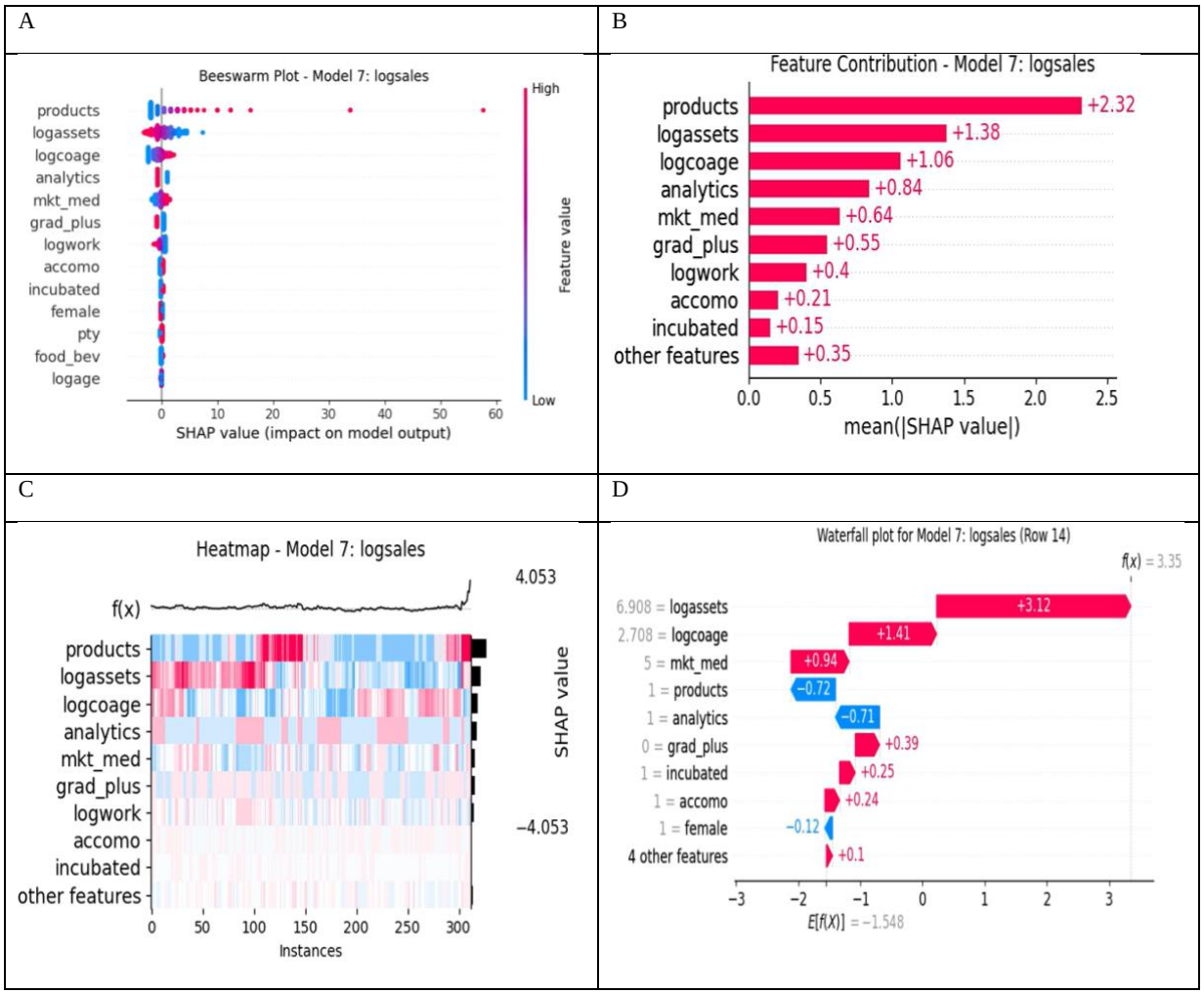

Figure 2: XAI analytics graphs, *Source:* Authors

Figure 2A shows the Beeswarm Plot demonstrates the global importance of all the model features in SMME resilient performance prediction as per the SHAP values of every individual in the dataset. In line with figure 2B, Beeswarn plot shows that number of new products, total assets, company age, analytics, number of marketing mediums and post graduate qualification are the top 5 ranked features which impacted SMME resilient performance. The figure shows that low vales of new products, firm age and marketing

mediums values (blue) reduce the predicted firm performance and conversely high values for trio (red) increased the performance prediction for SMMEs. As has been confirmed by the K4-RANN output, the Beeswarn plot shows that higher levels of assets dragged SMME resilience, with lower asset levels positively impacting performance. The plot also further indicated that conducting analytics slowed resilience of SMMEs across the country.

The global heatmap (figure 2C) shows the importance of input features (left side), with the black horizontal bars (right side) ranking the same based on their overall weight. The heatmap shows that new products were key drivers of SMME resilient performance. Essentially the heatmap implies that low f(x) values are associated with low number of products, and f(x) improves as new offerings increased. Finally, a Waterfall Plot (figure 2D) is produced for an SMME in row 14, below the x-axis, the SMME resilient performance across all observations is highlighted as E[f(x)] = 1.548 and the prediction for the selected firm is f(x) = 3.34 (top right corner of the chart). For this SMME, in comparison to the average predicted performance, total assets increased the predicted performance by 3.12. Depicting a similar positive effect, on predicted performance are firm age and number of marketing mediums. Conversely, number of new products and conducting analytics negatively affected predicted performance albeit. This shows the uniqueness of the company (in row 14) from the general global picture which indicated that number of new products positively influenced resilient performance and assets deleteriously influenced performance, which is opposite for this particular SMME.

Discussion and Policy implications

The main objective of this study was to implicate nonparametric XAI technique in modelling SMME resilient performance during the Covid-19 pandemic. This is inspired by previous studies which have shown that application of machine learning techniques produces accurate and reliable results compared to the traditional parametric techniques (Zhou and Gumbo 2021; Dash and Kajiji 2013). The findings from the study indicated that continuous innovation (captured) by new products is a key driver of company resilience especially during crises. This finding provides some important insights for SMME owners, requiring that they continue to explore new products that can be introduced to ensure sustainable growth. Government entities like Technology Innovation Agency (TIA), Small Enterprise Development Agency (SEDA) should facilitate access to technical support and funding to assist SMME owners' experiment with by exploring the introduction of new innovative products.

The study findings challenge the traditional business operational model of amassing assets, the negative effects of assets imply an asset light approach to resilient business performance. These results showed that experience (as proxied by company age) is crucial in surviving troubled times like the pandemic. This shows the need for structured interventions like start up incubators, accelerator programmes and techno parks to provide SMEs with support during their early years. Concernedly though is that despite widespread confirmation on the importance of conducting analytics (Farahani, Momeni and Amiri 2016; Obaid *et al.* 2018) and higher education levels (Garatsa and Dlamini 2021) and number of workers (Zhou and Gumbo 2021a) indicate that these features were not important in influencing resilient performance.

These findings require practitioners to utilize automated analytics platforms which can auto harvest and analyse internal and external data accurately and thus inform intelligent decision making that can ensure resilience during times of crises. To address the negative influence of workers on resilient performance, practitioners should only utilize skilled workforce by leveraging analytics tools that can track workers' productivity. There is need for government to devise training sessions in order to compliment entrepreneurs' educational backgrounds which in the South African context seem to be adversely impacting performance. More importantly, for the government, there is need to review the educational system and embed entrepreneurial mindset to ensure that this feature has the impact suggested by Herrington and Coduras (2019).

Finally, the importance of the XAI technique is noted, the analysis enables both business owners and other SME ecosystems players to appreciate the entrenched heterogeneity of small businesses and thus the need to depart from a "one-size fits all" approach. Whilst assets and marketing mediums were generally found to be inversely related with resilient performance for the sector in general, a specific look at an individual company (figure 2D) shows that this particular SME actually benefited from its asset base and high number of marketing mediums. This finding indicates that SME owners should not rely on generic models, especially AI algorithms which are by nature "black box" but rather utilize XAI techniques which allow an individual company to understand how the model output relates to its specific operations and thus customize its decision making.

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