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THE INVERTED-U RELATIONSHIP BETWEEN R&D AND PROFITABILITY: EVIDENCE FROM THE SLOVAK MEDICAL DEVICE INDUSTRY

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Summary. *In the knowledge economy, the activities of knowledge-intensive enterprises largely depend on the effectiveness of intellectual capital management and the processes of its creation – research and development (R&D). The present paper analyzes the relationship between the R&D and profitability of the Slovak medical device companies, which belong to high-value-added, knowledge-intensive industries. A sample of 26 companies operating in the Slovak medical device industry for the period of 2015 to 2019 is considered. For data analysis purposes, GRETL software is used. The current study deploys the panel data regression analysis methodology. A regression mod-*

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el is constructed that includes one dependent variable and four independent variables. Using the Breusch-Pagan test and the Hausman test, the feasibility of using the Fixed Effects Method as an estimated parameter for the regression model is substantiated. Diagnosis of the adequacy of this model is performed on the basis of the Normality test, Autocorrelation test, and Heteroscedasticity test, and the feasibility of model estimation is substantiated with robust standard errors. The modeling results show that there is a curvilinear (inverted-U) relationship between R&D and the profitability of Slovak medical device companies, which confirms the hypothesis of the study. RDI has a significant negative impact on ROA at a 1% level, and RDI2 has a significant positive impact on ROA at a 1% level. The current results suggest that more investment in R&D is better for profitability, but only within the zone of optimal R&D activities. Medical device companies that carry out minor R&D activities are encouraged to improve their R&D investment policy to improve their quality and effectiveness.

Keywords: *innovative management, inverted-U relationship, research and development, profitability, medical device companies.*

JEL Classification: *E22, O32.*

INTRODUCTION

The development of the knowledge economy and global competition, where the main source of value creation for business entities is making investments into R&D, innovations, and technological progress (Kabir, 2019; Ullberg, Edvinsson & Yeh-Yun Lin, 2021), provides for the need to identify the most effective directions for such investing. The existence of a high level of risk related to R&D investments, as well as uncertainty about the possibility of obtaining innovative products and services, causes scientists to pay considerable attention to analysing the impact of R&D activities on profitability, as well as identifying those areas for increasing profitability that can be used by companies' management in reviewing R&D investment policy.

A literature review on the problems of R&D investment shows, in general, that investing has a positive impact on business activities (Griliches, 1979; Archarungroj & Hoshino, 1999; Del Monte & Papagni, 2003; Jen Huang & Ju Liu, 2005; Nord, 2011; Özkan, 2022). However, studies conducted by many scientists provide a significant number of warnings related to the feasibility, intensity, and effectiveness of R&D investments for a diverse range of enterprises varying by share of high-tech or low-tech sectors, different stages of innovation, economic development, science intensity, etc. This is justified by the existence of a considerable number of factors affecting the effectiveness of R&D investments for a specified company. As a result, the above-mentioned leads to a lack of universal rules on the procedure for implementing and determining the appropriate volume of R&D investments which enables companies to reach the expected level of profitability.

In our empirical study, we focus on the specific features of an enterprise as well as its external business environment and the peculiarities of the industry. The results of this research enable managers of enterprises to form and incorporate changes into R&D investment policy. This matter is relevant for knowledge-intensive enterprises as they are referred to as cornerstones of the knowledge economy, since their creation of value largely depends on the effectiveness of R&D investment (Van Hemert & Nijkamp, 2010; Doloreux, Shearmur & Rodriguez, 2016; Özkan, 2022). The absence of a linear relationship between the volume of R&D investment and the level of profitability of the enterprise further requires the determination of such a relationship for a particular industry (Jen Huang & Ju Liu, 2005; Fortune & Shelton, 2012; Booltink & Helmhout, 2018; Qi & Deng, 2019; Chou et al., 2022). This enables us to identify a system of parameters, based on which a completely new or adjusted existing R&D investment policy of a company can be built.

The hypothesis of the study is the existence of an inverted-U relationship between the R&D and profitability of knowledge-intensive enterprises. We assume that not all R&D activities by knowledge-intensive enterprises have a positive impact on their profitability. The peculiarities of the industry, the region and many other external factors affect the the amount of R&D, which has a positive impact on profitability. To identify the most effective R&D amount and provide management with recommendations on R&D investment policy, it is necessary to conduct a separate empirical study on the example of a group of enterprises belonging to one industry in one country.

The object of this study is the performance of Slovak medical device companies which belong to a knowledge-intensive industry – which is, in its turn, highly value-added – for the 2015–2019 period. The medical device industry is characterized by active R&D investment and a rapid pace of technological innovation. However, in this industry, it takes a long time to launch new products, and there are always regulatory issues due to safety and validity (Yeom et al., 2021). The incurring of R&D costs and registration costs related to intellectual property rights form the basis for competitive advantages for medical device companies, i.e., a fundamental driver of their profitability. In this regard, for such enterprises the development of an effective R&D investment policy is one of the priority tasks for management.

Although this industry accounts for a relatively small share of total industrial production in the Slovak Republic, it is actively supported financially and institutionally by the government via the creation of a variety of new opportunities for potential investors. This includes stimulating cooperation between companies and scientific institutions, developing a program of investment incentives, establishing knowledge transfer from an academic environment to a medical device business, and creating conditions for benefiting from synergy with the pharmaceutical industry. Having more than one hundred historical examples of successful medical devices that were produced in Slovakia and wide support of this industry from the government, in recent years Slovakia has become an increasingly attractive investment destination for companies producing single-use medical equipment. Most of the medical equipment produced in Slovakia is designated for foreign markets. In accordance with the Recovery and Resilience Plan of Slovakia, investments into the healthcare system increased to 1.16 billion euros in 2021 (Slovak Investment and Trade Development Agency, 2022). Another reason for choosing the object of the study is that the Slovak medical device market is one of the more developed in the Central and Eastern European regions. Entering the eurozone, the terms of trade with Slovak enterprises were significantly simplified and unified, and the pricing system became more transparent, which, in turn, greatly facilitated relations with importers. Considering the case of Slovak medical device companies, the study of the impact of R&D on these companies' profitability is particularly interesting both from the perspective of belonging to knowledge-intensive industries and in terms of the active governmental support of further development of such businesses in the Slovak Republic.

This paper is structured as follows: section 1 provides a literature review; the data and methodology are explained in section 2; the results are presented in section 3; section 4 contains a discussion and future research perspectives; and section 5 summarizes the conclusions of this study.

LITERATURE REVIEW

In the context of the development of the knowledge economy, characterized by an increase in investment into innovation and technological progress worldwide, more and more scientific attention is paid to the problem of the ratio of innovative efforts of enterprises and the return on them (Franko, 1989; Del Monte & Papagni, 2003; Danielson & Press, 2005; Qi & Deng, 2019). At the level of enterprise, the main indicators of such a relationship are investments in R&D and profitability. The classic authors of economic theory, J. Schumpeter and K. Arrow, considered the problem of the dependence of innovative development on the level of development of competition and the strong market position of a company. However, the management of a company is interested more in reverse dependance, which shows the relationship between R&D and profitability. This enables them to determine a satisfactory amount of investment in R&D to achieve the maximum level of profitability or determine the possible losses/expenditures of the company that it is to incur to achieve the planned goals.

Several scientists have studied this issue based on the contribution of Griliches (1979), who first addressed the role of R&D in ensuring productivity growth. His fundamental ideas were to consider R&D not only as costs, but also as capital, alongside the need to determine return on R&D expenditures for various sectors of the economy while ignoring lagged R&D effects on profitability.

Analysis of papers on the impact of R&D expenditures on financial performance or profitability of a company shows that studies were conducted by scientists on the examples of various sectors of the economy, including: firms in the chemical and pharmaceutical industry (Archarungroj & Hoshino, 1999); manufacturing firms (Del Monte & Papagni, 2003); non-finance firms (Natasha & Yanthi, 2009); pharmaceutical companies (Nord, 2011); pharmaceutical firms (Fortune & Shelton, 2012); manufacturing firms (Ayaydin & Karaaslan, 2014); oil production companies (Varahrami, 2015); manufacturing companies (Lome, Heggeseth & Moen, 2016); mining firms (Rafiq, Salim & Smyth, 2016); pharmaceutical companies (Freihat & Kanakriyah, 2017); medical device companies (Luo, Hu & Yu, 2018); pharmaceutical companies (Dalvadi & Mansuri, 2018); production companies (Erdogan & Yamaltdinova, 2019); Big Data companies (Qi & Deng, 2019); pharmaceutical companies (Eldawayaty, 2020); and industrial firms (Özkan, 2022). Moreover, the examples of companies at different levels of innovative capacity and technological development (i.e., high-, medium-, low-intensity), and in different countries worldwide (e.g., China, Egypt, Italy, India, Indonesia, Iran, Japan, Jordan, Norway, Taiwan, Turkey, USA) have been considered.

In such studies, authors mainly determine the presence of the positive significant impacts of the different indicators which characterize the R&D activity of the company (R&D costs, R&D expenditures, R&D intensity, R&D intensity squared) on different types of indicators of financial performance or profitability (IRR, ROA, ROE, ROS, GPM, EPS, Operating Income Margin, Ordinary Income Margin, Profit Margin, Yearly Growth Rate, Aggregate Growth). As some results show, companies engaged in R&D coped with the consequences of the financial crisis more effectively (Lome, Heggeseth & Moen, 2016). Moreover, companies more active in R&D are more profitable than younger non-innovative firms (Rafiq, Salim & Smyth, 2016).

The basis for determining the impact of R&D on profitability is often chosen to be the activities of enterprises for different periods of time, from 3 to 10 years. Various methods, such as the method of least squares, logistic regression, panel data regression analysis with different estimators (fixed effect method, random effect method), are used to assess the extent of the impact.

Thus, a significant number of researchers confirm the existence of a positive linear effect of R&D on the profitability of companies. At the same time, some scientists have discovered no significant relations of R&D with profitability (Del Monte & Papagni, 2003; Eldawayaty, 2020; Özkan, 2022), or in some cases even a negative relation with profitability indicators (Eldawayaty, 2020). This can be partially caused by the imitation of the process of creating innovations by the enterprises (Del Monte & Papagni, 2003), their low-quality level (Fortune & Shelton, 2012) or the possibility of obtaining a return on R&D in subsequent reporting periods (Özkan, 2022). The rationale for no significant or negative relations through the recognition of such reasons still indicates that scientists support the position on the existence of a linear relationship between R&D and profitability.

However, some scientists have found the presence of a nonlinear relation, characterized by a change in the level of R&D impact on profitability depending on the number of R&D investments of the company. Thus, Jen Huang and Ju Liu (2005) discovered that innovation capital investments have an inverted U-shaped curvilinear relationship with performance. The presence of the same relationship was found by Erdogan and Yamaltdinova (2019) when studying the impact of R&D impact on the financial performance of production companies listed in Borsa, Istanbul; by Booltink and Helmhout (2018) in the case of the non-high-tech European SMEs; and by Chou et al. (2022) in a study of Taiwanese food firms. Data from the above-mentioned studies reveals that R&D has a positive significant impact on profitability, and R&D squared has a significant negative impact. Subsequently, expanding R&D investments has a marginal diminishing or even negative effect on profitability.

Studies by Fortune and Shelton (2012) and Qi and Deng (2019) show a reverse nonlinear relation: the indicator of R&D has a negative impact on profitability, whereas R&D squared has a positive one. This means that investments in R&D have a positive effect on the profitability of the company within a certain optimal range only. In case of going beyond such a range – towards either increasing or decreasing the number of investments in R&D – a negative impact on the profitability of a company is observed. We refer to the studies which indicate the existence of a positive or negative linear impact of R&D on profitability to be a special case of an inverted-U relationship between such variables. Considering the above, the objective of this study is to investigate the existence of a non-linear relationship between R&D and the profitability of Slovak medical device companies.

In the following section, the data and research methodology are explained and the hypothesis of the study is tested. Then, the data analysis results, limitations and implications are discussed, and future research perspectives are proposed.

DATA AND METHODOLOGY

To test the suggested research hypothesis in this study, the activities of 26 Slovak medical device companies (Appendix A) for the 2015–2019 period were analyzed. The data used in this study was obtained from the annual financial statements of Slovak companies, available on the official websites of the companies, as well as from the Slovak FinStat (2022) database. The 2015–2019 period was chosen for analysis taking into consideration the fact that the financial statements of companies in the Slovak Republic are published in statistical databases with a time lag of up to 1.5–2 years. Therefore, 2019 was the last year with full and reliable financial information available for conducting our research.

According to the classification of SK NACE 2, the companies chosen for this study belong to group 32500: "Manufacture of medical and dental instruments and supplies". In terms of form of ownership, medical device companies are mainly represented by limited liability companies (24), one company is a joint-stock company, and one is a general partnership. The analysed population of companies has the following structure by type of ownership: private domestic – 94%; international with a predominant private sector – 3%; foreign – 3%.

To explain the relation between R&D and profitability, one dependent variable and four independent variables (R&D variables, control variables) were chosen. The variables used in the analysis and their calculations and abbreviations are given below in Table 1.

Table 1. Variable definitions and abbreviations

Variable	Calculation	Abbreviation
Dependent Variables		
Return on Assets	Net turnover/Total Assets	ROA
Independent Variables		
R&D Variables		
Research and Development Intensity	R&D costs/Total Sales	RDI
Research and Development Intensity Squared	Squared function of R&D	RDI2
Control Variables		
Leverage	Total liabilities/Total Assets	LEV
Size	Logarithm of Total Assets	l_S

Source: *compelled by the authors*

Return on Assets (ROA) ratio was used as a dependent variable, which reflects the profitability of the enterprise in relation to the assets invested to generate revenue. This ratio actually reflects the quality of assets used, regardless of their size, characterizing their financial and operational performance. The choice of ROA as a dependent variable, in relation to which the impact of R&D of the enterprise was studied, was also made by Archarungroj and Hoshino (1999), Jen Huang and Ju Liu (2005), Danielson and Press (2005), Ayaydin and Karaaslan (2014), Varahrami (2015), Erdogan and Yamaltdinova (2019), Qi and Deng (2019), Eldawayaty (2020), and Özkan (2022).

The dynamics of ROA of the Slovak medical sphere and medical device companies during the 2015–2019 period is presented in Figure 1.

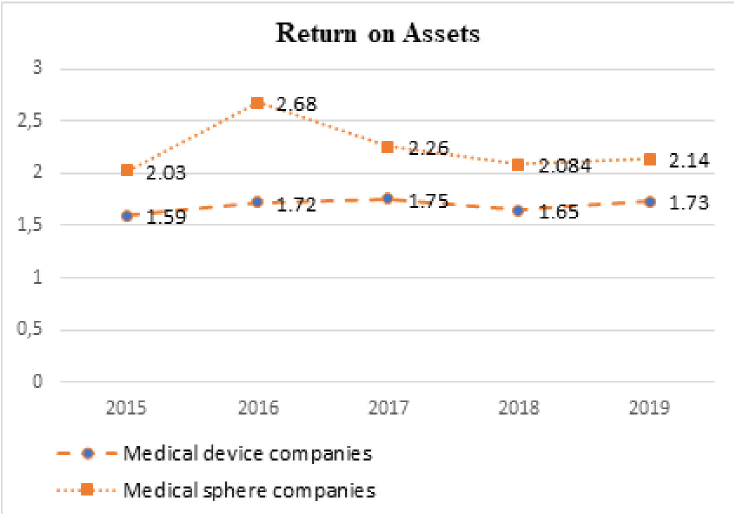

Figure 1. Development of ROA in the Slovak medical sphere and medical device companies in the 2015–2019 period

Source: *developed by the authors*

Figure 1 shows that the average value of ROA during the five-year period (2015–2019) underwent movements or fluctuations. For medical device companies, ROA ratio increase is seen during the 2015–2017 and 2018–2019 periods, and a decrease in ROA ratio is observed from 2017 to 2018. In 2017–2018, the general tendency of ROA for the medical device companies illustrates the general changes in this indicator for the medical service companies in the Slovak Republic.

The independent variables identified for this study were divided into two groups. They were calculated based on the use of the financial statements of the Slovak medical device companies, as well as updated financial information disclosed by the FinStat (2022) database. The first group of independent variables comprises the variables that characterize R&D activities, i.e., R&D intensity (RDI) and R&D intensity squared (RDI2). The choice of these two variables is grounded based on prior research which reveals that R&D intensity is an indicator of R&D investment that may result in financial performance. R&D intensity is calculated as the ratio of R&D costs to total sales of a company. R&D intensity was applied to detect the non-linear relationship between R&D and profitability. These two variables are also used in a number of studies carried out by Fortune and Shelton (2012), Booltink and Helmhout (2018), Qi and Deng (2019), Erdogan and Yamaltdinova (2019), Eldawayaty (2020); Özkan (2022), and Chou et al. (2022).

To avoid the impact caused by other variables that are excluded from our model, this paper refers to prior research (Jen Huang & Ju Liu, 2005; Booltink & Helmhout, 2018; Qi & Deng, 2019; Ievdokymov et al., 2020; Eldawayaty, 2020; Chou et al., 2022; Serpeninova et al., 2022; Zavalii, Vikarchuk & Constantinou, 2022). Furthermore, two company characteristics were chosen to be control variables: leverage (LEV) and company size (l_S).

To determine the existence of an inverted-U relationship between R&D and profitability for Slovak medical device companies, panel data analysis was used. After controlling R&D variables and control variables, we have the following empirical model:

ROA it = α + β1 RDI it + β2 RDI2 it+ β3 LEV it + β4 l_S it + ε it

where: ROA – dependent variables; $_i$ = entity and $_t$ = time;
α – identifier;
μ – variance introduced by the unit-specific effect for unit i;
β – regression coefficient;
RDI, RDI2, LEV, l_S – independent variables; $_i$ = entity and $_t$ = time;
$ε_{it}$ – error term.

The theoretical framework of the study is given below in Figure 2.

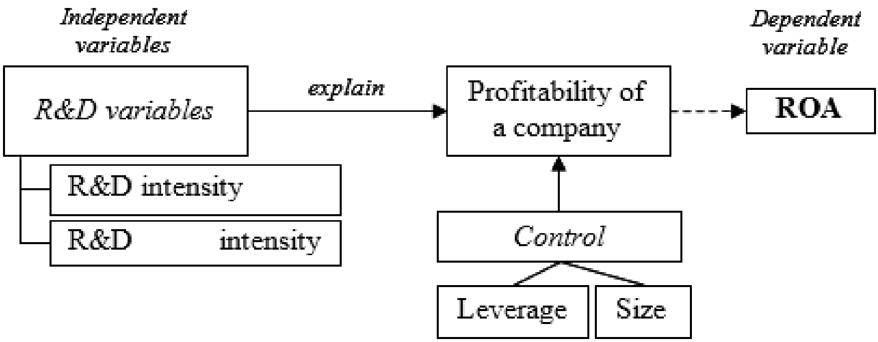

Figure 2. Conceptual framework of the study

Source: *developed by the authors*

RESULTS

Table 2 presents the descriptive statistics for each variable (observation, mean, median, standard deviation, minimum, maximum).

Table 2. Descriptive statistics of variables for this study

Variables	*Observation*	*Mean*	*Median*	*St. Dev.*	*Minimum*	*Maximum*
ROA	130	1.69	1.46	1.12	0.00247	7.54
RDI	130	0.218	0.144	0.253	0.0192	1.87
RDI2	130	0.111	0.0208	0.342	0.000	3.51
LEV	130	0.598	0.535	0.460	0.0609	2.32
l_S	130	11.2	11.0	1.42	8.08	16.2

Source: *calculated via Gretl software package*

From Table 2 it can be concluded that the largest deviations in variables are related to ROA and l_S. The differences between the minimum and the maximum values of ROA point out that the profitability levels of medical device companies are quite distinct. For some variables (ROA, LEV, l_S), the mean value is greater than the standard deviation, thus the data in these variables has a small distribution. In particular, standard deviation for RDI is 0.253. The average leverage ratio is 0.598, which means that approximately 60% of the total assets of medical device companies are financed by taking out loans.

Based on the constructed correlation matrix (Figure 3), where correlation coefficients between the variables of a model are given, it is generally possible to conclude the absence of a multicollinearity problem. The indicator of correlation between RDI and RDI2 is 0.9, which may indicate the partial existence of a problem between independent variables. However, Özkan (2022) states that this is normal in the regression analysis performed to check the effect of interrelated variables on the financial performance indicators.

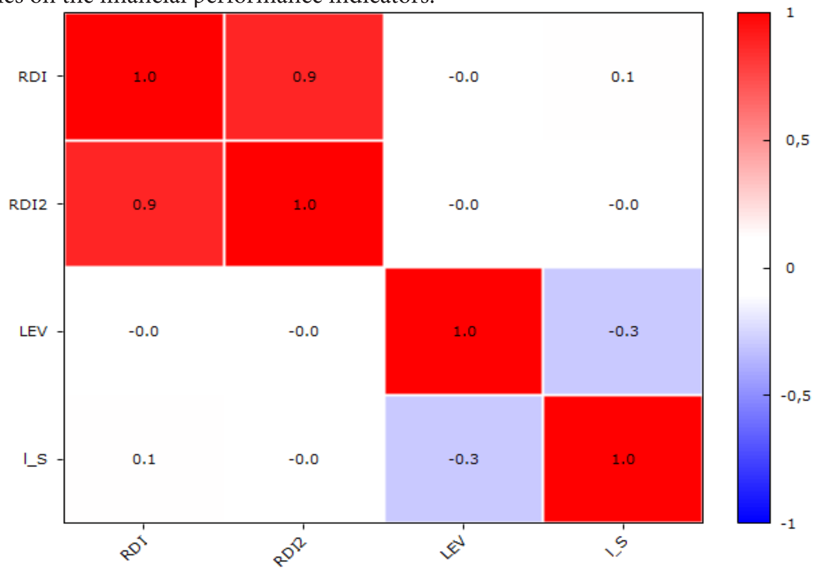

Fig. 3. Correlation matrix of the model

Source: *calculated via Gretl software package*

Before carrying out regression analysis of panel data, we chose a method that adequately corresponds to the data of the formed model. Having applied the *F*-statistics test, it was established that for the value $F(25, 100) = 19.1524$, *p*-value (8.47724e-028) is less than 0.05, which testifies against the null hypothesis regarding the adequacy of the pooled OLS model, and confirms the feasibility of using the Fixed effects method (FEM). The feasibility of preferring this method to the Random effects method (REM) was also confirmed by the application of the Hausman test and the Breusch-Pagan test. Thus, the *p*-value (0.0146436) of the Hausman test is less than 0.05, which refutes the null hypothesis regarding the consistency of REM estimates in favor of FEM.

The p-value (3.71094e-033) of the Breusch-Pagan test is less than 0.05, which also testifies against the null hypothesis regarding the adequacy of the pooled OLS model, and, in turn, confirms the feasibility of using FEM.

In order to check the adequacy of a model with data on the activity of the medical device companies and to identify ways of its improvement, the model should be diagnosed through the Normality test, the Autocorrelation test, and the Heteroscedasticity test using the Gretl software package.

The results of the analysis of the normality of the distribution of the residuals of a model made it possible to reveal the non-normality of the distribution of errors. In particular, this was the case for the p-value of 2.24623e-017, which is less than 0.05 and does not confirm the null hypothesis regarding the normality of the distribution of residuals. Applying the Wooldridge test for autocorrelation in panel data made it possible to reveal the absence of first-order autocorrelation, since the value of $F(1, 25) = 4.21696$ with p-value = 0.0506228, which is greater than 0.05, confirmed the null hypothesis regarding no first-order autocorrelation. To determine the level of heteroscedasticity of the model, the non-parametric Wald test was used, which enabled the identification of its presence. In particular, it made it possible to obtain p-value = 0. This value is less than 0.05, as a result of which the null hypothesis – that the objects have the same variance of errors – is not confirmed, and there is heterogeneity of observations characterized by unequal variance of the random error of the model.

The unsatisfactory results of the Normality test and the Heteroscedasticity test indicate the low adequacy of the model for the data used. To improve it, the use of robust estimators was proposed, which allow outliers in a model to be identified and their impact on the results of panel data regression analysis to be minimized or eliminated. Such a practice of model estimation with robust standard errors is quite common among scientists who analyze the relationship between the R&D and profitability of a company (Özkan, 2022, Chou et al., 2022).

Tables 3 and 4 present the results of analysis carried out using FEM. The use of FEM allows the β-coefficients of the model to be effectively estimated based on the fact that α are fixed unknown parameters of the model (omitted or unobserved), which are independent of errors ε_{it}. It also allows the influence of such parameters that define the individual characteristics of the objects being studied to be estimated. The estimation of such parameters is carried out by including a dummy variable for each object, which are fixed effects that are constant for each object, i, for the corresponding period.

Table 3. FEM (Robust standard errors) using observations 1–130

Variable	Coefficient	Standard error	***z***	***p***-value	Significance by ***t***-statistics
const	6.08097	1.56272	3.891	9.97e-05	***
RDI	−3.10908	0.516056	−6.025	1.69e-09	***
RDI2	1.19868	0.258445	4.638	3.52e-06	***
LEV	1.94665	1.02429	1.900	0.0574	*
l_S	−0.447317	0.174332	−2.566	0.0103	**

*Note: * Significant at the 10% level; ** Significant at the 5% level; *** significant at the 1% level.*

Source: *calculated via Gretl software package*

Table 4. FEM (Robust standard errors) using observations 1–130

Indicator	Value	Indicator	Value
Mean dependent var.	1.689815	S.D. dependent var.	1.122728
Sum squared resid.	14.03078	S.E. of regression	0.374577
LSDV *R*-squared	0.913713	Within *R*-squared	0.549584

Source: *calculated via Gretl software package*

Based on the regression results of the model, we derived the following equation:
ROA = 6.08097 – 3.10908 RDI + 1.19868 RDI2 + 1.94665 LEV – 0.447317 l_S

The results of regression analysis using FEM (Robust standard errors) (Table 3) indicate that all chosen independent variables for the model are statistically significant, but with different levels (the presence of corresponding asterisks). Multicollinearity between independent variables was not detected, in the presence of which one of the variables would be automatically rejected by the Gretl software. The most significant parameters of the model are Const (*p*-value = 9.97e-05), RDI (*p*-value = 1.69e-09), and RDI2 (*p*-value = 3.52e-06) – i.e., these indicators have the most impact on ROA.

Applying the equation of the model obtained, we found that some variables (const, RDI2, LEV) have a positive relationship with ROA, while others, i.e., RDI, l_S, have a negative one. In particular, the more detailed content of the regression equation coefficients is as follows: 1) if RDI is increased by 1, then ROA decreases by 3.10908; 2) if RDI2 is increased by 1, then ROA increases by 1.19868 relatively; 3) if LEV is increased by 1, then ROA increases by 1.94665; and 4) an increase of l_S by 1 causes a 0.447317 decrease in the ROA ratio.

Table 4 indicates that the coefficient of determination (LSDV *R*-squared) of the model is 0.913713. This means that 91.37% of the variation of the ROA can be explained by the variation of the independent variables (const, RDI, RDI2, LEV, l_S), while the remainder of the impact is caused by other variables that are not the subject of this study. The value of within *R*-squared shows that 54.96% of the variance of ROA within medical device companies is captured by the model.

DISCUSSION

This study examines the role that R&D expenditures play in the profitability of Slovak medical device companies. Rather than arguing that R&D investments have a significant positive or negative impact on the profitability of medical device companies (Luo, Hu & Yu, 2018; Yeom et al., 2021), we show that there is a curvilinear (inverted-U) relationship between the two above-mentioned variables. To be more specific, as a result of panel data regression analysis it has been determined that, while R&D intensity has a significant negative impact on profitability at a 1% level, at the same time R&D intensity squared significantly positively influences profitability at the 1% level. This confirms conclusions regarding the limited role of R&D in ensuring the profitability of the enterprise due to limitations in the process of creating innovations or their low-quality level (Del Monte & Papagni, 2003; Fortune & Shelton, 2012; Luo, Hu & Yu, 2018). Thus, R&D has a positive effect on the profitability of medical device companies only when a certain critical input volume is achieved. At the same time, taking into consideration the objective factors justifying the impossibility of the constant growth of a company's profitability – e.g., market volumes, production capacity of the company, etc. – there is an initial critical volume of R&D, after which a negative relation with profitability is observed. The gap between the critical input and output volumes of R&D forms a zone of optimal activities, which is characterized by a positive impact on the profitability of the company.

The results of regression analysis enabled it to be established that in order to increase the profitability of Slovak medical device companies, the annual amounts of R&D investments are to be increased. Such suggestions are consistent with the results obtained by Luo, Hu & Yu (2018), which suggest that medical device enterprises with higher R&D expenses present better operational performance. At the same, an important issue is determining the optimal level of R&D investments, which is in the scope of future research. This is because it is this optimal value that should be the starting point for establishing the R&D investment policy of a company by the management. Jen Huang and Ju Liu (2005) defined the optimal level of R&D investments as 6.39% for the top 1,000 Taiwanese companies. Booltink and Helmhout (2018) found the critical threshold for investments in R&D for non-high-tech SMEs to be 2.1%. Knowing the available amount of R&D of the enterprise and the value of the initial critical amount of R&D, it is possible to determine the potential to invest in R&D and bring it into accordance with the general strategy of the company's development.

Based on the actual values obtained, which characterize the non-linear relation between R&D and profitability, two types of such inverted-U relations can be distinguished. In the first case, R&D has a positive significant impact on profitability, and R&D squared has a negative one (Jen Huang & Ju Liu, 2005; Erdogan & Yamaltdinova, 2019; Booltink & Helmhout, 2018; Chou et al., 2022). In the second case, the opposite situation can be observed, i.e., R&D negatively influences profitability, while R&D squared has a positive impact (Fortune & Shelton, 2012; Qi & Deng, 2019). The results of our study support the second scenario. Depending on the type of inverted-U relationship between R&D and profitability, managers are expected to set up the R&D investment policy of a company accordingly. That is, decisions are to be made to increase, decrease or maintain the existing volume of R&D investments in order to achieve the optimal level of profitability.

The results of panel regression analysis also made it possible to identify the presence of a significant positive impact of LEV on ROA at the 10% level, and the presence of a significant negative impact of l_S on ROA at the 5% level. The latter contradicts the results of the study by Archarungroj and Hoshino (1999), which revealed the positive role of larger firm size in ensuring the strength of the relationship between R&D and profitability.

Some limitations should be taken into account when considering the results of our study. Firstly, in our study ROA was chosen as a profitability indicator of medical device companies, which is influenced by the R&D expenditures incurred by a company. Our study results can be expanded and clarified by further studies in which other profitability indicators as dependent variables can be applied. Second, the list of independent variables that characterize the R&D activities of medical device companies can be expanded. In particular, such indicators could include the number of registered patents, the amount of internally generated intangible assets of the company (patent rights), R&D Investment (internally and externally-sourced), R&D Intensity and Degree of Internationalization, Intangible Asset Intensity, and R&D growth rate, which are widely mentioned by other authors (Danielson & Press, 2005; Fortune & Shelton, 2012; Booltink & Helmhout, 2018; Luo, Hu & Yu, 2018; Qi & Deng, 2019). Third, when carrying out panel data regression analysis, the assumption that annual R&D influences annual profitability was made. However, considering the creative and innovative nature of R&D activities, return on R&D investments may manifest itself not only in the current year, but may have a far more prolonged nature.

In addition, it is necessary to investigate the impact of lagged R&D effects on the profitability of medical device companies in future research.

CONCLUSION

The present study was performed to analyze the relation between R&D activities and the profitability of Slovak medical device companies using the panel data of 26 companies over the 2015–2019 period. Carrying out such research is especially relevant under the conditions of the rapid development of the Slovak medical products market and the implementation of the Slovak government's protectionist policy in this area. Research was conducted using panel data regression analysis. The Return on Assets ratio was chosen as the dependent variable characterizing the company's profitability. Four independent variables were chosen to explain it, i.e., Research and Development Intensity, Research and Development Intensity Squared, Leverage, and Size for the period.

Based on the application of the Breusch-Pagan test and the Hausman test, the feasibility of using the fixed effects method as an estimate parameter for the suggested empirical model was substantiated. The diagnosis of the adequacy of this model was carried out on the basis of the Normality test, the Autocorrelation test and the Heteroscedasticity test, applying the Gretl software package. Having revealed its low level of adequacy, the expediency of model estimation with robust standard errors was further substantiated.

Our study makes a significant original contribution to the existing scientific literature by giving empirical evidence of the relationship between R&D and company profitability. The research results obtained in the paper disprove the statement regarding the expediency and effectiveness of any investments in R&D in knowledge-intensive enterprises, despite the active development of the knowledge economy. In order to make effective investments in R&D, the limitations that are imposed on the company by the amount of such investments and that are caused by other factors, i.e, the size of the enterprise and leverage, should be taken into account.

The results of panel regression analysis demonstrated the existence of a curvilinear (inverted-U) relationship between R&D and profitability of medical device companies, which, in turn, confirmed the hypothesis of the study. Apart from this, the independent variable, RDI, has a significant negative impact on ROA at the 1% level, and RDI2 has significant positive impact on ROA at the 1% level. This shows that medical device companies with higher R&D intensity present better financial performance. However, for companies where R&D investments do not exceed the critical input volume, there is a negative relationship between R&D and profitability. Thus, these research results suggest that more investment in R&D is better for profitability, but only within the zone of optimal R&D activities. Medical device companies with an insufficient amount of R&D investment, which is smaller than their critical input volume, need to improve R&D investment policy towards increasing the quality and effectiveness of R&D activities.

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Appendix A
Sample for Panel Data Regression Model:
Financial Data of 26 Slovak Medical Device Production Companies

No.	Company	No.	Company
1	ALLdent s.r.o.	14	PGdent s.r.o.
2	AMD Zubná technika, s.r.o.	15	PROCORP, spol. s r.o.
3	BET-ROCK s.r.o.	16	PRODATIK, s.r.o.
4	BUFFALO - DENT s.r.o.	17	Profi Dental Design s. r. o.
5	CHIRANA Medical, a.s.	18	Protet, s.r.o.
6	CHIROMEGA s.r.o.	19	ŠAÁRDENT, s.r.o.
7	DENT-ART spoločnosť s ručením obmedzeným	20	SIMBA ZL, s.r.o.
8	DMF - DenTech, s.r.o.	21	VI DENTIA s.r.o., stomatologické laboratórium
9	Estelio, s.r.o.	22	VILADENT, spol. s r.o.
10	F-dent, spol. s.r.o.	23	ViVa Protetik s.r.o.
11	KO - lens, spol. s r.o.	24	ZUB - TECH, s.r.o.
12	PE EM, stomatologické laboratórium, s.r.o.	25	Zubná technika - Halušková, v.o.s.
13	PEGAS DENT, spol. s r.o.	26	Zubná technika Mgr. Peter Blaho, s.r.o.