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An Empirical Model to Measure Research and Development's Impact on SMEs' Manufacturing Production Growth

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Abstract:

This study intends to construct and validate an empirical model to measure the impact of research and development (R&D) contribution on production growth within Small and Medium-sized Enterprises (SMEs) in the manufacturing sector. Though its confidence is well known, the specific role that good R&D plays in company growth and productivity has not been clearly defined. To fill this gap, this study suggests a novel method for identifying and quantifying the impact of R&D on the production of SMEs. Short-term production is used to design and rebuild a mathematical model based on the production growth theory findings from the literature review. By adding R&D as an input, the rebuilt model is improved. To test the model's effectiveness, we collected input-output data from 15 machinery manufacturing SMEs over a four-year period. Our findings demonstrate a statistically confidence contribution of R&D to production growth in 11out of 15 machinery manufacturing SMEs, with a 95% confidence levels significant at (p-value <0.05). This effect size serves as our best estimate of the impact's size within the broader population of machinery manufacturing SMEs. The robustness of these results highlights the model's value in assessing the contribution of R&D to production growth, particularly in the machinery manufacturing sector. The study's novelty lies in its introduction of a new quantitative framework to the manufacturing domain, potentially advancing our understanding of the role of R&D in firm performance. By providing a method to measure this previously intangible factor, our model offers both theoretical insights and practical implications for manufacturing SMEs seeking to optimize their R&D strategies for enhanced growth. This research contributes to bridging the gap between R&D theory and quantifiable business outcomes, offering a valuable tool for both academics and practitioners in the field of manufacturing development.

Keywords: Research and Development, Manufacturing SMEs, Production Growth, Empirical Modelling, Quantitative Analysis, Performance Measurement, Innovation Management.

I. Introduction And Background

The goal of this study is to develop a new model to evaluate the research and development (R&D) contribution to production growth within Small and Medium-sized Enterprises (SMEs) in the manufacturing sector. The established model is tested and enhanced using production data as inputs to assess the degree of confidence in the contribution of R&D to production growth. Effective use of inputs is necessary for the growth of machinery production. R&D for production planning, quality control, raw materials for products, capital, and skilled labor are all crucial inputs to the machinery production process. Input optimization is essential to achieving sustained production growth. In most cases, it is clear that the important stakeholders are not fully focusing on supporting production resources through the optimization of capital, skilled labor, raw materials, and R&D capabilities. R&D is a proven higher value-added input for manufacturing machinery, and it is one of the factors that determine the growth of machinery production. This contributes to the improvement of product quality and the attainment of greater productivity in production. In both developed and developing countries, the manufacturing sector accounts for roughly half of the GDP. Process machinery and the enterprises that produce it are essential in this regard. Small businesses that create machinery are frequently classified as manufacturers of components for larger enterprises that manufacture machinery. Small businesses that manufacture machinery in developing countries are significant on both a social and economic level for a variety of reasons, such as facilitating the flow of money throughout society and generating employment opportunities. Due to their widespread distribution throughout rural areas, manufacturing SMEs make up a significant portion of the workforce. It can confidently hire a certain number of technical workers in local economies [1]. As a result, manufacturing SMEs are crucial to rural economies and have a direct link to reducing poverty. SMEs are essential to economic growth in this regard. Thus, SMEs that manufacture machinery have the ability to support economic expansion [2]. However, R&D is an essential component of the machinery manufacturing process, and it is crucial to understand how it contributes to production growth. To the best of our knowledge, no model exists at this time in the published papers and books that can quantify the contribution of R&D to the production growth of SMEs in manufacturing sector. Therefore, it is crucial to develop such a model. By developing and evaluating a production growth model pertaining to labor, capital, raw materials, and R&D, this study aims to fill this gap.

*A. **Problem Statement***

The results of the production growth literature assessment show that there are no published empirical models for calculating the contribution of R&D to production growth. The inquiry regarding this disclosed fact is, "What is the form of the empirical model for assessing the significance level of R&D contribution to production growth?" This study aims to answer this question and is being conducted to address this issue.

*B. **Objectives of the Study***

This study's main goal is to assess how R&D affects the performance of SMEs that manufacture machinery by (developing a model, testing the developed model, and validating the developed model), employs the significant level in order to accomplish this study objective.

*C. **Scope of This Study***

Utilizing the production function, an empirical model has been constructed. The fitness of the created model was evaluated by using data from 15 machinery manufacturing SMEs for over a four-year period. The statistical method of significance level has been used to validate the developed model. Software from the Statistical Package of Social Sciences (SPSS) was utilized to analyze the data and determine the level of significance. In this regard, it is believed that the model is appropriate for assessing the contribution of R&D to production growth if the contribution is found within the 95% significant level.

*D. **Significance of the Study***

Creating a model to assess the impact of R&D to the growth in production within SMEs in the manufacturing sector is the innovative aspect of this study. This study would expand the manufacturing SMEs' knowledge base.

This paper is organized as follows: the introduction and background were placed in section (I). Section (II) presents a comprehensive review of relevant literature and theoretical foundations. Section (III) details the methodology and empirical model development. Section (IV) presents the results and analysis of this study. Finally, Section (V) conclusion and future directions.

II. Literature Review on Theory of Growth

The literature review reveals significant gaps in empirical research concerning manufacturing SMEs' production growth assessment. Despite numerous performance measurement models for machinery manufacturing SMEs, there is a notable absence of frameworks specifically evaluating R&D's contribution to production growth. The existing literature demonstrates disconnect between performance measurement systems and practical R&D implementation. In the following we highlight the important inputs to machinery production process.

*A. **Capital in Manufacturing SMEs and Production Growth***

Capital stands as a crucial input for manufacturing SMEs, playing a vital role in achieving business sustainability and fostering production growth. This term encompasses the financial resources utilized by manufacturing SMEs to procure machinery, infrastructure, and raw materials essential for sustaining production activities. A significant challenge faced by manufacturing SMEs lies in the restricted access to formal financial systems and business capital [3]. Broadly speaking, manufacturing SMEs rely on two primary sources of funding: equity and debt. Equity means internal funds such as owners' savings, retained profits, contributions from partners, and private investments [4]. To facilitate production operations, business proprietors carefully manage funds from suitable sources in adherence to business norms, often resorting to debt financing. However, existing literature hypothesizes a positive correlation between funding magnitude and the growth of manufacturing SMEs, with larger fund sizes being linked to accelerated business expansion, as noted by [5]. They also advocate for SMEs to have easy access to both formal and informal financial institutions to secure the necessary funds for sustaining their business operations. A lack of adequate financial inputs may impede business growth, underscoring the critical role of capital in driving the success and expansion of manufacturing SMEs [6].

*B. **Labor Skills and Production Output Growth***

The skills and educational levels of the labor force stand out as pivotal factors for manufacturing SMEs during phases of production growth. The Cobb-Douglas production function (1928) briefly illustrates the indispensable link between labor and production, emphasizing that without labor, there can be no production [7]. Research by [8] reveals that manufacturing SMEs in Thailand often grapple with significant technical inefficiencies. These enterprises find themselves ensnared in a situation where production heavily relies on labor inputs. Particularly in Thailand, unskilled labor in production is typically associated with low-value-added activities. Moreover, [9] emphasize that companies must adeptly leverage skilled labor to ensure smooth production processes. They suggest that firm size can be increased by gaining better access to skilled labor and enhancing labor skills through advancements in education and training programs. The imperative of enhancing poor labor skills to tackle organizational challenges effectively highlight by [10]. Existing literature highlights a positive correlation between labor productivity and manufacturing efficiency, reinforcing the notion that skilled labor acts as a value-added input crucial for the growth of manufacturing SMEs [11].

*C. **Raw Materials and Production Growth***

Within manufacturing plants, the utilization of raw materials plays a crucial role in driving output growth, as highlighted by [12]. Their research underscores the positive correlation between waste reduction of raw materials in the production process and the economic performance of manufacturing enterprises. Maintaining a low level of raw materials inventory costs and effectively managing the economic performance within the raw material supply chain emerge as dominant factors influencing production growth. The efficiency of raw materials utilization serves as a key indicator of production expansion, emphasizing the critical importance of optimizing raw materials utilization for overall growth [13].

*D. **R&D Contribution to Production Growth***

In today's dynamic manufacturing landscape, R&D plays an important role in development sustainable growth and fostering innovation within machinery manufacturing processes. This essential element not only increases operational efficiency but also enhance technological progress [14]. The symbiotic relationship between strong R&D skills and advanced engineering knowledge is becoming increasingly important for manufacturing SMEs to succeed [15]. Three essential components make up the complex field of R&D: production improvement, technological advancement, and operational process improvement [16]. Together, these elements support production growth by strengthening three fundamental pillars: efficient use of resources, strategic quality control, and process efficiency improvement [17]. To take advantage of these benefits, production managers need to be actively involved in R&D, focusing on eliminating non-value-added tasks and addressing capacity constraints. Nonetheless, SMEs encounter significant hurdles in attracting and retaining skilled R&D professionals who can drive innovation in both products and processes [18] SMEs' capacity for long-term growth is frequently hampered by this lack of human capital [19]. Studies indicate that successful manufacturing SMEs typically allocate 3-5% of their revenue to R&D activities, highlighting the critical the importance of continuous investment in innovation [20]. The impact of R&D investments shows a clear effect on productivity. Research reveals that a 1% rise in R&D spending correlates with a 0.6-0.8% uptick in productivity gains [21]. Furthermore, SMEs with structured R&D programs exhibit survival rates 20-30% higher over five-year periods compared to those lacking such initiatives [22]. In the age of digital transformation, the integration of Industry 4.0 principles has further heightened the strategic significance of R&D in manufacturing SMEs [23]. Contemporary R&D practices have evolved to incorporate cutting-edge technologies, including data analytics, artificial intelligence, and automation, significantly augmenting both product development and process optimization capabilities [24].

E. Production Growth in Machinery Manufacturing SMEs

The growth of production in machinery manufacturing SMEs is closely linked to efficient use of resources during the manufacturing process [25]. Studies suggest that production growth is significantly impacted by the reduction of non-value-added elements in physical production components, including capital, labor, raw materials, and R&D activities [26]. Various research works have highlighted key factors contributing to firm production growth, such as knowledge management, strategic planning, workforce competencies, and asset optimization [27]. In the modern industrial landscape, maintaining a harmonious growth trajectory across all operational sides is imperative for sustainable progress [28]. Technical and economic efficiencies are key benchmarks for measuring production growth in manufacturing settings [29]. Research highlights the significant role of enhanced R&D capabilities in driving sustainable production growth, establishing a direct link between R&D investments and productivity enhancements [30]. Companies with structured R&D programs typically exhibit efficiency rates 25-35% higher than those lacking such initiatives [31]. Recent analyses of machinery manufacturing SMEs emphasize the critical importance of managerial proficiency in coordinating four essential elements: capital utilization, labor productivity, raw material optimization, and integration of R&D [32].

F. Production Growth Model

The production growth model fundamentally operates through strategic resource reallocation, shifting assets from lower to higher productivity sectors [33]. This study's production growth model includes five inputs: R&D, quality of raw materials, labor skills, capital investment, and new technologies in manufacturing machinery. The relationship between input expansion and production growth occurs within the structured architecture of production functions, establishing a clear correlation between resource utilization and production generation [34],[35]. The production function serves as a mathematical representation of the relationship between manufacturing inputs and resultant production. This framework provides a simplified model of the input to production transformation process. Two fundamental variables govern production growth dynamics: temporal progression and input utilization [36]. This relationship can be visualized as shown in Fig 1.

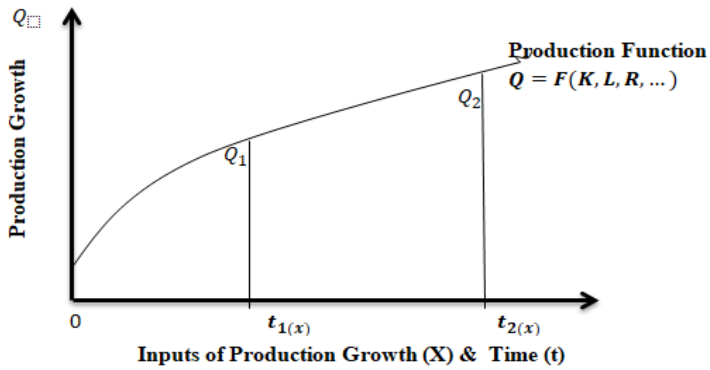

Figure 1: Production Growth According to Time, (ΔQ/Δt).

Over time, enhancements in labor efficiency and R&D capabilities contribute to production expansion (ΔQ/Δt). This relationship can be expressed mathematically as:

$$\frac{\Delta Q}{\Delta t} = \frac{Q_2 - Q_1}{t_2 - t_1} \qquad (1)$$

where Q_2–represents final production quantity; Q_1–represents initial production quantity; t_2–represents final time period; t_1–represents initial time period.

G. Components of Growth

The production growth rate illustrated in Fig 1 and presented by mathematical model in equation “(1)” represents the cumulative effect of all input contributions, including raw materials, capital, labor, and R&D.

Each input contributes distinctly to the overall growth rate ($\Delta Q/\Delta t$). This relationship can be expressed through the Component of Growth [C(g)] equation:

$$C(G) = \frac{individual\ Input\ Growth}{Total\ Production\ Grouth} = \gamma \frac{G_{in}}{G_{tq}} \quad (2)$$

Where G_{in}–represents individual input growth; γ–represents the efficiency coefficient of the individual input; G_{tq}–represents total production growth.

H. The Effect Time to Production Growth

Changes do place over time, and the contribution is not constant. Over time, a technical person or professional body tends to accumulate expertise that improves their capacity to contribute. The exponential distribution of this kind of skill development has been recognized by [37]. Thus, equation “(3)” can be used to show the growing capability of contribution:

$$A(t) = A_0 e^{\theta_t} \quad (3)$$

Where θ–Time efficiency parameter of inputs of a production process is also known as a technological parameter [38]. “Equation (3)” indicates that the contribution is time dependent.

I. Theory of Significant Level

Measuring the significant of production growth can be obtained by several ways. Typically, 0.05 significant and 95% confidence levels or 0.1 significant and 90% confidence level are employed. The P-value is frequently employed solely for assessing the degree of significance. “Equation (4)” displays the mathematical concept of significance.

$$t = \frac{(\bar{X} - x)}{\frac{\sigma}{\sqrt{n}}} \quad (4)$$

Where σ–the standard deviation; n–the sample size; $x_{(i\ldots,n)}$–the production growth of manufacture; $\bar{X}$–the average of production growth If signifiancy is measued at 95% level, then the P- value <0.05 or P-value >0.05. If appears P- value <0.05 then growth is significant. If appears P-vaule >0.05, then growth is not significant.

III. Methodology

The primary objective of this study is to create a model that can assess the impact of R&D on the production growth of machinery manufacturing SMEs. This model is constructed based on a production function and is empirically tested using data gathered from 15 machinery manufacturing SMEs over a period of four year. The significance level statistical method has been employed to validate the effectiveness of the developed model. Data analysis and the determination of significance levels were conducted using SPSS software. It is assumed that the model will be considered suitable for evaluating the contribution of R&D to production growth if this contribution is identified within the 95% significant level. This rigorous statistical approach aims to provide a robust framework for understanding the relationship between R&D efforts and the overall growth of production within machinery manufacturing SMEs.

A. Characteristics of Variables Used

a) Dependent Variable:

The production growth (G_{tq}) of machinery manufacturing SMEs is dependent variable.

b) Explanatory Variables:

1. Capital investment: Labour work on manufacturing process and Raw Materials are used.
2. R&D: The total costs that are used to developed production process of machinery manufacturing SMEs.

B. Model Building and Testing Procedure

The comprehensive process of model building and testing, which outlines the various stages and methodologies involved in developing and evaluating the model, is illustrated in detail in Fig 2, providing a visual representation that enhances the understanding of each step in this critical analytical framework.

IV. Model Building, Testing and Validation

In this section, we dig into the complex process of constructing, testing, and validating a model designed to evaluate the impact of R&D on the production growth of machinery manufacturing SMEs. This fundamental phase represents a critical juncture in our study, aimed at clarifying the relationship between R&D investments and the overall expansion of production capabilities within this sector.

A. Model Development:

The foundation of our research lies in developing a comprehensive model rooted in the principles of a production function. This model is precisely constructed to capture the detailed dynamics between R&D activities and the subsequent growth in production output observed within machinery manufacturing SMEs. By integrating key variables and parameters, we seek to create a robust framework that can effectively quantify the contribution of R&D endeavours to the overall production growth of machinery manufacturing SMEs in this sector [39]. Production model is shown in equation "(5)".

$$\mathrm{Log}(Q) = \log(A) + \alpha\log(K) + \lambda\log(R) + \beta\log(L) + \gamma\log(R\&D) \tag{5}$$

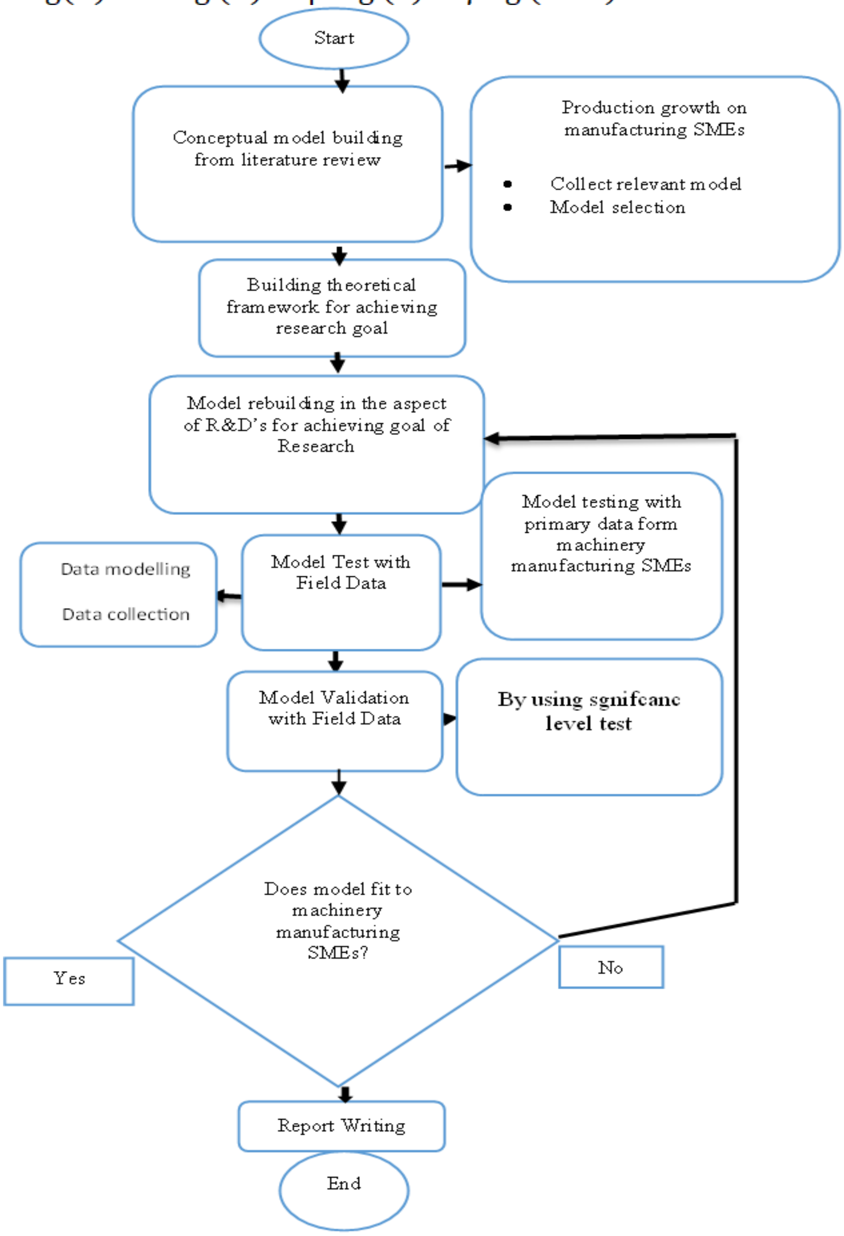

Figure 2: The Procedure Model Building and Testing

where Q(t)–average output of production over time t; A–transformation factor from inputs to production; K–capital of machinery and production operations; R–raw materials used; L–number of labours on the manufacturing process R&D needs for production growth.

The conceptual model of production growth model with above mentioned inputs is shown in Fig 3.

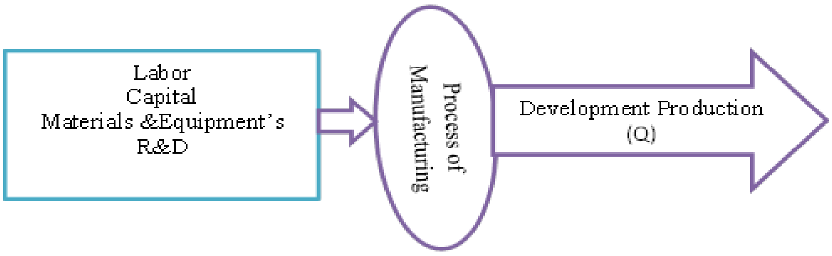

Figure 3: Conceptual Production Growth Model

Based on Fig 3, the mathematical model is to measure production growth of machinery manufacturing SMEs which can be presented by equation "(6)":

$$G(Q) = \propto_1 G(K) + \beta_1 G(L) + \lambda_1 G(R) + \gamma_1 G(R\&D) \quad (6)$$

Where G(Q)–total production growth and combined of contribution of growth rate of labor G(L), capital G(K), raw materials G(R) and research and development G(R&D); $\alpha_1, \beta_1, \lambda_1$ and γ_1 – they are factor efficiency parameters inputs of capital, labour, raw materials and R&D. This growth is due to skills growth staff of engineering, labour, and development of over time. The theory of contribution to production growth that state in equation "(2)" and equation "(6)" are allowed us to state that the R&D contribution to total of production growth is a ratio of R&D development to total production growth. This logic could be presented by equation "(7)".

$$\mathrm{C(R\&D)} = \frac{\text{R\&D development}}{\text{Total production grouth}} = \gamma \frac{G(R\&D)}{G(Q)} \quad (7)$$

The growth of production is not static and changes occur with the experience of labour and development involved in production process. A professional body or a technical person tends to gain experience over time which is used to enhance the contribution capability. This type of skill growth is known as the exponential distribution [39]. Therefore, the increasing capability of contribution can be presented by the equation "(3)". Equation 3 indicates that the contribution is time dependent. If the equations 7 and 3 are combined in results, the time dependent contribution model gets a new shape which can be presented by the equation "(8)":

$$\mathrm{C(R\&D)} = \gamma(\mathrm{t}) \frac{G(R\&D)}{G(Q)} e^{\theta_t} \quad (8)$$

"Equation (8)" indicates that the value of C (R&D) depends on the elasticity of productions [γ (t)] and time efficiency parameter of skill θ_t. In conclusion, equation "(8)" can be used to assess how R&D contributes to total production growth.

B. Testing and Data Analysis:

To validate the effectiveness of our model, empirical data sourced from 15 machinery manufacturing SMEs over a period of four year is meticulously examined. Through rigorous statistical analysis, including the application of the significance level method, we aim to rigorously test the developed model against real-world data. By leveraging the analytical capabilities of the SPSS, we dig deep into the dataset to unveil insights into the relationship between R&D initiatives and production growth.

For model testing we used input of process time-series data of fifteen (15) machinery manufacturing SMEs of the year (2016-2020). We analysed collected data by using SPSS software is shown in Appendix. The findings are the value of effect size (R^2) is 0.992 which indicates that 99.2 present inputs have used in production. The DW statistics 2.2 indicates that auto correlation is within acceptable limit. The estimated value of production growth rate of labour, capital, raw materials and R&D are (α_1) = 0.066; (β_1) = 0.641; (λ_1) = 0. 64 and (γ_1) = 0. 650 respectively. The details analysis is shown below:

The R&D contribution to production growth model is presented by equation "(8)" and time effect on production growth model is presented by equation "(6)". The detail analysis of both equations is Estimate growth model on SMEs1 shown below in tables 1,2and3:

$G\ (Q) = 0.066G(K) + 0.641G(L) + 0.64\ G(R) + 0.650\ \mathrm{G}(R\&D),$

$G\ (Q)$= 0.066*(-0.08624) + 0.641*(0.12341) + 0.64 *(0.06412) +0.65 *
(0.07230),

$G\ (Q)$= 0.161428. The results for other machinery manufacturing SMEs are listed in table 1.

Table 1: Estimate inputs- production growth model

Industry	Av α*G(K)	Avβ*G(L)	Av λ*G(R)	Av γ*G(R&D)	Av G(Q)
Machinery manufacturing SMEs1	-0.00569	0.07910	0.04103	0.04699	0.161428
Machinery manufacturing SMEs2	0.05179	0.06438	0.04631	0.07415	0.059158
Machinery manufacturing SMEs3	0.01566	0.07325	0.09285	0.08403	0.066448
Machinery manufacturing SMEs4	0.01754	0.02805	0.01753	0.05301	0.029033
Machinery manufacturing SMEs5	0.09321	0.31662	0.47621	0.013567	0.224902
Machinery manufacturing SMEs6	0.0203	0.21871	0.06432	0.03706	0.0850975
Machinery manufacturing SMEs7	-0.106	-0.3862	0.07491	-0.0057	-0.105747
Machinery manufacturing SMEs8	0.02823	0.17105	0.04532	0.04387	0.0721175
Machinery manufacturing SMEs9	0.01574	0.18241	0.20256	0.16009	0.1402
Machinery manufacturing SMEs10	0.20839	0.03763	-0.0583	0.08393	0.0679125
Machinery manufacturing SMEs11	0.10571	-0.0069	-0.2563	0.06185	-0.02391
Machinery manufacturing SMEs12	0.00743	0.31816	0.07191	0.09317	0.1226675
Machinery manufacturing SMEs13	0.00517	0.08114	0.00821	0.00746	0.025495
Machinery manufacturing SMEs14	0.00308	0.09132	0.09132	0.00975	0.0488675
Machinery manufacturing SMEs15	0.02823	0.17105	0.04532	0.04387	0.0721175
Average	**0.027656**	**0.09598**	**0.0642135**	**0.053806**	**0.0695477**

The growth model equations "(3)" and "(8)" has estimated to determine the total production growth;
Estimate the Contribution of R&D Growth Model

$\mathrm{C(R\&D)} = \gamma(\mathrm{t})\frac{G(R\&D)}{G(Q)}e^{\theta_t}$, $\mathrm{A(t)} = \mathrm{A_0}\ \mathrm{e}^{\theta t}$

$\frac{A_{2013}}{A_{2009}} = e^{\theta t}, Ln\left(\frac{A_{2020}}{A_{2016}}\right) = -0.04713,$

θ= ln(Q2/Q1) /4

Than $\theta = \frac{(0.008062)}{4} = , e^{\wedge}\ 0.0020155 = 1.0020175, Cg\ (R\&D) = 0.065 * (1.109766) * (1.0090414)$

The total average, $C(G(R\&D)) \approx 1.022555$

The results are listed in Table 2;

Table 2 Estimate R&D Growth Model

Industry	γ	θ	Av-e^θ	gm/gQ	C(G(R&D))
Machinery manufacturing SMEs1	0.65	0.0020155	1.012757	1.085317	0.94552
Machinery manufacturing SMEs2	0.65	0.0136054	1.015221	-0.26465	-0.3183
Machinery manufacturing SMEs3	0.65	0.011792	1.01421	0.826382	0.733495
Machinery manufacturing SMEs4	0.65	-0.00983	0.976281	1.013165	0.89766
Machinery manufacturing SMEs5	0.65	0.0584	1.032468	1.023524	0.921351
Machinery manufacturing SMEs6	0.65	-0.00152	1.012196	1.203903	0.939523
Machinery manufacturing SMEs7	0.65	-0.00698	0.995708	0.844476	1.8475182
Machinery manufacturing SMEs8	0.65	0.094215	1.014801	1.06663	0.935206
Machinery manufacturing SMEs9	0.65	0.047684	1.032635	1.38125	1.108164
Machinery manufacturing SMEs10	0.65	-0.145219	1.00314	1.103007	0.951365
Machinery manufacturing SMEs11	0.65	0.00875	0.992983	1.517941	1.542658
Machinery manufacturing SMEs12	0.65	0.00536	1.00584	1.276049	0.965024
Machinery manufacturing SMEs13	0.65	0.000239	1.001517	1.232071	0.97013
Machinery manufacturing SMEs14	0.65	0.012487	1.019369	2.504272	1.876453
Machinery manufacturing SMEs15	0.65	0.006639	1.006495	0.833167	0.534172
Average	**0.65**	**0.006830171**	**1.0090414**	**1.109766933**	**1.022555**

Table 3: Estimate R&D Contribution to production Growth

Sample of SMEs	Contribution R&D to production Growth C(G(R&D))	Seginfcant level of Contribution R&D to production Growth P-Value
Machinery manufacturing SMEs1	0.94552	0.0003*
Machinery manufacturing SMEs2	-0.3183	0.08530
Machinery manufacturing SMEs3	0.733495	0.0002*

Machinery manufacturing SMEs4	0.89766	0.0003*
Machinery manufacturing SMEs5	0.921351	0.0003*
Machinery manufacturing SMEs6	0.939523	0.0047
Machinery manufacturing SMEs7	1.8475182	0.0003*
Machinery manufacturing SMEs8	0.935206	0.0003*
Machinery manufacturing SMEs9	1.108164	0.0002*
Machinery manufacturing SMEs10	0.951365	0.0005*
Machinery manufacturing SMEs11	1.542658	0.1539
Machinery manufacturing SMEs12	0.965024	0.0005*
Machinery manufacturing SMEs13	0.97013	0.0084
Machinery manufacturing SMEs14	1.876453	.0002*
Machinery manufacturing SMEs15	0.534172	0.0002*
Average	**1.022555**	

*One tail test at 95% confidence level

The final shape of R&D contribution to production Growth model is shown in equation "(9)".

$$C(G(R\&D) = 0.65\frac{G(R\&D)}{G(Q)}e^{\theta_t} \quad (9)$$

The factors $0.65\ G\ (R\&D)$ indicates the R&D contribution to production Growth. Table 2 indicates that (11) machinery manufacturing SMEs out of (15) is confidence. "Equation (9)" indicates that the value of g (R&D) depends on [γ1 (t)] and time efficiency parameter θ_t. "Equation (9)" represent a model that could be used to evaluate R&D contribution to production Growth. Thus, objectives of this study that stated in section [I-part B] are achieved.

*C. **Validation and Significance:***

The ultimate goal of this phase is to validate the model's effectiveness in assessing the impact of R&D on production growth within machinery manufacturing SMEs. The model's credibility hinges on its ability to identify and quantify the contribution of R&D activities to production growth with a high degree of statistical significance, typically within the 95% confidence level. Through this meticulous validation process, we aim to establish the model as a reliable tool for evaluating the strategic implications of R&D investments on the sustainable growth of machinery manufacturing SMEs.

Model validation is conducted at (15) machinery manufacturing SMEs by using equation "(4)". Detail analysis of validation is listed in Table 4.

Estimate P-value for measuring production growth SMEs1 by Using t-test: $t = \frac{\overline{(X}-x)}{\frac{\sigma}{\sqrt{n}}}$ for Standard deviation, where the standard deviation σ of C(G(R&D) in SMEs $\sigma = \sqrt{1/n\ (x_i - \mu)^2}$; n–the sample size of SMEs; x_i – the average C(G (R&D)) to15 machinery manufacturing SMEs within operating time (2016-2020); μ –the total average of C(G(R&D)); $\bar{X}$ –the total average of C(G(R&D))

$\sigma = \sqrt{1/15\ (0.0046)^2}$ = 0.00118771

Table 4 The model estimates the actual growth

Industry	Model Estimate (%)	Actual growth (%)
Machinery manufacturing SMEs1	14.63	13.2
|Machinery manufacturing SMEs2	20.31	10.5
Machinery manufacturing SMEs3	22.6	17.45
Machinery manufacturing SMEs4	9.87	7.6
Machinery manufacturing SMEs5	7.91	6.9
Machinery manufacturing SMEs6	8.54	10.3
Machinery manufacturing SMEs7	18.63	9.1
Machinery manufacturing SMEs8	6.36	6.62
Machinery manufacturing SMEs9	9.52	8.6
Machinery manufacturing SMEs10	4.26	6.22
Machinery manufacturing SMEs11	7.51	6.3
Machinery manufacturing SMEs12	10.19	7.5
Machinery manufacturing SMEs13	7.33	8.5
Machinery manufacturing SMEs14	24.18	8.54

Machinery manufacturing SMEs15	12.15	7.4
Average	**12.266**	**8.982**

Then $t = \frac{\sqrt{15*((\overline{\times}-\times))}}{0.12596348} = \frac{0.93100876}{0.15096539} = 6.1670344$, the value from the t-table is given below;
P-vale =1- P, 1- 0.9997 = 0.003.
The estimated value of degree of significance is reported in Table 2 at Column three (3) in section [IV-part B]. The significance test is conducted at 0.95 present confidence levels. The p-value of contribution to production growth is found to be 0.0002 which is less than 0.05. The location of p-value is outside 0.95. This finding demonstrates that R&D contribution (as inputs) to production growth is significance. The total production growth factor of machinery manufacturing SMEs 1 is found to be 14.63 that stated in table 4.

These findings indicate that about 95% of R&D resources have been used in production process that contributed significantly to achieve total production growth 14.63%. The significance level test of 15 machinery manufacturing SMEs are listed in Table 2 and column 3; that demonstrate R&D contribution of 11 machinery manufacturing SMEs out of 15 SMES are significance. These findings state that the developed model is quite fit to evaluate R&D the contribution to production growth of machinery manufacturing SMEs. Thus, the part objective of this study that stated in section [I-part B] is achieved.

*D. **Scenario Analysis of Research Findings***

The study's scope includes developing a model to assess how R&D contributes to production growth, as well as testing and validating the model. The model for assessing the contribution of R&D to production growth is constructed using the model building approach described in [section III-part B] and the theory of growth model described in [section II-parts F, G, & H] as well as in equation "(2) ". Where "Equation (9)" displays the final shape of the specified model. Thus, research objective as stated in section [I-part B] was achieved.

Model testing was conducted based on the method stated in section [I-part C] and section [III-part B]. The test results were reported in section [IV-part B] and Table 1. The validation of the developed model is conducted based of the procedure stated in section [IV-part C] and in Table 2. Findings suggest that developed model is to be found quite fit to explain the R&D contribution to production growth. Thus, the second and third part of research objectives that were stated in section [I- part B] are achieved.

V. Conclusion and Future Directions

The aim of this study was to construct and assess a model for evaluating the impact of R&D on the production growth of machinery manufacturing SMEs. The model created was put to the test across fifteen machinery manufacturing SMEs using input-output data from 2016 to 2020. Validation of the model was carried out at a 95% confidence level across the same fifteen SMEs. The outcomes of the testing and validation process highlighted that the R&D contribution to production growth was statistically significant at a 95% confidence level for 11 machinery manufacturing SMEs (p-value <0.05). These results highlight the utility of the developed model in assessing the impact of R&D on production growth within machinery manufacturing SMEs. Consequently, the research objective outlined in section [I-part B] regarding model development, testing, and validation has been successfully accomplished.
Undoubtedly, this model represents a novel contribution to the manufacturing domain, introducing fresh insights and knowledge to the field. The novelty of this work emphasizes the necessity for further exploration in this area, suggesting that future studies are imperative for developing a comprehensive model to evaluate the R&D contribution to production growth across various manufacturing industries.

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References

1. Czarnitzki, D., Delanote, J. R&D policies for young SMEs: input and output effects. Small Bus Econ 45, 465–485 (2015).

2. Taiwo, M. A., Ayodeji, A. M., & Yusuf, B. A. (2013). Impact of small and medium enterprises on economic growth and development. American Journal of Business and Management, 2(1), 18.
3. Lee, N., Sameen, H., & Cowling, M. (2015). "Access to finance for innovative SMEs since the financial crisis." Research Policy, 44(2), 370-380.
4. Berger, A. N., & Udell, G. F. (2006). "A more complete conceptual framework for SME finance." Journal of Banking & Finance, 30(11), 2945-2966.
5. Khan, S. Impact of sources of finance on the growth of SMEs: evidence from Pakistan. Decision 42, 3–10 (2015).
6. Rajamani, K., Akbar Jan, N., Subramani, A. K., & Nirmal Raj, A. (2022). Access to finance: Challenges faced by micro, small, and Medium Enterprises in India. Engineering Economics, 33(1), 73–85.
7. Cobb, C. W., & Douglas, P. H. (1928). "A Theory of Production." The American Economic Review, 18(1), 139-165.
8. Charoenrat, T., & Harvie, C. (2013). Technical Efficiency of Thai Manufacturing SMES: A Stochastic Frontier analysis. Australasian Accounting Business and Finance Journal, 7(1), 99–121.
9. Robertson, P.L. (2003), "The role of training and skilled labour in the success of SMEs in developing economies", Education + Training, Vol. 45 No. 8/9, pp. 461-473.
10. Wan Hooi, L. and Sing Ngui, K. (2014), "Enhancing organizational performance of Malaysian SMEs : The role of HRM and organizational learning capability", International Journal of Manpower, Vol. 35 No. 7, pp. 973-995.
11. Islam, S. and Syed Shazali, S.T. (2011), "Determinants of manufacturing productivity: pilot study on labor - intensive industries", International Journal of Productivity and Performance Management, Vol. 60 No. 6, pp. 567-582.
12. Schroeder, R. G., Bates, K. A., & Junttila, M. A. (2002). A resource - based view of manufacturing strategy and the relationship to manufacturing performance. Strategic Management Journal, 23(2), 105‑117.
13. Varma, V., Reklaitis, G., Blau, G., & Pekny, J. (2007). Enterprise-wide modeling & optimization—An overview of emerging research challenges and opportunities. Computers & Chemical Engineering, 31(5–6), 692–711.
14. Liu, X., Yang, M., Shao, Z., Liu, L., & Gu, W. (2024). Assessment of impacts of mineral raw material resource efficiency on enterprise performance. Resources Policy, 90, 104803.
15. Lenny Koh, S.C., Demirbag, M., Bayraktar, E., Tatoglu, E. and Zaim, S. (2007), "The impact of supply chain management practices on performance of SMEs", Industrial Management & Data Systems, Vol. 107 No. 1, pp. 103-124.
16. Raymond, L., & St-Pierre, J. (2010). "R&D as a determinant of innovation in manufacturing SMEs." Technovation, 30(1), 48-56.
17. Radas, S., & Božić, L. (2009). "The antecedents of SME innovativeness in an emerging transition economy." Technovation, 29(6-7), 438-450.
18. Hall, B. H., Lotti, F., & Mairesse, J. (2009). "Innovation and productivity in SMEs: empirical evidence for Italy." Small Business Economics, 33(1), 13-33.
19. Terziovski, M. (2010). "Innovation practice and its performance implications in small and medium enterprises (SMEs) in the manufacturing sector." Strategic Management Journal, 31(8), 892-902.
20. Branzei, O., & Vertinsky, I. (2006). "Strategic pathways to product innovation capabilities in SMEs." Journal of Business Venturing, 21(1), 75-105.
21. Ortega-Argilés, R., Vivarelli, M., & Voigt, P. (2009). "R&D in SMEs: a paradox?" Small Business Economics, 33(1), 3-11.
22. Freel, M. S. (2000). "Strategy and structure in innovative manufacturing SMEs: The case of an English region." Small Business Economics, 15(1), 27-45.
23. Love, J. H., & Roper, S. (2015). "SME innovation, exporting and growth: A review of existing evidence." International Small Business Journal, 33(1), 28-48.
24. Hoffman, K., Parejo, M., Bessant, J., & Perren, L. (1998). "Small firms, R&D, technology and innovation in the UK: a literature review." Technovation, 18(1), 39-55.
25. Bhattacharya, M., & Bloch, H. (2004). "Determinants of innovation." Small Business Economics, 22(2), 155-162.
26. O'Regan, N., & Ghobadian, A. (2004). "The importance of capabilities for strategic direction and performance." Management Decision, 42(2), 292-313.
27. Foreman - Peck, J., Makepeace, G., & Morgan, B. (2006). "Growth and profitability of small and medium - sized enterprises: Some Welsh evidence." Regional Studies, 40(4), 307-319.

28. Oke, A., Burke, G., & Myers, A. (2007). "Innovation types and performance in growing UK SMEs." International Journal of Operations & Production Management, 27(7), 735-753.
29. Golovko, E., & Valentini, G. (2011). "Exploring the complementarity between innovation and export for SMEs' growth." Journal of International Business Studies, 42(3), 362-380.
30. Edwards, T., Delbridge, R., & Munday, M. (2005). "Understanding innovation in small and medium-sized enterprises: a process manifest." Technovation, 25(10), 1119-1127.
31. Wolff, J. A., & Pett, T. L. (2006). "Small - firm performance: Modeling the role of product and process improvements." Journal of Small Business Management, 44(2), 268-284.
32. Rothwell, R., & Dodgson, M. (1991). "External linkages and innovation in small and medium - sized enterprises." R&D Management, 21(2), 125-138.
33. Calantone, R. J., Cavusgil, S. T., & Zhao, Y. (2002). "Learning orientation, firm innovation capability, and firm performance." Industrial Marketing Management, 31(6), 515-524.
34. Romijn, H., & Albaladejo, M. (2002). "Determinants of innovation capability in small electronics and software firms in southeast England." Research Policy, 31(7), 1053-1067.
35. Massa, S., & Testa, S. (2008). "Innovation and SMEs: Misaligned perspectives and goals among entrepreneurs, academics, and policy makers." Technovation, 28(7), 393-407.
36. Avermaete, T., Viaene, J., Morgan, E. J., & Crawford, N. (2003). "Determinants of innovation in small food firms." European Journal of Innovation Management, 6(1), 8-17.
37. Hadjimanolis, A. (2000). "A resource-based view of innovativeness in small firms." Technology Analysis & Strategic Management, 12(2), 263-281.
38. Freel, M. S. (2005). "Patterns of innovation and skills in small firms." Technovation, 25(2), 123-134.
39. Elaswad, & Dagroum.,(2024). Research and development (R&D) Contribution Production Growth of machinery manufacturing SMEs: A Review. Journal of total science Volume(8),Issus (32),Sep-2024,ISSN:2518-5799.

Appendix

SPSS Output;

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.996[a]	.992	.992	.02709	.992	2425.751	4	75	.000	2.207
a. Predictors: (Constant), GM, GR, GK, GL										
b. Dependent Variable: GQ										

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	.000	.003		-.038	.970	-.006	.006		
	GL	.641	.041	.513	12.944	.000	.660	.862	.046	21.728
	GK	.066	.007	.110	7.516	.000	.061	.092	.681	1.468
	GR	.64	.002	.213	26.310	.000	.068	.079	.834	1.199
	GR&D	. 650	.032	.063	1.530	.061	-.010	.164	.046	21.708
a. Dependent Variable: GQ										

(α_1) =0.066; (β_1) =0.641; (λ_1) =0.64 and (γ_1) = 0.650