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Contents

Research Articles

Research Articles

OVERALL LABOR EFFECTIVENESS AS A TOOL FOR MEASURING PERFORMANCE IN A GIVEN COMPANY

Zdeněk Brabec[1]; **Helena Jáčová**[2]
Technical University of Liberec, Faculty of Economics,
Department of Finance and Accounting,
Studentská 1402/2, 461 17 Liberec 1, Czech Republic
e-mail: [1]zdenek.brabec@tul.cz; [2]helena.jacova@tul.cz

Abstract

To remain competitive, a company needs to increase the productivity of its production equipment, which can be monitored using the Overall Equipment Effectiveness indicator. The article aims to describe the modification of the Overall Equipment Effectiveness indicator into the indicator of Overall Labor Effectiveness in a given company. The advantage of this indicator is that it monitors not only the use of the employee's labor pool but also the actual costs spent on the product. In addition to that, the impact of the introduction of this indicator on the economic performance of a given company is analyzed. To do so, four periods before and four periods after the introduction of the Overall Labor Effectiveness indicator were analyzed using four selected financial ratios. The value of the Overall Labor Effectiveness indicator is currently in the range of excellent values, i.e. the firm uses production time very efficiently. The results of the analyzed financial ratios show that the introduction of the Overall Labor Effectiveness indicator increased the performance of the given company.

Keywords

Competitiveness; Financial ratios; Losses; Productivity; Performance indicator.

Introduction

Current trends in financial management aim to analyze the company's performance using the shareholder value creation indicator. This concept is based on value management theory. This is a consistent application of the criterion of maximizing the net present value that the company is able to create for its owners, i.e., maximizing shareholder value.

Over several decades, a wide range of measures has been developed to express a company's performance. The changes in usage of various measures reflect the development of views on measuring company performance from profit margins and return on invested capital to modern concepts based on value management and shareholder value creation. Performance measurement systems containing benchmarks are proposed to support the company's strategy.

Many companies in the manufacturing industry both abroad and in the Czech Republic are nowadays using the Overall Equipment Effectiveness indicator (OEE) to measure and manage their performance. This indicator has been modified into several so-called derived indicators based on various requirements in the efficiency assessment. One of the derived indicators is the Overall Labor Effectiveness (OLE). However, the application of the Overall Labor Effectiveness indicator is not very common in practice. In addition to that, this indicator is not of great interest to scientists; its usage was mentioned e.g., by Braglia et al. [1] or Deepak et al. [2]. For this reason, the authors of this article have focused on the issue of calculating this indicator and its application in the selected company. Furthermore, the influence of the OLE indicator's introduction on the company's performance was also analyzed.

1 Literature Research

Parmenter [3] states that many companies use wrong measures that are incorrectly called key performance indicators (KPIs). He recommends rule 10/80/10, i.e., there are ten key results indicators, 80 performance indicators, and ten key performance indicators in the company. Other authors, such as Kaplan and Norton [4], also addressed the number of indicators and recommended a maximum of 20 key performance indicators. Remeš and Goswami [5] list five basic business performance measures categories (types). However, very few companies monitor their correct key performance indicators. The reason is that very few companies, responsible persons, consultants, etc., know what a key performance indicator is.

One method of measuring performance that companies widely use is "Overall Equipment Effectiveness (OEE)" [6]. Overall equipment efficiency (OEE) is an indicator of production equipment efficiency, which compares the efficiency of individual production equipment and entire production lines. In the 1960s, it was compiled by Seiichi Nakajima from the Nippon Denso company for the Japanese Institute of Plant Maintenance. This is a crucial indicator that helps to detect the hidden capacity of production machines, i.e., to identify losses. Utilization of hidden capacities helps increase productivity, reduce product prices, secure competitive advantage, and ultimately increase the company's operating profit. The OEE indicator aims to minimize wastage, increase output and quality measures, and thus improve efficiency [7]. The proper using of the OEE indicator requires using appropriate tools enabling real-time management of equipment [8]. This is consistent with the findings of Yazdi et al. [9], who studied the relationship between the OEE indicator and individual aspects of industry 4.0. The usage of the OEE indicators was further studied e.g., by Li et al. [10], Di Luozzo et al. [11], or Aminuddin et al. [12].

2 Research Objectives

The article's main aim is to measure the introduction of the indicator of Overall Labor Effectiveness on the performance in a given company. The modification is called Overall Labor Effectiveness, and it is designed to analyze capacity losses caused by human capital-related downtime in the form of absenteeism or shift changes. The main reason for introducing this indicator is to monitor the use of the labor force (worker), i.e., its productivity. This indicator is relatively new; there are only a few research articles focused on this topic. The advantage of this indicator is that it monitors not only the use of the employee's labor pool but also the actual costs spent on the product. Furthermore, the article analyzes the influence of the introduction of the OLE indicator in a given company operating in the automotive industry in the Czech Republic. Therefore, with the help of selected ratios, the economic performance of a given company in four periods before and four periods after the introduction of OLE has been analyzed.

3 Methodology

Based on literature research, the Overall Equipment Effectiveness indicator was characterized. Furthermore, the primary three subcomponents of the OEE indicator were defined. Subsequently, the method of its calculation was described. Additionally, three online consultations using Google Meet (April, August, and November 2021) were conducted with the CFO of the analyzed company. The analyzed company is a subsidiary of a multinational company, and its main business is the production of one single component for the automotive industry. The company carries out only the final assembly of a given component, and at the same time, each manufactured component undergoes a final inspection. The analyzed company is classified as a large enterprise according to all the measures (net assets, turnover,

and employees). In these consultations, questions were directed to the following basic information:

- what reasons led the company to modify the OEE indicator to an OLE indicator,
- where the company has drawn experience and information for the introduction of the OLE indicator,
- how the company has set up the calculation of the modified OLE indicator and how it has verified the accuracy of its predictive power,
- how the indicator was communicated to the staff,
- how the trade union and the employees reacted to the new indicator,
- how long it took to introduce the indicator in the enterprise,
- what the enterprise sees as the benefits of introducing the OLE indicator.

Based on the information mentioned above, the formula for calculating the OLE indicator is presented, including the characteristics of its subcomponents. The calculation of the OLE indicator value is based on specific values reported by the company, which had to be adjusted by a single coefficient not to disclose specific information.

To assess the impact of the introduction of the OLE indicator on the financial results, data obtained from the Magnus Web database was used, namely from the basic financial statements, including other supplementary data. Four periods before and four periods after the introduction of the OLE were analyzed. For this analysis, the following four indicators were chosen to compare the impact of OLE: Net Profit per Employee, Earnings before Interest and Taxes per employee, Return on Assets, and Return on Sales.

4 Overall Equipment Effectiveness Indicator

The OEE value is vital information for companies that continuously want to improve and streamline their production processes. This indicator comprises several components (parameters) that can be evaluated separately and thus influence the overall effectiveness. OEE helps maximize the company's assets to the availability of time (Availability) in producing output (Performance) with the best product quality (Quality) [13].

The overall effectiveness of the equipment is an effective tool for identifying bottlenecks. It can be integrated with other continuous improvement tools and techniques [14]. It is used in improvement programs such as downtime management (DTM), lean manufacturing, Six Sigma, or Kaizen. Hence, the indicator of overall equipment effectiveness (OEE) is suitable for reducing the identified losses and thus improving both performance and quality in production, leading to an increase in the company's operating profit.

The OEE indicator captures information on the availability, performance of production facilities, and production quality. The resulting values of these three sub-indicators are affected by certain losses. Sohal et al. [15] identified the following six main losses related to availability, performance, and quality:

- poor productivity and lost yield due to poor quality,
- set-up and adjustment for product mix change,
- production losses when temporary malfunctions occur,
- differences in equipment design speed and actual operating speed,
- defects caused by malfunctioning equipment, and
- start up and yield losses at the early stage of production.

Jonsson and Lesshammar [16] classified these losses into the three following groups: downtime losses (availability), speed losses (performance), and quality losses. Each group consists of two subgroups that characterize the losses in more detail, see Table 1.

Tab. 1: *Losses affecting the resulting values of individual factors of OEE*

Category of losses	Factor of OEE	Type (subgroup) of losses	Examples of losses
Downtime	Availability	Breakdown losses	Equipment failure Damage to the instrument Unscheduled breaks Waiting for work to be assigned Errors in logistics in the delivery of input material
		Set-up and adjustment losses	Heating processes Tool change
Speed loss	Performance	Idle losses (machine does not work)	Temporary disorder Change in production Defective material delivered
		Speed reduction	Difference between construction speed and operating speed Poor technical condition of the machine Unskilled labor
Quality	Quality	Machine run-up	Heating processes Failure to comply with standards
		Quality defects	Failure to comply with technological procedures Defective input material (scrap production) Machine failure Unclear task assignment Employee errors

Source: Own elaboration based on [17] and [18]

4.1 The Calculation of the Overall Equipment Effectiveness Indicator

The OEE consists of three sub-components: machine usage (availability), machine performance, and quality level of production. The calculated values of these individual components are multiplied together to obtain the resulting OEE value. Its value is given as a percentage of the utilization of the standardized capacity of the equipment. Simply put, it determines the percentage of production time that is genuinely productive. If the OEE indicator is equal to 100%, it means 100% quality (good products only), 100% performance (as fast as possible), and 100% availability (no downtime). If the value of the OEE is greater than 85%, it usually represents excellent values, meaning that the company works very efficiently. However, the resulting percentage varies according to the type of production - while in batch or piece production, the percentage is, in principle, smaller, in mass and highly automated production, it is between 90 and 100% [8]. The OEE indicator is calculated using formula 1.

$$\text{OEE} = \text{Availability rate} \times \text{Performance efficiency} \times \text{Quality rate} \times (100\%) \quad (1)$$

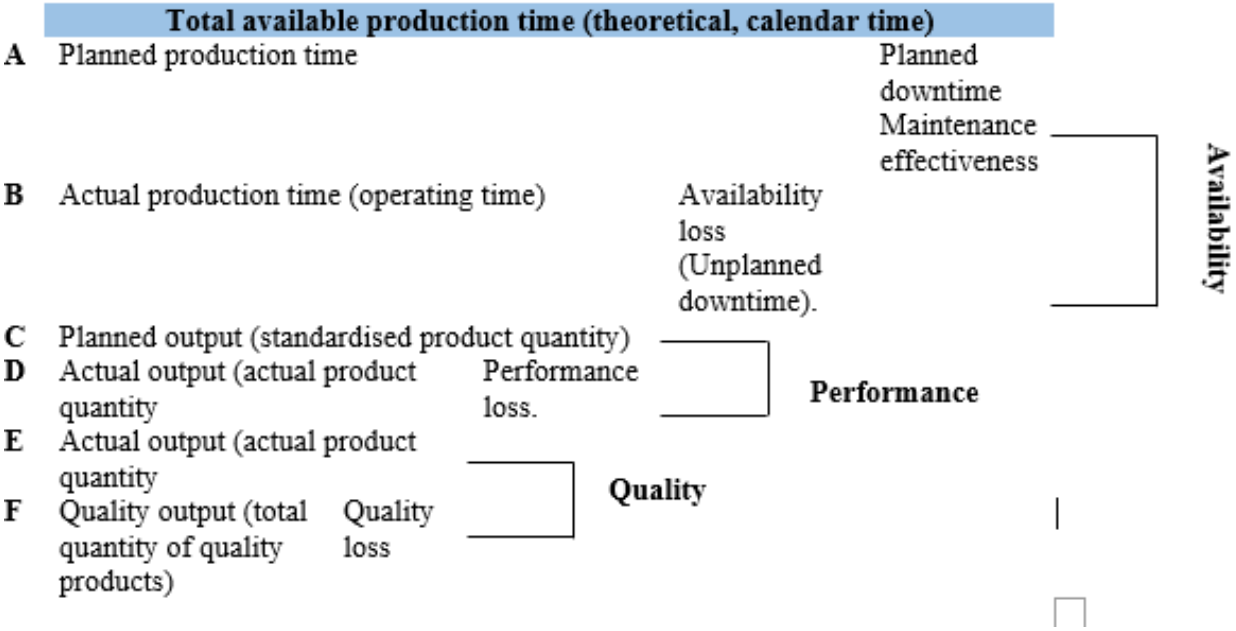
The exact definition of OEE differs between applications and authors. Table 2 shows the two approaches applied by Nakajima [19], the original author of OEE, and De Groote [20].

Tab. 2: *The calculation of the OEE indicator*

Indicator	Nakajima [19]	De Groote [20]
Availability (A)	$\frac{\text{Loading time} - \text{downtime}}{\text{Loading time}}$	$\frac{\text{Planned production time} - \text{Unplanned downtime}}{\text{Planned production time}}$
Performance (P)	$\frac{\text{Ideal cycle time} \times \text{output}}{\text{Operating time}}$	$\frac{\text{Actual amount of production}}{\text{Planned amount of production}}$
Quality (Q)	$\frac{\text{Input} - \text{volume of quality defects}}{\text{Input}}$	$\frac{\text{Actual amount of production} - \text{nonaccepted amount}}{\text{Actual amount}}$
OEE	(A) × (P) × (Q)	(A) × (P) × (Q)

Source: Own elaboration based on [19] and [20]

Figure 1 shows the input values that are used to calculate the individual components of the OEE indicator. The total available time represents a period of 7 days per week and 24 hours per day. There are periods when production is neither realized nor scheduled within this time frame. This is planned downtime, which includes days off work and public holidays falling on a working day.



Source: Own elaboration based on [15]

Fig. 1: *Illustration of the main components of OEE*

In order to capture critical data and to examine how production contributes to overall company performance, it is vital to measure and understand how to quantify failures in the production process. Management experts commonly refer to OEE measurement as the best metric for identifying losses, advancing progress, and improving production equipment productivity. By measuring OEE, important information can be obtained on how to improve the production process systematically. Most manufacturing companies, even today, have an OEE score of about 60% and are more likely to encounter companies with OEE values below 45% than companies with OEE values above 85% [21].

Today, many companies in the field of industrial automation, not only abroad but also in the Czech Republic, deal with the measurement and evaluation of OEE, which offer consulting

services and specific software, applications, and entire systems for data collection, evaluation, and presentation.

4.2 Application of the OEE Principles to the Workforce in the Analyzed Company

Following the new requirements in the evaluation of effectiveness, so-called derived indicators have been developed, which are focused on either the equipment or the enterprise level. One of the most widely used indicators is the Total Equipment Effectiveness Performance (TEEP). The next derived indicator is Production Equipment Efficiency (PEE). Other derived indicators correspond to the specific requirements of particular industries (Overall Asset / Procedure Effectiveness – OAE, OPE). For expressing the efficiency of the whole enterprise, the Overall Factory Effectiveness (OFE) indicator is used [22].

The analyzed company has implemented its modification of the OEE indicator, namely the indicator of labor efficiency (OLE). In this modification, capacity losses, which in the case of OEE represent downtime, set-up, and adjustment, are replaced by human capital-related downtime in the form of absenteeism or shift changes. Similarly, capacity losses in the case of OEE are replaced by missing processes, lack of training, or staff working non-standard. The last part of the OEE indicator focuses on quality, which focuses on quality errors, the need for rework, or start-up errors. These quality-reducing factors are retained in the modification of the OEE to OLE in the case of quality error and need for rework. At the same time, the ramp-up error factor is modified to the non-compliance with processes factor. To calculate the Overall Labor Effectiveness, the analyzed company adjusted the calculation of the individual components as shown in formulas 2, 3, and 4.

$$\text{Availability} = \frac{\text{Productive time} + \text{External extra work}}{\text{Total production time}} \tag{2}$$

$$\text{Performance} = \frac{\text{Number of faultless products x standard time} + \text{External extra work}}{\text{Productive time} + \text{External extra work}} \tag{3}$$

$$\text{Quality} = 1 - \frac{\text{Scrapping costs}}{\text{Material costs}} \tag{4}$$

4.3 Process of Implementation of the OLE Indicator in the Analyzed Company

To succeed in a competitive market, the company consistently applies a customer-oriented management system. For this reason, it is constantly improving and enhancing its production processes and introducing indicators that will lead to improved production efficiency and quality. The key performance indicator in the analyzed company is modifying the OEE indicator to the OLE indicator.

When the company decided to monitor the OLE indicator, it first had to answer the question, “Why introduce and monitor this indicator?” Firstly, the company decided to use only one comprehensive indicator instead of a variety of indicators to measure and manage its performance. The customers put pressure on the company to keep the cost of the required products as low as possible. Therefore, it was necessary to start monitoring the use of individual employees’ work funds to avoid unnecessary downtime and achieve the highest possible labor productivity. The introduction of a single OLE indicator will lead to the determination of all employees’ bonuses. At the same time, it will increase the motivation of each employee. This will align with the goals of the company and its employees.

The second question was, “Where to get experience and information to implement the OLE indicator?” Selected employees completed training on the use of the OLE indicator, where they could discuss the issue and problems with the implementation of the indicator with

companies that already had the indicator in place or were implementing it. Finally, yet importantly, it was necessary to draw on the theoretical information provided in the literature or professional articles.

In the next step, it was necessary to ask, "How to set the calculation of the indicator and adapt it to the conditions of the company?" Several years ago, the company had data available for individual production lines and individual shifts. Based on this data, the company was able to determine a formula for calculating the OLE indicator and set appropriate goals. Subsequently, the calculation of the given indicator had been performed for several previous years, which showed that in some parameters the calculation was not accurate. The formula has been modified to provide relevant information based on these findings.

The input values for the calculation of Overall Labor Effectiveness (OLE) in the analyzed enterprise, which are presented in Table 3, were adjusted by a constant coefficient. Based on the given data, formulas 2, 3, and 4 were used to calculate individual components of the OLE indicator.

Tab. 3: *The calculation of Overall Labor Effectiveness*

Initial situation		**Shift time structure**	**Hours**
Shift length	8 hours	Productive time	130.0
Lunch break	30 minutes	Internal extra work	0.0
Number of workers in the line	20 workers	External extra work	6.5
Number of handlers in the line	1 worker	Waiting for material	0.0
Standard time	125 minutes per 100 pieces	Manipulation	7.5
		Machine repairs	6.0
Shift recording		Production changes	6.0
Number of production changes	3 times per shift	Training	0.0
Time to change production	6 minutes	Sampling	10.0
Technical downtime	18 minutes	Total production time	166.0
Production of samples	30 minutes		
Additional material inspection	1 worker		
Number of faultless products	6,000 pieces		
Material costs	900,000 CZK		
Scrapping costs	3,750 CZK		

Source: Own

$$\text{Avalability} = \frac{130.0+6.5}{166.0} \times 100 = 82.23\%.$$

$$\text{Performance} = \frac{[(6{,}000 \times 125):100]:60+ 6.5}{130.0+6.5} \times 100 = \frac{125+6.5}{136.5} \times 100 = \frac{131.5}{136.5} \times 100 = 96.34\%.$$

$$\text{Quality} = 1 - \frac{3{,}750}{900.000} \times 100 = (1 - 0.00417) \times 100 = 0.99583 \times 100 = 99.583\%.$$

OLE = (0.8637 x 0.9634 x 0.99583) x 100 = 82.86%.

The resulting value of the OLE indicator corresponds to a good performance but it should be increased to over 85%, which is the mark of excellent companies.

4.4 Impact of the Introduction of the OLE Indicator on the Economic Results of the Analyzed Company

Since the company does not wish to disclose specific OLE data, data from the Balance Sheet, Profit and Loss Statement, and other supplementary data gathered from the MagnusWeb database were used to assess the impact of the introduction of OLE in the analyzed company. The average values of selected financial ratios calculated for the monitored indicators before and after the introduction of the OLE indicator are presented in Table 4. The years 2020 and 2021 were not included in the analysis period as the economic results are already affected by the impact of the Covid-19 pandemic.

Tab. 4: *Average values of selected indicators before and after the introduction of the OLE indicator*

Ratio	**Average values of selected ratios before introducing the OLE indicator**	
	2012 – 2015	**2016 – 2019**
ROA (in %)	7.20	8.63
ROS (in %)	3.22	3.80
EAT per one full-time employee (in thousands CZK)	154.35	208.88
EBIT per one full-time employee (in thousands CZK)	209.08	228.20

Source: Own elaboration based on the data from MagnusWeb database

The net profit per employee in the first year after the OLE indicator was introduced declined. In the following years, the EAT ratio gradually increased, and the values in each year significantly exceeded the values before introducing the OLE indicator. After introducing the OLE indicator the average EAT per employee increased by approximately 50,000 CZK. The same development was also observed in the EBIT per employee. After introducing the OLE indicator the average EBIT per converted employee increased by approximately 20,000 CZK.

Next, the development of two profitability ratios (ROA and ROS) was analyzed. The inputs used to calculate the ROA ratio were net profit and total assets. The introduction of the OLE indicator led to an increase in the Return on Assets ratio. After the introduction of OLE, the average ROA ratio increased by 1.4%. A similar development was observed for the ROS indicator. After introducing the OLE indicator the average ROS ratio increased by 0.6%.

Based on the results, it can be concluded that the introduction of the OLE indicator led to an increase in the company's performance. From the results of the monitored ratios, it can be concluded that the enterprise uses production time productively and, therefore, minimizes time losses. The correct identification of time losses has probably led to increased profits, which is reflected in an increase in profitability values. Data on product scrap rates were not provided, so it is not possible to determine whether there has been a reduction in scrap rates.

5 Discussion

The advantage of this indicator for the company was that its introduction did not entail significant interventions in management. The indicator was introduced in the company within six months. This brief period of time was due to the fact that the company had the necessary data from several years back, on which it could verify the design, functionality, and informative power of the OLE indicator. In terms of the achieved value of the OLE indicator presented in Table 3, the result ranks the analyzed company among the companies that work very efficiently, i.e. that they use production time effectively. The introduction of the OLE

indicator also led to an increase in the financial performance indicators, as shown in Table 4. The obtained results relate only to the analyzed company, and for this reason, these results cannot be generalized.

Generally speaking, the OEE and derived indicators cover all the causes of time loss that can be considered in a given situation. In addition to that, these indicators can be expressed in monetary units almost immediately. There is no need to wait for the publication of financial statements to calculate the loss. In terms of quality, the issue of the production of defective products entered the subconscious mind of employees, which led to its reduction. However, it is necessary to realize that the production of a defective product may not be caused only in the production process but may be caused by other influences, such as the defective material supplied, etc. [1]. When evaluating the resulting values of the OLE indicator, it is always necessary to consider the field of business and the type of production. Furthermore, the OLE indicator monitors the use of the employee's labor pool and the actual costs spent on the product [2]. Other authors, such as Bonci et al., suggest introducing a new LEAN-ROLE indicator that can identify the employees' contribution to the customer's value [23].

Conclusion

The OLE indicator must be taken as a concept covering everything that happens in the production process. The reason for the introduction of this indicator was to monitor the use of the labor force (worker), i.e., his productivity. It is also crucial for employees to be given one indicator that they can monitor themselves, which has also led to a modification of the remuneration system. This indicator affects the bonuses of all employees based on their work performance. Employees see (understand) that this is a fair distribution of bonuses and therefore accept this indicator. The introduction of the OLE indicator has led to an increase in employee awareness of the importance of production.

The authors would like to continue with their research by preparing a questionnaire survey, which would focus on companies with the same field of business as the analyzed company. The results of the research would provide interesting information, since the OEE, OLE indicators or other modifications of the OEE indicator and their impact on financial performance are not a very common topic of research articles.

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CELKOVÁ EFEKTIVITA PRÁCE JAKO NÁSTROJ PRO MĚŘENÍ VÝKONNOSTI V DANÉM PODNIKU

Pro udržení konkurenceschopnosti je velmi důležité, aby společnost zvyšovala produktivitu svých výrobních zařízení, což lze sledovat pomocí ukazatele Celkové efektivity zařízení. Článek pojednává o modifikaci ukazatele Celkové efektivity zařízení na ukazatel Celkové efektivity práce v rámci daného podniku. Výhodou tohoto ukazatele je, že monitoruje nejenom využití pracovního fondu zaměstnance, ale i skutečné náklady výroby daného produktu. Dále je analyzován vliv zavedení tohoto ukazatele na ekonomickou výkonnost daného podniku. Za tímto účelem byly analyzovány 4 vybrané ukazatele ve 4 letech před zavedením ukazatele Celkové efektivity práce a ve 4 letech po jeho zavedení. Hodnota ukazatele Celkové efektivity práce v současnosti nabývá hodnot, které lze označit za výborné, a proto lze konstatovat, že podnik využívá výrobní čas efektivně. Výsledky analyzovaných finančních ukazatelů dokazují, že zavedením ukazatele Celkové efektivity práce došlo ke zvýšení výkonnosti daného podniku.

DIE ALLGEMEINE ARBEITSEFFIZIENZ ALS INSTRUMENT ZUR BEWERTUNG DER LEISTUNG EINES BESTIMMTEN UNTERNEHMENS

Um wettbewerbsfähig zu bleiben, ist es für ein Unternehmen sehr wichtig, die Produktivität seiner Produktionsanlagen zu erhöhen, was mit dem Indikator der Gesamteffizienz der Ausrüstung überwacht werden kann. In diesem Artikel wird die Modifizierung des Indikators der Gesamteffizienz der Ausrüstung Indikators in den Indikator der Gesamtarbeitseffektivität in einem Unternehmen erörtert. Der Vorteil dieses Indikators besteht darin, dass er nicht nur die Nutzung des Arbeitskräftepools der Arbeitnehmer überwacht, sondern auch die tatsächlichen Kosten für die Herstellung des Produkts. Außerdem werden die Auswirkungen der Einführung dieses Indikators auf die wirtschaftliche Leistung des Unternehmens analysiert. Zu diesem Zweck wurden vier Perioden vor und vier Perioden nach der Einführung des Indikators der Gesamtarbeitseffektivität anhand von vier ausgewählten Finanzkennzahlen analysiert. Der Wert des Indikators liegt derzeit im Bereich dessen, was als exzellente Werte bezeichnet wird, d.h. das Unternehmen nutzt die Produktionszeit sehr effizient. Die Ergebnisse der analysierten Finanzindikatoren zeigen, dass die Einführung des Indikators der Gesamtarbeitseffizienz die Leistung des Unternehmens erhöht hat.

CAŁKOWITA EFEKTYWNOŚĆ PRACY JAKO NARZĘDZIE POMIARU WYNIKÓW W DANYM PRZEDSIĘBIORSTWIE

Aby zachować konkurencyjność, przedsiębiorstwo musi zwiększyć produktywność urządzeń produkcyjnych, co można monitorować za pomocą wskaźnika Ogólnej Efektywności Wyposażenia. Celem artykułu jest opisanie modyfikacji wskaźnika Ogólnej Efektywności Wyposażenia na wskaźnik Ogólnej Efektywności Pracy w danym przedsiębiorstwie. Zaletą tego wskaźnika jest to, że monitoruje on nie tylko wykorzystanie puli pracy pracownika, ale również rzeczywiste koszty wydatkowane na produkt. Dodatkowo analizowany jest wpływ wprowadzenia tego wskaźnika na wyniki ekonomiczne danego przedsiębiorstwa. W tym celu przeanalizowano cztery okresy przed i cztery okresy po wprowadzeniu wskaźnika Ogólnej Efektywności Pracy, wykorzystując cztery wybrane wskaźniki finansowe. Wartość wskaźnika Ogólnej Efektywności Pracy znajduje się obecnie w przedziale wartości doskonałych, czyli firma bardzo efektywnie wykorzystuje czas produkcji. Wyniki analizowanych wskaźników finansowych wskazują, że wprowadzenie wskaźnika ogólnej efektywności pracy zwiększyło wydajność danego przedsiębiorstwa.

FUZZY PAYBACK PERIOD OF INVESTMENT INTO MODERNIZATION OF PRODUCTION NETWORK

Simona Hašková[1]; **Jiří Kučera**[2]; **Róbert Kuchár**[3]
Institute of Technology and Business in České Budějovice,
School of Expertness and Valuation, Research Group of Business Finance,
Okružní 517/10, 370 01 České Budějovice, Czech Republic
e-mail: [1]haskova@mail.vstecb.cz; [2]kuceraj@mail.vstecb.cz; [3]kuchar@mail.vstecb.cz

Abstract

The difference between the result of managerial calculations and reality can be largely attributed to uncertainty. In the case of discounted payback period (DPP), it concerns uncertain capital expenditures, positive cash flows, and discount rates. To resolve this problem the intervals of possible values instead of uncertain point values should be regarded. This idea is projected in defining the significant points of the input parameters for the DPP calculation from which the significant points of the fuzzy payback period (FPP) in the sense of triangular fuzzy numbers (TFN) are derived. For the TFN ranking, the weighted method is used. The FPP numerical formula thus becomes flexible in terms of the possibility of expressing faith in the incidence rate of the input data. The existing literature omits to regard negative weights for positive and/or negative cash flows in the FPP calculation. In the application, the relations are applied to the quantification of the FPP interval of possible values, by means of which the investment plan for the modernization of the lignite power plant is evaluated.

Keywords

Fuzzy payback period; Discounted payback period; Investment decision; Production network; Uncertainty.

Introduction

Management practice uses several methods to decide on investing in a long-term business plan. Some of them are based on a one-criterion evaluation of economic efficiency. The most significant representatives include net present value, internal rate of return, and discounted payback period. When it comes to the input components of these criteria, they are often associated with uncertainty, which usually has two main sources, the vagueness of the rules and external circumstances beyond the decision-maker. [1]

1 Research Subject

The aim of this article is to show how uncertainty stemming from uncontrollable circumstances can be dealt with, at least partially. For example, the discounted payback period (DPP) determined in a conventional manner e.g. in [2] will almost certainly differ from the actual payback period. This is because the calculation is based on a mathematical model of vague notions that the farther or riskier a project's cash flow (CF_i) is, the less significant value is today. [3] This is because today's money has a bigger value than the same amount expected in the future. However, most of the difference between the DPP calculation result and reality is due to uncertainty associated with ignorance of the exact future capital expenditure points (CF_0), CF_i and discount rate (r). There is a greater chance of estimating the

intervals in which the respective point values of the indeterminate variables will be located than correctly estimating the point values themselves. It follows that we will be more successful in estimating the result of the criterion calculation if we use the intervals of possible values instead of indefinite point values. [4]

The article presented builds on this idea and further develops it, inspired by the works of Kahraman [5] and Banerjee and Roy [6]. For the purposes of calculating the discounted payback period (DPP), the "conventional" relationship valid for the point values CF_0, CF_i, and r is first reformulated to the relationship valid for the intervals of possible values $\boldsymbol{CF_0}$, $\boldsymbol{CF_i}$ and $\boldsymbol{r}$.

Within the calculus of intervals represented by their significant points $\boldsymbol{CF_0}$, $\boldsymbol{CF_i}$, and $\boldsymbol{r}$, the significant points of the fuzzy discounted return (FPP) interval are derived. This procedure is demonstrated in the evaluation of the perspective of the investment plan for the modernization of a conventional lignite power plant by the FPP criterion. The fuzzy return criterion is calculated for a specific implementation in the given regional conditions.

The contribution of the article is a new perspective of using the ranking function for ranking the triangular fuzzy numbers according to Chiu and Park [7], which is based on the weight parameter w, the value of which is determined by the evaluator. This allows him/her, based on currently available information, knowledge, and experience, to evaluate the input data flexibly and thus enter into an otherwise "mechanical" computational process. The method presented in this way is meaningful for practice and user-friendly.

2 Literature Review

The investment in the project is characterized by an initial capital expenditure with the subsequent assumption of its gradual return. Marić et al. [8] provide an overview of several static and dynamic methods designed for the economic evaluation of projects. Bhandari [9] and others in their work prove that static methods do not achieve as good results as dynamic methods. The basic dynamic methods of investment evaluation include payback period (DPP), net present value (NPV), and internal rate of return (IRR). There is a relationship between them [8]. Shinoda [10] encourages companies to select the evaluation methods that are most appropriate and accurate for determining the return on investment given the size of the project.

From a theoretical point of view, Bhandari [9] dealt with the discounted payback method. This is the first period in which the accumulated value of net discounted cash flows equals or exceeds the capital investment. The DPP result is compared with the maximum allowable payback period or other criteria, such as the economic life of the project. Bhandari [9] compared this method with other investment evaluation methods. He then presented arguments about its advantages, which are the simplicity of the method, easy calculation, the ability to measure the profitability of the investment, liquidity determination of the investment, and risk reflection. The DPP criterion is widely used in many areas. For example, return on investment in photovoltaic power plants [11], return on investment in various ecological investment projects focused on building heating (insulation, low-energy buildings, biomass boilers, solar thermal systems, and heat pumps) [12], return on investment in agriculture in poultry farming and dairy production [13].

The use of multicriteria analyzes has been shown to be very effective in determining DPP investment [14]. Fuzzy arithmetic has a place in multicriteria evaluation [15]. Dick [16] introduces a comprehensive fuzzy approach as a new topic of computational intelligence. All research in the field of complex fuzzy systems has so far focused on conjunction, disjunction, and negation operators. In this approach, Pythagorean fuzzy sets are extended by the terms

anti-membership and anti-non-membership to the already known terms membership and non-membership.

Fuzzy payback period (FPP) is an extension of the concept of the payback method for real cash flows [17]. The construction of the real cash flows generated by the project requires an estimate of future revenues and costs, which depends on many parameters such as the size of inflation, the interest rate, etc. [18]. These variables are uncertain in nature and, unless reliable information on their probability occurs, statistical methods are not appropriate to estimate them. If the source of uncertainty is incomplete information, it is possible to represent the values of variables using fuzzy numbers, which can be interpreted as fuzzy subsets of a set of real numbers satisfying some other conditions. Fuzzy numbers make it possible to model improbability phenomena in a simple way. [19]

Ratiu et al. [20] show that the fuzzy approach is able to capture uncertainty in the development of cash flow and interest rates. Its advantage is the ability to consider both financial and non-financial indicators; it allows, for example, to combine risk dimension, financial return, and non-financial factors [21]. In terms of determining the risk of an investment project, it is possible to use a fuzzy approach to evaluate quantitative and qualitative characteristics through the interpretation of input parameters by fuzzy sets. In this case, the fuzzy approach can function as a decision-making system that assesses whether the risk concern of a given project is justified or not. [22]

Vijayakumar et al. [23] compiled a ranking of evaluation criteria for investment projects. For the overall evaluation of the project, it is good to consider the NPV, DPP, investment size, cost and profitability, and time to make a profit. For the final evaluation of projects, they used a fuzzy approach, which processed the point results of the above criteria and quantities. Sergi et al. [24] propose fuzzy extensions for the most used capital budgeting techniques. It is an extension of NPV methods, equivalent uniform annual value, and benefit-cost ratio (B / C) to interval evaluation of investments using interval-valued Fermatean fuzzy sets and algebraic and aggregation operations.

Briozzo et al. [25] dealt with the modeling of missing data using a fuzzy approach and, for the purposes of applying traditional methods for project evaluation, including the DPP method, analyzed its use. They add that using the fuzzy approach has many advantages. The fuzzy method contributes additional information to the result obtained by the traditional method. The fuzzy method can be applied as a complex method for determining and estimating all input quantities and for individual evaluation of individual components separately, as shown by Ak et al. [26] when evaluating the investment in the wastewater treatment system.

Banda [27] applied a fuzzy payback period to evaluate investment in mining projects and to evaluate mining methods. The financial and technological aspects of individual project variants were evaluated. Kahraman et al. [28] dealt with the implementation of fuzzy logic into other methods used to evaluate investment projects, including FPP. In [29], Kahraman focused on software development, which includes, among other things, a function for evaluating an investment project using FPP. Computational software capable of synthesizing the results of dynamic methods NPV, IRR, cost-benefit ratio and DPP was designed and developed by Samartkit and Pullteap [30]. Fuzzy approach was subsequently used to evaluate the level of probability of the rate of return and the payback period of the investment project.

3 Methodology

The discounted payback period method (DPP) considers the time needed to cover the initial investment costs of the project. The calculation of the DPP considers the time value of money, and thus makes it possible to provide a more objective result with regard to the time and risk

factor than the calculation of the undiscounted return. In the following, let us denote C_0 as the investment expense, CF_i as the net return generated by the investment for the period i and r as the discount rate of the project. If $CF_i > 0$ then:

$$\sum_{i=1}^{m} CF_i(1+r)^{-1} \geq CF_0, \tag{1}$$

where m represents the return horizon considering the time value of money. According to the DPP criterion, the investment is realized when discounted payback period is shorter than its economic lifetime.

In the case of uncertain values CF_0, CF_i and r, we substitute into (1) for CF_0, CF_i and r the symbols of the triples of real numbers $CF_0 = (CF_{0l}, CF_0, CF_{0r})$, $CF_i = (CF_{il}, CF_i, CF_{ir})$ and $r = (r_l, r, r_r)$, composed of significant points of intervals of possible uncertain values. Left index l, respectively the right index r in the respective trio indicates the smallest, respectively the largest element of the set of values. The middle number indicates the value of the most common or unexpected element - it is a number whose value we estimate under the standard approach in risk conditions.

For the Triangular Fuzzy Number (TFN) generally represented by the three parameters $\boldsymbol{A} = (a_l, a, a_r)$, for which $a_l \leq a \leq a_r$ applies, and defining the payback period it holds (2):

$$\left(\sum_{i=1}^{m}\left(\frac{CF_i^{l(y)}}{(1+r^{r(y)})^i}\right), \sum_{i=1}^{m}\left(\frac{CF_i^{r(y)}}{(1+r^{l(y)})^i}\right)\right) \geq \left(\left(CF_{2(0)} - CF_{1(0)}\right)y + CF_{1(0)}, \left(CF_{2(0)} - CF_{3(0)}\right)y + CF_{3(0)}\right), \tag{2}$$

where $CF_{k(0)}$ represents the k-th parameter of the triangular fuzzy number CF_0, $CF_i^{l(y)}$ is the left representation of the triangular fuzzy CF_i, $CF_i^{r(y)}$ is the right representation of the triangular fuzzy CF_i, $r^{r(y)}$ is the right representation of the discount rate, $r^{l(y)}$ is the left representation of the discount rate.

If the discount rate varies across periods, then for $(1+r^{r(y)})^i$ and $(1+r^{l(y)})^i$ it holds (3):

$$\prod_{i'=1}^{i}\left(1+r_{i'}^{r(y)}\right), \prod_{i'=1}^{i}\left(1+r_{i'}^{l(y)}\right) \tag{3}$$

There are a few methods for ranking Triangular Fuzzy Numbers (TFNs), for example, Jain [31], Chiu and Park [7], Kaufmann & Gupta [32], and others.

Methods can take different ranking results and most of them require complex mathematical calculations. Chiu and Park [7] present a weighted method for ranking Triangular Fuzzy Numbers with parameters (a_l, a, a_r) as follows (4):

$$\left(\frac{a_l+a+a_r}{3}\right) + wa, \tag{4}$$

where $w \in \langle 0,1 \rangle$ is the value determined by the nature and size of the value a. Another ranking method that does not require complex mathematical calculations is the graded means method (5):

$$\left(\frac{a_l+4a+a_r}{6}\right) \tag{5}$$

which Shanmugasundari & Ganesan [33] used to solve the fuzzy transportation problem.

4 Data

The data of the investment plan for the modernization of a conventional lignite power plant consisting of the implementation of PtG technology were obtained from the article by Straka [34]. Based on the knowledge of technological parameters and production possibilities of the future installation of PtG technology (Power to gas), the author estimates the annual cash flow (CF), which is captured in Table 1.

To carry out the process of so-called methanation (splitting into methane) of emitted CO_2 Straka in [34] estimates electricity consumption for one year at 56,134 MWh, while the current price of 1MWh on the market is around 131 € (at the time of the investment calculation in 2021). The author estimates the water consumption for the methanation process due to the supply of hydrogen at 4,806.5 m^3 at an average price of 3.5 € / m^3. The fixed operating costs of the entire facility are estimated at € 430,500. The total annual expenditure is calculated at € 7,800,877.

The author calculates annual revenues from the operation of the facility as follows: sales of produced oxygen due to the production possibilities of the technology are estimated at € 12,819,384, sales of methane at € 1,551,184, sales of waste heat the author estimates at € 645,227. Recycling of waste CO_2 reduces its emissions into the atmosphere, which results in a reduction in the cost of obtaining emission allowances. The price of the emission allowance per 1 ton of CO_2 emitted was at the level of € 25 at the time of the investment calculation. Due to the amount of recycled CO_2, this represents a saving of € 146,905. The budgeted value of the annual cash flow is € 7,361,823.

Tab. 1: *Estimation of cash flows*

Item	**Amount**	**€ / unit**	**€ / year**
Electricity consumption	56,134 MWh	131 € / MWh	7,353,554.00 €
Water consumption	4,806.5 m^3	3.5 € / m^3	16,823.00 €
Fixed operating costs	430,500	€	430,500.00 €
Total expenditure			7,800,877.00 €
Oxygen sales	8,546,256 kg	1.5 € / kg	12,819,384.00 €
Sales of methane	1,666,625 kg = 23,152 MWh CH4	67 € / MWh NG	1,551,184.00 €
Sales of waste heat	11,731 MWh	55 € / MWh	645,227.00 €
Saving CO2 emission allowances	5,876,208 kg	25 € / ton of CO_2	146,905.00 €
Total revenue			15,162,700.00 €
Annual cash flow			**7,361,823.00 €**

Source: Own processing based on Straka [34]

Capital expenditures for the implementation of PtG technology are estimated at € 21,525,000. A detailed breakdown of investment items is given in Table 2.

Tab. 2: *Breakdown of capital expenditures*

Investment item	**Price (€)**	**Note**
3 alkaline electrolyzers of 3.56 MW, a total of 10.68 MW	12,390,000.00	1,180 € / kW
2 medium pressure gas tanks (O_2 and H_2)	2,940,000.00	490 € / kg
Methanation reactor	2,478,000.00	20 % ALE*
CO_2 capture unit	2,478,000.00	20 % ALE*
Other and unforeseen expenses	1,239,000.00	10 % ALE*
Total investment costs	**21,525,000.00 €**	

*Purchase price of alkaline electrolyzer

Source: Own processing based on Straka [34]

Straka [34] used the conventional approach to calculate the discounted payback period of 3.8 years at a discount rate of 8% and 5.1 years at a discount rate of 15%. Given the estimated lifetime of the project since its commissioning, the results of the return show a promising investment.

As part of the evaluation of the project, Straka [34] admitted the occurrence of risk and projected it into two different values of discount rates. Further on, we will deviate from the author's conventional approach and consider the occurrence of factors that are inherently uncertain, and their impact on the return result may be significant. Uncertainty in the fossil fuel market (N1), uncertainty on the part of the EU towards conventional power plants (emission allowance prices, fines, taxes) (N2), uncertainty about energy market prices (N3), uncertainty in product gas prices (N4) and/or uncertainty in technology acquisition prices (N5). These uncertain factors are reflected in the uncertain values of CF, capital expenditures, and project discount rate.

The logic of reflecting the effects of uncertainty on the evaluation criterion is directly offered at the time of the ongoing "energy revolution". Let us consider the rapid development of energy market prices, caused by societal pressure to increase the carbon neutrality of EU Member States and the transition to fully renewable energy sources [35], which is currently stimulated by the Russian-Ukrainian war [36], the turbulent development of prices in the market for technologies, energy, building materials or services, driven by pandemic restrictions and the slowdown in efforts to curb mining earlier. [37]

Uncertainty factors N1-N5 have an impact on the uncertainty of the project input data, which can in fact be projected in the intervals of possible values of the input investment CF_0, annual cash flow CF_i generated for the lifetime of the project and discount rate r as $CF_0 = (CF_{0l}, CF_0, CF_{0r})$, $CF_i = (CF_{il}, CF_i, CF_{ir})$ and $\boldsymbol{r} = (r_l, r, r_r)$, where index 0, respectively *I*, indicates the period of capital expenditures in year 0, respectively, the period of positive cash flows. Left index *l*, respectively the right index *r*, indicates the smallest, respectively, the largest element of the set. The middle number indicates the value of the most common or most expected element (the value we estimate under the standard risk approach).

Table 3 shows the intervals of possible CF_0 values, annual CF_i and $\boldsymbol{r}$ identical for the expected lifetime of the investment.

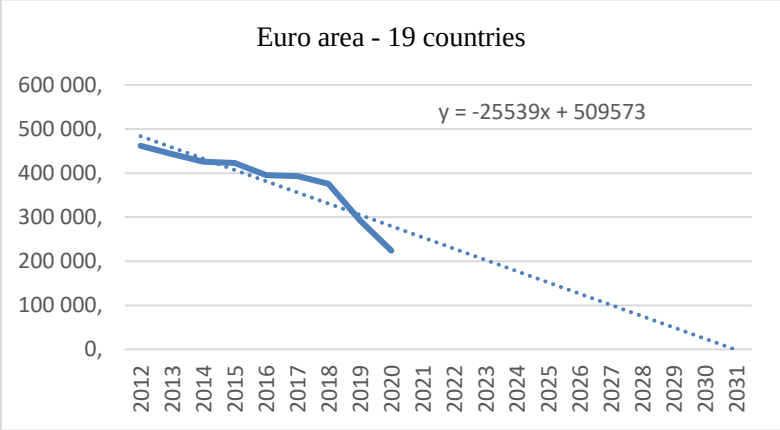
Tab. 3: *Intervals of limit values of uncertain variables*

Uncertain variable	CF_0 in thousands €	Annual CF_i in thousands €	Annual $\boldsymbol{r}$ in %
Range of possible values	(-25,502; -21,252; -17,001)	(5,889, 7,361, 8,833)	(8; 11.5; 15)

Source: Own

The range of possible values of the interval CF_0 and CF_i was determined by a deviation of +/- 20% from the budgeted value, see Tables 1 and 2, the range of possible values of the interval ***r*** is defined by the minimum and maximum rate *r* reflected in the standard DPP calculation.

The minimum lifetime of the investment, resulting from the forecast for coal mining in the Eurozone, is estimated at 9 years if the investment is put into operation in 2022. [38] The estimate was made based on data representing the development of fuel coal production in thousands of tons in the period 2012-2020 in the Euro area region of 19 countries. The trend of this development and its future approximation is shown in Figure 1.



Source: Own processing based on [38]

Fig. 1: *Development of mining in the Euro region of 19 countries*

5 Results

In accordance with the methodology in part 2 and according to (4), we use the classification method to sort the Triangular Fuzzy Numbers (TFN) according to Chiu & Park [7].

In case that of $w = 0.2$ for positive and negative *CF* (Table 3) we get (in thousands €):

$$X_0 = (-(25{,}502 + 21{,}252 + 17{,}001)/3) + 0.2(-21{,}252) = -25{,}500$$

$$\mathrm{TFN}_1 = \frac{1{,}472y + 5{,}889}{1.15 - 0.035}, \frac{-1{,}472y + 8{,}833}{1.08 + 0.035} = (5{,}281;\ 6{,}602;\ 7{,}923)$$

$$X_1 = 7{,}922$$

Due to the identical interval of annual *CF´*s across the project lifetime, the interval of possible values of TFN_i, hence the fuzzy value X_i, where $i = 1\ldots m$, and m represents the year of the project in which the investment is repaid, is the same. In this case, $m = 3.21$

The result of the method is a dependent variable of the subjective choice of weight *w*. Given that investment flows tend to have a different nature of "certainty" than the income flows generated by the investment, this is considered in the following such that $w_0 > w_{CF}$, where index 0, respectively, *CF*, is the weight of capital expenditure, respectively of a positive cash flow. We base on the findings of proven practice that projected capital expenditures are a safer flow than projected revenue flows. In the case where $w_0 = w_{CF}$, respectively, $w_0 < w_{CF}$, expresses the evaluator neutral attitude to the occurrence of CF_0 and CF_i, respectively, the evaluator tends to believe in a higher value of the occurrence of future positive flows compared to negative flows.

Consider the turbulent period 2021/2022, within which the uncertainties N1-N5 can be identified. As a result, the evaluator chooses $w_0 = 0.5$ and $w_{CF} = 0$. Then

$$X_0 = (-(25{,}502 + 21{,}252 + 17{,}001)/3) + 0.5(-21{,}252) = -31{,}878,$$

$$TFN_1 = \frac{1{,}472y+5{,}889}{1.15-0.035}, \frac{-1{,}472y+8{,}833}{1.08+0.035} = (5{,}281;\ 6{,}602;\ 7{,}923),$$

$$X_1 = 6{,}602.$$

In this case m = 4.82.

Table 4 presents the results of m when w_0 = 0.5 for X_0 = -31,878 and w_{CFi} = 0, 0.1, 0.2, 0.3, 0.4 and 0.5 to calculate X_i from the range of possible TFN_i values.

Tab. 4: *Fuzzy discounted payback period of the project in the number of years m depending on the weight w for the calculation of X_i from the range of possible values TFN_i*

w_{CFi}	X_i	m
0.0	6,602	4.82
0.1	7,262	4.39
0.2	7,922	4.02
0.3	8,582	3.71
0.4	9,244	3.45
0.5	9,903	3.22

Source: Own

6 Discussion

The contribution at the theoretical and practical level shows how it is possible to, at least partially, cope with circumstances that cannot be described in a conventional way. Under certain circumstances, the DPP determined by the deterministic relation (1) may differ significantly from the actual payback period. Therefore, relation (1) valid for point values CF_0, CF_i and r was reformulated to relation valid for intervals of possible values CF_0, CF_i and $\boldsymbol{r}$ and defined by TFN relation (2). The weighted method according to Chiu & Park [7] was used for TFN ranking. The reason for choosing the Chiu & Park´s method is the possibility of choosing the weight w, which allows the evaluator to express his / her subjective opinion about the occurrence of the middle cash flow "a" of the interval.

The result of the FPP investment is a dependent of a weight change w. With the evaluator's equivalent expectation of positive and negative flows (for w = 0.2 and 0.5), the payback period is 3.2 years (the same fuzzy return is calculated according to (5)). In comparison with the results according to Straka [34] it is a return of 7 months, respectively almost 2 years shorter (depending on the choice of the minimum or maximum discounted rate considered by the author).

The approach of equal access to investment and income flows is contradicted by Kothari et al. [39]. Based on empirical data, about 50,000 observations for the period 1972-1997 they analyzed the relative contributions of current R&D investments and long-term, tangible assets investments to future revenue variability. The conclusions showed that both types of investment generate future benefits that are more uncertain compared to investment expenditures, with the benefits of R&D investment being less certain than the benefits of investing in long-term, tangible assets.

Reflecting the greater uncertainty about future revenues compared to capital expenditures and considering several specific uncertainties N related to the task, the weight of the average investment expenditure "a" was further set at 0.5. The positive mean flow "a" in line with the expectations associated with the greater uncertainty was evaluated with a weight less than 0.5 (w_{CFi} = 0, 0.1, 0.2, 0.3, 0.4). Under these conditions, the fuzzy payback period **FPP** = (3.45,

4.14, 4.82) years, where the middle number can be interpreted as the subjectively most expected value of the payback period. Given the estimated lifespan of the investment of 9 years, this is a very promising project.

At $w_{CFi} = 0$, fuzzy X_i is equal to the arithmetic mean of the *CF* limits. A weight $w > 0$ indicates a higher expectation of the occurrence of the mean value "*a*" with an impact on the fuzzy intake X_i towards the right limit value or exceeding it. The same applies to the behavior of fuzzy expenditures X_0 - with the increased *w* the expenditures grow in the direction to the left of the mean value "*a*".

Using the weighted ranking method assumes a positive *w*. Negative value of *w* would have the opposite effect on X_0 and X_i, but not on the FPP result. The strategy of "weighing" negative and positive flows in the same direction (with a "+" or "-" sign) is unsustainable from a practical point of view. The nature of the sign *w* for a given type of flow and its magnitude has to be primarily given by the evaluator's reasonable belief in the occurrence of the most promising value "*a*".

In our case, when $w_0 = 0.5$ and $w_{CFi} = 0$, 0.1, 0.2, 0.3, 0.4 and 0.5, the choice of the positive sign type for both flows can be justified as follows: due to the identified uncertainties, both investment costs, especially technology acquisition prices, and income flows, mainly due to rising electricity and heat prices, may increase.

The ranking method with weighs determining the most promising middle value of the *CF* of the project allows the decision maker to flexibly evaluate the input data according to currently available information, according to his/her knowledge and experience under identified uncertainties related to a particular task.

The current literature considers only positive $w \in \langle 0, 1 \rangle$ for positive and negative flows for the purposes of FPP calculation, thus not considering the possibility of negative weights for flows for which a decrease compared to the mean value "*a*" can be expected.

Conclusion

In the world of economics and management, most decision-making problems are characterized as a complex process for which complete information is often not available. The result is usually the difference between the results of the numerical criteria on which the decision-makers rely and the reality. This is largely due to the uncertainty associated with not knowing the exact point input values of the managerial or financial criterion. This fact is circumvented in the article by the fact that instead of uncertain point values we start from the intervals of possible input values. Methodologically, this idea is solved by defining significant points of intervals CF_0, CF_i and *r* and significant points of discounted payback interval (DPP) derived from them. Triangular Fuzzy number for calculating fuzzy discounted payback period (FPP) is defined, which is a parameter for evaluating an investment plan of lignite power plant modernization.

For the TFN ranking, a weighted method was used, based on the weight *w*, which evaluates the mean value of the interval. This allows the evaluator to reflect its own subjective opinion about the occurrence of the middle value of flows. The numerical formula for FPP thus becomes flexible in terms of the possibility of expressing faith in the incidence rate of input data, depending on the currently available information, knowledge, and experience of the evaluator within identified uncertainties related to a particular task. The current literature does not consider negative weights for the subjective evaluation of the mean values of positive and/or negative cash flows, which can cause significant inaccuracies in the outcome in confrontation with reality.

The results of the calculation answer the question of whether the payback period of the project with respect to the expected lifetime of the investment is a promising project. Given the FPP = (3.45, 4.14, 4.82) years, where the middle number is interpreted as the subjectively most expected value of return and the estimated lifespan of the investment is 9 years, it is possible to judge so.

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FUZZY DOBA NÁVRATNOSTI INVESTICE DO MODERNIZACE PRODUKČNÍ SÍTĚ

Rozdíl mezi výsledkem manažerského propočtu a skutečností lze do velké míry přičíst na vrub neurčitosti. V případě diskontované doby návratnosti (DPP) může jít o nejisté vstupy na úrovni investičních výdajů, cash flow a diskontní sazby. S tímto se lze částečně vyrovnat tím, že místo neurčitých bodových hodnot se vychází z intervalů možných hodnot. Metodologicky je toto řešeno definováním významných bodů vstupních parametrů pro výpočet DPP a z nich odvozených významných bodů intervalu fuzzy doby návratnosti (FPP) ve smyslu trojúhelníkových fuzzy čísel (TFN). Pro klasifikaci TFN je použita vážená metoda. Početní formule FPP se tím stává flexibilní z hlediska vyjádření víry v míru incidence vstupních dat v závislosti na aktuálně dostupných informacích, znalostech a zkušenostech hodnotitele. Dosavadní literatura tento aspekt pomíjí. Prakticky jsou dané vztahy aplikovány na vyčíslení intervalového odhadu FPP, který je parametrem pro zhodnocení investičního záměru modernizace hnědouhelné elektrárny.

UNSCHARFE AMORTISATIONSZEIT DER INVESTITION IN DIE MODERNISIERUNG DES PRODUKTIONSNETZWERKS

Der Unterschied zwischen dem Ergebnis einer Managementkalkulation und der Realität ist größtenteils auf Unsicherheit zurückzuführen. Im Fall von diskontierten Amortisationszeiten (DPPs) können dies unsichere Investitionsausgaben, Cashflows und Abzinsungssätze sein. Dies kann teilweise kompensiert werden, indem anstelle von unbestimmten Punktwerten Intervalle möglicher Werte ausgedrückt werden. Methodisch wird dies gelöst, indem die signifikanten Punkte der Eingangswerte für die DPP-Berechnung und die signifikanten Punkte des daraus abgeleiteten Fuzzy-Return-Intervalls (FPP) im Sinne von dreieckigen Fuzzy-Zahlen (TFN) definiert werden. Zur Klassifizierung von TFN wird ein bewährtes Verfahren verwendet. Die FPP-Berechnung wird somit flexibel dank der Möglichkeit, die Rate im Auftreten von Eingabedaten auszudrücken. Die vorhandene Literatur vernachlässigt diesen Aspekt. In der Praxis werden diese Beziehungen zur Quantifizierung der FPP-Intervallschätzung verwendet, die den Investitionsplan für die Modernisierung des Braunkohlekraftwerks bewertet.

ROZMYTA STOPU ZWROTU INWESTYCJI W MODERNIZACJĘ SIECI PRODUKCYJNEJ

Różnica między wynikiem obliczeń menedżerskich a rzeczywistością wynika w dużej mierze z niepewności. W przypadku zdyskontowanego okresu zwrotu (DPP) mogą to być niepewne dane wejściowe dotyczące nakładów inwestycyjnych, przepływów pieniężnych i stopy dyskontowej. Można to częściowo skompensować, bazując na przedziałach możliwych wartości zamiast na niepewnych wartościach punktowych. Metodologicznie jest to rozwiązywane poprzez zdefiniowanie ważnych punktów wartości wejściowych do obliczenia DPP oraz wyprowadzonych z nich ważnych punktów przedziału rozmytej stopy zwrotu (FPP) w sensie trójkątnych liczb rozmytych (TFN). Do klasyfikacji TFN stosuje się metodę ważoną. Formuła obliczeniowa FPP staje się w ten sposób elastyczna pod względem możliwości wyrażenia wiary w częstość występowania danych wejściowych zależnie od aktualnie dostępnych informacji, wiedzy i doświadczeń oceniającego. Istniejąca literatura pomija ten aspekt. W praktyce zależności te są stosowane do ilościowego oszacowania okresu FPP, który jest parametrem służącym do oceny przedsięwzięcia inwestycyjnego modernizacji elektrowni na węgiel brunatny.

NEW APPROACHES TO THE APPLICATION OF BUSINESS INTELLIGENCE IN THE STRATEGIC MANAGEMENT PROCESS

Petra Kašparová
Technical University of Liberec, Faculty of Economics,
Department of Business Administration and Management,
Studentská 1402/2, 461 17 Liberec 1, Czech Republic
e-mail: petra.kasparova1@tul.cz

Abstract

This article aims to find the optimal links and ways to use the outputs of business intelligence in strategic company management effectively. A total of 41 tools supporting individual phases of the strategic decision-making process were selected within the literature search. They were divided into six successive stages: mission and vision determination, environment analysis, setting long-term goals, strategy formulation, implementation, and, finally, monitoring. The particular techniques were subsequently assigned to the utilization rate of business intelligence within their application. The resulting model connects the outcomes obtained from the evaluation with the scheme of the strategic planning process inspired by literary review. The most appropriate application of business intelligence takes place in the phases dealing with analyzing the company situation, such as environmental analysis and strategy monitoring. According to the obtained results, the involvement of business intelligence outputs should not be overlooked even in the stages devoted to setting long-term goals and formulating strategy.

Keywords

Business intelligence; Strategic management; Strategy; Strategic planning process.

Introduction

The period of the last two years has convinced us even more that the only certainty in both personal and professional life is change. To quickly address these changes, organizations must be able to use business intelligence when creating a strategy. These procedures processing data into information can be effectively applied in agile risk management, the implementation of artificial intelligence systems and data analysis, which enable informed decisions to be made. Work processes and activities affected by the Covid-19 pandemic are additionally going to be improved.

The events of recent months have further "shortened" the period that managers expect in strategic planning. Moreover, the business intelligence should facilitate and, above all, speed up all the processes and procedures carried out within the framework of drawing up an appropriate strategic plan. The research subject is how and when to apply these methods in strategic management. The integration cannot be solely specified for the decision phase on a suitable strategy. The effort intentions to include business intelligence outputs appropriately in the entire strategic planning process.

The presented article first maps the approaches to the strategic planning process. It presents three models showing the whole process in clear diagrams. A specific strategic planning process represents a way to achieve defined strategies. Many approaches to phasing the whole process can be found in the literature. The primary stages that are repeated in publications

include situation analysis, strategy formulation, its implementation and subsequent ongoing control and monitoring [1], [2], [3].

The most frequently used tools supporting a strategic planning process are subsequently assigned to individual phases. Based on the literature review, a total of 41 techniques were included in the analysis. Each tool was also evaluated by the utilization rate of business intelligence in the application within strategic planning. The newly created scheme, based on own evaluation and a selected model from the literature review, represents the main benefit of the research. It shows the most appropriate involvement of business intelligence in the strategic planning process.

1 Literature Review

Today, the management of an organization is unthinkable without strategic thinking. The manager must know the strategic position of the organization, assess the impact of rapidly changing conditions, monitor the internal and external environment of the company, and choose the optimal time period for changing the strategy [4].

1.1 Business Intelligence and Strategic Management

To maintain optimal business processes and meet customer requirements, it is essential to manage activities across the enterprise and supply chain through agile management-based strategies. An agile approach to business intelligence means an organization's ability to respond to change through strategic risk management, the adoption of artificial intelligence technologies and the ability to perform comprehensive data analysis. Specifically, collecting, interpreting, and presenting meaningful data help managers make effective decisions and take necessary actions [5].

In one of the studies [6] dealing with the critical success factors in implementing business intelligence, the following factors were given the most importance: top management support, clearly defined business goals and needs, active employee engagement and user support. The results of this study can help companies allocate resources based on the assigned importance of indicators at the strategic planning stage and subsequently achieve better results [6]. Specifically, business intelligence can be used, for example, in creating a SWOT analysis, optimizing the reallocation of resources, ensuring cost efficiency or creating overviews of the state of the organization for immediate decision-making [7].

According to Grossmann and Rinderle-Ma [8], there are four possible scenarios for adapting business intelligence to strategic planning:

1) **BI and strategic management are separated**: BI outputs are just standardised reports intended for a specific part of the organisation. They only fulfil the short-term goals of a specific department.
2) **BI as support for monitoring organisational performance**: monitoring is done in the context of monitoring the set measurable objectives. The application of BI is already formulated within the framework of setting strategic goals.
3) **BI as a means of feedback in formulating a strategy**: a typical result of this scenario is an agreed balanced scorecard. BI is already used in the strategy optimisation process.
4) **BI as an essential source for strategic planning**: the results of BI are used directly in the definition of the strategy and thus provide essential inputs for the creation of a strategic plan at the top management level.

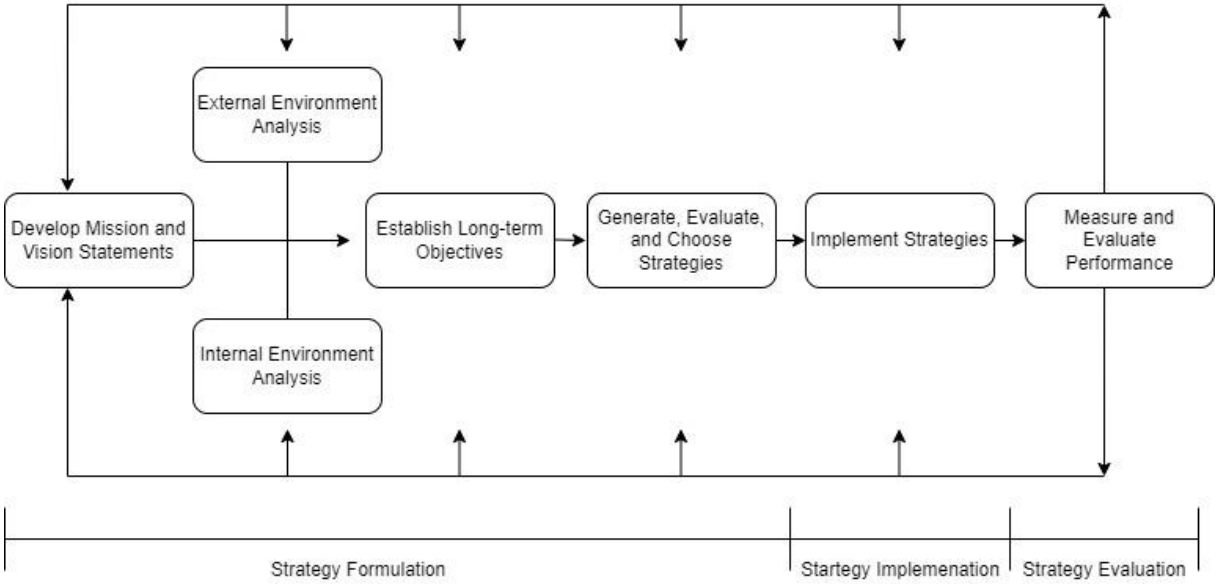
The submitted research aims to identify the possibilities and optimal use of BI in checking the suitability of the strategy (scenario no. 3) and in its formulation (scenario no. 4).

1.2 Strategic Planning Process

In a broader sense, overall strategic management can be understood as a management method that, thanks to which, managers design and implement a selected strategy that is subsequently intended to lead the organization to a sustainable competitive advantage [1]. In the next part of the chapter, three selected approaches are presented with a brief description of their pros and cons.

1.2.1 David's Strategic Management Process Model

Perhaps one of the most widely used models was presented by Fred David in 2009. The strategic management process is divided into three primary phases: strategy formulation, implementation and evaluation conclusion [3]. Each phase is further divided into several steps, which are shown in Figure 1.



Source: Own processing according to [3]

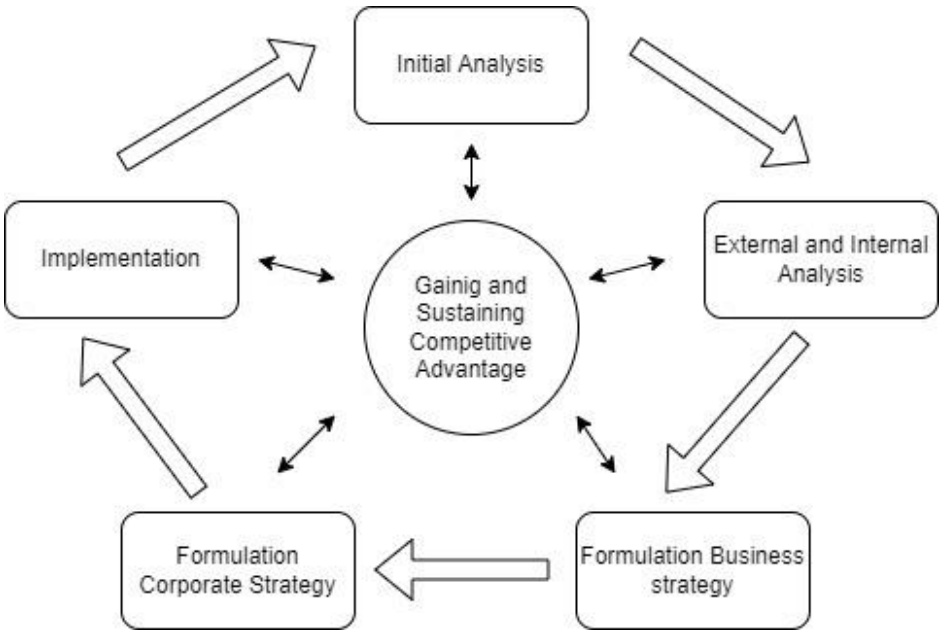
Fig. 1: *David's strategic management process model*

The model includes the main and intermediate phases strategic planning should go through. The diagram represents the entire process as a continuous sequence of individual steps that follow one another. If necessary, the two-sided arrows show how the whole process can be taken back one or more steps without the manager going back to the beginning of his planning. It primarily differs from other models in that the analytical part is included in the formulation phase, and the assessment of the implementation of the strategic plan is not preceded by monitoring of the implementation [9].

1.2.2 Analysis-Formulation-Implementation (AFI) Strategy

Rothaermel in [1] designed a different scheme. The main phases (analysis, formulation, and implementation) and their steps are shown in a circle, illustrating the strategic planning process as a continuous activity. However, the arrows only show a one-way procedural direction. When the environmental conditions change, for example, in the formulation phase, the model does not show the possibility of going back even one step [10]. As can be seen in Figure 2, the author also divides the analysis phase in the first stage into two separate steps:

the initial analysis is followed by an external and internal analysis of the situation. At the center of the model associated with all these activities Rothaermel emphasizes the main objective of strategic management: "Gaining and maintaining a competitive advantage".

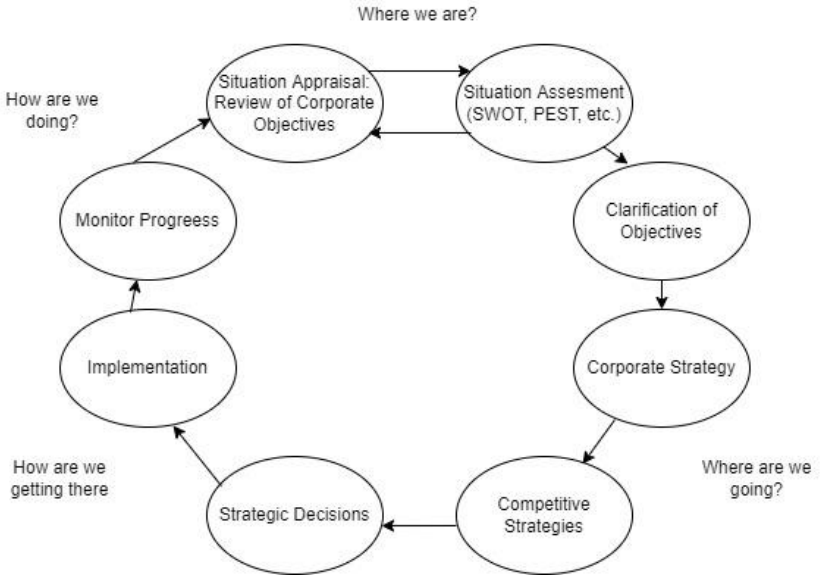


Source: Own processing according to [1]

Fig. 2: *Analysis-Formulation-Implementation (AFI) strategy*

1.2.3 Thompson and Martin's Strategic Management Framework

Thompson and Martin in [2] proposed a similar type of scheme to Rothaermel in [1]. The individual phases are arranged in a circle, and the sequence of steps is also shown in only one direction. However, the authors divide the whole process into a little more detail, into a total of 8 phases. They are also accompanied by basic strategic questions that managers should not forget when planning strategy. Thompson and Martin's framework for strategic management is presented in Figure 3.



Source: Own processing according to [2]

Fig. 3: *Thompson and Martin's Strategic Management Framework*

The literature review also included an examination of tools that support management decision-making at each stage of the strategic planning process. For better clarity and continuity in their further utilization, these tools are presented in the following chapter.

2 Research Methodology

In the next phase of the study, 41 tools that support the individual stages of the strategic planning process were selected to the research [1], [2], [3], [9], [10], and [11]. The designated techniques were subsequently assigned to the individual phases. The classification of tools into individual phases is based on David's Strategic Management Process Model. This approach offers a division involving all crucial phases. In contrast, AFI Strategy omits or merges some phases together, and Thompson and Martin's Strategic Management Framework divides the whole process in too much detail. For this reason, the optimal variant of the division into a total of 6 phases was found. From these approaches, the principle of a circular scheme with a smaller number of steps (AFI Strategy) and supporting questions supplementing the individual phases (Thompson and Martin's SMF) were included in the model.

The selected approach serves to link the obtained results with the theoretical basis and divides the entire process into the following parts: develop mission and vision statements, environment analysis, establish long-term objectives, strategy formulation, strategy implementation, and monitoring of the strategy. Table 1 shows the tools already categorized to the phases.

In the third column of Table 1 the assigned rates of business intelligence utilization in applying individual techniques can be found. In other words, the business intelligence utilization rate expresses the ability of business intelligence to support the appropriate application of tools or techniques that are used in strategy planning. Therefore, if the management plans to define the mission of its business, it is very likely that it does not use the outputs of business intelligence (none utilization rate). In contrast, the involvement of business intelligence in the processing of PEST or SWOT analysis appears to be very suitable (high utilization rate).

The values were determined based on the author´s long-term research on business intelligence with the involvement of a literature search of tools supporting the strategic planning process. Each of them was examined individually, and the utilization rate of BI during its application was evaluated. It was based on previous research focused on the role of business intelligence in business processes, primarily of a decision-making nature [12], [13], [14], and [15]. The scale divided techniques into four categories. For those for whom the use of data and its conversion into relevant information plays a key role, a high level of engagement was determined. Tools applying BI outputs as practical support have been categorized as having a middle utilization rate. The rest of the tools were sorted into categories with low use (business intelligence results as one of many supportive tools) and no utilization rate, where the BI application can be labelled as nonessential.

Tab. 1: *Assigned utilization rate of BI to selected techniques*

Phase	Tool / technique supported strategic management process	Utilisation rate of BI	Numeric Expression
Develop mission and vision statements	Develop mission statements	None	0
	Develop vision statements	Low	1
Environment analysis	PEST	High	5
	SWOT	High	5
	Core competencies	Middle	3
	Porter's 5 Forces	High	5
	Competitor profile matrix	Middle	3
	External factor evaluation matrix	High	5
	Internal factor evaluation matrix	High	5
	Benchmarking	Middle	3
	Business financial analysis	High	5
	Financial ratios	High	5
	Scenarios forecasting	High	5
	Market segmentation	Middle	3
	Value chain analysis	High	5
	VRIO	Low	1
Establish long-term objectives	SMART	Low	1
	Critical success factors	High	5
	Unique selling proposition	Middle	3
Strategy formulation	Scenario planning	Low	1
	SPACE matrix	High	5
	Boston Consulting Group matrix	High	5
	GE-McKinsey matrix	High	5
	Porter's generic strategies	Middle	3
	Bowman's strategy clock	Middle	3
	Porter's diamond	Middle	3
	Game theory	Low	1
	What if analysis	Low	1
	QSP matrix	High	5
Strategy implementation	Policies	None	0
	Motivation	None	0
	Resistance management	Low	1
	Leadership	None	0
	Stakeholder impact analysis	High	5
	Changing organizational structure	Low	1
	Performance management	Low	1
Strategy monitoring	Strategy evaluation framework	Middle	3
	Balanced scorecard	High	5
	Benchmarking	Middle	3
	Customer satisfaction	High	5
	CBA	High	5

Source: Own

For further processing, the verbal assessment was converted into a numerical expression (see the fourth column). The conversion is presented in Table 2.

Tab. 2: *Conversion table*

Utilization rate	Numeric expression
None	0
Low	1
Middle	3
High	5

Source: Own

3 Research Objectives

The article aims to find a suitable business intelligence application in the strategic company management. The utilization rate of business intelligence was assigned to the techniques facilitating the strategic planning process, and the results were subsequently incorporated into the selected scheme of the strategic planning process from the literature review.

4 Research Results

The assigned business intelligence utilization rates (UR) for each tool were averaged for each stage of the strategic planning process. The results are shown in Table 3.

Tab. 3: *Average utilization rate of business intelligence (min 0, max 5)*

Phase	Average UR
Develop mission and vision statements	0.50
Environment analysis	4.14
Establish long-term objectives	3.00
Strategy formulation	3.20
Strategy implementation	1.14
Strategy monitoring	4.20

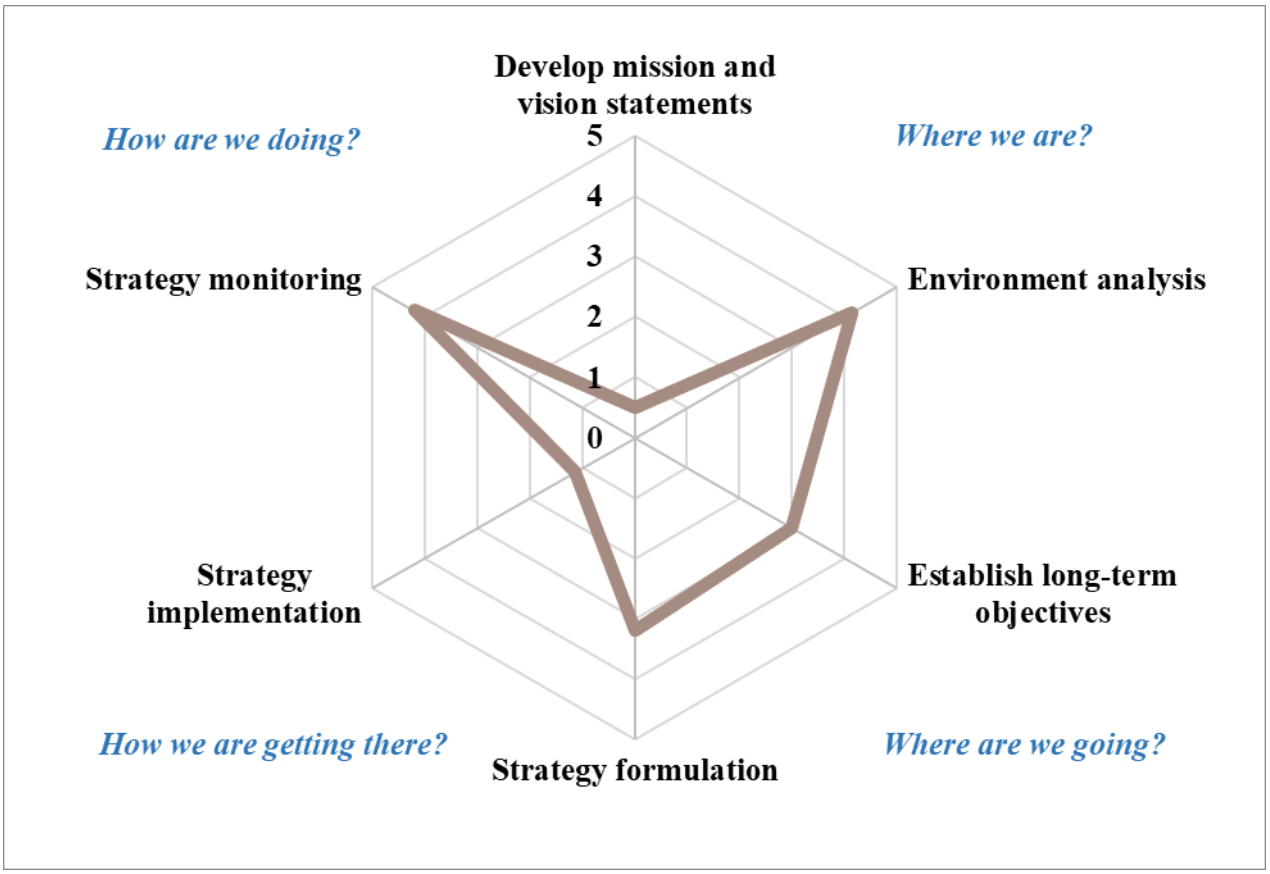
Source: Own

As mentioned above, the phases were selected according to the literature search to capture the essence of the partial steps of the strategic planning process best. The given division was further supplemented by simple strategic questions according to Thompson and Martin, which aptly supplement the titles of individual stages and give them a clear direction of thinking. The final model can be seen in Figure 4.

Specifically, it is based on a circular scheme; two versions were presented in the literature search. The process's continuity is maintained, further underlined by the addition of fundamental strategic issues. The own processing results of business intelligence involvement in the strategic planning process were then included in the middle of the model using a ray graph.

From the obtained interconnection, it is evident that the most probable and, likely, also the most frequent application of business intelligence takes place in the phases dealing with the current analysis of the situation in which the company finds itself. So, this is an environment analysis phase where the manager asks the question: where are we? For example, using techniques such as PEST or SWOT is typical for this step, where the correct transformation of data into information plays a crucial role in their compilation.

Business intelligence can similarly be applied in the monitoring phase, where management already responds to the question 'how are we doing?' that means again where we are, but this time after the implementation of the strategy. When companies implement business intelligence, they primarily count on them in processes where a deep analysis of the available data, typical of both phases expressed above, is required.



Source: Own

Fig. 4: *Model of business intelligence application in strategic management process*

The presented model suggests another possible (for some companies completely new) application of business intelligence within strategic management. In order to fulfil the third or even the fourth scenario, managers must involve the information obtained from the company data in the following stages of the process. The outputs indicate that their appropriate use can be expected in formulating the long-term company goals (the average value of BI use was 3). Techniques such as Critical Success Factors or Unique Selling Proposition may be involved at this stage.

However, according to the results, the phase of the formulation strategy, where the average value of BI utilization was 3.2, requires integration that is even more effective. Thus, the possible application of BI in this phase of the process could already be described as significant. Different types of matrices are frequently applied in the strategy formulation stage. These offer a systematic approach to the allocation of investments between business units (GE-McKinsey matrix), product portfolio analysis (Boston Consulting Group matrix) or help to determine the appropriate strategy (Space matrix). They are connected, as is traditionally associated with business intelligence, by the concept of situational analysis. From corporate management point of view the involvement of business intelligence outputs should not be overlooked even at this stage and scenario No. 3 could then be gradually fulfilled within the organization.

Conclusion

This article aimed to find the appropriate application of business intelligence in strategic planning. A new interconnection scheme was compiled by evaluating the significance of the application of business intelligence within the most frequently used tools supporting strategic

planning. The newly introduced model presents the best-known directions of BI use in business processes and suggests new possibilities for the application.

A ray graph was selected for the presentation of the results, which suitably complemented the theoretical model showing the strategic planning process in a circle. This connection thus offers a new perspective on the possible use of BI on a theoretical level. In terms of subsequent practical application across organizations, business intelligence promoters face problems from the very beginning.

Although the outputs presented in the article show a broad application of business intelligence across such a complex process as setting the overall company direction, its implementation is not entirely standard in companies. As follows not only from the author's previous research, business intelligence is not implemented in many companies [12], [16], [17]. However, previous specific research has shown that active users of business intelligence outputs do not hesitate to incorporate available results into their decision-making process [14]. Their involvement then increases with the experience gained. Therefore, owners and managers should not delay the possible implementation of these innovative practices.

The limitation of the presented research may be the sole inclusion of selected self-evaluation tools in connection with business intelligence. Although the author has been dealing with the topic for a long time, the perception of using business intelligence can be (positively) influenced. In the next phase of the research, it is planned to expand the results with qualitative research among experts. Furthermore, a more comprehensive range of techniques and tools could be included in the research so that the obtained outputs give the most objective picture of the researched situation.

Acknowledgements

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NOVÉ PŘÍSTUPY K APLIKACI BUSINESS INTELLIGENCE V PROCESU STRATEGICKÉHO ŘÍZENÍ

Tento článek má za cíl najít optimální vazby a cesty, jak efektivně využít výstupy business intelligence v rámci strategického řízení podniku. Tato integrace napomáhá manažerům implementovat podnikové strategie a snadno je přizpůsobovat změnám prostředí. V rámci literární rešerše bylo vybráno celkem 41 nástrojů podporujících jednotlivé fáze strategického procesu plánování, které byly rozděleny do šesti po sobě jdoucích etap: stanovení mise a vize, analýza prostředí, stanovení dlouhodobých cílů, formulace strategie, její implementace a nakonec monitoring. Následně byla jednotlivým technikám přiřazena míra možného využití business intelligence v rámci jejich aplikace. Výsledný model propojuje získané výsledky z hodnocení se schématem strategického procesu plánování inspirovaného literární rešerší. Nejčastější uplatnění nástrojů BI probíhá ve fázích zabývajících se rozborem situace, ve které se daná společnost nachází, jako jsou analýza prostředí a monitoring strategie. Dle získaných výsledků by zapojení business inteligence výstupů nemělo být přehlíženo ani v etapách věnujících se stanovení cílů a formulaci strategie.

NEUE ANSÄTZE ZUR ANWENDUNG VON BUSINESS INTELLIGENCE IM STRATEGISCHEN MANAGEMENTPROZESS

Dieser Artikel zielt darauf ab, die optimalen Verbindungen und Wege zu finden, um die Ergebnisse von Business Intelligence im strategischen Management effektiv zu nutzen. Im Rahmen der Literaturrecherche wurden insgesamt 41 Werkzeuge ausgewählt, die einzelne Phasen des strategischen Planungsprozesses unterstützen. Sie waren in sechs aufeinanderfolgende Phasen unterteilt: Missions- und Visionsbestimmung, Umfeldanalyse, Festlegung langfristiger Ziele, Strategieformulierung, Umsetzung und schließlich Überwachung. Anschließend wurde den jeweiligen Werkzeugen der Nutzungsgrad von Business Intelligence innerhalb ihrer Anwendung zugeordnet. Das resultierende Modell verbindet die aus der Evaluation gewonnenen Ergebnisse mit dem Schema des strategischen Planungsprozesses, das von den Literaturrecherchen inspiriert ist. Die häufigste Anwendung von BI-Werkzeugen findet in den Phasen statt, in denen es um die Analyse der Unternehmenssituation geht, wie z. B. Umfeldanalyse und Strategieüberwachung. Nach den erzielten Ergebnissen sollte jedoch die Einbeziehung von Business Intelligence-Ergebnissen auch in den Phasen, die der Festlegung langfristiger Ziele und der Formulierung der Strategie gewidmet sind, nicht übersehen werden.

NOWE PODEJŚCIA DO STOSOWANIA ANALITYKI BIZNESOWEJ W PROCESACH ZARZĄDZANIA STRATEGICZNEGO

Celem niniejszego artykułu jest znalezienie optymalnych powiązań i sposobów na efektywne wykorzystanie wyników analityki biznesowej w ramach strategicznego zarządzania przedsiębiorstwem. Połączenie to pomaga menadżerom we wdrażaniu strategii przedsiębiorstwa i ich łatwym dostosowywaniu do zmian otoczenia. W ramach kwerendy literatury wybrano łącznie 41 narzędzi wspomagających poszczególne etapy strategicznego procesu planowania, które podzielono do sześciu po sobie następujących etapów: określenie misji i wizji, analiza otoczenia, określenie celów długoterminowych, sformułowanie strategii, jej wdrożenie i monitoring. Następnie do poszczególnych technik przyporządkowano stopień możliwego wykorzystania analityki biznesowej w procesie ich stosowania. Końcowy model łączy uzyskane wyniki oceny ze schematem strategicznego procesu planowania zainspirowanego kwerendą literatury. Narzędzia analityki biznesowej są najczęściej stosowane na etapie zajmującym się analizą sytuacji, w której znajduje się dane przedsiębiorstwo, czyli analizą otoczenia oraz monitorowaniem strategii. Bazując na uzyskanych wynikach należy stwierdzić, że zastosowanie analityki biznesowej efektów nie powinno być pomijane również na etapie poświęconym określeniu celów i sformułowaniu strategii.

SUSTAINABLE CITY LOGISTICS OF LAST-MILE DELIVERY AND RETURNS ON THE E-COMMERCE MARKET. VARIOUS GROUPS OF STAKEHOLDERS' PERSPECTIVES – AIMS AND SCOPE OF THE PROJECT

Maja Kiba-Janiak[1]; Katarzyna Cheba[2]; Jarosław Witkowski[3]; Agnieszka Jagoda[4]; Agnieszka Skowrońska[5]; Tomasz Kołakowski[6]; Anna Baraniecka[7]; Jakub Marcinkowski[8]; Magdalena Mucowska[9]

[1, 3, 4, 5, 6, 7, 8, 9] Wrocław University of Economics and Business, Faculty of Management, Department of Strategic Management and Logistics, Komandorska 118/120, 53-345 Wrocław, Poland

[2] West Pomeranian University of Technology, Faculty of Economics, Department of Applied Mathematics in Economics, Janickiego 31, 71-210 Szczecin, Poland

e-mail: [1]maja.kiba-janiak@ue.wroc.pl; [2]katarzyna.cheba@zut.edu.pl; [3]jaroslaw.witkowski@ue.wroc.pl; [4]agnieszka.jagoda@ue.wroc.pl; [5]agnieszka.skowronska@ue.wroc.pl; [6]tomasz.kolakowski@ue.wroc.pl; [7]anna.baraniecka@ue.wroc.pl; [8]jakub.marcinkowski@ue.wroc.pl; [9]magdalena.mucowska@ue.wroc.pl

Abstract

The paper presents the research project implemented at Wrocław University of Economics and Business led by Eng. Maja Kiba-Janiak, Ph.D., Prof. of WUEB, financed by the National Science Centre in Poland, granted based on the decision number 2018/31/B/HS4/03711. The project answers the challenges created by the dynamically growing e-commerce market. Attractive purchase prices, low cost, short time, and convenient delivery places motivate consumers to shop online, which is a challenge for e-trade services and transport companies. Meeting the expectations of e-clients in terms of delivery of the purchased products leads to congestion, pollution, and road accidents. The project is the conceptualization of a model of sustainable city logistics in the field of last-mile delivery and the returns on the e-commerce market, including the tools stimulating stakeholders to change their preferences in terms of the last-mile delivery and goods return, making them more sustainable (environmentally, socially and economically).

Keywords

Sustainable city logistics; E-commerce; Last-mile delivery; Returns.

Introduction

The problems related to congestion, pollution of the natural environment, and the growing number of road accidents resulting from goods deliveries constitute a vital and up-to-date topic of city logistics. The development of the e-commerce market and the increasing demands of customers in this area intensified these problems. Issues related to the last-mile deliveries and returns are discussed in various scientific articles, however, usually in a narrow dimension. The existing research referring to the discussed issue is fragmentary, usually concerns a particular city, and focuses mainly on a limited group of stakeholders. Meanwhile, the minimization of the negative effects of the last-mile delivery organization applies to a

wide range of stakeholders (e-clients, e-trade services, transport companies (especially CEP), local governments, and inhabitants), which has been highlighted in many EU projects. However, there is a lack of scientific research that may indicate the tools, which can lead to a change in preferences of city logistics stakeholders in the area of last-mile delivery and returns on the e-commerce market, and the possibility of changing these preferences to more sustainable (including environmental, economic and social aspects). The above-presented topics constitute the main reasons for conducting research, including the various stakeholders' perspectives and identifying instruments that may change preferences regarding the last-mile delivery organization in provincial capital cities.

1 Project Description

A fast-growing e-commerce market and the increasing customer requirements in terms of speed and frequency of deliveries contribute to more and more interference in the last-mile of the supply chain [1], [2], and [3]. Research indicates that the last-mile deliveries are 5 to 23 times more expensive than shopping in a retail store (depending on the size of the package and service delivery). At the same time, customers are not willing to pay the higher delivery costs [4]. Providing delivery to the individual customer within a day or even a few hours is a growing challenge for the transport companies. However, more and more frequent deliveries result in environmental pollution, congestion, road accidents, increased delivery costs, and costs related to congestion formation and environmental pollution [5].

City logistics of last-mile delivery and returns in the e-commerce market is one of many areas of Urban Freight Transport (UFT). It can be defined as "*a series of activities and processes that are necessary for the delivery process from the last transit point to the final drop point of the delivery chain*" [6]. It can be viewed from three perspectives represented by various stakeholders: from the demand side (demand for goods purchased online, represented by individual customers and companies, institutions), supply (delivery of goods purchased online, represented by mostly courier, express and parcel companies – CEP and e-commerce services and online shops) and its physical environment regulated by the local government [7]. Each city logistics stakeholder in the field of last-mile delivery has its preferences and expectations. E-customers choose companies that deliver goods faster and cheaper than others. The authorities put the good of all inhabitants above the individual needs of enterprises, transport companies focus on low delivery costs, often ignoring environmental pollution or congestion problems, and e-commerce services compete to satisfy individualized customer needs. A sustainable approach to city logistics of last-mile delivery and returns, taking into account the perspective of key stakeholders (local government, e-commerce services (such as Zalando), e-customers (people who do shop online) and courier, express, parcel companies (CEP) is needed to solve these problems.

Based on the existing literature definitions of city logistics [8], [9], [10], [11], [12] and [13], and the definition of sustainable development presented in the report [37], it can be assumed that sustainable city logistics of last-mile delivery and returns on the e-commerce market concern the planning, implementing, coordinating and controlling of processes on urbanized areas related to the last-mile delivery and the returns of goods purchased online with the accompanying information, in order to reduce costs, reduce environmental degradation and increase road safety, obtained as a result of a compromise developed among the diverse preferences of stakeholders.

Many reasons lead to researching sustainable city logistics of last-mile delivery and returns on the e-commerce market. Among them, the following can be distinguished:

- **a literature gap** in terms of the conceptualization of the model of sustainable city logistics of last-mile delivery and the returns on the e-commerce market, taking into account the perspective of all groups of stakeholders as well as tools motivating them to change preferences in the last-mile delivery and returns in a sustainable manner (environmental, social and economic);
- **an empirical gap** in terms of city logistics stakeholders' preferences' analysis in the field of last-mile delivery and returns on the e-commerce market and the possibility of changing them to more sustainable ones (including the environmental, economic and social aspects);
- **the need to make improvements in the strategies for urban development** in the field of city logistics following the fast-growing e-commerce market, including three scenarios (the pessimistic, optimistic, and business as usual ones) for the development of sustainable city logistics of last-mile delivery on e-commerce market taking into account stakeholders' ability to change preferences in this area.

1.1 Research Objective

The project's scientific objective is to conceptualize a model of sustainable city logistics in the field of last-mile delivery and the returns on the e-commerce market, including the perspective of all stakeholders. The model will include the tools that stimulate the change of stakeholders' preferences regarding the last-mile delivery and goods return to be organized sustainably (environmentally, socially, and economically).

The cognitive objective is to analyze the preferences of various stakeholders in terms of the last-mile deliveries and returns and identify factors that may motivate them to make sustainable choices in this area.

While the methodical objective is to develop a tool with the usage of the conjoint analysis to identify the preferences of various groups of stakeholders and the possibility of their change in the last-mile delivery and returns in order to organize them in a sustainable manner.

1.2 Methods of Research

In the first stage of the research secondary data analysis was used to assess and compare e-commerce markets in Poland, the EU and Brazil. CAWI – standardized Computer-Assisted Web Interview was conducted in the third stage of the research. The applied research tool is a questionnaire consisting of closed-ended questions. The research tool includes the methodology used in the conjoint analysis. The research was conducted on a sample of 1100 clients that make purchases online. The selection of the sample was on a quota basis. The general population was e-customers in all province and capital cities in Poland. The research sample was selected in a quota sampling manner: the amounts for individual cities, age (4 categories) and gender of respondents. The structure of the respondents was determined based on the data of Statistics Poland (Główny Urząd Statystyczny). The research sample was extracted from the database purchased by the specialized research company selected to carry out the research. The standardized and partially structured interviews are used in the fourth stage of the research. The standardized focused interviews are conducted among the most recognizable e-commerce services by the e-costumers, such as RTVEuroAGD, Rossmann, Empik, Tesco, and DOZ – Dbam o Zdrowie. For the interviews with representatives of courier services the following were selected: DPD, DHL, UPS, GLS, Poczta Polska and Inpost, so the companies who concentrate around 80% of the entire CEP (courier, express and parcel) market [14]. Accordingly, electronic surveys (standardized and structured interviews) are conducted with representatives of 18 capitals of 16 provinces (stage 5). Research tools

include the methodology used in the conjoint analysis. An expert panel is the qualitative research and will be conducted in Wroclaw after the relevant research among the city logistics stakeholders in last-mile delivery on the e-commerce market. The expert panel will be attended by outstanding experts/researchers from abroad and Poland who have experience and knowledge in the city logistics of the last-mile delivery on the e-commerce market.

2 Significance of the Project

In terms of the last-mile and returns in the e-commerce market, sustainable city logistics is playing an increasingly important role. According to the C3 Solutions report, e-commerce has become one of the biggest problems in the supply chain in the 21st century [15]. In just five years, from 2012 to 2017, the number of people making purchases over the Internet worldwide has increased by more than 200% [16]. Poland was among the ten countries where the growth rate of purchases made in online stores was the highest in the last quarter of 2017 [16]. E-commerce European research shows that Polish Internet customers (e-customers) change delivery times more frequently than e-customers from other European countries. In 2016, almost 70% of Polish e-customers indicated the need to change the delivery date [17]. At the same time, among the factors motivating e-customers to make more frequent purchases via the Internet are low delivery costs (62%). Courier companies are trying to adapt their services to the growing requirements of consumers through customizing them. The goods are delivered more frequently and in a faster way. As a result, in the cities there are observed growing problems regarding congestion, environmental pollution and the increasing number of road accidents. Freight transport in city is responsible for 25% of CO_2 emissions in the city [18], and it is believed to be the one which pollutes the air more than the long-distance transport due to the short distances and stops required by the traffic organization and distribution in the city [7]. What is more, increased traffic causes fatal road accidents, which in some cities exceed 100 people per million inhabitants [19]. In addition, according to the calculations of the European Commission, the costs of congestion in European cities are almost 100 billion euros or about 1% of EU GDP per year [20].

In recent years, the European Union is increasingly focused on developing sustainable urban freight transport by introducing legislation and formal directives. As a result of these activities, many strategic documents contain long-term goals of freight transport and environmental protection [21]. In the Green Deal, specific targets for ecological transport in the city were developed [22]. The ultimate goal is to organize CO2 emission-free freight transportation in cities by 2030 [22]. In response to the guidelines of the European Commission, several projects have been created (ENCLOSE, C-LIEGE, NOVELOG, CIVITAS, STRAIGHTSOL etc.), which have developed guidance and policies to develop transportation plans, including the sustainable urban freight transport. Among these guidelines, it can be highlighted the three main ones [23]: Sustainable Urban Transport Plans (SUTP), Sustainable Urban Mobility Plans (SUMP), and Sustainable Urban Logistics Plans (SULP). The sustainable approach to urban freight transport is also noted in other many EU projects, such as BESTUFS (I, II), City Log, City Move, C-LIEGE, eDRUL, FLEAT, GRASS, START-A, SUGAR, TRAILBLAZER [24], SULPiTER. These projects focus on various aspects of urban freight transport, particularly on reducing the environmental pollution in the city, improving the coordination and cooperation between stakeholders, and improving the formulation of plans for sustainable urban freight transport. In only one of the above presented EU projects, the study concerned logistics in the e-commerce market (eDRUL).

An increase in initiatives related to sustainable mobility has also been observed in Poland. However, these activities concern primarily public transport. However, many Polish local

authorities consider freight transport an area relating exclusively to private enterprises [25]. This problem is also noticeable in foreign scientific publications that present the issues of sustainable city logistics in the area of freight transport [7], [10], [26], and [27]. In the literature, an interest in city logistics in terms of last-mile delivery and returns on the e-commerce market has also increased over several years; however, many publications typically refer to the individual problems such as analysis of the e-commerce impact on the last-mile delivery [28], [29], and [30], the study on e-customer opinion on alternative solutions for the shipments purchased via the Internet concerning the home deliveries [2], [5], [31], and [32], research among logistics companies dealing with the goods deliveries on the e-commerce market [1], the search for the last-mile problem-solving ways through optimization models [33], the use of intelligent information systems [34], or an attempt to calculate external costs of city logistics in the field of last-mile delivery on the e-commerce market [30].

2.1 Innovative Values of the Project

The innovative nature of the project stems from several reasons. First of all, both in the EU projects and the subject literature, there are no studies related to a comprehensive approach, including the perspective of all groups of stakeholders to the problem of sustainable city logistics of last-mile delivery and returns on the e-commerce market. In scientific publications, there is a deficit of studies demonstrating a comprehensive approach to sustainable city logistics of last-mile delivery and returns that include the perspective of all stakeholders and the identification of tools that stimulate the change of stakeholders' preferences in this area in terms of sustainable manner (environmental, social and economic). The city logistics of last-mile delivery and returns is an essential subsystem of the city's logistics system, which has not yet been thoroughly investigated.

Secondly, no research has been yet conducted in order to identify factors that motivate stakeholders (such as e-customers, couriers, express, parcel companies - CEP, e-commerce services, and local governments) to change their preferences in terms of more sustainable deliveries (including environmental, economic and social aspects) and returns of goods purchased via the Internet.

2.2 International Cooperation

Moreover, the tool developed during the research to analyses the preferences of the last-mile delivery stakeholders in the e-commerce market and identify factors that may affect their change was applied in Brazil by a group of researchers under the leadership of prof. L. K. de Oliveira. The choice of Brazil for the comparative analysis was a result of a few reasons. Firstly, the e-commerce market in Brazil is growing as rapidly as in Poland. Brazil was the leader in e-commerce spending in 2020 [35]. Next, the CPI index is relatively higher in Brazil. It means that the prices of goods purchased in significant quantities by the population of the cities increase yearly more than in Poland, even though the level of GDP per capita in Brazil is 50% lower than in Poland. At the same time, the level of CO2 emissions (from transportation) is three times higher in Brazil than in Poland [36]. These will verify the tool in different environmental and cultural conditions in terms of its universality. A comparative analysis of the research results carried out in two different countries: Poland and Brazil can provide additional relevant conclusions.

The project will gain significant value by involving outstanding experts from abroad (prof. M. Browne, prof. R. van Duin, prof. Gernot Liedtke, dr M. Piecyk, and prof. L. K. de Oliveira), four well-recognized experts in city logistics from Poland together with the representatives of the different groups of stakeholders. The experts will participate in an expert panel during which an assumption for an original model of sustainable city logistics in the field of last-mile

delivery and returns on the e-commerce market will be developed, including the perspectives of all groups of stakeholders, as well as tools encouraging their changes in preferences in this field in a sustainable manner (environmental, social, and economic). The model will consider three scenarios diagnosed by the experts (e.g. optimistic, pessimistic and business as usual) and can support local authorities in strategic planning in sustainable city logistics. The model can be also helpful for e-commerce services and CEP companies in planning long term activities in the field of last-mile delivery.

Conclusion

The project will contribute to a better understanding of the preferences of the last-mile stakeholders in the e-commerce market and the factors enabling their change. Thus, it should be the basis for cooperation between stakeholders and help local governments formulate and implement city logistics strategies. The results of research and the proposed model of sustainable city logistics of last-mile delivery and returns, which includes the stakeholders' preferences in this field, as well as tools motivating to change these preferences, will contribute to the development of the theory of management science in the area of sustainable city logistics.

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dr. hab. inż. Maja Kiba-Janiak, prof. UEW; dr. hab. Katarzyna Cheba, prof. ZUT;
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dr. Jakub Marcinkowski; mgr. Magdalena Mucowska

UDRŽITELNÁ MĚSTSKÁ LOGISTIKA DORUČOVÁNÍ NA POSLEDNÍ MÍLI A VRACENÍ ZBOŽÍ NA TRHU ELEKTRONICKÉHO OBCHODOVÁNÍ. POHLEDY RŮZNÝCH SKUPIN ZÚČASTNĚNÝCH STRAN – CÍLE A ROZSAH PROJEKTU

Článek představuje výzkumný projekt realizovaný na Vysoké škole ekonomické a obchodní ve Vratislavi vedený ing. Majou Kiba-Janiak, Ph.D., profesorkou WUEB, financovaný Národním vědeckým centrem v Polsku, udělený na základě rozhodnutí číslo 2018/31/B/HS4/03711. Projekt reaguje na výzvy, které přináší dynamicky rostoucí trh elektronického obchodování. Atraktivní nákupní ceny, nízké náklady, krátká doba a výhodná místa dodání motivují spotřebitele k nákupům online, což je výzva pro služby elektronického obchodu a dopravní společnosti. Splnění očekávání e-zákazníků, pokud jde o doručení zakoupených produktů, vede k dopravním zácpám, znečištění ovzduší a dopravním nehodám. Předmětem projektu je konceptualizace modelu udržitelné městské logistiky v oblasti doručování na poslední míli a vracení zboží na trhu elektronického obchodování, včetně nástrojů stimulujících zúčastněné strany ke změně preferencí doručování na poslední míli a vracení zboží, čímž se stanou udržitelnějšími (ekologicky, sociálně a ekonomicky).

NACHHALTIGE STADT-LOGISTIK DER LETZTEN MEILE-LIEFERUNG UND RETOUREN AUF DEM E-COMMERCE-MARKT. PERSPEKTIVEN VERSCHIEDENER STAKEHOLDER – ZIELE UND UMFANG DES PROJEKTS

Der Artikel stellt ein Forschungsprojekt vor, das an der Wirtschaftsuniversität Wrocław unter der Leitung von Dr. hab. Ing. Maja Kiba-Janiak, Prof. EU, finanziert vom Nationalen Wissenschaftszentrum Polens, erteilt auf der Grundlage der Entscheidung Nr. 2018/31 / B / HS4 / 03711. Das Projekt antwortet auf die Probleme des sich dynamisch entwickelnden E-Commerce-Marktes. Attraktive Einkaufspreise, niedrige Kosten, kurze Lieferzeiten und bequeme Lieferorte motivieren Verbraucher zum Onlinekauf, was E-Commerce-Dienstleister und Transportunternehmen vor Herausforderungen stellt. Die Erfüllung der Erwartungen von Online-Kunden in Bezug auf die Lieferung gekaufter Produkte führt zu Verkehrsstaus, Umweltverschmutzung und Verkehrsunfällen. Das Projekt beinhaltet die Entwicklung eines Konzepts für ein nachhaltiges städtisches Logistikmodell für Lieferungen auf der letzten Meile und E-Commerce-Retouren, einschließlich Tools, um die Interessengruppen zu motivieren, ihre Präferenzen für Lieferungen auf der letzten Meile und Retouren zu ändern, um sie nachhaltiger (ökologisch, sozial und wirtschaftlich) zu machen.

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W artykule przedstawiono projekt badawczy realizowany na Uniwersytecie Ekonomicznym we Wrocławiu pod kierownictwem dr. hab. inż. Mai Kiby-Janiak, prof. UE, finansowany ze środków Narodowego Centrum Nauki w Polsce, przyznanych na podstawie decyzji numer 2018/31/B/HS4/03711. Projekt odpowiada na problemy, jakie stwarza dynamicznie rozwijający się rynek e-commerce. Atrakcyjne ceny zakupu, niskie koszty, krótki czas i dogodne miejsca dostawy motywują konsumentów do zakupów online, co stanowi wyzwanie dla usług e-handlu i firm transportowych. Spełnienie oczekiwań e-klientów w zakresie dostawy zakupionych produktów prowadzi do zatorów komunikacyjnych, zanieczyszczenia środowiska i wypadków drogowych. Projekt polega na opracowaniu koncepcji modelu zrównoważonej logistyki miejskiej w zakresie dostaw ostatniej mili i zwrotów na rynku e-commerce, w tym narzędzi motywujących interesariuszy do zmiany preferencji w zakresie dostaw ostatniej mili i zwrotów towarów, dzięki czemu staną się one bardziej zrównoważone (środowiskowo, społecznie i ekonomicznie).

IMPACTS OF PREFERENCE-DRIVEN PEER-TO-PEER ELECTRICITY TRADING ON DISTRIBUTION GRID LEVEL

Jens Maiwald
Zittau/Goerlitz University of Applied Sciences,
Faculty of Business Administration and Engineering,
Theodor-Koerner-Allee 16, 02763, Zittau, Germany
e-mail: jens.maiwald@hszg.de

Abstract

Until now, the ongoing German Energy Transition primarily takes place on the system's supply-side, while the demand-side remains rather unaffected. This article discusses how consumer behavior can be influenced by flexible electricity prices to align demand with generation. Therefore, a combination of two different approaches is used, (I) The Cellular Approach and (II) Agent-Based Modelling. In a simulated regional energy market area covering a whole distribution grid, all types of consumers are allowed to trade electricity peer-to-peer regarding each consumer's preferences. The results show that energy purchases can be stimulated individually by flexible pricing and met preferences. Moreover, benefits occur for the whole region and potentials arise to smooth the exchange balance to the superordinate grid level.

Keywords

Cellular approach; Agent-based modelling; Regional energy markets; Flexible pricing mechanism; Proactive consumer behavior.

Introduction

To always gain the indispensable equilibrium between generation and consumption, flexibility options are crucial factors for the security of electricity supply. The importance of these options will increase while the German energy transition progresses. Because up to now flexibility is mainly provided by controllable supply-side actors [1]. But due to the dependence on weather conditions, Renewable Energy Sources (RES) cannot be considered controllable.[1] Furthermore, volatility and decentralism become permanent supply-side characteristics. In contrast, the demand-side will hardly change as consumption remains rather inflexible in spatial as well as in temporal sense. Therefore, the organizational effort for gaining the equilibrium increases tremendously [2], [3].

Nevertheless, increasing shares of decentral generation units provide a rising potential for enhanced interconnection of supply and demand on local grid levels. As it is no longer sufficient to only manage supply-side, supply and demand have to be managed and adjusted mutually. Therefore, it is indispensable to create more flexibility on the demand-side [4]. However, still it has not been answered satisfactorily how to change or influence consumer behavior effectively.

As the generation of electricity out of RES is highly weather dependent, technologies allowing the temporal decoupling of generation and consumption are required. Without a doubt, battery storage systems and power-to-x-technologies will be part of the overall solution

[1] The only exceptions are hydroelectric and biogas power plants.

to evade this dependency. Moreover, the so-called demand-side management is an eligible approach for shifting or cutting load peaks to a certain extent [4], [5]. The other part of the overall solution will be the consumers themselves [6].

1 Regional Energy Market Model

1.1 Research Subject

As already described in the introductory part, it will be a matter of making adjustments also on the consumption and not only generation side in future electricity supply systems. While there are already tried and tested technical solutions, it has not been answered satisfactorily yet which contributions financial incentives can make. In order to find out how to change consumer behavior and which effects emerge due to this, a model is set up depicting individual consumer behavior in a regional energy market.

First of all, it has to be stated that this model is not an equilibrium model for minimizing overall system costs assuming perfect foresight, but rather for simulating consumer behavior and investigating possible impacts on the supply system. Therefore, two different methodological approaches are combined: (I) Agent-Based Modelling (ABM) and (II) the so-called "Cellular Approach" (CA). ABM allows to implement individual consumer behavior whereas the CA depicts the technical basis for peer-to-peer electricity trading.

A short note to the Reader: The following sections provide merely a condensed model description. For a full description, the former publication [7] is recommended.

1.2 Research Methods

1.2.1 Agent-Based Modelling

ABM is the method of choice for simulating behavior patterns. These models can portray an economic system in which orderly behavior can emerge as a result of interaction between heterogeneous agents, none of whom has any understanding of how the overall system functions [8], [9]. Furthermore, ABM enables to investigate several system levels in different degrees of abstraction. Especially the interdependency between the microscopic level, where agents act, and the macroscopic level, where system behavior emerges, can be observed [10].

That means, ABM allows to simulate imperfect markets and competition. Therefore, agents represent various market participants acting with strategic behavior based on asymmetrical information.

The REMM is built in NetLogo 6.2.2.[2]

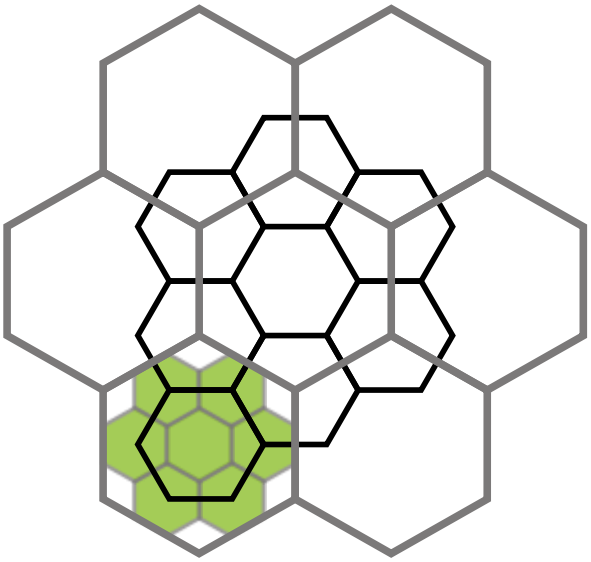
1.2.2 Cellular Approach

As mentioned in the introductory part, Germany's goal is to integrate high shares of fluctuating RES. With regard to the challenge of adjusting supply and demand mutually, this requires new approaches with an increased degree of system control. The CA is such an approach and offers a broad range of potential benefits for integrating RES in local distribution grids, while always balancing supply and demand on the lowest possible level.

Therefore, the CA is based on so-called "Energy Cells". Cells are defined by the ability to generate, consume, and even store energy. Each cell's goal is to reach the equilibrium

[2] For more information about NetLogo, see https://ccl.northwestern.edu/netlogo/.

between generation and consumption by itself. If this goal cannot be reached alone, every cell can connect to other cells and, thereby, build superordinate energy cells in turn, see Figure 1.



Source: Author's own compilation based on [11]

Fig. 1: *Schematic illustration of energy cells*

To rephrase this and give a short example, imagine a private household operating a PV roof-top system. In this example, the household is the lowest possible cell, always trying to fit its own electricity consumption to its own individual generation and vice versa. In case the self-supply by the PV system is higher than its own consumption, this household connects to other cells in the supply system, maybe to another household, and sells its leftover electricity. Or in contrast, buys electricity from other cells if their own demand is higher than the self-supply.

Since the logic of the CA not only provides a technical concept, the feasibility of which is, by the way, confirmed in [12], but also a concept for peer-to-peer trading, the combination of ABM and CA allows to observe emerging consumer behavior in a counterfactual (regional) energy market scenario. Each agent represents one market participant, and accordingly one sub-ordinate energy cell, acting by its own preferences and trying to equilibrate its own generation and consumption.

1.3 Model Structure

1.3.1 Overview

The Regional Energy Market Model (REMM) is set up for a simulation period of one year in a one-hour resolution beginning from January 1st. The modeled electricity system is a typical local distribution grid with its characteristic producing and consuming entities, covering an area of 100 km^2 partitioned as a predefined 10 by 10 mesh with 100 patches each of 1 km^2. The model is set up very variable and, therefore, able to cover and simulate various supply and demand scenarios. For running the model according to the author's purposes, an exemplary scenario is implemented, which is comparable to the supply system of Zittau, a small town in eastern Germany with roundabout 26,500 inhabitants. The supply system of Zittau is operated by the Local Utility Company (LUC), which ties in perfectly with the idea of the CA and the model structure. Once built to supply higher amounts of consumers, the local grid is slightly oversized so that no grid constraints exist in the model.

The REMM covers the three typical representative consumer groups:

- Private Households – model name: Residentials with Standard Load Profile (RSL)
- Trade, Commerce & Service – model name: Business with Standard Load Profile (BSL)
- Industry – model name: Business with Measured Load Profile (BML)

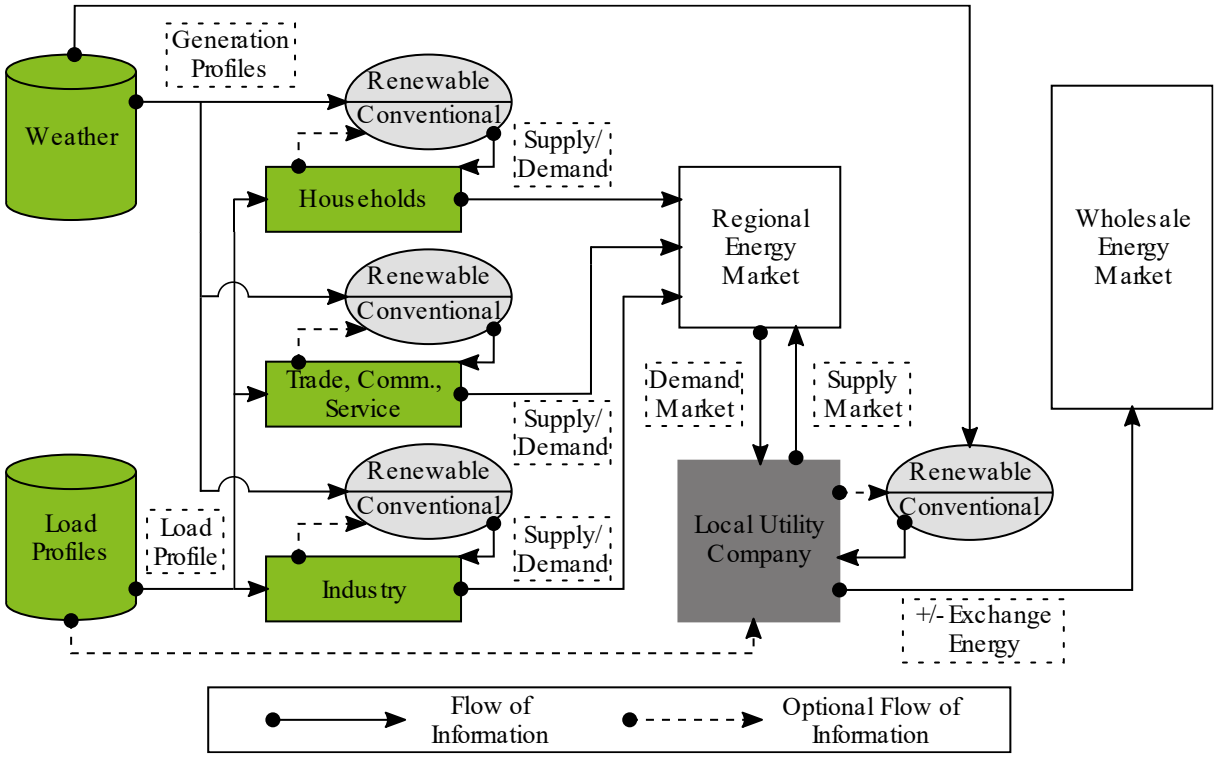
Basically, similar to other economic models, the REMM distinguishes between supply and demand as leading variables. However, particularly in future energy supply systems, the former, relatively solid boundaries between producer and consumer tend to be blurred. More and more so-called "Prosumers" will enter the market, whose role as producers or consumers depends on how high their own energy generation is compared to their consumption. Based on the CA, literally every REMM entity could act as a producer or consumer out of the systems view respectively as a seller or buyer out of the market's view (see Fig. 3).

As mentioned above, an exemplary simulation scenario corresponding to the supply system of Zittau is implemented in the REMM. In numbers: 15,407 RSL, 1,638 BSL and 108 BML agents.

1.3.2 Local Utility Company

As there is a local market and a local supply system, there consequently has to be a system operator who ensures the regional equilibrium between generation and consumption at any time. In REMM, this is the LUCs responsibility. Therefore, the LUC has various options. One can be to use its own renewable as well as conventional generation units. Another is to sell or buy electricity from the interregional wholesale market depending on regional over- or under capacities respectively.

The LUC is modeled as a passive agent, due to the fact that the model's observations are all about consumer behavior. Passive means that the LUC acts without any intention of making a profit, maintaining the overall system, and reading the market to meet the consumer's demand.



Source: Author's own compilation

Fig. 2: *Schematic overview of the REMM and its entities*

Figure 2 provides an overview over the whole system and entities.

1.3.3 Demand-Side

RSL and BSL agents are characterized by standard load profiles, published by the German Electricity Association.[3] The implemented simulation scenario uses H0 (dynamic) for RSL and G0 for BSL agents. These profiles are standardized to an annual consumption of 1,000 kWh and have to be scaled up to use them in the model. Therefore, each hourly value of the profiles is multiplied by a coefficient randomly chosen out of a domain, which was chosen according to statistical data, and is assigned to each of these agents before the simulation starts.

For BML agents, of course, no standard load profiles exist. Therefore, empirical load profiles were created, which were derived from actually measured profiles of several real existing companies, which are comparable to those companies typically connected to the distribution grid. By this, three load profiles were generated representing different types of companies.

All these entities are consciously modeled out of the systems perspective. That means they are mainly characterized by two attributes, consumption and demand. While consumption describes the total electricity need of an agent per time step, demand describes his hourly electricity purchase from the grid. For most of the agents applies consumption equals demand. However, some agents (prosumers) are able to partially generate their own electricity, so that their demand is smaller than their consumption.

For more detailed information please consult the recommended literature in Sections 1.1 and 1.3.1.

1.3.4 Supply-Side

As already mentioned above, theoretically every demand-side agent could also be a supplier out of the systems perspective as long as he operates a generation unit. Since this is not very probable, the model user can predefine how many of them operate a generation unit via the model's interface. But, which agent becomes a so-called prosumer is still a random decision by the model.

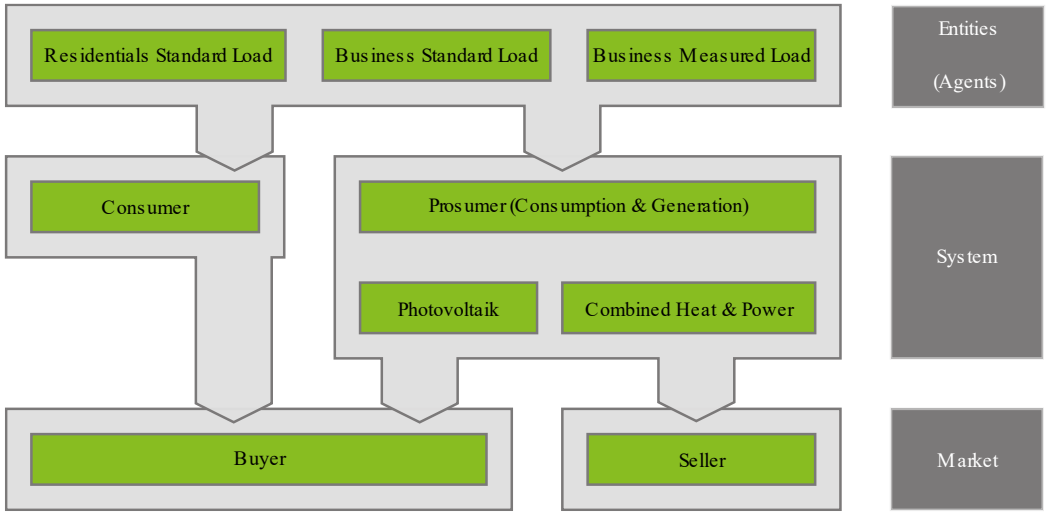
To simulate generation characteristics properly, several possibilities are given. Prosumer can own a PV roof-top system and/or a Combined Heat and Power (CHP) unit, which is operated either with natural gas or biogas (see Fig. 3). Once a generation technology is assigned, the model adjusts its capacity to the annual consumption pattern of the operating agent. By this, different generation characteristics are integrated into the REMM. Volatile feed-in through RES is represented by PV systems, controllable renewable generation by CHP units operated with biogas and controllable conventional generation characteristics by CHP with natural gas.

To determine what amount of electricity can be generated hourly by PV systems, a database with exogenous weather data is linked to the model. CHP units are operated in a heat-controlled mode. Therefore, the daily average temperatures were determined based on the exogenous weather data. If the average temperature of the following day falls below the heating limit, defined in the model's interface, the CHP system is switched on for the next full 24 h and operates on nominal load.

Of course, each prosumer prefers to consume its self-generated electricity prior to cover its own consumption. In times, where generation is greater than consumption, prosumers sell

[3] Verband der Elektrizitätswirtschaft (VDEW)

their leftover electricity at the regional market. If generation is lower than consumption, prosumers will buy the missing electricity at the market, see Figure 3.

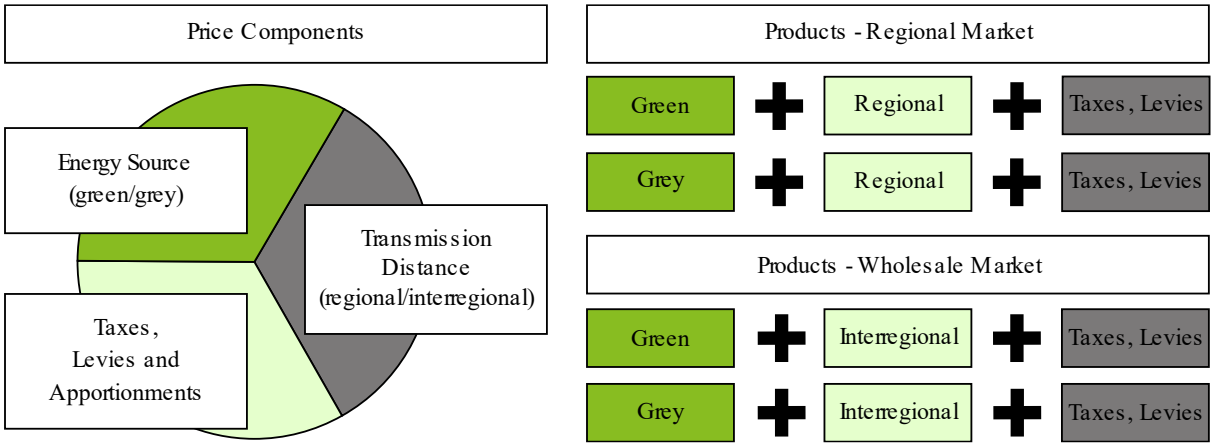


Source: Author's own compilation

Fig. 3: *Entities and their roles*

1.4 Market and Pricing

Figure 4 shows the pricing mechanism within the REMM. As in reality – at least in Germany – there are three different price components: (I) generation, (II) transmission and (III) taxes, levies and apportionments. As (III) accrues for all products, it would make no sense to consider them further in the following explanations.



Source: Author's own compilation

Fig. 4: *Electricity price components and market products*

Each consumer is free to act according to their own preferences. That means, in every time step each agent is free to choose between electricity generated from conventional sources (grey) or from renewable sources (green). Furthermore, they are free to choose whether they prefer electricity generated in the same region or outside the region. Combining these different possibilities results in four different market products: (I) Green Regional, (II) Grey Regional, (III) Green Interregional and (IV) Grey Interregional.

As Figure 2 shows, agents have only direct access to the regional market section. However, that does not mean that they are only able to buy regional products. As the LUC is the connector between the regional and the wholesale market, interregional products are offered

via the LUC. Within the region all prosumers are allowed to offer their self-generated left-over electricity at the regional market, as a regional product.

As there are different price components and several product characteristics to choose, of course the overall electricity price differs from product to product (I – IV). For reasons of simplicity, the simulation works with fixed prices for every time step. That means, neither the regional nor the interregional market owns a further pricing mechanism, like the merit-order approach. In the REMM it is the LUCs responsibility to set the prices.

For purchasing the grey product, consumers only have to pay the so-called "base price", whereas for the green product, an additional price premium for green energy has to be paid. This premium is comparable with the German Renewable Energies Act Levy (known as "EEG-Umlage"). The premium can be treated as a subsidy for RES.

$$p_{source} = \begin{cases} p_{base} & : \ Grey\ product \\ p_{base} + p_{green} & : \ Green\ product \end{cases} \quad (1)$$

By choosing between regional or interregional products, every consumer decides about the height of the grid fee. The model's world is a 10 by 10 mesh with 100 patches. All prosumers located on one of these patches are considered producers offering regional electricity. On the contrary, all electricity generated not within this area is considered interregional. Both, the regional and the interregional grid fee, can be predefined by the user in the model's interface.

$$p_{grid} = \begin{cases} p_{reg} & : \ Regional\ Purchase \\ p_{trans} & : \ Interregional\ Purchase \end{cases} \quad (2)$$

As mentioned, the component for taxes, levies and apportionments accrues for all products. So, the overall electricity price results in dependence of the chosen product as:

$$p_{el} = p_{source} + p_{grid} + p_{tax} \quad (3)$$

1.5 Consumer Behavior and Decision Making

Each Agent in the REMM is parametrized with three preferences, which are the initial point for all decisions made by these agents: (I) environmental awareness, (II) regional awareness and (III) budget, as a marker describing his cost sensitivity. Every preference is a value between zero and one.

Tab. 1: *Domains for consumer preferences*

Awareness	Domain
environmental	$e \in]0;1]$
regional	$l \in]0;1]$
budget	$c \in]0;1]$

Source: Own

Environmental awareness describes each agent's individual esteem for green energy sources. Regional awareness represents each agent's preference for electricity generated in a local context. For both, a value close to one indicates a high preference, a value close to zero a low preference. Budget describes his individual assessment of higher costs. It is directly dependent on one agent's income (RSL), respectively on one agent's earnings (BSL and BML) and expresses in his preference for the price. Here, on the contrary, a value close to one indicates a high sensitivity for higher costs, a value close to zero a low sensitivity, which would mean that these agents are more likely to pay higher prices.

In a two-step decision process, all consumers take a new decision at every time step which electricity product they preferably want to purchase. For this, each agent calculates personal utility values taking into account his own preferences and then compare green and grey in the first step respectively regional and interregional products in the second step. Of course, a product, which provides the biggest utility value, is chosen.

Similar to the approach in [13], the utility values for stage one are calculated as follows. Each agent compares an intrinsic value with the (negative) value of (higher) costs. The intrinsic value is calculated under the estimation that one extra unit of the price premium for green electricity can be converted in exactly one unit of an abstract personal good, which can be interpreted as well-being or moral satisfaction. The intrinsic value results out of the agent's environmental awareness combined with its price sensitivity and the amount of the price premium. By this logic, the intrinsic value for the purchase of grey electricity is 0.

$$u_{intr,i,t} = \begin{cases} 0 & : \ grey \\ e_i \cdot \sqrt{p_{green,t}} \cdot c_i & : \ green \end{cases} \tag{4}$$

The (negative) effect of (higher) costs caused by the base price component and the extra price premium for electricity out of RES results under each agent's price sensitivity and the amount of the price components.

$$u_{cost,i,t} = \begin{cases} c_i^2 \cdot p_{base,t} & : \ grey \\ c_i^2 \cdot \left(p_{base,t} + p_{green,t}\right) & : \ green \end{cases} \tag{5}$$

The overall utility functions for stage one result by combining the intrinsic value with the cost value for the purchase of green or grey electricity.

$$U_{grey,i,t} = 0 - c_i^2 \cdot p_{base,t} \tag{6}$$

$$U_{green,i,t} = e_i \cdot \sqrt{p_{green,t}} \cdot c_i - c_i^2 \cdot \left(p_{base,t} + p_{green,t}\right) \tag{7}$$

Analogous to stage one the utility values for stage II result out of the comparison between the intrinsic values and the values of costs. It is assumed, that the intrinsic value exists only for the purchase of electricity generated in a regional context. The intrinsic value for interregional purchase is 0.

$$u_{intr,i,t} = \begin{cases} l_i^2 \cdot \sqrt{p_{reg}} \cdot c_i & : \ regional \\ 0 & : \ interregional \end{cases} \tag{8}$$

Similar to stage one the functions for the value of costs result considering each agent's price sensitivity and the corresponding price component.

$$u_{cost,i,t} = \begin{cases} c_i^2 \cdot p_{reg} & : \ regional \\ c_i^2 \cdot p_{trans} & : \ interregional \end{cases} \tag{9}$$

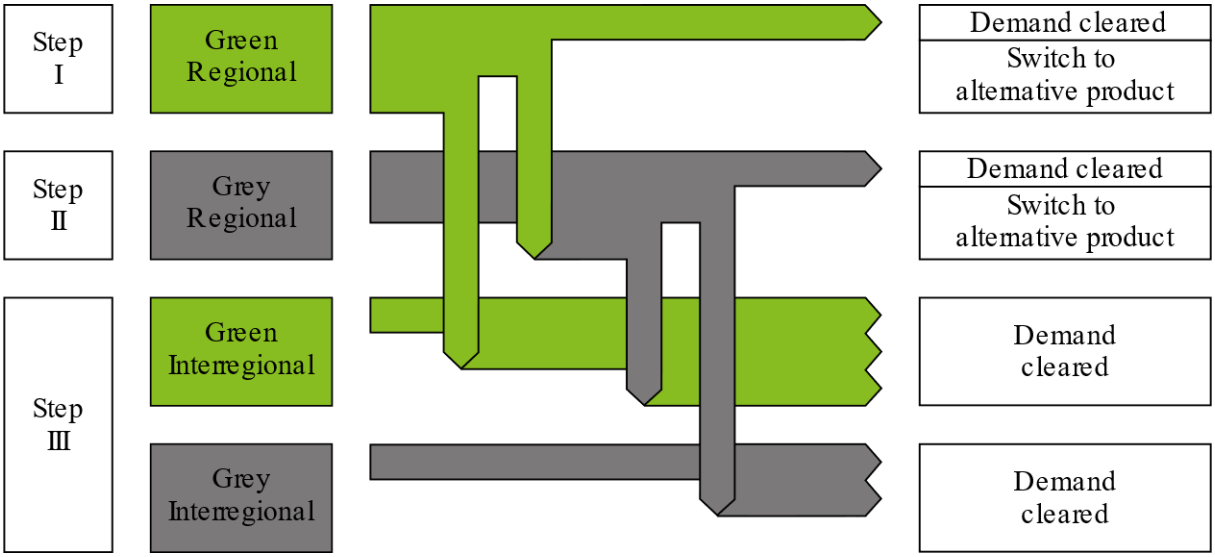
The overall utility functions for stage two result by combining the intrinsic value with the cost value for the regional or interregional purchase.

$$U_{reg,i,t} = l_i^2 \cdot \sqrt{p_{reg}} \cdot c_i - c_i^2 \cdot p_{reg} \tag{10}$$

$$U_{trans,i,t} = 0 - c_i^2 \cdot p_{trans} \quad (11)$$

1.6 Market Clearing

In the REMM it is the LUC's responsibility to clear the market. Due to the inherent characteristics of generation through RES and CHP units, the regional market is highly volatile. Consequently, situations can arise where parts of the preference-driven demand cannot be met. Situations with regional oversupply are not crucial for the simulation, because of the assumption that leftover electricity could be sold at the wholesale market at any time. In contrast, situations with undersupply of both or at least one regional product are challenging. A decision has to be made, who of the applying agents gets served and who has to switch to another product, and on which basis this switching decision happens. In the REMM this decision is based on each agent's Willingness To Pay (WTP). The WTP can be calculated out of the several utility functions. By equating the functions (6) and (7) and converting to p_{green}, the height of the price premium can be calculated at which an agent would just about prefer the green product to the grey one. Analogous this works for the WTP for the regional product by equating the functions (10) and (11) and converting to p_{trans}. The clearing process for regional under capacities is carried out in 3 steps (see Fig. 5).



Source: Author's own compilation

Fig. 5: *Market clearing scheme*

At first, the green regional market section gets cleared. Therefore, all applying agents are listed on the basis of their WTP for green. Agents with high a WTP are served first, and agents with a low WTP last.

$$wtp_{green,i} = \left(\frac{e_i}{c_i}\right)^2 \quad (12)$$

Not served agents switch to an alternative product. Since the initial decision on green and regional is already made, decisive for switching is which of the two predicates the agent would like to keep. Indicators for this decision are the individual preferences for environmental and regional awareness. A weighting for both is already given during the model set-up. If environmental awareness is greater equal regional the agent switches to the green interregional product. If environmental awareness is small the agent switches to grey regional.

In step two all section grey regional is cleared covering all agents who would like to purchase this product right from the beginning and also those who were not served in the first clearing step and subsequently decided on grey regional as their alternative product. Analogous to step one, agents with a high WTP are served preferred.

$$wtp_{reg,i,t} = \frac{l_i^4}{2c_i^2} + \frac{l_i^2}{c_i} \cdot \sqrt{\frac{l_i^4}{4c_i^2} + p_{trans}} + p_{trans} \tag{13}$$

Those agents who cannot be served switch to an alternative product. Since the product green regional is not available any longer, agents are only still free to choose between the interregional green or grey product. For this, the already calculated utility values can be used since it is a decision between green and grey. Consequently, all agents who have already decided to choose grey electricity in the initial decision continue to purchase grey. Only agents who were not supplied with green electricity in clearing step I and switched to grey regional due to a higher regional awareness will switch back to the green but interregional product.

In step three, all agents that were not served yet in the first two clearing steps and all those who initially decided to purchase interregional electricity are regarded and served. It is one of the model assumptions, that the LUC can always meet the demand for interregional products via the wholesale market.

2 Simulation

2.1 Scenarios and Parameters

The parameters for this chapter's simulations, in addition to those already addressed above, are given below in Table 2. This work focuses on the observation of two different pricing strategies within two different levels of RES integration in the supply system.

Tab. 2: *Parameters for simulation scenarios*

	Fix Price		**Flex Price**	
Deviation LP	5%		5%	
Share PV	5%	15%	5%	15%
Share CHP	5%	15%	5%	15%
Share Biogas	33%	50%	33%	50%
p_{base}	7.5 ct / kWh		7.5 ct / kWh	
p_{green}	6.5 ct / kWh		[2; 6.5] ct / kWh	
p_{trans}	7.5 ct / kWh		7.5 ct / kWh	
p_{regio}	10.5 ct / kWh		10.5 ct / kWh	

Source: Own

The first pricing scenario is an ordinary scenario with fixed prices for all price components. The given prices in Table 2 are aligned with the actual level of the real price components in Germany in 2020. The fix price scenario serves as the base case for the observation. In contrast to that, simulations are carried out where the pricing for the extra premium for green energy is flexible. In this given scenario the price premium may vary between 2 and 6.5 ct/kWh. The implemented price mechanism depends on the amount of generated electricity out of RES. The higher the current generation is in comparison to the actual installed capacity, the lower gets the price and vice versa. By this, it can be observed which effects flexible pricing will cause.

Moreover, it will be observed which influence higher shares of RES will have on these effects. For this, two different RES expansion scenarios are simulated. In the first scenario, 5% of the agents of each consumer group operate a PV roof-top system and another 5% with a CHP unit, of which 33% operate their unit with biogas whereas 67% use natural gas. In the second scenario, 15% each operate a PV roof-top system or CHP unit and 50% of the CHP operators use biogas.

The first value in Table 2 is an additional, random value and represents the permitted deviation an agent's electricity consumption is allowed to vary. Since the REMM works with standard load profiles, it is advisable that not all agents of the same group are treated with the same scaling factor and purchase exactly the same amount of electricity per time step.

2.2 Results and Discussion

Since the scenarios explained above refer to the investigation of the effects of flexible green electricity prices, it seems reasonable to focus specifically only on this point in the following. Therefore, the evaluation of the simulation is primarily focused on the product 'green regional'. Furthermore, the following graphs consistently deal with the same four parameters. Firstly, 'generation' that resembles the whole region's generation of green electricity. Secondly, 'Sales Volume' that results out of the fact, that prosumers preferably use their self-generated electricity to meet their demand. Only the left-over electricity is sold at the market. Thirdly, 'Demand fix' that resembles the demand for 'green regional' in the fix price (base case) scenario. And finally, 'Demand flex' representing the demand for 'green regional' in the flex price scenario. All graphs resemble the average results over five full model runs for each scenario.

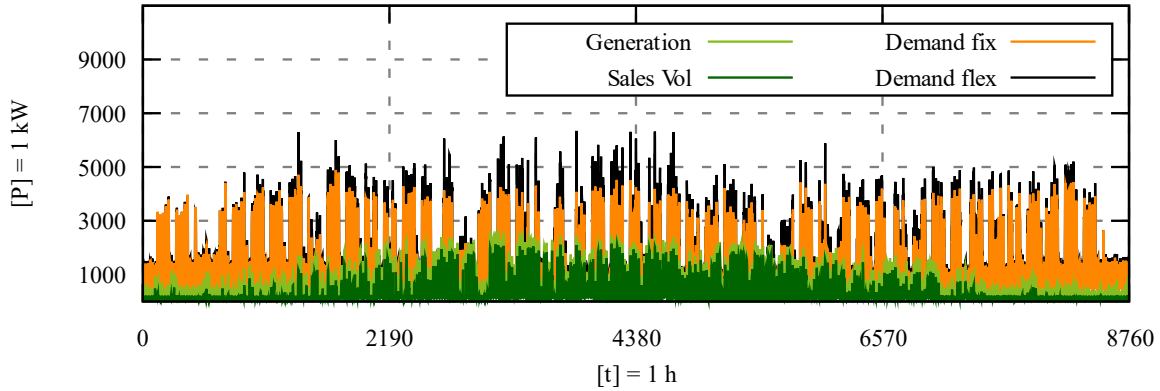


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Fig. 6: *Demand for 'green regional' in fix and flex price scenario and 5% RES over one year*

Figure 6 shows the demand for 'green regional' in the fix and flex price scenario within the 5% RES expansion scenario over one year from January 1st. Although this figure does not provide any details due to the density of the values, several initial results are already included. What hits the eye first is the fact that the available sales volume of 'green regional' is seemingly never enough to meet the overall demand, neither in the fix price nor in the flex price scenario. Moreover, the height of the gap between generation and sales volume (which is equal to the self-consumption) seems not to have a crucial impact on whether the regional demand could be met or not. And last but not least, Figure 6 shows pretty clear that the flexible pricing mechanism causes higher demand for 'green regional' even in low RES scenarios. At this point, it should be noted, that this increase in demand is not an actual, physical change in consumption, since the agents in the model cannot shift their consumption

to another time step, but only the electricity's place of origin. It merely shows a potentially increasable absorption of regional willingness to pay, in times with high renewable generation.

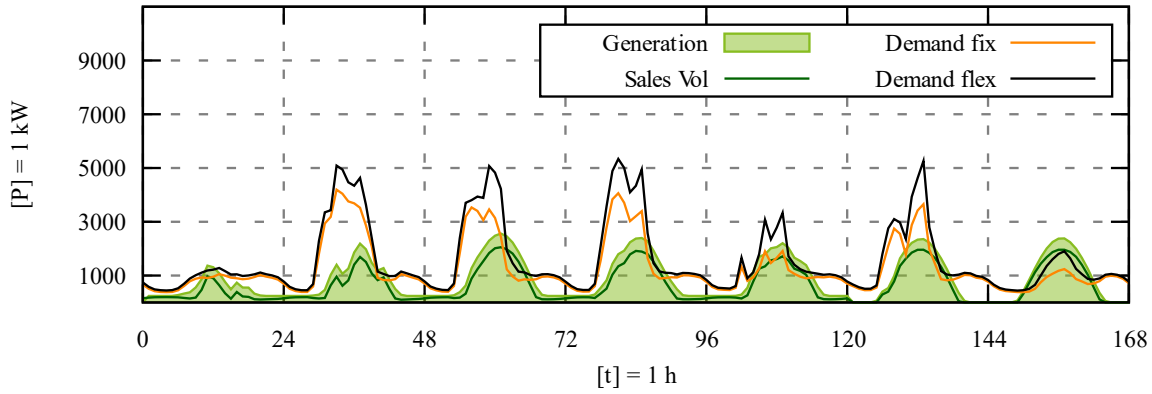

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Fig. 7: *Demand for 'green regional' in fix and flex price scenario and 5% RES over one week in May*

Figure 7 shows the demand for 'green regional' product in the fix and the flex price scenario within the 5% RES expansion scenario over one week in month May. This month is chosen because it belongs to the transitional period between summer and winter and resembles one ordinary, average generation scenario. The impressions provided through Figure 6 are essentially confirmed and, moreover, more details are shown. One of these details is that there are hours, especially in the afternoon, when the sales volume does exceed the demand. On the one hand, it means that the demand for 'green regional' can be met. On the other hand, sales volume exceeds the demand in the fix price scenario, which means the regionally generated electricity is transferred into the transmission grid. But Figure 7 also shows that in the flex price scenario the demand in the afternoon hours could be increased in a manner to nearly match the sales volume.

Another point that is not so obvious at first glance is the different temporal occurrence of the curve's peaks. The several peaks of the demand curves mainly occur a few hours before the generation peaks at noon.

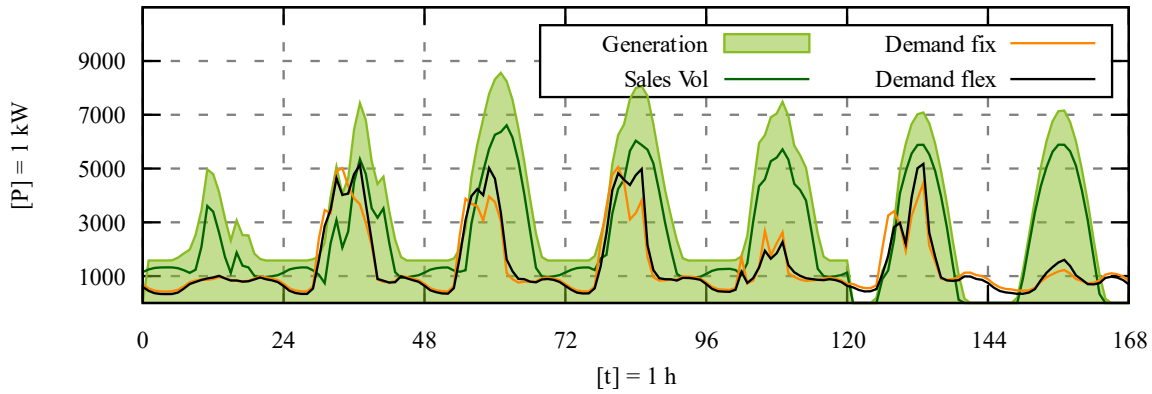

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Fig. 8: *Demand for 'green regional' in fix and flex price scenario and 15% RES over one week in May*

Figure 8 shows the demand for 'green regional' in the fix and flex price scenario over one week in May, but this time within the 15 % RES expansion scenario. What changes to the 5%

RES scenario is, that now most of the time generation respectively sales volume exceeds the regional demand. However, it can be observed that in fix price scenario, the demand curve exceeds the sales volume on most days namely in the forenoon. Even though it is not perfect, the curve of the flex price scenario aligns much better.

As mentioned, while discussing Figure 7, it was noticeable that there was a slight offset between the different curve's peaks. In Figure 8 it seems that this offset is still there, but smaller. According to the current state of verifying these results, this has two reasons. One is that there is indeed a slight shift in demand towards noon due to falling prices. The other is probably an optical reason. Due to the larger and wider form of the curve, it looks like the demand peaks and the generation peak fit better. But in the end, it is more a shift of the generation curve upwards, than a rightward shift of the demand.

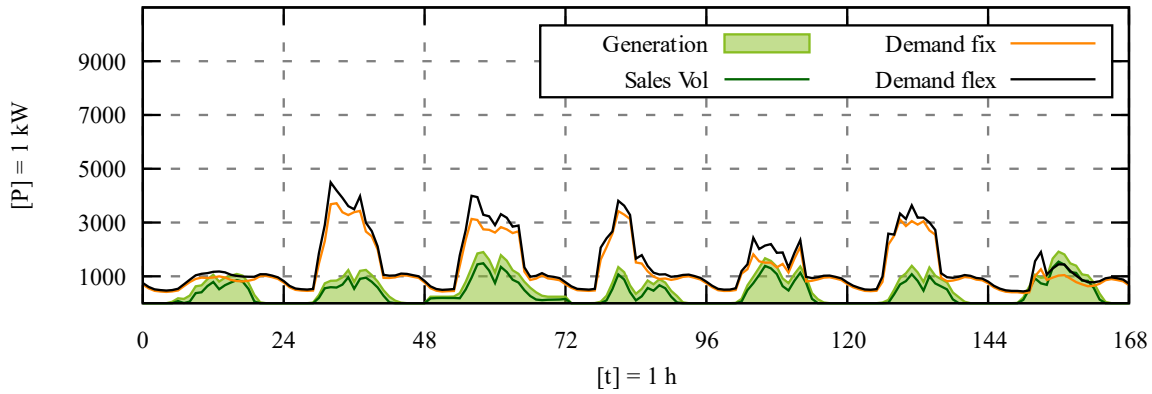

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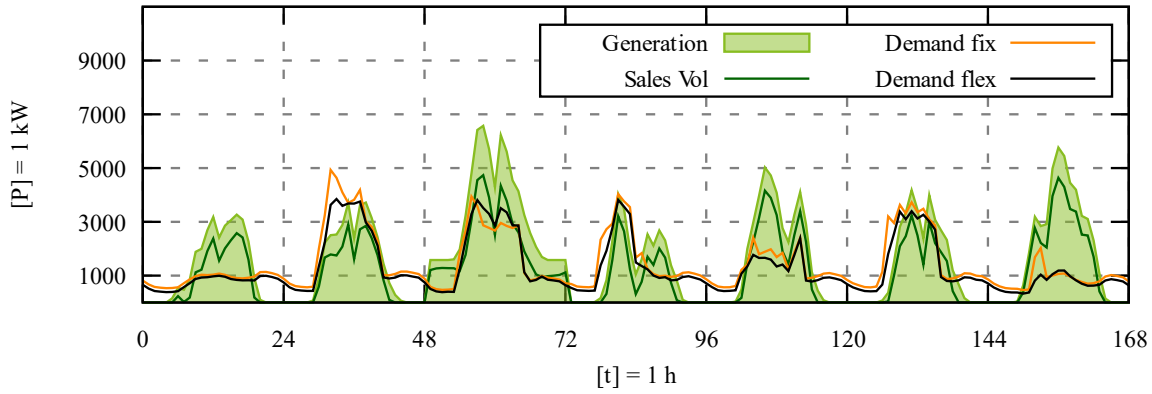
Fig. 9: *Demand for 'green regional' in fix and flex price scenario and 5% RES over one week in July*

Figure 9 shows the demand for 'green regional' in the fix and flex price scenario within the 5% RES expansion scenario, but now over one week in July. In theory, electricity consumption tends to decrease in summer compared to the transitional period, like in the month of May. However, temperatures rise in summer, which means that green electricity generation from CHP units will probably cease, which, in the end, will lower the sales volume. And this is exactly what can be observed in Figure 9.



Source: Own

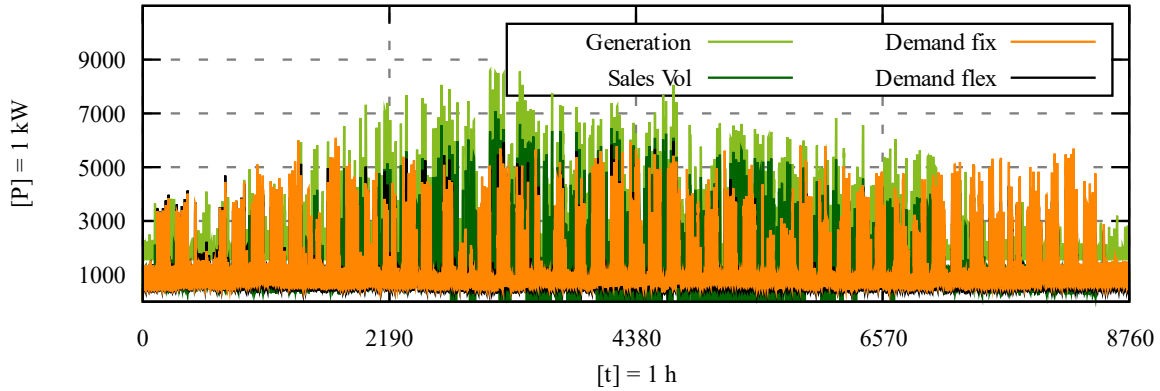
Fig. 10: *Demand for 'green regional' in fix and flex price scenario and 15% RES over one week in July*

Demand in July is significantly lower compared to May. Both curves proceed considerably flatter. Even the effect of increasing the demand due to flexible prices is much less significant.

But of course, since the generation through CHP units ceased and only PV serves the market, the decreasing effect on the price is not given. And this also causes, that the sales volume exceeds the demand only in a very small number of hours.

Figure 10 shows the demand for 'green regional' in the fix and flex price scenario again for the same week in July, but this time within the 15% RES expansion scenario. Generation during nighttime is again zero, which obviously means that CHP units are still not running due to the high temperatures. But at noon generation and sales volume is much higher due to higher shares of PV. With the exception of the first and the last day, it seems that sales volume and consumption match relatively well.

But what hits the eye at the second glance, is that in some hours the demand in the flex price scenario is below the demand of the fix price scenario. According to the current state of verifying these results, this could be caused by randomly chosen model parameters during the set-up of the model before each simulation starts. But also plausible is the following. The LUC sets the price based on the ratio between the amount of the actual generation and the installed capacity. Since all CHP units are switched off and PV systems do not seem to be running at full load either, this ratio is very low, which in turn causes there are only few price incentives and consumers do not buy.



Source: Own

Fig. 11: *Demand for 'green regional' in fix and flex price scenario and 15% RES over one year*

Figure 11 shows the demand for 'green regional' in the fix and flex price scenario within the 15% RES expansion scenario over one year. Compared to Figure 6 (one year within the 5% scenario), it is noticeable that the spreads between the fix and flex price scenario are not as wide. However, demand and sales volume seem to match a little bit better due to the changed face of the generation pattern, however, the figure does not reveal any details.

Conclusion

The results have shown that flexible pricing mechanisms have various advantages and can provide targeted incentives for purchasing at the right time step. For an energy system that is becoming increasingly decentralized anyway, this has a relieving effect and the transferred amount of regionally generated electricity into higher grid levels can be reduced.

However, the results have also shown that the mechanism for setting the price premium based on the ratio of the actual generation to the installed capacity does not always lead to the desired incentives within the selected scenarios. For practical application, therefore, a different approach may have to be taken. And moreover, sometimes no extra pricing

mechanism is needed if the generation scenario and the consumption structure basically match.

It must be emphasized again that the current study was only about setting buying incentives and that it was not about the actual shift in the physical purchase of electricity. This approach plays a role in the currently ongoing, further investigations, based on the results shown here.

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Účinky preferenčního obchodování s elektřinou peer-to-peer na úrovni místní distribuční sítě

Energetická transformace v Německu doposud probíhá primárně na straně nabídky systému, zatímco strana poptávky zůstává spíše nedotčena. Tento článek pojednává o tom, jak lze chování spotřebitelů ovlivnit flexibilními cenami elektřiny, aby se sladila poptávka s výrobou. Proto se používá kombinace dvou různých přístupů, (I) Celulární přístup a (II) modelování založené na inteligentních agentech. V simulované oblasti regionálního trhu s energií pokrývající celou distribuční síť mohou všechny typy spotřebitelů obchodovat s elektřinou peer-to-peer podle preferencí každého spotřebitele. Výsledky ukazují, že nákupy energií lze individuálně stimulovat flexibilním stanovením cen a splněnými preferencemi. Navíc dochází k výhodám pro celý region a vznikají potenciály k vyrovnání směnné bilance na úroveň nadřazené sítě.

Auswirkungen von Präferenzgesteuertem Peer-to-Peer-Stromhandel auf lokaler Verteilnetzebene

Bisher findet die deutsche Energiewende vornehmlich auf der Angebotsseite statt und sorgt für teilweise massive Veränderung in diesem Bereich. Die Nachfrageseite hingegen blieb bislang eher unbeeinflusst. In diesem Beitrag wird diskutiert, wie Verbraucherverhalten durch flexible Strompreise so beeinflusst werden kann, dass sich die Nachfrage an die Erzeugungscharakteristika anpasst. Dazu wird eine Kombination aus zwei verschiedenen Ansätzen genutzt: (I) Der zellulare Ansatz und (II) die agentenbasierte Modellierung. In einem simulierten regionalen Energiemarktgebiet, welches ein lokales Verteilnetz umfasst, können die einzelnen Verbraucher der unterschiedlichen Verbrauchsgruppen unter Berücksichtigung ihrer individuellen Präferenzen gleichberechtigt Strom handeln. Die Ergebnisse zeigen, dass Energiekäufe durch flexible Preise und die Berücksichtigung von Präferenzen individuell angeregt werden können. Darüber hinaus ergeben sich Vorteile für die gesamte Region und Potenziale zur Minderung der Austauschenergiemengen mit der übergeordneten Netzebene.

Skutki preferencyjnego handlu energią elektryczną w systemie Peer-to-Peer na poziomie lokalnej sieci dystrybucyjnej

Transformacja energetyczna w Niemczech odbywa się do tej pory przede wszystkim po stronie podażowej systemu, podczas gdy strona popytowa pozostaje raczej bez zmian. W artykule omówiono, w jaki sposób na zachowania konsumentów mogą wpływać elastyczne ceny energii elektrycznej, dopasowujące popyt do produkcji. Dlatego stosuje się połączenie dwóch różnych podejść (I) Cellular Approach i (II) Agent-Based Modeling. W symulowanym obszarze regionalnego rynku energii, obejmującym całą sieć dystrybucyjną, wszystkie typy odbiorców mogą handlować energią elektryczną w systemie peer-to-peer zgodnie z preferencjami każdego z nich. Wyniki pokazują, że zakupy energii mogą być indywidualnie stymulowane przez elastyczne ceny i zaspokojone preferencje. Ponadto generowane są korzyści dla całego regionu oraz powstaje potencjał w zakresie równoważenia bilansu wymiany z wyższym poziomem sieci.

BALANCE SHEET RULES AND THEIR INFLUENCE ON BUSINESS PERFORMANCE – AN EMPIRICAL STUDY

Marta Nosková[1]; **Petra Taušl Procházková**[2]; **Eva Jelínková**[3]
University of West Bohemia, Faculty of Economics,
Department of Business Administration and Management,
Univerzitní 22, 306 14 Plzeň, Czech Republic
e-mail: [1]mnosk@kpm.zcu.cz; [2]pprochaz@kpm.zcu.cz; [3]jelinkov@kpm.zcu.cz

Abstract

The study aims to examine in detail the impact of compliance with balance sheet rules on business performance. To examine this premise, data from small and micro businesses in the Czech Republic (total number 2,537) were statistically tested using t-test and Mann-Whitney U test. Particular attention was paid to the value of the return on equity indicator (as a business performance indicator), and the changes in this value between the business groups that comply and those that do not comply with these rules. The results suggest that the positive effect of balance sheet rule compliance on business performance cannot be confirmed, nor the predominant compliance among businesses was proven. Thus, the discussion of whether the balance sheet rules need regularly appear in the current business economics literature should be open. The results are presented and discussed in this paper, together with their limitations.

Keywords

Balance sheet rules; Business performance; Business performance measurement; Impact.

Introduction

Balance sheet rules are understood as a well-known part of the business economy theory. They present recommendations on how to manage balance and stability in financing. Such recommendations are still common in German-speaking countries, as well as in the Czech Republic or Slovakia. By following these rules, businesses should achieve long-term financial stability due to the specific structure of assets and liabilities. Balance sheet rules are commonly understood as one of the tools for financial analysis. Financial analysis is conducted mainly to obtain information about a company's financial management and, thus, to support the stabilization of the company's financial health. Financial analysis results can influence companies' financial strategies and, thus, their business competitiveness. Despite its importance, limited attention is paid to the compliance of business sheet rules within companies' financial strategies. As López Salazar et al. [1] argue, financial analysis and its parts represent basic features that support company strategy. However, they point out that little attention has been paid to micro and small companies. They argue that micro and small businesses use a limited scope of financial information to make decisions, and the priority is often given to operating activities, not to developing financial plans. Nonetheless, the importance of financial decisions is clear, and its management contributes to the failure or growth of a company.

The concept of balance sheet rules originates from German-speaking countries [2], [3], [4], [5] and is related to streams in the business economy known as 'Betriebswirtschaftslehre'. As such, logically, these recommendations are still very common in the business economy and

management theory in Central and Eastern Europe (e.g., Germany, Czech Republic, and Slovakia). However, how updated the balance sheet rules in the current business economy and management are and whether it is possible to provide empirical evidence of their relation to business performance management remain unanswered. To support this research topic, only two papers (in English with no timespan limitation) that focus on balance sheet rule(s) were found in the research database Web of Science [6], [7] and one paper (same searching criteria) was found in database Scopus [8]. The lack of available research papers could be considered as a limitation for our research interest. On the other hand, this fact supports our assumption that the relation between business performance management and balance sheet rules approach should be a topic of research interest.

The remainder of this paper is organized as follows. The first section provides a theoretical background on the issue of each balance sheet rule, as well as business performance. This section aims to focus on the insufficiently covered research area of balance sheet rules to justify the following empirical research and formulate the research question. The next section describes the methodological approach that was used, followed by the empirical section, in which data on micro and small businesses are statistically tested to answer the given research question. Then the results and limitations are discussed in relation to the presented data.

1 Theoretical Background

As mentioned above, balance sheet rules are considered a guide for the general financing of businesses, and their application allows the maintenance of financial stability [9]. They provide a guideline for businesses to remain financially healthy for long-term periods, secured in terms of liquidity, and thus profitable. To achieve these aims, balance sheet rules recommend maintaining an appropriate level of financial indicators in the financial and capital structures of businesses.

While several balance sheet rules exist, this study focuses on the three most-mentioned rules in the literature (e.g. [10], [11], [12]): the golden balance sheet rule, risk equalization rule, and pari rule. In addition, we consider these three rules as the ones that are most connected with business performance, which is discussed in the text below.

1.1 Balance Sheet Rules

The golden balance sheet rule (1R) is considered one of the best-known rules (e.g. [13], [12]), and it represents a basic recommendation for financial and capital structures. Essentially, the golden balance sheet rule is based on the unification of maturity dates in financing; thus, the financing period is coordinated according to the capital commitment period [14]. According to this rule, fixed assets and a part of the current assets should be financed using internal capital (equity) and long-term debts, current assets, subsequently, from short-term debts/liabilities. In other words, long-term assets should be financed using a balanced ratio of equity and long-term debt. Short-term assets should be financed, according to this rule, using the short-term available capital [15], [16]. The consistency in the assets and liabilities´ side of the balance sheet is an essential parameter for the assessment of business creditworthiness and rating; hence, it is an important part of the strategic financial planning of businesses.

The golden balance sheet rule primarily assesses maturity dates, but not the type of financing: equity or debt [16]. Having 100%, or slightly higher, long-term passives (equity and long-term debts) and fixed assets shares is considered the optimal situation. In the literature, this indicator is known as the degree of capitalization; in German, it is known as Anlagedeckungsrad II [15], [17], [10]. The existing literature (e.g. [12]) stated that the optimal capitalization degree level is 1.0. As such, by reaching this optimal level, the net

working capital is zero. This rule can also be measured using the net working capital or working capital ratio [18].

Based on the level of the golden balance sheet rule compliance, three approaches to financing a company are identified: conservative, aggressive, and moderate. A conservative approach to financing entails using long-term capital to finance not only long-term assets but also short-term assets, which means that companies tend to use mostly long-term finance sources to finance their daily operations. On the other hand, an aggressive method of financing entails using short-term sources of financing for both short-term and long-term assets. This may lead to illiquidity. A moderate approach lies in the middle between aggressive and conservative approaches, with the suggestion that short-term finance sources should be used to finance fluctuating current assets. Likewise, long-term finance sources should be used to finance permanent current assets [19], [20], [13].

Further, to address the question of the type of financing, the risk equalization rule (2R) is used. This rule considers the risk position of businesses and deals with capital structure and splitting of passives into equity and debt/liabilities [21], [16], [22]. In principle, with higher involvement of debt, business profitability increases. On the other hand, bankruptcy risk also increases. Thus, a higher level of equity provides business independence and creditworthiness [16]. For the stability and sustainability of businesses, it is recommended that equity and debt be split equally, or with a higher proportion of equity [23], [11]. This recommendation leads to better creditworthiness in companies, while the effect of financial leverage is not effective. Over the decades, changes in the level of measured values have been noted; currently, the proportion of 1:2 is considered better for firm profitability [24], [25].

The third rule is called the pari rule (3R), and it serves as an additional rule to the above-mentioned rules. It is connected with the bankruptcy law and the consequence of covering losses called ‘pari passu’. The ‘pari passu’ provides the basic principle applicable in bankruptcy law. According to this principle, creditors who belong to the same group, according to the hierarchy of claims, should be treated in the same manner [26]. The pari rule is important, especially in situations where companies apply for additional debt financing. The pari rule recommends that a company should use as much equity as it can invest in fixed assets, ideally less, to create space for long-term debt financing [11]. The company should maintain the so-called healthy debt; meaning, it uses debt capital to an acceptable extent. If the company becomes bankrupt, then all liabilities are satisfied from the equity, namely, the state, banks, creditors, and subsequently, the owners. This is why financing by equity poses a far greater risk for business owners than that by debt capital.

While these rules are based on relatively old literature [2], [3] and were not updated or empirically tested in the last decades, they still regularly appear in the current literature on business economics [17], [18], [10], [19], [16], [13], [22]. Further, these are still considered suitable indicators of business profitability [15] and one of the main principles of financial management in businesses [27]. Particularly, the golden balance sheet rule is still considered to guarantee or prevent liquidity problems and payment difficulties [16].

As for the current empirical testing (as well as the current theoretical approach), only a few scientific papers (see Introduction) currently deal with balance sheet rules; thus, a significant research gap was identified. However, to support the importance of balanced sheet rules compliance, it was decided to focus further on research in areas that are related to individual rules.

Regarding the first golden balanced rule, there are currently many papers related to the research on business financial structure and the optimal level of net working capital in relation to corporate profitability [28], [29], [30], [31], [32]. Particularly, regarding the topic of net

working capital, managing it and attaining its optimal level in relation to firm profitability has become a popular research subject in recent years [33], [34], [35], [36], [37] [38], [39].

Deloof [37] and Howorth and Westhead [39] stated that the optimal level of working capital maximizes business value and significantly improves corporate profitability. Jacková [30] states that financial structure, as well as its optimal level, is involved in achieving stability, prosperity, and overall efficiency of companies. Having a working management team plays a significant role in the overall corporate strategy of maximizing firm value and profitability [28], [29], [32], and it is considered a key part of the overall business strategy to create shareholder value. The optimal ratio between current assets and debts, which is an important part of the financial planning of up-to-date businesses [33], [40], indicates the existence of an optimal level of working capital which improves business performance.

The findings by Baños-Caballero et al. [34], [35] proved that an optimal level of working capital investments, which maximizes business value and profitability, exists. Non-compliance with this optimal level has a negative effect on value creation and causes a decrease in profitability. Firm managers should aim to maintain the optimal level as much as possible and avoid any deviations from it that could destroy firm value. The authors find an inverted U-shaped relationship between working capital and firm performance, which implies that an optimal level of investment in working capital balances the costs and benefits of investments in working capital and leads to the maximization of firm value.

Aktas et al. [33] excluded the possibility that better performance is driven by increasing firm risk, following the adoption of the aggressive working capital policy. This finding is also supported by Nazir and Afza [41], who found a negative relationship between the aggressiveness of working capital policies and profitability. Overall, these studies find that the value of working capital and, thus, compliance with the golden balance sheet rule (1R) should have a positive impact on business performance.

In addition, the topic of optimal capital structure and its positive impact on company performance is not new in the scientific literature. Dvouletý and Blažková [42] proved that higher use of debts in the capital structure lowers a firm's productivity (measured by the total factor productivity [TFP] indicator) as well as its negative equity. Spitsin et al. [31] demonstrated that effective management of capital structure could increase the profitability of companies by 16–22%. Their results indicate that a U-shaped relationship exists between company performance and capital structure, with an optimal level of borrowed capital in proportion to total assets/liabilities. In addition, Azhagaiah and Gavoury [43] prove that capital structure has a significant influence on companies' profitability.

Maintaining financial and capital structure is important, especially for small companies, because they are generally associated with a higher proportion of current assets (in comparison to large firms), less liquidity, volatile cash flows, and a reliance on short-term debt [39], [44]. It is also recommended that smaller firms should adopt formal working capital management routines to reduce the probability of business closure, as well as to enhance business performance.

Overall, these studies find that the capital structure and, thus, the compliance of the risk equalization rule (2R) and the pari rule (3R) (which represents the combination of 1R and 2R) should have a positive impact on business performance.

1.2 Business Performance and its Measurement

It can be logically assumed that company managers can influence their company's performance through their own decisions. The broad performance management topic deals

with this issue. As Cokins [45, p. 75] states, 'performance management is not a process; rather it is the integration of multiple methodologies, such as customer relationship management, strategy maps, balanced scorecards, and lean/Six Sigma quality management'. Clearly, whether performance management consists of these different methods cannot be easily measured; therefore, it is measured using many methods, which mostly depend on the specific needs of individual businesses.

Traditionally, indicators such as effectiveness (actual output / expected output), efficiency (resources expected to be consumed / resources actually consumed), and productivity (output / input) are used for business performance measurement [46].

Historically, financial indicators have been predominant, which led Kaplan and Norton [47] to propose a balanced scorecard methodology. In business performance literature, this predominance is still valid, which was confirmed using a systematic review of the research on family business performance by Williams [48], who found that 84% of the examined research used financial data only to measure performance. The form of indicators differs; some studies use the absolute form, such as Sales, Income, Turnover, Costs, Profit, Assets, Fixed Capital, and Investments, among others. (e.g. [49], [50], [51]). Others use relative forms, such as Return on Assets (ROA), Return on Equity (ROE), Return on Sales (ROS) [52], [53], [54] or market-based forms, such as Tobin's Q or QRATIO [55], [56]. This is also confirmed by Williams [48] (2018), who states that the seven indicators most frequently used in business performance studies (from studies on family businesses published in peer-reviewed journals, from 1980 through 2015) are ROA, Sales, Profit, Tobins'Q, ROE, Return on Investment (ROI), and ROS.

In this study, business performance is measured using ROE as the ratio of the enterprise's net profit to capital invested by the owner.

$$ROE = \frac{EBT}{Equity} \tag{1}$$

This is because, although the business's ability to appreciate the capital of owners is very important in businesses, in small and micro businesses, it is essential because, very often, owners also manage their businesses. Thus, they can indirectly influence the value of this indicator with their own decisions. Preliminary research was also conducted, and other indicators such as ROA, ROS, and IN99 were used; however, the study results are similar.

1.3 Research Objective

Findings from the above-mentioned literature review support the theory of balance sheet rules and an optimal level of debt, liabilities, and capital structure. At this optimal level, a balance is achieved between risk and efficiency in businesses. In the literature review, many articles have dealt with the topic of net working capital and capital structure separately, but no study connects these two financial management topics or attempts to examine their impact on business performance.

In response to the positive effects on business performance, balance sheet rules theory, as well as the empirical proof that an optimal level of net working capital and optimal capital structure exist, it raises the question of whether compliance with the balance sheet rules can positively affect business performance.

Thus, this study focuses on conducting investigations to obtain such empirical evidence. Using empirical data, this study aims to explore the possible effect of compliance with the balance sheet rules on business performance for micro and small businesses in the Czech

Republic. By conducting empirical research, this study's main benefit is that it examines whether the optimal level stated by each balance sheet rule has some justification in business reality.

Based on the theory presented in the previous sections, the following research question was formulated:

Q: Does compliance with the balance sheet rules positively affect business performance of micro and small enterprises?

One of the assumptions made in this study is that financial stability should logically lead to higher business performance; thus, we do not consider any significant difference between long-term financial balance/stability and business performance.

2 Research Methodology

2.1 Statistical Methods of Research

Proving the relationship between selected factors and business performance is a very difficult task, which is limited by the existing methods. Largely, these types of studies aim to prove the correlation between different quantities. However, researchers must consider that the proven correlation does not automatically imply causation.

The indicators derived from individual balanced rules are shown in Tab. 1.

Tab. 1: *Indicators developed to assess the ability of businesses to follow the balance sheet rules*

Rule	Indicator	Recommended value
1R	(equity + long term debt) / fixed assets	0.8-1.2
2R	equity / total liabilities	0.4-0.6
3R	fixed assets / equity	>1

Source: Own

From the nature of the compiled indicators, (regarding balanced rules) it is obvious that the correlation analysis cannot be processed because its results would not be meaningful. This is because the 'best values' are not the highest or the lowest, but those falling within a certain range. Thus, the authors decided to divide all the companies into different categories, depending on how successful they were at complying with the balanced rules. These categories are as follows.

Category A: Enterprises that comply with all three rules
Category B: Enterprises that comply with at least 2 rules
Category C: Enterprises that comply with at least 1 rule
Category D: Enterprises that comply with just 1 rule

First, basic descriptive statistics (min, max, median, and average) were calculated. Data were tested for normality using the Shapiro-Wilk test, which showed that the data were not normally distributed. However, parametric statistics could be used because the sample size is large enough not to distort the results [57].

As such, to answer the research question, each category was analyzed using *t*-tests (unpaired two-sample *t*-tests) together with descriptive statistics.

T-tests should reveal whether the differences between the ROE values of two groups of enterprises (that comply and do not comply with the rules) within each category are significant. However, the data did not fulfill the assumption of homogeneity of variance; thus,

the results could be distorted. Therefore, the non-parametric equivalent of the t-test (Mann-Whitney U test) was used as well. All calculations were conducted using the program STATISTICA 12 StatSoft CR, s. r. o.

2.2 Data

To examine the relationship between balance sheet rules compliance and business performance, the dataset for this study is based on 2,537 businesses. All data were collected from the Database Albertina – Gold edition (Bisnode, 2018). The original aim was to examine the entire dataset of micro and small businesses in the Czech Republic (middle and large businesses were excluded because of their higher probability of cash pool financing, which would distort the results). Unfortunately, there were approximately 10,000 such business entities in the Czech Republic, which could not be analyzed due to technical issues. Thus, only one region (the Pilsen region) was selected and tested to answer the research question. The resulting 2,537 entities represent the whole population of micro and small businesses in the Pilsen region; however, in this study, they are considered a random selection of the entire population of micro and small businesses in the Czech Republic.

From the original dataset of 2,537 businesses data for approximately 100 businesses were deleted because of error values of ROE. Further, the data for 745 businesses, whose fixed assets had a value of 0, were also deleted (as this made it impossible to calculate the first and third indicators of the balance sheet rules). In addition, 10 businesses were excluded because of their extreme ROE values (above 1,000% and less than 1,000%). Finally, 1,682 enterprises were included in the analysis.

3 Research Results

Tab. 2 shows the descriptive statistics of the ROE and rule indicators, as well as their recommended values (median and average can provide interesting information when compared to recommended values).

Tab. 2: *Descriptive statistics (n = 1,682, small and micro businesses in the Pilsen region, 2018)*

	Max	Min	Median	Average	Recommended
ROE	776.470	–781.400	18.325	29.449	
1R	41,737.000	0.008	2.156	38.041	0.8-1.2
2R	1.321	0.002	0.534	0.526	0.4-0.6
3R	126.976	0.000	0.555	1.793	>1

Source: Own processing of [58]

However, from this table, it is not possible to assess how businesses successfully comply with these rules, and simple data filtering had to be done. The results for each category are as follows:

Category A: 53 businesses comply with all three rules (1,629 do not).
Category B: 274 businesses comply with at least two rules (1,435 do not).
Category C: 832 businesses comply with at least one rule (850 do not).
Category D: 249 businesses comply with the first rule, 336 comply with the second rule, and 546 comply with the third rule.

It is obvious that most businesses do not successfully comply with the rules. Only 53 companies (out of 1,682) comply with all three rules, and less than half comply with at least one. More detailed results are presented in Tab. 3, which shows additional descriptive

statistics of the ROE values for the groups of businesses, according to their ability to comply with the rules.

Tab. 3: *Descriptive statistics of ROE divided into categories A, B, and C (n = 1,682, small and micro-businesses in the Pilsen region, 2018)*

		A		B		C	
		Comply	**Do not comply**	**Comply**	**Do not comply**	**Comply**	**Do not comply**
Number		53	1629	247	1435	832	850
ROE	Average	14.75	**29.93**	18.06	**31.40**	**31.49**	27.45
	Median	7.58	**18.66**	15.70	**18.66**	**20.35**	17.12
	Min	–25.99	–781.40	–507.56	–781.40	–781.40	–202.94
	Max	72.29	776.47	355.00	776.47	776.47	478.65

Source: Own processing of [58]

In Tab. 3 the higher median and average ROE values (within each group) are marked in bold. Contrary to the expected results, in two cases, ROE is higher in the group of businesses that do not comply with the rules. Although this low value of ROE could be attributed to the very low number of cases (and their statistical insignificance), if the rules could positively affect business performance, the ROE values would be much higher in this group and not the opposite. Only the third group (C: businesses that comply with at least one rule) had higher average and median ROE values in the group that complied. Thus, this could indicate the possible influence of balance sheet rules on business performance. To answer the research question, further calculations were performed.

Additionally, it is interesting to examine which rule is the most often followed. Out of 1,682 businesses, 32% (546 in total) comply with the third rule. The most important rule, the golden rule, is followed in the least cases (only 15 % of all businesses). In Tab. 4, descriptive statistics of ROE for businesses that comply with individual rules (Category D) are shown. The largest ROE, in terms of median and average, was found in businesses that comply with the third rule.

Tab. 4: *Descriptive statistics of ROE for businesses that comply with the rules (Category D), according to recommended values for 1R, 2R, and 3R (n = 1,682, small and micro businesses in Pilsen region, 2018)*

Comply		**1R**	**2R**	**3R**
Number		249	336	546
ROE	Average	17.60	29.24	31.59
	Median	13.85	18.02	21.53
	Min	–507.56	–88.00	–781.40
	Max	355.00	706.93	776.47

Source: Own processing of [58]

Subsequently, a t-test was performed, and the results are presented in Tab. 5 (group of businesses that follow the rules is marked as F, and the opposite is marked as DF). Unfortunately, the assumption of homogeneity of variance was not met (see the right part of Tab. 5); thus, the assumptions of this statistical test are violated, and its results cannot be used. (It is clear that the results would not support the possible positive effect of balance sheet rules on business.)

Tab. 5: *T-test results (n = 1,682, small and micro businesses in Pilsen region, 2018)*

Var.	*t*-test							Levene	
	Mean (F)	Mean (DF)	*t*	d.f.	*p*	Valid N (F)	Valid N (DF)	Levene	*p*
A	14.75	29.93	-1.37	1,680	0.17	53	1,629	5.64	0.02
B	18.06	31.40	-2.44	1,680	0.01	247	1,435	0.85	0.36
C	31.49	27.45	1.04	1,680	0.30	832	850	51.24	0.00

Source: Own processing of [58]

The next logical step was to use the non-parametric equivalent of the unpaired two-sample *t*-test, which is the Mann-Whitney *U* test. The results are presented in Tab. 6. According to the results, the null hypothesis ('the distributions of both populations are equal') is rejected in groups A and B (at the significance level $\alpha = 0.05$), which indicates that the ROE values of these groups of businesses differ. This could support the premise of the positive effect of balance sheet rules on business performance; however, from Tab. 3, it is clear that the median of these categories is higher in both cases in the group of businesses that do not follow the rules. This would indicate opposite results than expected. In addition, the U test revealed equal distributions of both populations (F and DF) were found in group C (*p*-value > 0.05), which can be interpreted as follows: values of ROE are not significantly different within each group (although median values suggest otherwise, see Tab. 3).

Tab. 6: *Mann-Whitney U test results (n=1,682, small and micro businesses in Pilsen region, 2018)*

Var.	Rank Sum (F)	Rank Sum (DF)	*U*	*Z*	*p*-value	Valid N (F)	Valid N (DF)
A	33,975	1,381,428	32,544	-3.053	0.002	53	1,629
B	191,257	1,224,146	160,629	-2.353	0.019	247	1,435
C	711,496	703,907	342,232	1.141	0.254	832	850

Source: Own processing of [58]

Thus, from the presented results (especially in Tab. 3 and Tab. 6), it is clear that there is no evidence that the balance sheet rules positively affect the business performance of micro and small businesses. In contrast, the results (for categories A and B) confirm that the group that does not follow the rules has better performance. In addition, when the rules were examined in more detail using descriptive statistics (Tab. 4), it was found, that rules are not mostly followed. In most cases (32%), businesses follow the third rule. Out of these three rules, the third is also the rule which fulfillment is related to the highest average value of ROE. Thus, based on the results of this study, partly due to the small share of the businesses, that do follow the rules, it cannot be proven that the balance sheet rules positively affect the business performance of micro and small businesses, and the research question cannot be answered positively.

Conclusion

This study focuses on the practical usefulness of balance sheet rules. It aimed to prove the positive effect of balanced sheet rule compliance on business performance, using empirical data. Real data for micro and small businesses from the Pilsen region in the Czech Republic (total number 2,537) were tested using statistical methods (mainly Mann-Whitney U test). However, this positive effect was not proven (median and average ROE values for the groups of businesses that comply with at least two rules were lower than those who do not comply with them, this difference was proven by Mann-Whitney *U* test), and neither was the predominant compliance among businesses. The research question "Does compliance with the

balance sheet rules positively affect the business performance of micro and small enterprises?" cannot be answered positively. Thus, the empirical testing indicates that balance sheet rules need not regularly appear in the current business economics literature. However, future research, for example, using data from different regions, years, and industries, is necessary to prove this statement further.

This study also presented a very important finding: there is a significant research gap in the topic of balanced sheet rules. Relatively many scientific sources from the time of the topic's origin can be found (solely German-language sources); however, since then, there are almost none, and these rules are simply used by authors of business economics literature without any changes. Only a few studies dealing directly with balance sheet rules can be found in the current scientific literature, despite the fact that similar topics (such as working capital or capital structure) are often dealt with in research studies.

There are some limitations to this study. First, to determine whether this result is generally valid for all types of companies, it would be advisable to conduct this research on larger companies (assuming that it would be possible to exclude companies financed by cash pooling). In addition, it would be interesting to compare the results of this analysis performed on different industries (to check for any differences in results). The second limitation may result from the selected business performance indicator (ROE), because different results could be expected when choosing different indicators. However, preliminary research was conducted to test other suitable indicators (ROA, ROS, and IN99), and the results of this analysis were similar. Third, similar to other studies examining business performance factors, this study also cannot assume that correlation implies causation. Thus, even if the results indicate that those businesses that follow the rules have higher ROE values, it cannot be assumed that this is the only responsible factor. Otherwise, in this study, the low ROE values of the businesses that follow the rules could be caused by other factors. In fact, ROE values are affected by various factors that cannot be effectively controlled by researchers (for example, the obvious ones are efficient production processes, marketing, and management; others include luck and coincidence), and it is almost impossible to assess the influence of a single selected one—balanced sheet rule compliance. However, we believe that if there is a significant substantial influence of this particular factor, the result of this analysis would at least suggest it and not otherwise.

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BILANČNÍ PRAVIDLA A JEJICH VLIV NA VÝKONNOST PODNIKU – EMPIRICKÁ STUDIE

Studie si klade za cíl podrobně prozkoumat, zda má dodržování bilančních pravidel vliv na výkonnost podniku. Pro ověření tohoto předpokladu byla statisticky testována data za malé a mikropodniky v ČR (celkový počet 2 537), a to pomocí t-testu a Mann-Whitneyho U testu. Zvláštní pozornost byla věnována ukazateli rentability vlastního kapitálu (jako ukazateli výkonnosti podniku) a změnám jeho hodnoty mezi skupinami podniků, které pravidla dodržují, a těmi, které tato pravidla nedodržují. Výsledky naznačují, že pozitivní vliv dodržování bilančních pravidel na výkonnost podniku nelze potvrdit, stejně jako nelze pozorovat jejich dodržování ve větším měřítku. Bylo by tedy vhodné otevřít diskuzi o tom, zda je potřeba, aby se bilanční pravidla pravidelně objevovala v současné literatuře podnikové ekonomiky. Zmíněné výsledky jsou zobrazeny a diskutovány v tomto článku spolu s omezeními výzkumu.

BILANZREGELN UND IHR EINFLUSS AUF DEN UNTERNEHMENSERFOLG – EMPIRISCHE STUDIE

Ziel der Studie ist es, die Auswirkungen der Einhaltung von Bilanzregeln auf den Geschäftserfolg im Detail zu untersuchen. Um diese Prämisse zu überprüfen, wurden Daten von Klein- und Kleinstunternehmen in der Tschechischen Republik (Gesamtzahl 2 537) statistisch mit dem t-Test und dem Mann-Whitney-U-Test getestet. Besonderes Augenmerk wurde gelegt auf den Wert der Kennzahl Return on Equity (als Kennzahl der Unternehmensleistung) und die Veränderungen dieses Werts zwischen den Unternehmensgruppen, die diese Regeln einhalten, und denen, die diese Regeln nicht einhalten. Die Ergebnisse deuten darauf hin, dass der positive Effekt der Bilanzregeleinhaltung auf die Geschäftsentwicklung nicht bestätigt werden kann, ebenso wenig wie die überwiegende Einhaltung der Bilanzregeln bei den Unternehmen nachgewiesen werden konnte. Damit sollte die Diskussion offen sein, ob die Bilanzregeln regelmäßig in der aktuellen betriebswirtschaftlichen Literatur auftauchen müssen. Diese Ergebnisse werden in diesem Artikel zusammen mit ihren Einschränkungen vorgestellt und diskutiert.

ZASADY BILANSOWE I ICH WPŁYW NA WYNIKI PRZEDSIĘBIORSTWA – BADANIA EMPIRYCZNE

Celem badań jest szczegółowe zbadanie wpływu przestrzegania zasad bilansowych na wyniki przedsiębiorstwa. Aby zbadać tę tezę, dane z małych i mikroprzedsiębiorstw w Czechach (łączna liczba 2 537) przeanalizowano statystycznie za pomocą testu t i testu U Manna-Whitneya. Szczególną uwagę poświęcono wskaźnikowi rentowności kapitału własnego (jako wskaźnikowi efektywności przedsiębiorstwa) oraz zmianom jego wartości pomiędzy grupami przedsiębiorstw, które przestrzegają zasad a tymi, które ich nie przestrzegają. Wyniki sugerują, że nie można potwierdzić pozytywnego wpływu przestrzegania zasad bilansowych na wyniki przedsiębiorstwa, tak samo jak nie można zauważyć ich przestrzegania w większej skali. Warto by więc otworzyć dyskusję, czy jest konieczne, by zasady bilansowe regularnie pojawiały się we współczesnej literaturze ekonomiki przedsiębiorstw. W niniejszym artykule zostały przedstawione i omówione wskazane wyniki, a także elementy ograniczające badania.

GENERATION X, Y, AND Z PREFERENCES FOR CAR-SHARING IN DIFFERENT SITUATIONS

Pavel Pelech[1]; **Julie Holendová**[2]
Technical University of Liberec, Faculty of Economics,
Department of Marketing and Trade,
Studentská 1402/2, 461 17 Liberec 1, Czech Republic
e-mail: [1]pavel.pelech@tul.cz; [2]julie.holendova@tul.cz

Abstract

The aim of this article is to assess the influence of different generations (X, Y, and Z) on their willingness to prefer a shared car to their own car in specifically defined situations. The research was conducted from December 2021 to March 2022 and involved 741 respondents, equally distributed among the three generations analyzed. The findings of the research suggest that different generations of respondents will not have different preferences for using car-sharing in different situations. Significant differences between generations were only found in the situation where car-sharing would be preferred on the way to school or work. In other cases, no significant dependence between generations was shown. All generations of respondents can imagine using a car share more regularly during travel and entertainment, but not so much with children to clubs or when shopping and running errands at the authorities. This fact can be useful for marketers who need to discern the motives for customer participation in the sharing economy or the car-sharing segment. At the same time, marketing knowledge in connection with the sharing economy will be enhanced.

Keywords

Car sharing; Generation X; Generation Y; Generation Z; Marketing communications; Sharing economy.

Introduction

The development of technology, especially the interactive environment thanks to Web 2.0, has enabled, among other things, the emergence of the sharing economy. Its importance is growing not only locally but also globally, not only in terms of its financial volume but also in terms of the number of products that participants in the sharing economy are willing to share [1]. One of the most visible products of the sharing economy is car sharing. It has been reported that sales in this segment will reach almost USD 13 billion worldwide in 2022 and even USD 16.5 billion in 2026, of which the Czech Republic is expected to have sales of approximately USD 66 million. More than 60 million customers worldwide are expected to use car-sharing in 2026, including approximately 400,000 customers in the Czech Republic. Almost the entire volume of sales (95%) will be generated in the online environment [2]. Platforms that will mediate the sharing between the product owner and the one who needs the product in the sharing economy environment will need to know their customers in detail, their wants, needs, and concerns that will arise in relation to sharing products.

There is a wealth of information on sharing products and the sharing economy in general in academic publications and scientific articles. In the context of car sharing, for example, Turon [3] discusses the difficulties that car-sharing users may encounter from the moment they register on the platform, through the reservation of car-sharing, its use, and its return.

Chapman et al. [4], in turn, address whether car sharing will lead to a reduction in car use and hence emissions, alluding to the necessary change in behavior between those who have a car and those who will need one. Kolleck [5] also mentions the impact of car sharing on sustainability. Shared cars in conjunction with marketing are discussed, for example, by Luan et al. [6] or Liang et al. [7]. Luan et al. [6] discuss the general benefits of car-sharing and present the characteristics of a typical user of DriveNow's car-sharing service, according to which the typical car-sharing user is a male, aged 25-45, with above-average income, without children, living in the city, who uses the car-sharing service in his free time. Liang et al. [7] search for an optimal pricing mechanism for setting the price of car sharing.

The right targeting and set-up of marketing communications will be key for platforms that mediate sharing. Without a proper definition of the customer segment and mapping of their needs, the marketing communication of the platforms will not be effective [8].

Based on a study of the literature, a knowledge gap was identified where the dependence of each generation (X, Y, and Z) on their willingness to prefer a car-sharing platform to their own car in specifically defined situations was not investigated for marketing communication purposes. This article will first focus on the literature review that relates to the sharing economy and car-sharing. This is followed by a description of the research objectives and methods used. Finally, the results of this article are summarized and possible areas for further research are outlined.

1 Literature Review

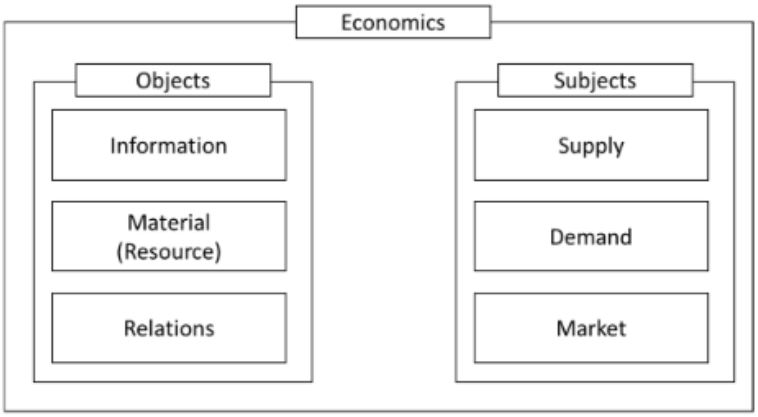
The literature review will be based on a search of academic and scientific publications on the sharing economy and car-sharing.

1.1 Sharing Economy

The sharing economy is "*a socio-economic system based on the sharing of resources*" [9, p. 113], which should lead to reduced production and positive environmental impacts. Its emergence is associated with the Fourth Industrial Revolution, as during the First and Second Industrial Revolutions, there was a strong emphasis on ownership. It was not until the Third Industrial Revolution that brought a gradual change in the view of ownership, which allowed the sharing economy to fully develop during the Fourth Industrial Revolution. Of course, the sharing economy itself is not new, as sharing was already taking place in the days before the Fourth Industrial Revolution, but it was only the online environment that came with the Fourth Industrial Revolution that allowed the sharing economy as we know it today to become more visible and fully-fledged [10].

The rise of the sharing economy is most visibly associated with two companies – Uber and Airbnb – that have enabled consumers to access individual's private property [11]. The sharing economy could not exist without supply, demand, and the market. In addition, information, resources, and linkages are essential to its functioning [10], as shown in Figure 1.

The market that stands between supply and demand in the sharing economy is the platform. This platform gathers resources, provides information and creates relationships between actors in the sharing economy [10]. The platform is a two-sided market, with unused assets on offer on one side and demand for them on the other. Thanks to money, the unused assets reach the demand side, i.e. both parties benefit [12]. In addition to asset owners and consumers, there are prosumers in the sharing economy market, a type of people who act on both the supply and demand side (supply one type of asset, demand another type of asset) [13].



Source: [10, p. 3].

Fig. 1: *Fundamental factors of the sharing economy*

1.2 Car Sharing

There is no single definition of car sharing. Car sharing can be defined as "*a membership-based, self-service, short-term car access system with a network of vehicles for which members pay by time and/or distance*" [14, p. 160] or "*a membership program intended to offer an alternative to car ownership under which persons or entities that become members are permitted to use vehicles from a fleet on an hourly basis*" [15, p. 2].

Car-sharing can take several forms. In general, car sharing is most commonly encountered in the following two forms:

- there are designated stations where you can pick up your car and where you need to return it, or
- stations are not defined, i.e., a car can be found anywhere and left anywhere (so-called free-floating car sharing) [16].

Car sharing has the biggest potential for development in densely populated urban areas, where reducing the number of cars can contribute to a better environment [17]. The typical car-sharing user is a young, educated and affluent person for whom car-sharing is a way to protect the environment, change social behavior, or simply a cost or convenience benefit [18].

2 Knowledge Gap and Research Objectives

Travel scenarios, i.e., situations where one uses a shared means of transport, have been addressed by several authors. Xu [19, p. 14-16] examines three scenarios of car-sharing use (day-time business trips and evening entertainment trips in the city center; commuting trips in off-peak time; city short-distance tourism travels). It looks at the length of car-sharing use, the area in which car-sharing takes place, and car-sharing fees. It does not examine demographic characteristics. Car sharing in terms of time, space and frequency without demographic links is also examined by Tong et al [20]. Generation Y in relation to mobility is examined by Suchanek et al [21]. They analyze consumer behavior in relation to sustainable mobility without considering travel scenarios.

The analysis of the articles showed that there is a knowledge gap, where it is not clear whether different generations of respondents prefer different travel scenarios.

The main objective of this research was to determine whether there is a relationship between the generation of respondents and the situation where they might prefer to car-share to owning a car. Four sub-objectives have been defined:

1. To determine whether there is a relationship between the generation of respondents and their willingness to prefer car-sharing when traveling to work or school.
2. To determine if there is a relationship between the generation of respondents and their willingness to prefer car-sharing when shopping and going to the office.
3. To determine if there is a relationship between the generation of respondents and their willingness to prefer car-sharing when traveling in general and when going for entertainment.
4. To determine whether there is a relationship between the generation of respondents and their willingness to prefer car-sharing when traveling with children to clubs.

The data to achieve these objectives were obtained through extensive quantitative research.

3 Data and Methodology

The quantitative research was carried out from December 2021 to March 2022 and involved a total of 794 respondents, from which respondents belonging to Generation X, Y, or Z were selected. Specifically, 741 respondents were evenly split between the three analyzed generations.

The classification of the generations by their year of birth is based on the classification used by the Pew Research Center, i.e., the generations are defined as follows:

- Generation X: 1965 – 1980,
- Generation Y: 1981 – 1996.
- Generation Z: 1997 – 2012 [22].

All respondents were contacted via an online questionnaire to obtain more information about the participants in the sharing economy. For the purpose of this research, data from the section of the questionnaire that focused on customer preferences in terms of car sharing usage were used. Respondents were asked to identify the situations in which they would prefer to use a car-sharing service to owning a car, regardless of price. They had the following scenarios to choose from:

- travel to work/school,
- shopping and authorities travel,
- travel and entertainment,
- travel with kids to activities.

For each of these categories, respondents were asked to indicate whether they could imagine a preference for a shared car to their own car. The data collected were ordinal in nature, so it was re-coded: (1) regularly, (2) occasionally, (3) never.

To test whether there is a significant relationship between the generation of the respondents and the situation where they could prefer a shared car to their own car, the following hypotheses were defined:

H0: There is no significant relationship between the generation of respondents and the situation where they might prefer a shared car to their own car.

H1: There is a significant relationship between the generation of respondents and the situation where they might prefer a shared car to their own car.

For each category, the frequencies of the responses of each generation of respondents were found. Descriptive statistics and the Kruskal-Wallis test were used to evaluate the data due to the ordinal nature of the data analyzed.

4 Results and Discussion

The obtained data were examined for their validity and reliability. Content validity was achieved because the questionnaire was constructed based on the study of literature and similar marketing research. Reliability was evaluated using Cronbach's Alpha internal consistency coefficient, which took the value of 0.7462. The internal consistency of the obtained data can be considered sufficient, as the threshold of 0.7 was exceeded, which is crucial to confirm the reliability of the obtained data [23].

The results of the Kruskal-Wallis test and descriptive statistics are shown in Table 1.

Tab. 1: *Kruskal-Wallis test and descriptive statistics*

Generation	Indicator	Travel to work/school	Shopping and authorities travel	Travel and entertainment	Travel with kids to activities
X	Mean	2.1052	2.2510	2.0243	2.4089
	Median	2	2	2	2
	SD*	0.7360	0.6063	0.7096	0.6366
	N**	247	247	247	247
Y	Mean	1.9879	2.1984	1.8907	2.3644
	Median	2	2	2	2
	SD*	0.7296	0.7079	0.7101	0.6961
	N**	247	247	247	247
Z	Mean	2.1457	2.1741	1.9798	2.4251
	Median	2	2	2	2
	SD*	0.6889	0.6611	0.7568	0.6637
	N**	247	247	247	247
Kruskal-Wallis test P-value		0.0441	0.5059	0.1156	0.6522
Significance		S***	NS****	NS****	NS****

*standard deviation; **number; ***significant; ****non-significant.

Source: Own

Only by using car-sharing for traveling to work/school the Kruskal-Wallis H test indicated that there is a significant difference in using car-sharing for traveling to work/school between the different generations, $\chi^2(2) = 6.25$, $p = 0.0441$. In other reasons for using car-sharing the Kruskal-Wallis H test indicated that there not is a significant difference between generations ($\chi^2(2) = 1.36$, $p = 0.5059$ for shopping and authorities traveling; $\chi^2(2) = 4.32$, $p = 0.1156$ for travel and entertainment; $\chi^2(2) = 0.85$, $p = 0.6522$ for travel with kids to activities). This means that we reject hypothesis H0 for only one option of car-sharing use, namely car-sharing for traveling to school or work, where the test shows a significant difference between generations.

The Kruskal-Wallis test identified that the mean ranks are not statistically equal but the multiple comparisons do not show enough evidence for a statistical difference between any pair of groups. We used multiple comparisons. The corrected α using the Bonferroni correction method is 0.01667. You can see the results of these multiple comparisons in Table 2.

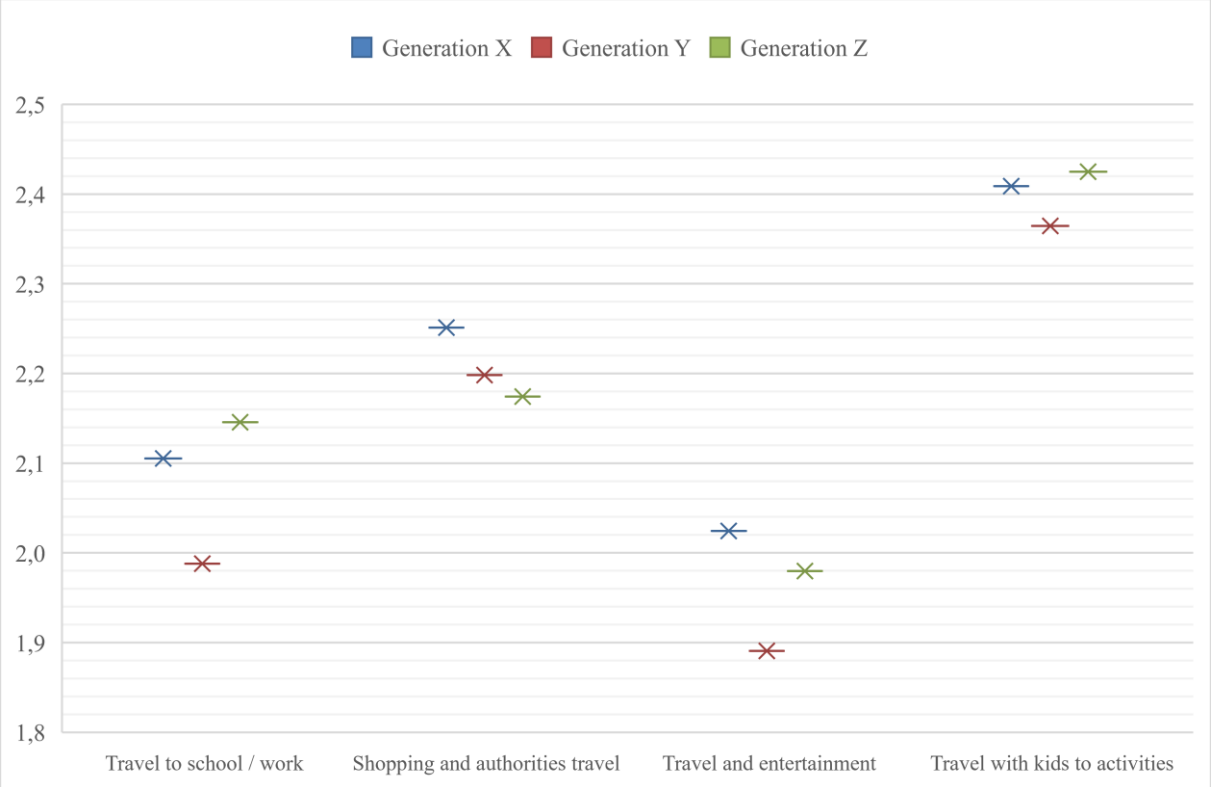
Tab. 2: *Multiple comparisons (p-values)*

Generations	Travel to work/school	Shopping and authorities travel	Travel and entertainment	Travel with kids to activities
X and Y	0.0689	x	x	x
X and Z	0.5656	x	x	x
Y and Z	**0.0167**	x	x	x

Source: Own

Table 2 shows that there is the biggest difference between Generations Y and Z when it comes to using a car-share to travel to work or school. For the other two groups, there was no significant difference between the generations of respondents.

We sorted the data according to their mean values. In Figure 2 it is possible to see in which situations different generations prefer car sharing.



Source: Own

Fig. 2: *Mean comparison by generation and preferred situation*

Figure 2 shows that car-sharing will be most preferred to owning a car by Generation Y for travel and entertainment, followed by Generation Z in the same case. On the other hand, Generation Z will least prefer a shared car to their own car when traveling with their children to clubs.

Conclusion

The sharing economy represents an economic trend that is attracting attention in many countries around the world. It is generally acknowledged that the sharing economy will have an impact on the functioning of many areas. For example, when traveling, people do not need to use the accommodation services of official accommodation establishments or car rental companies. Experts are evaluating this trend from many angles, with evaluations from a marketing point of view being less frequent. By studying the literature and scientific

publications, it has been found that the sharing economy in the context of marketing communication has scientific potential, which this article has decided to exploit.

The main objective of this research was to find out whether there is a relationship between the generation of respondents and the situation where they might prefer a car-sharing service to owning a car. The research, which took place in the Czech Republic from December 2021 to March 2022 and involved 741 respondents, evenly divided between the three generations analyzed (X, Y, Z), showed that there is no significant relationship between the respondents' generation and the situation where they might prefer a shared car to their owned car. A significant relationship between the generations in the situation where they would prefer a shared car to their own was only confirmed for the use of a shared car when traveling to work or school. This significant relationship was found between Generations Y and Z. This means that platforms setting up marketing communications do not need to significantly address the targeting of marketing communications to a specific group of respondents in the case of marketing communications for car-sharing offers but need to focus on the marketing message as such.

It is worth mentioning that there are limiting factors to this article. In particular, the fact that this is not a representative survey, and the findings cannot be generalized is essential.

Acknowledgments

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PREFERENCE SPOTŘEBITELŮ PŘI VYUŽÍVÁNÍ SDÍLENÝCH AUT

Cílem tohoto článku je posoudit vliv jednotlivých generací (X, Y, Z) potenciálních zákazníků sdílené ekonomiky na jejich ochotu preferovat sdílené auto oproti autu vlastnímu v konkrétních definovaných situacích. Výzkum probíhal od prosince 2021 do března 2022 a zúčastnilo se ho 741 respondentů, kteří byli rovnoměrně rozděleni mezi všechny tři analyzované generace. Závěry výzkumu naznačují, že jednotlivé generace respondentů nebudou mít odlišné preference využívat sdílené auto v různých situacích. Všechny generace respondentů si dokážou více představit používat sdílené auto pravidelně během cestování a zábavy, ale už ne tolik s dětmi na kroužky, nebo při cestách do práce či školy. Tato skutečnost může být využitelná marketingovými odborníky, kteří potřebují rozklíčovat motivy pro účast zákazníků ve sdílené ekonomice, resp. v segmentu sdílených aut.

VERBRAUCHERPRÄFERENZEN FÜR CARSHARING

Das Ziel dieses Beitrags ist es, den Einfluss verschiedener Generationen (X, Y, Z) von potenziellen Sharing-Economy-Kunden auf ihre Bereitschaft zu untersuchen, in bestimmten Situationen ein gemeinsam genutztes Auto einem eigenen Auto vorzuziehen. Die Untersuchung wurde von Dezember 2021 bis März 2022 durchgeführt und umfasste 741 Befragte, die gleichmäßig auf die drei untersuchten Generationen verteilt waren. Die Ergebnisse der Studie deuten darauf hin, dass die verschiedenen Generationen der Befragten keine unterschiedlichen Präferenzen für die Nutzung von Carsharing in verschiedenen Situationen haben. Alle befragten Generationen können sich eher vorstellen, ein Carsharing regelmäßig für Reisen und Vergnügungen zu nutzen, weniger jedoch, wenn sie ihre Kinder zu Spielgruppen bringen oder zur Arbeit oder zur Schule fahren. Diese Tatsache kann für Vermarkter nützlich sein, die die Motive für die Teilnahme von Kunden an der Sharing Economy oder dem Carsharing-Segment erkennen müssen.

PREFERENCJE KONSUMENTÓW DOTYCZĄCE KORZYSTANIA ZE WSPÓŁDZIELONYCH SAMOCHODÓW

Celem niniejszego opracowania jest ocena wpływu różnych pokoleń (X, Y, Z) potencjalnych klientów ekonomii współdzielenia na ich skłonność do preferowania samochodu współdzielonego od własnego pojazdu w określonych konkretnie sytuacjach. Badania przeprowadzono w okresie od grudnia 2021 do marca 2022 roku. Wzięło w nim udział 741 respondentów, którzy byli równomiernie rozdzieleni do trzech analizowanych pokoleń. Wyniki badań wskazują, że poszczególne pokolenia respondentów nie będą miały odmiennych preferencji co do korzystania z samochodu współdzielonego w różnych sytuacjach. Wszystkie pokolenia respondentów bardziej potrafią sobie wyobrazić regularne korzystanie z samochodu współdzielonego w ramach podróży i rozrywki, natomiast już nie w takim stopniu z dziećmi dowożonymi na kółka zainteresowań czy do celów dojazdu do pracy czy szkoły. Fakt ten mogą wykorzystać eksperci od marketingu, którzy potrzebują rozpoznać motywy uczestniczenia klientów w ekonomii współdzielenia lub w segmencie współdzielonych samochodów.

PERFORMANCE EVALUATION OF GOALKEEPERS OF SLOVAK FOOTBALL LEAGUE

Natalie Pelloneová[1]; **Michal Tomíček**[2]
Technical University of Liberec, Faculty of Economics,
Department of Business Administration and Management,
Studentská 1402/2, 461 17 Liberec 1, Czech Republic
e-mail: [1]natalie.pelloneova@tul.cz; [2]michal.tomicek@tul.cz

Abstract

Football is a popular sport in Slovakia. Every year football clubs spend large sums of money on buying individual players. However, there is a small number of scientific studies dealing with statistical, economic dimensions, and performance evaluation of football players. The performance of individual players, as well as the performance of the whole team, are very important indicators that predetermine the success of the whole club. The aim of this research is to develop a new system for evaluating the efficiency of football players and then apply this system to football practice and identify technically efficient players. The present research uses the data envelopment analysis, specifically the input-oriented Charness, Cooper, Rhodes model and the Andersen-Petersen super-efficiency model. Both models are empirically applied to only one group of football players, namely goalkeepers of the first and second Slovak football leagues in the 2020/21 season. The model proposed in this article attempts to incorporate greater objectivity into making decisions and thus may be an important step in developing a systematic methodology for evaluating not only goalkeepers but also other player positions.

Keywords

Football; Sport; Goalkeeper; Data envelopment analysis; Efficiency; Super-efficiency.

Introduction

The world of sport is constantly changing and evolving. The sports industry has been evolving in recent years, especially economically. The sums of money that are transferred between players in the sports industry today are incomparably higher than those of the last decade. One of the fastest developments has occurred in the world's most widespread sport, football. The transfer sums of the best players in the world exceed hundreds of millions of euros, in terms of Czech crowns it is in the order of billions.

In foreign developed Western countries, such as Spain, billionaire clubs backed by influential corporations or global oligarchs from the energy and petrochemical industries occupy Germany, France, and England, the top positions in the league tables. While the last places are occupied by formerly successful clubs with a rich history and tradition, which are now teetering between staying in the top competitions and relegation. The middle of the tables is usually very balanced both in terms of sporting performance and in terms of financial background of the clubs.

Football has a relatively long history in Slovakia and its popularity is quite high. In Slovakia, research by Machlica and Šiškovič [1] has recorded a relatively high number of football clubs and footballers relative to the population. Slovakia performs relatively above average in football compared to other countries, e.g., the national team was ranked 17th-29th in the

UEFA international rankings in 2020 according to Melek and Dedík [2]. In Slovakia, the wealth diversification of the individual clubs of one competition is not yet at such a level. However, a similar pattern applies to the Slovak top football competition. The clubs fighting for the top spot are backed by influential businesspersons or foreign corporations. The Slovak top competition is currently (2022) economically dominated by a club from the capital city together with, in recent years dominant, Dunajská Streda [3]. It can be concluded that the entry of entrepreneurs into the running of football clubs is a prerequisite for their further development and an increase in the probability of achieving potential success.

Some football clubs, such as Slovan Bratislava, Dunajská Streda or Spartak Trnava, are making significant profits, while others are experiencing negative financial results, such as Sereď and Senica. In this case, it is desirable to ask how the club in question manages its resources to achieve its results. The focus should be on whether the club is using its resources appropriately to achieve the best possible results. It is conceivable that a club whose players are relatively cheap can get "interesting" results [4].

1 Research Objectives

The aim of this article is to develop a model that can be used by clubs, managers and coaches to evaluate the efficiency of football players. Empirically, the model is applied to only one group of football players, namely goalkeepers of the first and second Slovak football leagues in the 2020/2021 season. The aim of the article is to analyze the efficiency of Slovak goalkeepers in the first and second league, which have very different resources [4]. The results of the research may be interesting not only for fans, but also for managers of football clubs and goalkeepers themselves. The resulting evaluation may reveal how players perform and may have an impact on their market value. Goalkeepers themselves will want to know which benchmark players to use for comparison when improving their own game. The model created could be used to not only improve the efficiency of goalkeepers' play and create individual training programs but for players in other positions.

2 Literature Review

In the following part of the article, selected authors who apply various statistical and mathematical methods to evaluate the performance of goalkeepers in different sports disciplines are briefly summarized. A large number of studies deal with the evaluation of handball goalkeepers, e.g., Medina et al. [5], Gómez-López et al. [6], Cvenić [7] and Pascual Fuertes et al. [8]. The study by Fuertes et al. [8] aims to analyze the effect of goalkeeper performance on handball team performance based on data from the last six seasons of the Asobal League. The research is based on linear regression analysis, mean comparison test and logit multinomial test. The results of their research indicated that goalkeepers' efficiency is a relevant variable to explain the performance of the whole team. Through their research, they concluded that higher goalkeeper efficiency translates into better team classification. They further add that top teams have better goalkeeper efficiency than other teams. In the sport discipline of futsal, Szwarc et al. [9], Oszmaniec and Szwarc [10] evaluate goalkeepers in their research.

Research on the efficiency of entire teams in football using data envelopment analysis has been carried out in various studies, e.g., Halkos and Tzeremes [11], Espitia-Escue and García-Cebrián [12], but usually neglected to analyze the efficiency of goalkeepers. Few studies have been conducted on goalkeepers in football e.g., Kapera [13] and Alp [14]. Alp [14] evaluates 32 goalkeepers from the 2002 FIFA World Cup using an output-oriented CCR model and the Andersen-Petersen super-efficiency model. Alp uses as output variables: the ratio / number of goals against per match, number of penalty kicks saved, number of other saves, free kicks

saved ratio per match, corner kicks saved ratio per match, fast breaks saved ratio per match, individual saves ratio per match.

Based on the above, it can be concluded that there are only a limited number of studies dealing with football players, especially goalkeepers. Thus, this article aims to add another method to the literature that can be used to evaluate football goalkeepers based on easily observable game statistics.

3 Methodology and Data

The aim of the research is to use data envelopment analysis to calculate the level of technical efficiency and then to evaluate and compare the efficiency of goalkeepers playing in the 1st and 2nd football league in Slovakia. Goalkeepers' efficiency in both competitions was analyzed in the 2020/2021 season. Goalkeepers' efficiency was evaluated only based on data from the regular game part of the two investigated football competitions.

3.1 Data Set

The first part of the article focused on the evaluation of the efficiency of goalkeepers playing in the top Slovak football league called Fortuna Liga. A total of 12 football clubs participated in the Slovak top football competition in the 2020/2021 season. The second part of the article was devoted to the evaluation of goalkeepers' efficiency playing in the 2nd Slovak league. A total of 15 clubs participated in the 2nd football league in the 2020/2021 season.

Only goalkeepers who played at least one game in the 2020/2021 season were included in the analysis. The database consists of 32 goalkeepers who played in the Fortuna Liga and 47 goalkeepers who played in the 2nd Slovak football league in the 2020/2021 season.

The data used for the research come from the official database of the Fortuna League [15] and is supplemented by databases of companies from the football environment. In particular, data from Livesport [16] and Transfermark [17] were used.

3.2 Data Envelopment Analysis

To calculate the technical efficiency of goalkeepers in the 1st and 2nd Slovak football league in the 2020/2021 season, the input-oriented CCR-I and then AP model was used. The DEA methodology is a non-parametric technique that helps to estimate the technical efficiency of a set of decision-making units (further DMUs). The efficiency score in the DEA method is bounded by an interval from 0 to 1, with a score of 1 being achieved by the efficient unit (in this case the goalkeeper). Input-oriented models help determine how much the inputs need to be reduced to make the evaluated unit efficient. The CCR model operates under the assumption of constant returns to scale, allowing the calculation of an overall technical efficiency score (further OTE) regardless of returns to scale [18]. The input-oriented CCR model evaluates the efficiency by solving the following linear programming problem.

Minimize
$$\theta_q \tag{1}$$

S.t.
$$\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = \theta_q x_{iq}, \qquad i = 1,2,\dots,m,$$
$$\sum_{j=1}^{n} y_{kj}\lambda_j - s_k^+ = y_{kq}, \qquad k = 1,2,\dots,r, \tag{2}$$
$$\lambda_j \geq 0, \quad j = 1,2,\dots,n,$$

where

λ_j, j = 1, 2, ..., n are weights of all DMUs,
s_i^-, i = 1, 2, ..., m and s_k^+, k = 1, 2, ..., r are slack/surplus variables, and
θ_q is the efficiency score of the DMUq.

In the second step of the research, the model by Andersen and Petersen (1993) was applied to the data. This model allows the efficient unit to achieve efficiencies greater than 1 for input-oriented models. The main advantage of this model is the possibility to further classify the efficient units. Jablonský and Dlouhý [19] formulate an input-oriented AP model assuming CRS using relations (3) and (4). If the unit under consideration is classified as efficient, then $\theta_q^{AP} > 1$.

Minimize
$$\theta_q^{AP} \tag{3}$$

S.t.
$$\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = \theta_q^{AP} x_{iq}, \quad i = 1, \dots, m,$$
$$\sum_{j=1}^{n} y_{kj}\lambda_j - s_k^+ = y_{kq}, \quad k = 1, \dots, r, \tag{4}$$
$$\lambda_j \geq 0, \quad j = 1, \dots, n, j \neq q,$$
$$\lambda_q = 0.$$

Eight variables were included in the DEA model due to the number of goalkeepers evaluated. The only input variable is the market value of each goalkeeper (further MV). On the other hand, the research will consider several outputs. The first output is the number of minutes played (further MIN). The importance in the team increases every time a goalkeeper is selected to play. This variable takes into account whether the goalkeeper played the whole game or came on as a substitute. Other output variables are close range shots saved (further CSS), mid-range shots saved (further MSS), long range shots saved (further LSS), stopped shots (further SS), supersaves (further S), and accurate passes (further AP). Table 1 summarizes the statistics on these variables.

Tab. 1: *Descriptive statistics of input and output variables*

Variable	**League**	**1st league**	**2nd league**
	Number of goalkeepers	**32**	**47**
Market value (thousand EUR)	Mean	228.91	94.15
	Standard deviation	197.88	80.46
	Max	1000	400
	Min	50	25
Minutes played	Mean	1143.44	826.77
	Standard deviation	1055.44	799.95
	Max	3144	2628
	Min	91	91
Close range shots saved	Mean	10.50	7.00
	Standard deviation	11.31	7.20
	Max	41	24
	Min	0	0
Mid range shots saved	Mean	17.81	13.64
	Standard deviation	19.15	11.77
	Max	62	47
	Min	0	0
Long range shots saved	Mean	15.16	11.72
	Standard deviation	16.68	11.57
	Max	57	48
	Min	0	0
Stopped shots	Mean	20.53	15.72
	Standard deviation	21.48	15.13
	Max	72	73
	Min	0	0
Supersaves	Mean	12.94	10.04
	Standard deviation	14.71	9.22
	Max	59	38
	Min	0	0
Accurate passes	Mean	335.22	256.89
	Standard deviation	339.04	246.56
	Max	1216	815
	Min	17	13

Source: Own

4 Results of the Research

The CCR-I model was applied to the data; the results are shown in Table 2. Table 2 shows that about 15% of the goalkeepers in the first football league are efficient. The obtained OTE score averages around 0.5. On the other hand, in the second football league, only 4% of the goalkeepers were efficient. The obtained OTE scores reach lower average values (about 0.38).

Tab. 2: *Efficiency results for both football leagues*

League	**Number of efficient units**	**Proportion**	**Average OTE score**
1st league	5	15.63%	0.4945
2nd league	2	4.26%	0.3795

Source: Own

The detailed results of the research are summarized in Table 3. The CCR-I model was applied to a set of 32 goalkeepers in the first league. The goalkeepers identified as efficient in the analysis are listed in Table 3. These are the five goalkeepers. It is typical for all goalkeepers that they achieved above average values in saves. On the other hand, their market value is below average. For example, Adrian Chovan was the best goalkeeper in terms of the variables mid-range shots saved and supersaves. He also achieved the highest market value of the efficient goalkeepers of the first league (EUR 300 thousand). The highest market value of the whole set of 32 goalkeepers of the first league was attributed to Dominik Greif (EUR 1 million). Dominik Greif, however, achieved a very low OTE score (0.197) and can be classified as an inefficient unit according to the CCR-I model.

Tab. 3: *Efficient goalkeepers in the 1st Slovak football league*

Name	**MV (thousand EUR)**	**MIN**	**CSS**	**MSS**	**LSS**	**SS**	**S**	**AP**
Tomas Jenco	100	1467	8	15	8	15	10	440
Tomas Frystak	150	2150	28	37	22	32	26	542
Igor Semrinec	150	1586	18	26	24	32	12	544
Matej Markovic	150	2332	16	23	28	29	21	558
Adrian Chovan	300	3141	31	62	56	62	59	1078
Mean	*170*	*2135.20*	*20.20*	*32.60*	*27.60*	*34.00*	*25.60*	*632.40*
Max	*300*	*3141*	*31*	*62*	*56*	*62*	*59*	*1078*
Min	*100*	*1467*	*8*	*15*	*8*	*15*	*10*	*440*

Source: Own

Table 4 below shows the efficient goalkeepers in the second league. From the set of 47 goalkeepers, only two goalkeepers were marked as efficient in terms of OTE score – Matej Luksch and Milan Vincler. These goalkeepers were above average in terms of the output variables in all saves. Goalkeeper Matej Luksch recorded maximum mid and long-range shots saved, stopped shots, and accurate passes in the 2020/21 season. These great stats ultimately resulted in an efficient score. This was a goalkeeper with a relatively low market value (75 thousand euros). The highest market value out of the entire set of 47 goalkeepers in the second league was attributed to Samuel Petras (EUR 400 thousand). Samuel Petras, however, achieved a very low OTE score (0.017) and can be classified as an inefficient unit according to the CCR-I model.

Tab. 4: *Efficient goalkeepers in the 2nd Slovak football league*

Name	**MV (thousand EUR)**	**MIN**	**CSS**	**MSS**	**LSS**	**SS**	**S**	**AP**
Matej Luksch	75	2500	18	47	48	73	22	815
Milan Vincler	50	1900	17	41	28	27	23	527
Mean	*62.5*	*2200*	*17.5*	*44*	*38*	*50*	*22.5*	*671*
Max	*75*	*2500*	*18*	*47*	*48*	*73*	*23*	*815*
Min	*50*	*1900*	*17*	*41*	*28*	*27*	*22*	*527*

Source: Own

On average, goalkeepers in the second league had to play more minutes to be efficient than goalkeepers in the first league. Efficient goalkeepers in the second league also had more saves on average, excluding supersaves, and also more accurate passes. The market value of efficient goalkeepers in the second league was also at a lower financial level than that of first league goalkeepers. In the second part of the research, the efficient goalkeepers were further classified using the AP model of super-efficiency. The results of this evaluation are summarized in Table 5.

Tab. 5: *Ranking of efficient goalkeepers*

Name	Nationality	Age	Height	League	Team	AP model	Ranking
Tomas Frystak	CZ	34	193	1st	Senica	1.6087	1.
Adrian Chovan	SK	26	192	1st	Zlate Moravce	1.1917	2.
Tomas Jenco	SK	33	182	1st	Pohronie	1.1828	3.
Matej Markovic	HR	25	192	1st	Michalovce	1.1781	4.
Igor Semrinec	SK	34	188	1st	Trencin	1.0093	5.
Matej Luksch	CZ	23	191	2nd	Liptovsky Mikulas	1.4427	1.
Milan Vincler	SK	28	189	2nd	Trebisov	1.4403	2.

Source: Own

The evaluation shows that the best-rated goalkeeper in the first Slovak football league is Tomas Frystak from the Czech Republic. In the second Slovak football league, the best-rated goalkeeper is also the Czech goalkeeper Matej Luksch.

Conclusion

The main aim of the thesis was to propose an approach to the analysis and evaluation of the best goalkeepers in two Slovak football competitions. The CCR-I model was used to evaluate the goalkeepers. Subsequently, the AP super-efficiency model was used to determine the ranking of the best goalkeepers.

In neither case were the most valuable goalkeepers assigned to a set of efficient units. This fact can be interpreted to mean that the most valuable goalkeepers in both competitions should have higher performance as measured by the above game statistics according to the CCR-I model. The research also showed that the market value of the efficient goalkeepers of the first league was at a higher financial level than the value of the goalkeepers of the second league.

Given the current economic and financial situation of football clubs, there is an increased need to know how efficiently a club is using its resources. Efficiency analysis is used to calculate the performance scores of players and to determine the deficiency aspects and the number of inefficient players. The advantage of the DEA methodology is to establish benchmarks for inefficient players and identify sources of inefficiency. Along with general insights and experiences, sports managers can consider DEA efficiency analysis when developing teams. This evaluation model should significantly contribute to the tactical preparation of goalkeepers for the match, distinguish the quality of individual goalkeepers more accurately, and evaluate the overall efficiency at the end of the match. Another possible extension of this method is its application to other player positions.

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HODNOCENÍ VÝKONNOSTI BRANKÁŘŮ SLOVENSKÉHO FOTBALU

Fotbal je na Slovensku oblíbené sportovní odvětví. Fotbalové kluby vynakládají každoročně nemalé peněžní částky na nákup jednotlivých hráčů. Přesto existuje malé množství vědeckých studií, které by se zabývaly statistickými, ekonomickými rozměry a hodnocením výkonnosti fotbalových hráčů. Výkony jednotlivých hráčů stejně jako výkon celého týmu jsou velmi důležité ukazatele, které předurčují úspěch celého klubu. Cílem tohoto výzkumu je vytvořit nový systém hodnocení efektivity fotbalových hráčů a následně tento systém aplikovat do fotbalové praxe a identifikovat technicky efektivní hráče. V předkládaném výzkumu je využito analýzy obalových dat, konkrétně vstupově orientovaného Charness, Cooper, Rhodes modelu a modelu super-efektivnosti Andersen-Petersen. Oba modely jsou empiricky aplikovány na pouze jednu skupinu fotbalových hráčů, konkrétně brankáře první a druhé slovenské fotbalové ligy v sezóně 2020/21. Model navržený v tomto článku se snaží do rozhodování začlenit větší objektivitu, a může tak být důležitým krokem při vývoji systematické metodiky hodnocení nejen brankářů, ale i hráčů na ostatních herních pozicích.

LEISTUNGSBEWERTUNG VON TORHÜTERN IM SLOWAKISCHEN FUßBALL

Fußball ist ein beliebter Sport in der Slowakei. Jedes Jahr geben die Fußballvereine große Summen für den Kauf einzelner Spieler aus. Es gibt jedoch nur wenige wissenschaftliche Studien, die sich mit den statistischen und ökonomischen Dimensionen sowie der Leistungsbewertung von Fußballspielern befassen. Die Leistung einzelner Spieler und die Leistung der gesamten Mannschaft sind sehr wichtige Indikatoren, die den Erfolg des gesamten Vereins vorhersehen lassen. Ziel dieser Forschung ist es, ein neues System zur Bewertung der Effektivität von Fußballspielern zu entwickeln und dieses System dann in der Fußballpraxis anzuwenden und technisch effektive Spieler zu identifizieren. Die vorliegende Untersuchung verwendet die Analyse von Umschlagdaten, insbesondere das input-orientierte Modell von Charness, Cooper, Rhodes und das Super-Effektivitäts-Modell von Andersen-Petersen. Beide Modelle werden empirisch auf eine einzige Gruppe von Fußballspielern angewandt, nämlich die Torhüter der ersten und zweiten slowakischen Fußballliga in der Saison 2020/21. Das in diesem Beitrag vorgeschlagene Modell versucht, eine größere Objektivität in die Entscheidungsfindung einzubringen, und kann daher ein wichtiger Schritt bei der Entwicklung einer systematischen Methodik zur Bewertung nicht nur von Torhütern, sondern auch von Spielern auf anderen Positionen sein.

OCENA SKUTECZNOŚCI BRAMKARZY SŁOWACKIEJ PIŁKI NOŻNEJ

Piłka nożna jest na Słowacji popularną dyscypliną sportową. Co roku kluby piłkarskie wydają duże sumy pieniędzy na zakup poszczególnych zawodników. Mimo to istnieje niewielka liczba opracowań naukowych, które dotyczą statystycznego, ekonomicznego wymiaru i oceny skuteczności piłkarzy. Wyniki poszczególnych zawodników, jak i wyniki całego zespołu są bardzo ważnymi wskaźnikami, które przesądzają o sukcesie całego klubu. Celem przeprowadzonych badań jest stworzenie nowego systemu oceny efektywności zawodników piłki nożnej, a następnie zastosowanie tego systemu w praktyce piłkarskiej i identyfikacja zawodników skutecznych technicznie. W ramach opisywanych badaniach wykorzystano analizę obwiedni danych, a konkretnie model Charnesa, Coopera, Rhodesa zorientowany na nakłady oraz model nadefektywności Andersena-Petersena. Oba modele zastosowano empirycznie tylko do jednej grupy piłkarzy, a mianowicie bramkarzy pierwszej i drugiej słowackiej ligi piłki nożnej w sezonie 2020/21. Zaproponowany w niniejszej pracy model próbuje wprowadzić do procesu decyzyjnego większą obiektywność, a tym samym może być ważnym krokiem w rozwoju systematycznej metodyki oceny nie tylko bramkarzy, ale także innych pozycji zawodników.

HOW UNIVERSITIES DETERMINE ECONOMIC DEVELOPMENT IN 27 EU MEMBER STATES

Olesya Petrenko
University of West Bohemia, Faculty of Economics,
Department of Economics and Quantitative Methods;
Univerzitní 22, 301 00 Pilsen, Czech Republic
e-mail: petrenko@ujp.zcu.cz

Abstract

Many European countries nowadays are collaboratively focused on bringing together the most up-to-date technologies and the brightest minds to deal with social, economic, and ecological matters and find a sustainable equipoise. Universities may help to produce appropriate knowledge for such challenges and foster economic and social innovation. This paper reviews evidence of existing bonds between tertiary education and economic growth measured in GDP per capita providing a quantitative evaluation of such dependencies using the now widely criticized Cobb-Douglas production function for building Ordinary Least Squares (OLS) and Bayesian Averaging of Classical Estimates (BACE) econometric models. The results obtained in this research showed that tertiary education expenditures and the numbers of mainly male BA and MA graduates (in technologies, sciences and medicine robustly and partially correlate with economic growth. Well-distributed investment in the development of tertiary education STEM majors can potentially strengthen universities' positive impact on sustainable economic growth.

Keywords

Economic growth; Tertiary education; Sustainable development; STEM majors.

Introduction

Rising interest in the role of tertiary institutions in economic growth is creating space for scientific discussions and research in education, the economics of education and human resources management [17], [2], [26]. It might therefore be important to determine what impact tertiary education organizations have on economic growth. One major theoretical issue that has dominated the field for many years is whether GDP and its derivatives are an adequate measure of economic growth and development. This concept has been challenged by a number of empirical studies [7], [16], [36], [37]. Moreover, scholars are now working hard to establish the definition of 'effective' universities and their impact on innovation implementation and the growth of regional economies. Huggins and Johnston described universities as drivers of the regional innovation system in 2009. According to some researchers [1], [25], [15], universities are viewed by society as a whole as social and educational venues that help individuals acquire specific skills to be able to meet economic needs, be capable of making an effective contribution to economic development and meet current market demands. According to contemporary research and related policies, economic growth is closely connected to the human capital endowment. For instance, Barro and Lee [5] point at causal relation between years of education and economic growth. Nevertheless, the relation seems less straightforward than defined in [16]. A simple causation relationship between education and growth may not always suit all the economies and is being questioned

especially during economic crises like the Global Financial Crisis (GFC) or the current Covid-19 pandemic. What might be of greater importance than the number of school years or the ratio of a well-educated population related to the whole population in general, is strategic planning of tertiary education. It was demonstrated in [26] that imposing strategical thinking (aligning priorities, values, and incentives of the university to those defined by local, regional, and or national authorities) for university management is one of the key elements needed to enhance a university's performance and efficiency. Several studies dealing with this issue have been published and serve as the outlook on performance measurement in higher education [8], [23], although very few models of performance measurement are to this day transferred from the for-profit sector and later adjusted to suit such public organizations.

1 Research Objectives

The process of building a transparent system that could help to determine the efficiency of a higher education organization would greatly need to be explained clearly to managers and policy makers so that synergy among policy makers, management, human resources, professionals, and students can be reached and the overall system can work more effectively, providing the world with better opportunities for sustainable growth. Statement of the problem: The cause-effect relationship between tertiary education and economic growth and development has been a focus of multiple research projects. However, so far there has been little discussion about the economic effects of tertiary education in European countries. This study attempts to determine the impact of higher education systems on economic growth within 27 EU Member states over the past few decades, as well as the effects of Master's and Ph.D. level graduates overall and divided by gender in the fields of science, medicine, and technology. The aim of the research: this study attempts to carry out reliable empirical estimates of the relationship between tertiary education and economic development in the selected European Union countries during the period of 2013-2019 in order to determine the impact of tertiary education on the economic development of the EU member states. Limitation of the research: In the framework of this study, several indicators of economic growth and development were used – the growth rate of real GDP per capita, GDP per capita in PPP price rates, and tertiary education represented by a share of the population holding a tertiary degree. Relationships between specific tertiary degrees in social sciences, technical sciences, chemistry, biology, etc., and economic growth were not considered in this paper, which is another limitation of the current research. Alternative measurements of economic growth were not used to create a data set. Despite these limitations, it is expected that the results of this research will be able to be used to consider further steps towards building sustainable education in the EU Member States.

Research Questions

1. What is the impact of the characteristics of higher education systems on economic growth in European countries?
2. What is the impact of human capital educated in science, technology, and medicine (Bachelor's and Master' level) on the economic growth?
3. What is the impact of male and female graduates (Bachelor's and Master' level) of all majors on the economic growth?
4. What is the impact of male and female graduates (Bachelor's and Master' level) majoring in science, technologies and medicine on growth?

2 Theoretical Background

In today's economy, tertiary educational services have become an important commodity as HR specialists recognize the employee's qualifications, knowledge, and skills to ensure

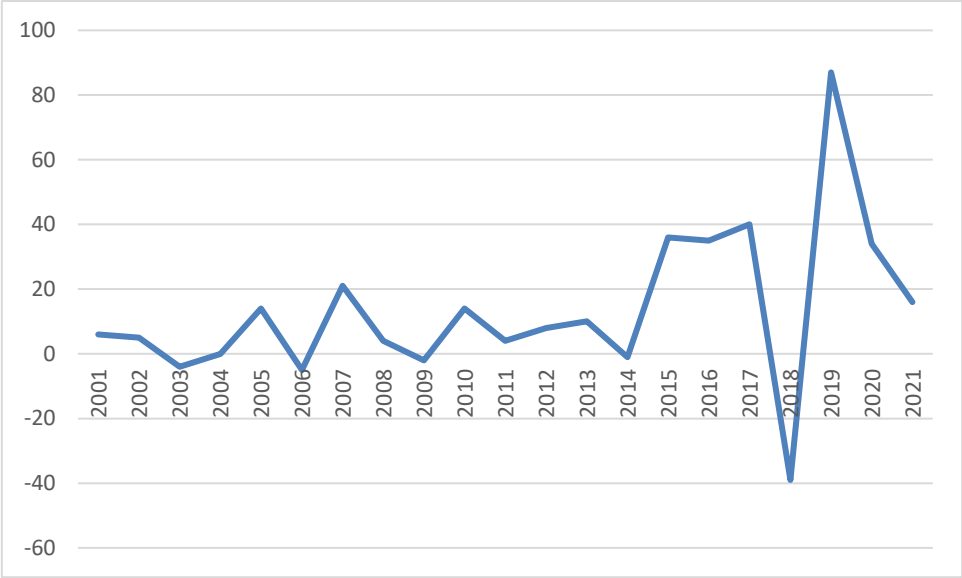
productivity and innovation within a number of businesses (trans-national corporations, medium-sized companies operating globally). Three key directions of education-growth relationship are defined in [14]: it is crucial to enhance the levels of knowledge, expertise, and skills of the population, transfer new knowledge and ideas responsibly and provide incentives for innovation within organizations and the economy as a whole.

In general, education can be considered one of the main factors of economic growth and technological progress [5], [21]. It has been claimed that economic growth leads to higher participation in tertiary education as well-educated human capital promotes greater economic performance. A lot of research has been focused on the cause-effect relationship between education in general (and tertiary education in particular) and economic growth [17], [5], [2], [9], [13], [14] with data gathered from developing and developed countries from 1960 to 2019. Both variables for education (tertiary education) and economic growth were measured in numerous ways. Therefore, the causal relationship between tertiary education and economic growth can be formally described by three main approaches: 1) education causes economic growth; 2) economic growth causes more people to seek tertiary education 3) the cause-effect relationship may function both ways. According to Hanushek and Woessman [19] who studied the relationship of cognitive skills in education and growth in multiple countries, adding more years of education on average does not ensure economic growth. The researchers argued that the differences in cognitive skills – in other words, what is known in certain countries, can be considered an explanatory variable for some of the differences in the economic development in various countries.

In accordance with UNESCO's Sustainable Development Goal 4 (SDG 4) for education [27] sustainability in tertiary education will be crucial for preparing current students to solve the most challenging tasks that the world's economy encounters in the near future. European Commission representatives stress in their reports that more STEM education in tertiary disciplines is needed by 2050 [38, p.13-14]. Another report clearly states that "we must spend more on research and education", therefore, it might be implied that more students will be supported to graduate from tertiary education programs [39, p. 56]. Sustainable tertiary education goals leave no choice to universities but to supply their potential graduates with global education and training so that fewer negative outcomes arise to be settled by future generations. Therefore, in order to complete SDG 4 it may be important to ensure that tertiary education gives students proper sources of knowledge and motivation to assess problems from various perspectives so that they are able to make informed decisions relying on multiple reputable sources of data available.

Tertiary education organizations need to define what efficiency in tertiary education is because researchers and educators worldwide often feel concerned about techniques how to pursue so-called "efficiency". A few estimation methods were developed in the late 20th century, such as non-parametric: e.g. data envelopment analysis (DEA) described in [12] and [4] and parametric: e.g. stochastic frontier analysis (SFA) operated by [3] and [6]. These methods greatly helped to define efficiency in the context of tertiary education. These concerns mainly stem from the idea that if educators and university staff in general start focusing more on being efficient, the very concept of higher education might suffer as more attention is given to meeting certain requirements, i.e. [20] and [24].

The term "efficiency" is typically explained as the opportunity to provide the best educational product for a given budget. It can generally work in two main directions: universities may use the same amount of resources to potentially acquire better results or lower the amount of resources to receive the same results than in previous periods. Over the last few decades it is becoming increasingly important to calculate and recognize the economic impact of universities and other organizations providing tertiary education, see Figure 1.



Source: Author's own calculations based on data from Clarivate Database 2022

Fig. 1: *Frequency change in the number of scientific research papers in economics per year, in counts, published via Web of Science 2001-2021 that feature the words "economic impact of universities" in their headlines and abstracts*

Huggins and Johnston [20] described universities as drivers of regional innovation system in 2009. It is crucial, however, to look at the structure of the human capital and build up a common system to manage it (recruit, train and sustain) in order to determine possibilities of sustainable growth in results in higher education.

3 Methods

The data was gathered from the Eurostat (2021), OECD (2021) and World Bank (2021) official databases. A list of variables and corresponding data sources can be found in Table 7. The criteria for choosing the variables were as follows: 1) Availability – the data are available for the majority of the current EU Members States from 1990 to present; 2) Consistency – congruent tertiary education data for the 27 EU Member States that was calculated and received by carrying out exactly the same procedure for years 2013-2019. Despite the fact that the period of six years could be considered to be an imitation of the current research, it is expected that a common relationship between tertiary education and economic growth will be found as the list of countries chosen for this study seems to be homogeneous as it consists of countries with developed economies according to the World Bank (2019).

The advantage of analyzing such a data set is data coherence – an important data quality component that ensures uniformity as well as existing logical connections and completeness of the dataset. Coherence could also enable the making of a logical distinction between concepts and target populations, which means that most major problems could be easily detected during the data preparation stage. These restrictions resulted in the selection of a few variables, their means and standard deviations are shown in Table 7.

To analyze the data, it was decided to use the Cobb-Douglas production function (CDPF) (1) using capital stock, capital and labor services, despite the fact that CDPF often returned a negative sign for capital [30], [31] and has been considered as "transformation of income identity" [29] and [10]. The main advantage of this function used in its general form is its ability to explain the aggregate output creation and economic growth visually. The function illustrates constant returns to scale ($\alpha + \beta = 1$) when elasticities of production on production factors equal factor shares, with both coefficients being positive numbers ranging [0, 1].

$$Y_t = A_t \cdot (K_t)^{\alpha} \cdot (L_t)^{\beta}, \quad (1)$$

where *A* is total factor productivity, *K* is capital, and *L* is labor.

Due to the fact that most of the uncertainty of the economic growth models' hinders agreement on specific factors that cause economic growth, this paper uses panel data models with country-specific fixed effects. Wooldrigde [28] pointed out that it might be more efficient to use Fixed Effects – Random Effects models instead of the regular OLS regressions while working with panel datasets in which there is heterogeneity. This approach to assess long-term and short-term economic growth has been commonly used in the economic literature due to its general simplicity. The main drawback might be a limited number of variables that could be explained empirically. Their quantity often depends on "whatever list the first researcher happened to select" [33].

To deal with the issue of biases, quite a few researchers also consider using Bayesian model averaging techniques [32] which may help to determine model uncertainty so that the relationship between model-specific estimates is assessed, revealed and explained. Following this idea, economists Sala-I-Martin, Doppelhofer and Miller [35] created a Bayesian Model Averaging of Classical Estimates (a so-called SDM's BACE approach) in order to understand which regressors should be included into cross-country linear regressions. Such models build estimates for every possible combination of variables by applying the weighted averaging OLS method in order to find out which variables do relate to growth robustly and how strong these relationships might be. Therefore, when designing the current research, it was decided to build an alternative model to compare and evaluate the results received from the Fixed Effects model.

More recently, literature on applied econometrics offers "extreme bounds analysis" which was designed to reveal robust empirical relationships for the determinants of economic growth. This test consists of two steps:

1. it is necessary to identify (by prior analysis) which variables could be related to economic growth;
2. to check if a variable *z* is robust, equation (2) for regressions needs to be solved:

$$\gamma = \alpha_j + \beta_{yj} \cdot y + \beta_{zj} \cdot z + \beta_{xj} \cdot x_j + \varepsilon, \quad (2)$$

where
y is a vector that represents fixed positions of the regressors (certain variables which are always included into regressions – e.g. income, investment rate, secondary school enrollment rate, rate of population growth [34]),
z is the variable to be examined, and
x is a "tool" vector which typically consists of a combination of three variables selected for the analysis.

The first tests performed at the beginning of the 1990s were widely criticized in the economic literature as they discarded most of the variables as not robust due to the fact that these regressors did not systematically correlate with economic growth. Consequently, Sala-i-Martin [35] suggested making a transition from "extreme bounds" to variables that would have a certain degree of confidence. Both theory and statistical calculations based on the BACE approach are explicitly explained in [35] and for that reason further theoretical description is omitted in this paper.

There has been much debate between economists on the subject of whether or not there is a fixed set of variables which can be robustly correlated with economic growth. In order to

answer the research questions listed in the introduction of this article, it is considered useful to find out estimates for growth from a much larger set of models with the help of the BACE approach.

4 Results

The null hypothesis to answer the first research question ("What is the impact of the characteristics of higher education systems on economic growth in European countries") was stated as: There is no impact of tertiary education characteristics on economic growth. We constructed an OLS model with fixed effects for the panel dataset having lagged variables of 4 years for bachelor students and 2 years for master students. The dependent variable was current GDP per capita in purchasing power parity (Table 1) with the R-squared of 0.79.

The regressors used for this model included the ones that are generally used by various researchers: gross capital formation, Thousand hours worked(as K and L variables for the Cobb-Douglas function), general economic variables (unemployment rate, population and population growth share, general government consumption expenditures, openness of the economy) and the variables that referred to tertiary education (total number of graduated bachelor and master students, government expenditures on tertiary education and share of the population aged 30-35 with a tertiary diploma). It could be assumed that graduated bachelor and master students have a positive impact on economic growth. The same dataset was used to form multiple BACE models, the results follow in Table 2.

Tab. 1: *Model 1: Fixed-effects, Robust (HAC) standard errors, dependent variable: LOG GDP in current PPP per capita*

	Coefficient	**Std. error**	***t*-ratio**	***p*-value**	
Constant	4.891050000	0.301363000	16.2300	<0.0001	***
Thousand hours worked	−0.000162264	0.000206555	−0.7856	0.4392	
Gross capital formation	0.001290160	0.000750301	1.7200	0.0974	*
Share of age group 30-35 with a tertiary diploma	−0.000644451	0.001286540	−0.5009	0.6206	
Unemployment rate	−0.006935170	0.002318630	−2.9910	0.0060	***
Growth of population share	0.000426793	0.000172614	2.4730	0.0203	**
Graduated bachelor students_4	3.11526e-06	1.53880e-06	−2.0240	0.0533	*
Graduated master students_2	2.02081e-06	8.50523e-07	2.3760	0.0252	**
Graduated Ph.D. students	−2.13229e-06	2.18339e-06	−0.9766	0.3378	
Government expenditures on tertiary education	0.009721160	0.038023200	0.2557	0.8002	
Government consumption expenditures	0.006115850	0.001735630	3.5240	0.0016	***
Openness of the economy	−0.001259470	0.001395340	−0.9026	0.3750	

Source: Own

The BACE modelling analysis method applying posterior moments with unconditional and conditional inclusion returned the following results: gross capital formation, unemployment rate robustly and marginally correlates with economic growth. The numbers of graduated bachelor students robustly moderately correlate with growth. The hypothesis of no impact of tertiary education on economic growth is rejected because total number of bachelor and master students robustly and positively correlate with GDP growth per capita both in the fixed effects model and BACE models.

Tab. 2: *BACE Models (61 models accepted out of 1024). Dependent variable: LOG GDP in current PPP per capita*

	PIP	Mean	Std. dev.	Cond. mean	Cond. std. dev
Constant	1.000000	4.296766	0.171460	4.296766	0.171460
Government expenditures on tertiary	0.999996	−0.120231	0.022694	−0.120232	0.022693
Thousand hours worked	0.914534	−0.000166	0.000075	−0.000182	0.000058
Gross capital formation	0.596062	0.002394	0.002323	0.004017	0.001592
Unemployment rate	0.588710	−0.002529	0.002504	−0.004295	0.001750
Graduated bachelor students_4	0.307443	0.000000	0.000000	0.000000	0.000000
Graduated master students_2	0.203128	0.000000	0.000000	0.000000	0.000000
Growth of population share	0.067852	−0.000004	0.000392	−0.000058	0.001503

Source: Own

The hypothesis to answer the second research question was stated as: There is no significant impact human capital educated in science and technology (Bachelor's, Master's and Ph.D. level) on economic growth. We constructed an OLS model with fixed effects for the panel dataset having lagged variables of 4 years for bachelor students and 2 years for master students. The dependent variable was current GDP per capita in purchasing power parity (Table 3) with the R-squared of 0.788. The results for graduated Ph.D. students did not return any statistically significant results which might mean that it is rather costly to educate prospective scientists and it takes time for the economy to positively react to high quality human capital. It could be assumed that graduated bachelor and master students have a positive impact on economic growth. The same dataset was used to form multiple BACE models, the results follow in Table 4.

Tab. 3: *Model 2: Fixed-effects, Robust (HAC) standard errors, dependent variable: LOG GDP in current PPP per capita*

	Coefficient	Std. error	*t*-ratio	*p*-value	
Constant	4.674090000	0.341751000	13.6800	<0.0001	***
Gross capital formation	0.001252570	0.000755304	1.6580	0.1093	
Share of age group 30-35 with a tertiary diploma	−0.000698896	0.001363940	−0.5124	0.6127	
Unemployment rate	−0.009768940	0.003306760	−2.9540	0.0066	***
Growth of population share	0.000437482	0.000160227	2.7300	0.0112	**
Government expenditures on tertiary education	−0.033137300	0.049195400	−0.6736	0.5065	
Government total education expenditures	0.038256000	0.025660700	1.4910	0.1480	
Government consumption expenditures	0.004575030	0.002762040	1.6560	0.1097	
Openness ratio	−0.000925810	0.001187970	−0.7793	0.4428	
Graduated bachelor students in sciences, technology and medicine_4	4.35001e-06	1.88375e-06	2.3090	0.0291	**
Graduated master students in sciences, technology and medicine_2	2.11347e-06	1.32463e-06	1.5960	0.0227	**

Source: Own

The BACE method returned the following results: Government consumption expenditures, the share of the population with a tertiary education diploma and government spending on tertiary education robustly and marginally correlate with economic growth. The gross capital formation, unemployment rate and numbers of graduated bachelor students robustly moderately correlate with growth. What changed from the first set of BACE modelling results is that the number of bachelor students graduating from majors linked to science, technology and medicine might correlate robustly and marginally with economic growth. The hypothesis of no impact of Master's and Bachelor's science, technologies and medicine students on economic growth is rejected as the number of students in such majors robustly and positively correlate with GDP growth per capita both in the fixed effects model and BACE models.

Tab. 4: *BACE Models (70 models accepted out of 1024), dependent variable: LOG GDP in current PPP per capita*

	PIP	**Mean**	**Std. dev.**	**Cond. mean**	**Cond. std. dev**
Constant	1.000000	4.262602	0.179509	4.262602	0.179509
Government expenditures on HE	0.999910	−0.120103	0.022934	−0.120113	0.022907
Employment by industry breakdowns	0.883652	−0.000154	0.000078	−0.000175	0.000058
Gross capital formation	0.625332	0.002577	0.002358	0.004121	0.001591
Unemployment rate	0.570417	−0.002449	0.002511	−0.004294	0.001770
Total graduated bachelor students in sciences and technology	0.532771	0.000000	0.000000	0.000001	0.000000
Total graduated master students in sciences and technology	0.180553	0.000000	0.000000	0.000000	0.000000
Growth of population share	0.066751	−0.000000	0.000387	−0.000007	0.001498

Source: Own

The hypothesis to answer the third research question was stated as: There is no significant impact the impact of men and women graduates (Bachelor's and Master's level) on the economic growth. We constructed an OLS model and underwent the same procedure (Table 5) with the R-squared of 0.834 and Durbin-Watson statistic of 1.72. It is visible that both female and male master and bachelor students tend to positively influence economic growth, however, the coefficients for men are larger in this model. These findings may point out that there might be a gender pay gap. It could be derived that male and female graduated bachelor and master students have a positive impact on economic growth. The results received with the application of BACE modelling to check the same hypothesis are demonstrated in Table 6 and show that the number of graduated bachelor male students might have robust marginal correlation with economic growth. However, the number of female graduate students, both educated at Bachelor's and Master's levels, demonstrate insignificant correlation with economic growth.

Tab. 5: *Model 3: Fixed-effects, Robust (HAC) standard errors, dependent variable: LOG GDP in current PPP per capita*

	Coefficient	**Std. error**	***t*-ratio**	***p*-value**	
Constant	4.746010000	0.301638000	15.730	<0.0001	***
Gross capital formation	0.001393160	0.000674290	2.066	0.0489	**
Unemployment rate	−0.006738990	0.002574910	−2.617	0.0146	**
Growth of population	0.000551393	0.000192559	2.864	0.0082	***
Government expenditures on HE	−0.062667600	0.051709000	−1.212	0.2364	
Openness ratio	−0.001786610	0.001423370	−1.255	0.2206	
Male Graduated bachelor students	1.19535e-06	5.54429e-07	−2.156	0.0405	**
Female Graduated bachelor students	1.21790e-06	5.84251e-07	−2.085	0.0471	**
Male Graduated master students	3.09333e-06	8.97448e-07	3.447	0.0019	***
Female Graduated master students	2.51806e-06	7.73175e-07	3.257	0.0031	***

Source: Own

Tab. 6: *BACE Models (237 models accepted out of 1094), dependent variable: LOG GDP in current PPP per capita*

	PIP	**Mean**	**Std. dev.**	**Cond. mean**	**Cond. std. dev**
Constant	1.000000	4.247664	0.185112	4.247664	0.185112
Government expenditures on HE	0.999934	−0.118010	0.023213	−0.118020	0.023194
Employment by industry	0.848613	−0.000150	0.000082	−0.000170	0.000059
Gross capital formation	0.602108	0.002442	0.002344	0.004055	0.001607
Unemployment rate	0.600080	−0.002640	0.002556	−0.004400	0.001771
Male graduated bachelor students	0.412162	0	0	0	0
Male graduated master students	0.238469	0	0	0.000001	0
Female graduated master students	0.158910	0	0	0	0.000001
Female graduated bachelor students	0.133351	0	0	0	0
Growth of population share	0.064747	−1e-06	0.000382	−1.3e-05	0.001499

Source: Own

Tab. 7: *Summary statistics, using the observations for 27 EU states, 2013-2019*

Variables	**Data source**	**Mean**	**Median**	**Std. dev.**
Dependent variable: LOG GDP in current PPP per capita	National Statistics Office Eurostat	4.58	4.56	0.162
Independent variables:				
Gross fixed capital formation by industry, deflated, mil.euro	Data Browser, Eurostat	9.70e+004	3.96e+004	1.53e+005
Share of age group 30-35 with a tertiary diploma	Data Browser, Eurostat: [edat_lfse_03]	40.9	42.7	9.20
Employment by A*10 industry breakdowns, thousand hours worked	OECD.org Average annual hours actually worked	1.22e+007	6.99e+006	1.54e+007
Government expenditures on tertiary education	Data Browser, Eurostat	0.904	0.900	0.350
Growth of population share	Data Browser, Eurostat	0.444	0.0214	4.05
Population in mil	Data Browser, Eurostat	16.4	8.74	21.6
Unemployment rate	Data Browser, Eurostat	8.79	7.35	4.91
Total graduated bachelor students	Data Browser, Eurostat	7.58e+004	3.88e+004	9.52e+004
Total graduated master students	Data Browser, Eurostat	5.20e+004	2.41e+004	7.22e+004
General government consumption expenditure, % GDP	World Bank National Accounts Data	19.7	19.4	3.26
Openness of the economies: exp-imp/gdp	World Bank National Accounts Data	4.83	3.00	7.61
Gross capital formation GDP	Data Browser, Eurostat	21.6	21.6	4.53
Total graduated bachelor students	Data Browser, Eurostat	7.58e+004	3.88e+004	9.52e+004
Male graduated bachelor students	Data Browser, Eurostat	3.00e+004	1.51e+004	3.94e+004
Female graduated bachelor students	Data Browser, Eurostat	4.58e+004	2.37e+004	5.85e+004
Total graduated master students	Data Browser, Eurostat	5.20e+004	2.41e+004	7.22e+004
Male graduated master students	Data Browser, Eurostat	2.12e+004	9.58e+003	3.13e+004
Female graduated master students	Data Browser, Eurostat	3.08e+004	1.41e+004	4.21e+004
Total graduated Ph.D. students	Data Browser, Eurostat	3.86e+003	1.91e+003	6.09e+003
Total graduated bachelors in technologies/sciences/medicine	Data Browser, Eurostat	2.41e+004	1.48e+004	3.04e+004
Total graduated master students in technologies/sciences/medicine	Data Browser, Eurostat	1.71e+004	6.41e+003	2.48e+004
Total graduated Ph.D. students in technologies/sciences/medicine	Data Browser, Eurostat	1.50e+003	835.	2.45e+003

Source: Own

The hypothesis to answer the last research question was stated as: There is no significant impact of male and female graduates (Bachelor's and Master's level) majoring in science, technologies and medicine on economic growth. The OLS model returned demonstrated that male bachelor and master students have a statistically significant positive effect on economic growth (0.0141 and 0.0108 correspondingly). Female bachelor graduates also have a positive correlation with growth, however, female master students returned a statistically insignificant coefficient of 0.22. The results received with the application of BACE modelling to check the same hypothesis are described below.

With the help of BACE analysis it might be possible to conclude that the number of graduated male bachelor students majoring in technologies, sciences and medicine might be robustly partially correlated with economic growth (0.64 value of PIP). Graduated male master students as well as female graduate students, both of Bachelor's and Master's levels, return insignificant correlation coefficients with economic growth (0.188 for male bachelor students, 0.15 for female bachelor students and 0.13 for female master students in sciences, technology and medicine). These results differ from the panel regression model where coefficients for graduated male bachelor and master students as well as female graduated bachelor students appeared to be significant.

Having performed OLS regression and Bayesian Averaging of Classical Estimates we found that such variables as the number of graduated bachelor and master students positively relate to growth.

It was discovered that bachelor and master male students who graduated majoring in sciences, technologies and medicine overall have higher robust coefficients associated with growth. The results of OLS panel data regression analysis are not always confirmed by BACE: female bachelor graduates also have a positive correlation with growth. However, female master students returned a statistically insignificant coefficient according to the OLS regression model, whereas it might be implied from the results of the same coefficients for BACE models that female graduates generally do not correlate robustly with growth. Therefore, it was particularly interesting to carry out the procedure for the final research question – What impact do male and female graduates (Bachelor's and Master's level) majoring in science, technologies and medicine have on the economic growth? It was confirmed that the number of graduated bachelor male students might have robust marginal correlation with economic growth. However, female graduate students, both Bachelor´s and Master´s levels, return insignificant correlation with economic growth.

5 Discussion

Further development of current research may focus on developing a set of indicators that measure the level of technological development in EU countries and including these into the dataset. Moreover, we find it interesting to perform analyses on STEM education with a further focus on gender, possibly answering the following questions: is STEM tertiary education more important for growth? How many women and men study STEM and does their number have any impact on the gender pay gap and/or the "glass door" or the "glass ceiling".

It is demonstrated that some components of human capital (the share of people with tertiary diploma, the share of young people in the economically active population) in combination with expenditures on higher education have statistically significant robust positive influence on economic growth in the countries of the European Union. It might be interesting to determine the spillover effects. We find it useful for the future analysis to break down the 27 countries into several groups and possibly include more variables for these groups. In this research we admittedly used a limited number of variables which might have caused more biased results.

The following questions still remain relevant:

1. Is there a set of fixed variables in tertiary education that robustly relate to economic growth?
2. What is the strength of this connection – partial or marginal?

Conclusion

It is crucial to proceed with the research of the STEM tertiary education for bachelor and master students and explore the relationship of gender differences between male and female graduates on economic growth to find out whether STEM education promotes economic growth in any way more efficiently than the total number of students. The results of this study might help to demonstrate to what extent the EU governments should invest in STEM tertiary education and foster economic development of prominent economies in other parts of the world.

STEM majors generally attract more male students, who have a statistically significant effect on economic growth, which often may mean that women might not have the same opportunities as men do in their careers. This may result in the finding that women fight both "glass door" and "glass ceiling" (both of these terms refer to horizontal or vertical discrimination of women in companies). To develop governmental strategies for tertiary education it might also be useful to understand how such a trend affects the pay gap between men and women in the countries of the European Union.

Governments may choose to assess these issues of glass door and glass ceiling among men and women with a focus on STEM tertiary education through designing policies on tertiary education that could motivate more women to participate in education programs majoring in STEM subjects. The initiatives to foster sustainable economic development through constant investment in the spheres of tertiary education that bring the most value to the economy seem undoubtedly helpful.

The results obtained by the current research, both methodological and empirical, are important to design regional development policies. These estimation techniques could be potentially used by education ministries to monitor the development of tertiary education organizations strengthening their positive impact on economic growth. Thus, calculations based on BACE modelling showed that higher education expenditures and the numbers of graduated (mainly male) bachelor and master students in technologies, sciences and medicine are significant predictors of economic growth in the EU Member States.

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JAK UNIVERZITY URČUJÍ EKONOMICKÝ ROZVOJ VE 27 ČLENSKÝCH STÁTECH EU

Mnoho evropských zemí se v současnosti společně zaměřuje na spojení nejmodernějších technologií a nejchytřejších myslí, aby se vypořádaly se sociálními, ekonomickými a ekologickými záležitostmi a nalezly udržitelnou rovnováhu. Univerzity mohou pomoci vytvářet vhodné znalosti pro takové výzvy a podporovat hospodářské a sociální inovace. Tento článek shrnuje důkazy existujících vazeb mezi terciárním vzděláváním a ekonomickým růstem měřeným v HDP na hlavu a poskytuje kvantitativní hodnocení těchto závislostí pomocí nyní široce kritizované Cobb-Douglasovy produkční funkce pro vytváření obyčejných nejmenších čtverců (OLS) a Bayesiánského průměrování klasických odhadů (BACE) ekonometrických modelů. Výsledky získané v tomto výzkumu ukázaly, že výdaje na terciární vzdělávání a počty převážně absolventů - mužů BA a MA (v technologiích, vědách a medicíně) robustně a částečně korelují s ekonomickým růstem. Dobře rozložené investice do rozvoje terciárního vzdělávání STEM mohou potenciálně posílit pozitivní dopad univerzit na udržitelný hospodářský růst.

WIE DIE UNIVERSITÄTEN DIE ÖKONOMISCHE ENTWICKLUNG IN DEN 27 MITGLIEDSSTAATEN DER EU BESTIMMEN

Viele europäische Staaten konzentrieren sich derzeit auf die Verbindung der modernsten Technologien und der klügsten Geister, damit diese sich mit sozialen, ökonomischen und ökologischen Angelegenheiten auseinandersetzen und ein nachhaltiges Gleichgewicht finden. Die Universitäten können bei der Schaffung geeigneter Kenntnisse für solche Herausforderungen helfen und wirtschaftliche und soziale Innovationen unterstützen. Dieser Artikel fasst die Beweise existierender Bindungen zwischen der tertiären Bildung und dem im HDP pro Kopf gemessenen ökonomischen Wachstum zusammen und liefert eine quantitative Bewertung dieser Abhängigkeiten mit Hilfe der zurzeit kritisierten Cobb-Douglas'schen Produktionsfunktion für die Bildung gewöhnlicher kleinster Quadrate (OLS) und der Bayes'schen Berechnung des Durchschnitts klassischer Schätzungen (BACE) ökonometrischer Modelle. Die in dieser Untersuchung gewonnenen Ergebnisse haben gezeigt, dass die Ausgaben für die tertiäre Bildung und die Anzahl der Absolventen (Männer mit BA- und MA-Abschluss in Technologien, Wissenschaften Medizin) robust und teilweise mit dem ökonomischen Wachstum korrelieren. Gut verteilte Investitionen in die Entwicklung der tertiären Bildung STEM können die positive Auswirkung der Universitäten auf das nachhaltige ökonomische Wachstum stärken.

W JAKI SPOSÓB UNIWERSYTETY DETERMINUJĄ ROZWÓJ GOSPODARCZY W 27 PAŃSTWACH CZŁONKOWSKICH UE

Wiele krajów europejskich skupia się obecnie wspólnie na łączeniu najnowocześniejszych technologii i najzdolniejszych umysłów w celu rozwiązania problemów społecznych, gospodarczych i ekologicznych oraz znalezienia trwałej równowagi. Uniwersytety mogą pomóc w generowaniu odpowiedniej wiedzy dla takich wyzwań i wspierać innowacje gospodarcze i społeczne. Niniejszy artykuł podsumowuje dowody na istniejące powiązania między szkolnictwem wyższym a wzrostem gospodarczym mierzonym w PKB per capita i przedstawia ilościową ocenę tych zależności, wykorzystując obecnie szeroko krytykowaną funkcję Cobba-Douglasa do tworzenia zwykłych najmniejszych kwadratów (OLS) i Bayesowskiego uśredniania klasycznych oszacowań (BACE) modeli ekonometrycznych. Wyniki uzyskane w ramach przeprowadzonych badań pokazały, że wydatki na szkolnictwo wyższe oraz liczba absolwentów, przeważnie płci męskiej, studiów licencjackich i magisterskich (w zakresie technologii, nauk i medycyny) są mocno i częściowo skorelowane ze wzrostem gospodarczym. Dobrze rozłożone inwestycje w rozwój kształcenia wyższego na kierunkach STEM mogą potencjalnie zwiększyć pozytywny wpływ uniwersytetów na zrównoważony wzrost gospodarczy.

LIST OF AUTHORS

Name	E-Mail and Page Number of Contribution	
Zdeněk Brabec	zdenek.brabec@tul.cz	7
Helena Jáčová	helena.jacova@tul.cz	7
Simona Hašková	haskova@mail.vstecb.cz	19
Jiří Kučera	kuceraj@mail.vstecb.cz	19
Róbert Kuchár	kuchar@mail.vstecb.cz	19
Petra Kašparová	petra.kasparova1@tul.cz	33
Maja Kiba-Janiak	maja.kiba-janiak@ue.wroc.pl	44
Katarzyna Cheba	katarzyna.cheba@zut.edu.pl	44
Jarosław Witkowski	jaroslaw.witkowski@ue.wroc.pl	44
Agnieszka Jagoda	agnieszka.jagoda@ue.wroc.pl	44
Agnieszka Skowrońska	agnieszka.skowronska@ue.wroc.pl	44
Tomasz Kołakowski	tomasz.kolakowski@ue.wroc.pl	44
Anna Baraniecka	anna.baraniecka@ue.wroc.pl	44
Jakub Marcinkowski	jakub.marcinkowski@ue.wroc.pl	44
Magdalena Mucowska	magdalena.mucowska@ue.wroc.pl	44
Jens Maiwald	jens.maiwald@hszg.de	54
Marta Nosková	mnosk@kpm.zcu.cz	71
Petra Taušl Procházková	pprochaz@kpm.zcu.cz	71
Eva Jelínková	jelinkov@kpm.zcu.cz	71
Pavel Pelech	pavel.pelech@tul.cz	86
Julie Holendová	julie.holendova@tul.cz	86
Natalie Pelloneová	natalie.pelloneova@tul.cz	96
Michal Tomíček	michal.tomicek@tul.cz	96
Olesya Petrenko	petrenko@ujp.zcu.cz	106

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