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Population Ageing as a Factor of Structural Changes in Unemployment

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Abstract

The aim of the paper was to analyse the relationship between the unemployment rate and population ageing. Regression and correlation analysis was used. The Spearman and Pearson correlation coefficients were also used. The research question one examined the relationship between the average age of the ageing population and the unemployment rate, suggesting a likely non-linear relationship. The research question two focused on the relationship between the average age of the population and the number of job seekers aged 50-64. The analysis showed that the linear model had limited accuracy while the use of a non-linear approach significantly improved the quality of the results and more complex and non-linear relationships between the investigated variables were pointed out. The research does not take into account socio-economic factors that may have a significant effect on the non-linear relationships between variables.

Keywords: Unemployment, population ageing, average age, regression analysis, correlation, Czech Republic, labour market

Introduction

Population ageing has recently become one of the most important demographic trends with significant impacts on the economy, the labour market and other economic variables. This trend is mainly associated with an increase in life expectancy and a decline in fertility. Population ageing is associated with several phenomena. These include rising income inequality, linked to lack of skills or health problems. Of course, these problems can significantly affect the individual's employability and thus have a significant impact on the level of overall unemployment (Hwang et al., 2021).

Population ageing can also result in a lower risk appetite among potential employers, which may eventually change the overall productivity (C. Liu et al., 2024). The COVID-19 pandemic was another factor, which has exacerbated problems of long-term unemployment, especially among young workers, pointing to the need to apply active labour market policies (Dhingra & Kondirolli, 2022). We can also examine the association between older populations and innovative activity in the context of unemployment. This relationship suggests that the innovative activity of older workers significantly decreases from a certain age onwards (Irmen & Litina, 2022). However, many older people choose to remain active, often bringing valuable knowledge and perceiving themselves as useful employees; this may contribute to the fact that even retired people remain at work or show a desire to return to work (Bjuhr et al., 2022). However, whether older people can be employed is also strongly affected by their health, especially chronic diseases. It is these barriers that may also contribute to higher unemployment rates (Cylus & Al Tayara, 2021).

Population ageing has far-reaching economic implications, and as it has recently become a hot topic, several important studies on this complex subject have been produced in the last few years. These studies have provided different views of the issue and helped us to better understand this socio-economic problem we are facing. In relation to the research questions of this thesis, field research addressing similar issues have been reviewed.

Grzenda (2019) examines socio-economic aspects of long-term unemployment in Polandin his 2019 study: Socio-economic aspects of long-term unemployment in the context of the ageing population of Europe: the case of Poland. Using Bayesian statistics, this paper finds significant shortcomings in the public / national family policy where especially post-maternity women and the elderly have a considerable disadvantage in the labour market. The study highlights that lack of knowledge and health problems largely contribute to their unemployment. Hsieh (2023) reached similar results using panel analysis where he found that lack of knowledge and skills may contribute to unemployment of older workers. At the same time, lack of access to training and good education are also important factors. It is also confirmed that the proper application of policies could mitigate the impact of overall unemployment and the impact on the labour market (Petrosky-Nadeau & Zhang, 2021). Fortunately, there is a growing interest in the topic of population ageing and adaptation, and the economic effects are subject to increasing investigation (Oprea & Vlădescu, 2024). The results of the study by Wang & Li (2021) suggest that even increased demand for health and social services may lead to significant market competition and unemployment. The Age Differences in Unemployment Risk and Reemployment Outcomes in Late Working Life in Sweden study conducted using regression Probit analysis identified that the risk of unemployment does not change significantly with age groups, but older people have much lower chances of re-employment (Öylü et al., 2024). Long-term unemployment also reduces the chance of returning to a permanent job. According to research conducted in China by Liu et al. (2023), population ageing can have an adverse impact on the country's economic growth. Panel analysis, which captures population changes over a longer period and correlation analysis were used to conduct this research. The study associates this negative impact on the economy with a reduction in the labour force, lower rates of innovation and a greater burden on the social and health systems. Dhingra & Kondirolli (2022) examined unemployment and specifically how the COVID-19 pandemic affected the labour market. However, the survey was primarily based on young people data between 2017 and 2021 using panel analysis. It was found that the unemployment rate did not change significantly with the pandemic, and young people are primarily at risk. But the population ageing effects may be responsible for many more changes. For example, the Population ageing, unemployment and house prices in South Africa study analysed the correlation between population ageing and house prices using panel and regression analysis. It was concluded that population ageing deteriorates housing market conditions, with rising unemployment slowing the growth of these prices (Simo-Kengne, 2019). A similar question to the one posed in this thesis was addressed by a German university, which examined the effect of age groups on unemployment in the US and how population ageing affects the regional levels of employment between 2000 and 2014. The study results suggest that the ageing U.S. population could reduce overall unemployment and the population ageing effects are long-lasting (Ochsen, 2021).

In order to answer the first research question, we need to look at methods addressing or dealing with similar issues. The first method to be used will be regression analysis, which was used in the research to describe the relationship between unemployment and house prices in the Simo-Kengne (2019) study. Next, correlation analysis used in research on China's ageing population on its economic growth could be applied. These methods will be used to measure their dependence.

The increase in the average age of the population may lead to an increase in the retirement age, which may result in more older workers and more job seekers. For example, Securing Employment of the Elderly legislation was passed in Japan, which mandates employers to provide employment until the age of 70 (Mori et al., 2024). Raising the retirement age may also have a direct effect on unemployment. A data analysis from 30 developed countries found that raising the retirement age can increase youth unemployment, but on the other hand reduce unemployment among older workers (Rozen-Bakher, 2020). This, in turn, may cause older workers to face specific challenges in the workplace and the overall labour market. These include adapting to new technologies, automation, robotics and using artificial intelligence (Alcover et al., 2021). Thus, the position of the older generation is strongly affected by their lack of familiarity with modern technologies. A study by Van Borm et al. (2021) was primarily focused on working people over the age of fifty and the result of their research was that older job seekers have in overall lower retraining / requalification opportunities, which may cause job concerns. It is certain that job fears can occur in any age group due to a variety of circumstances. Over the last few years, several research papers have always come to different conclusions when examining the older generation. However, for example, the Gender-Age Differences in Hiring Rates and Prospective Wages. Evidence from Job Referrals to Unemployed Workers study clearly shows that older job seekers (50-54 years old) are more successful in finding higher-paying jobs, and this success rate even increases when the job seeker is male. To analyse the data, the authors used the following statistical methods: regression analysis, descriptive statistics elements such as means and medians, and Propensity Score Matching (PSM), to compare groups with different characteristics as accurately as possible (Bamieh & Ziegler, 2023). Thus, the conclusion is that there are several influences in the labour market that work in favour and against older job seekers.

Regression and correlation analysis will be used to analyse data between the average age of an ageing population and the number of job seekers aged 50-64 using Spearman and Peason correlation coefficients as well as the coefficient of determination. The ability to use this secondary data allows the research to be focused and conducted for the research questions.

For both research questions, correlation and regression analysis will be used as the data processing method.

The aim of the thesis is to identify the relationship between population ageing and changes in unemployment. Specifically, the research focuses on the relationship between the average age of the ageing population and the unemployment rate in the Czech Republic between 2014 and 2023.

The following research questions are set to reach the goal:

Research on the relationship between unemployment and population ageing in the Czech Republic is relevant because it represents a significant demographic change, which our current society is facing, and has a major impact on the labour market and the economy as such. By understanding this relationship, public institutions can better design, develop and subsequently apply new policies.

RQ1: What is the relationship between the average age of the ageing population and the unemployment rate in the Czech Republic?

As the population becomes older, not only are the average ages increasing, but the labour market is also changing significantly. As a result of this demographic change, both the supply and demand for labour may change. Answering this question will determine whether there is a relationship between increasing average ages of the Czech population and the number of job seekers.

RQ2: What is the relationship between the average age of the ageing population and the number of job seekers aged 50-64 in the Czech Republic?

Methods and Data

Data collection will be based on secondary data collected by the Czech Statistical Office (CSO, 2024) and the Ministry of Labour and Social Affairs (MoLSA, 2024). All secondary data concerning the average age of population and the unemployment rate will be taken from the Czech Statistical Office (CSO, 2024) website and will be adjusted for seasonal effects. The input data will include a column with the average age, a column with the unemployment rate and a column with the given year, seeTab. 1.

The secondary data concerning job seekers will be taken from the Ministry of Labour and Social Affairs (MLSA, 2024) website. All data are publicly available from the institutions' websites. The input data consists of a column with the average age of the population and a column with the number of job seekers (aged 50-64), seeTab. 1.

Tab. 1: RQ2 input data: Average age of the population and the number of job seekers

Year	Average Age	Jobseekers
2014	41.70	157,328
2015	41.87	140,472
2016	42.05	125,970
2017	42.20	100,724
2018	42.33	82,670
2019	42.48	75,578
2020	42.58	97,796
2021	42.78	93,689
2022	42.61	95,656
2023	42.80	95,264

Source: Authors using the Czech Statistical Office and Ministry of Labour and Social Affairs data (2024).

Regression and correlation analysis methods will be used for the research, including the Spearman and Peason correlation coefficient and the coefficient of determination. These statistical methods will be applied using the TIBCO Statistica software and MS Excel will also be used for simpler analysis. For the research questions, the correlation analysis will investigate the relationship between the average age of the population and the unemployment rate and the relationship between the average age of the population and the number of job seekers aged 50-64.

This method will be used to identify the dependence between the variables and their mutual intensity, as shown by the value of the Pearson correlation coefficient using the least squares method.

Pearson correlation coefficient:

$$r_{xy} = r_{yx} = \frac{s_{xy}}{\sqrt{s_x^2 \cdot s_y^2}} = \frac{s_{xy}}{s_x \cdot s_y} \tag{1}$$

s_{xy}*......sample covariance, can be the values (-∞;∞)*

s_x......standard deviation of x empirical values
s_y......standard deviation of y empirical values

The numerator of the formula contains covariance, which has the following form:

$$S_{xy} = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x}) \cdot (y_i - \bar{y}) \tag{2}$$

The Pearson correlation coefficient can be the values from -1 to +1, and this very number will indicate whether there is a dependence, or how strong the dependence is. The value of rxy = 0 indicates that the variables are not correlated and therefore there is no dependence. The coefficient rxy = +1 indicates increasing dependence and rxy = -1 indicates decreasing dependence. The more the Pearson coefficient value approaches the absolute value of 1, the stronger is the dependence considered.

Next, a regression analysis will be carried out to construct a mathematical model and subsequently create a regression graph using a MS Excel spreadsheet. An inductive method will be used to assess the type of the regression function - the function will be selected based on the point graph. Subsequently, the coefficient of determination will also be simply determined using a MS Excel spreadsheet.

$$R_{yx}^2 = \frac{s_Y^2}{s_y^2} \tag{3}$$

sY...... variance of the actual observed values
sy...... variance of equilibrium values

The coefficient of determination shows how well the secondary input data fits a given regression curve. Most of the literature provides that the function can be considered sufficient quality from a value of 0.7 onwards. Of course, the higher the value, the better quality of the function.

Spearman's correlation coefficient will be applied using TIBCO Statistica and will be particularly useful for non-linear relationship of variables. This coefficient also measures non-linear relationships, specifically it measures the strength of the relationship between two quantities. For this coefficient, it is useful to choose hypotheses from which to infer the correlation:

- Null hypothesis H_0: a correlation exists.
- Alternative hypothesis H_1: a correlation does not exist

Whether the hypothesis is accepted or rejected will depend on p-value with a significance level of 0.05. If the p-value is greater than 0.05, the result is considered statistically significant. In general, the lower the p-value, the less likely it is that the selected statistical method or test indicates the truth of the null hypothesis. If the p-value is lower than 0.05, the result is considered statistically insignificant, and we accept the alternative analysis

The results of correlation and regression analysis are similar statistical methods complementing each other. Based on other studies of the topic, a dependence relationship between the two variables could be expected. Based on research and the results of other studies, a stochastic or minimal dependence can be expected.

Results

This chapter will present results of the analysis that we conducted. The analysis was aimed at obtaining answers to the defined research questions. For clarity, the results are divided into two sections, each focusing on one of the questions and graphically illustrating the results.

Research Question 1 Results

For research question 1, the data used will include the unemployment rate and the average age of the population with data set characteristics as shown inTab. 2.

Tab. 2: Data set characteristics: unemployment rate and average age of the population

Parameter	Unemployment Rate	Average Age of the Population
Mean	5.491710913	40.29658015
Standard error of the mean	0.388590924	0.337328617
Median	5.376145103	40.5
Standard deviation	2.163582701	1.87816625
Selection variance	4.681090102	3.527508464
Peakiness	-1.380748968	-1.071512547
Slant	-0.08977807	-0.35953738
Max-min difference	6.754570426	6.00640635
Minimum	2.068436941	36.79775
Maximum	8.823007367	42.80415635
Total	170.2430383	1249.193985
Number of values	31	31

Source: Authors using a data analysis add-in in MS Excel (2024).

The following results were collected using the above methods for research question 1. The Pearson correlation coefficient was (using the = EARSON function) -0.38451. This value describes a negative weak dependence of the variables (from 0.4 onwards it would be a medium dependence). Since the Person coefficient only describes a linear dependence, it is important to verify that it is indeed a linear dependence and, if necessary, verify the dependence using the Spearman coefficient.

Using a MS Excel spreadsheet, the input data was converted into a dot plot. By looking at the points, we cannot clearly determine whether there will be a dependence and whether the trend line will be linear. A linear trend line was used for a basic view of the dependence, which is shown inGraph 1.

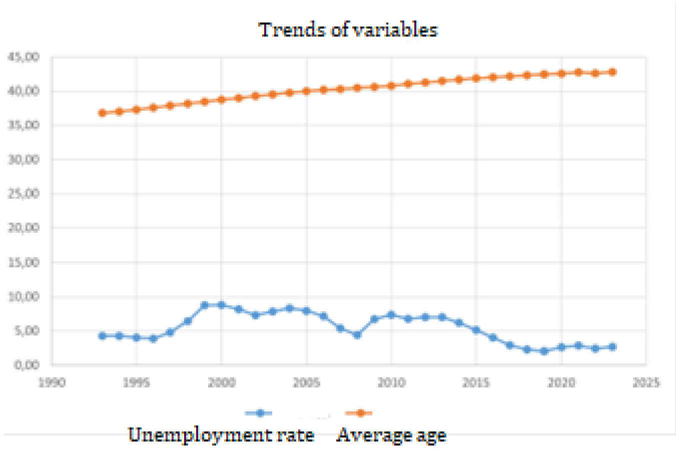
Graph 1 : Regression dot plot with a linear trend line for the research question 1

Source: Authors using MS Excel (2024).

The Graph shows that the regression dot plot equation is **y = -03338x + 42.13** and the coefficient of determination "R squared" (shown as R^2 in the Graph) is **0.1478** or **14.78%.** The coefficient of determination determines the quality of our estimated regression function, where we could conclude that the regression function is good quality from 0.7 onward.

Since the coefficient of determination is low, we need to consider other shapes of the trend line. Graph 2 shows that the average age has an increasing trend indicating population ageing while the unemployment rate has a fluctuating trend.

Graph 2 : Variables trends for the research question 1

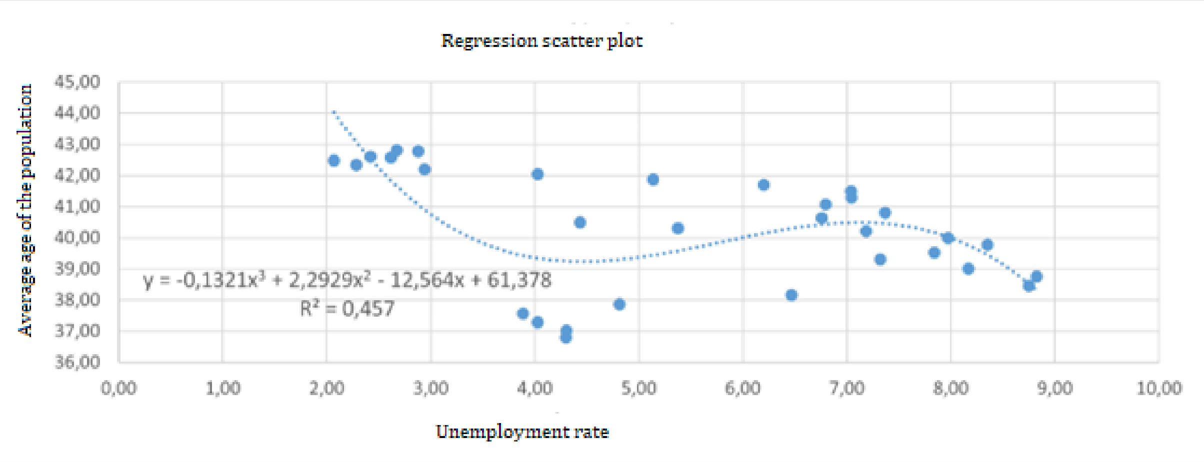


Source: Authors using MS Excel (2024).

Therefore, a polynomial trend line was applied, which fits the dots better and the coefficient of determination indicates a higher quality of the regression function: **45.7%,** see

Graph 3.

Graph 3 : Regression dot plot with a polynomial trend line for the research question 1



Source: Authors using MS Excel (2024).

Once the non-linearity of the relationship was established, the Spearman correlation coefficient (seeTab) was found to be **-0.48346.** This is a moderately strong negative relationship that describes how well the parameters fit the monotonic nonlinear function. The p-value is **0.005863**.

Tab. 4: Spearman correlation coefficient

Valid N	Spearman R	p-value
31	-0.483468	0.005863

Source: Authors using TIBCO Statistica (2024).

If we consider a significance level of 0.05, the result shows that it is statistically significant. Therefore, we reject the null hypothesis. This would imply that the alternative hypothesis H1 will be accepted as likely true. A correlation probably exists here.

Research Question 2 Results

The data set characteristics for the average age of the population and the number of job seekers aged 50-64 are provided in

Tab. 3.

Tab. 3: Data set characteristics: Average age of the population and the number of job seekers aged 50-64

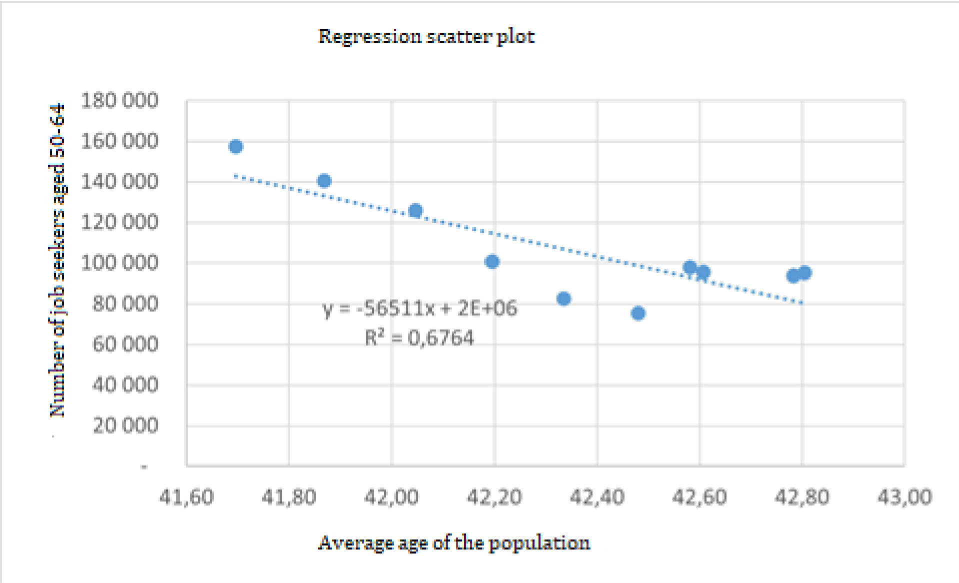
Parameter	Average Age of the Population	Number of Job Seekers (50-64 years)
Mean	42,33957657	106514,7
Standard error of the mean	0,120381997	8271,627299
Median	42,40739229	96726
Standard deviation	0,380681299	26157,18222
Selection variance	0,144918252	684198181,8
Peakiness	-0,986987155	0,063185802
Slant	-0,443018921	1,000201314
Max-min difference	1,10817635	81750
Minimum	41,69598	75578
Maximum	42,80415635	157328
Total	423,3957657	1065147
Number of values	10	10

Source: Authors using a data analysis add-in in MS Excel (2024).

The Pearson correlation coefficient was **-0.822440243** (again using the =PEARSON function), which indicates a strong negative correlation. This means that if the average age of the population is increasing, the number of job seekers aged 50-64 is decreasing. This coefficient describes a linear relationship (dependence), which in this case also describes the relationship of these variables.

Using a MS Excel spreadsheet, the data were entered into a dot plot (Graph 4), which illustrates the downward trend of a likely linear relationship. A linear trend line with the equation **$y = -56511x + 2*10^9$** and the coefficient of determination **$R^2 = 0.6764$** or **67.64%** were entered into the Graph. The coefficient of determination then shows that this is a medium quality regression model, and this model therefore explains the data reasonably well.

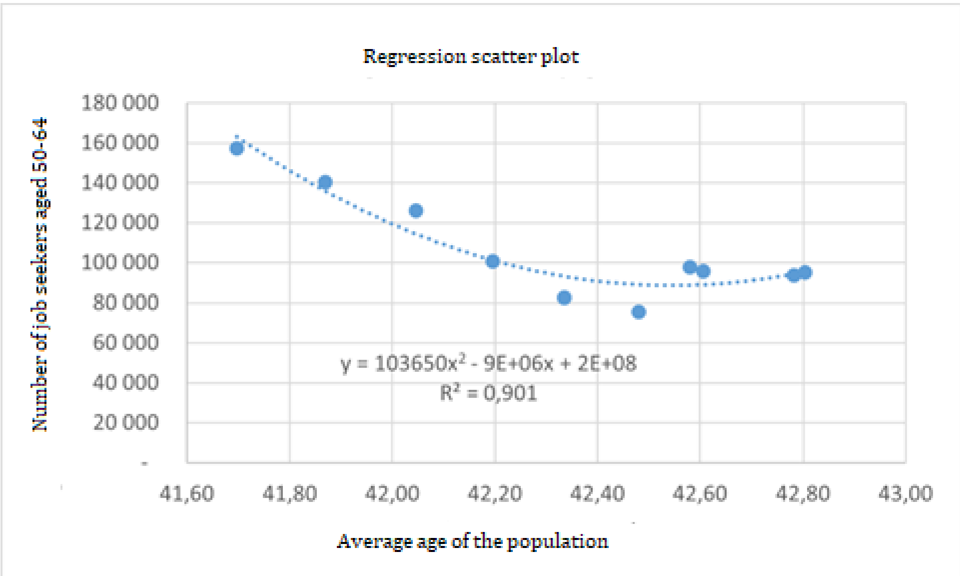
Graph 4 : Regression plot with a linear trend line for the research question 2



Source: Authors using MS Excel (2024).

Even though the coefficient of determination was 67.64%, the possibility that this was not a linear trend line was considered. When a polynomial trend line (Graph 5) was applied, the coefficient of determination increased to **R^2 = 0.901** or **90.1%.** Thus, there is a possibility that no linear relationship exists here.

Graph 5 : Regression dot plot with a polynomial trend line for the research question 2



Source: Authors using MS Excel (2024).

For a possible nonlinear relationship, the Spearman correlation coefficient (Tab. 4) was also applied and the result was -0.696970, indicating a strong negative correlation.

Tab. 4: Spearman correlation coefficient

Valid N	Spearman R	p value
10	-0.696970	0.025097

Source: Authors using TIBCO Statistica (2024)

Furthermore, the p value was also calculated using TIBCO Statistica, which is 0.025097. The result illustrates a statistical significance, and hence rejection of the null hypothesis and acceptance of the alternative hypothesis, which would imply a likely absence of correlation.

Discussion

The following research questions were asked:

RQ1: What is the relationship between the average age of the ageing population and the unemployment rate in the Czech Republic?

The Pearson correlation coefficient of -0.38451 revealed a weak relationship (dependence) between the variables. The same was revealed by the regression analysis of the linear dot plot where the coefficient of determination illustrated a low-quality function (14.78%), i.e. the function only simulates the relationship between the variables at 14.78%. Higher quality can be achieved by applying a non-linear trend to the dot plot. The polynomial trend line corresponds to a coefficient of determination 45.7%. This is a slight improvement, but still not a high enough value to consider the function as good quality. The Spearman correlation coefficient -0.48346 and the p-value 0.005863 indicate a moderately strong negative relationship between the variables. Based on a significance level of 0.05, the statistical significance was established and subsequently the null hypothesis was rejected. These results conclude likely not correlated variables. If there is a relationship between the variables, it is not a linear relationship but a different type of non-linear relationship. The possible non-linearity of this relationship was also concluded by Ochsen (2021) who also pointed to various factors that may influence this relationship such as commuting and younger workers entering the workforce more quickly. Similar results were also obtained by Rozen-Bakher (2020) who emphasised the non-linear effect, namely increasing youth unemployment and decreasing senior unemployment. The research conducted for the first research question only focused on quantitative research and one of the identified shortcomings / limitations of the research is mainly that the research does not take into account socio-economic factors, and therefore the results may lead to general conclusions. Another limitation may be the time scale for observing the variables.

RQ2: What is the relationship between the average age of the ageing population and the number of job seekers aged 50-64 in the Czech Republic?

The Peason correlation coefficient reached -0.82244, indicating a significant negative relationship. Regression analysis from the dot plot demonstrates moderate model quality with a coefficient of determination 0.6764. This level of the coefficient of determination could indicate a linear relationship (dependence) of these variables. The coefficient of determination increases to 90.1% when using the non-linear model, indicating that this model better explains the relationship between the variables. The Spearman correlation coefficient is -0.696970. It is therefore appropriate to consider, similar to the first research question, whether the model is linear or non-linear. The p-value reached a value of 0.025097. Based on the significance level of 0.05, the result was concluded as statistically significant. This p-value result indicates a likely absence of correlation. Although the results provided valuable and important insights into unemployment and population ageing, the limitations of the research should be considered. Although the linear regression function suggests a moderate quality function, the validation of the non-linear model suggests that the relationship may be much more complex, thus other alternative methods need to be used, and deeper data analysis is required to provide clearer results. The Propensity Score Matching method, for example, could provide more accurate results as it also takes into account other factors that could bias the result (Bamieh & Ziegler, 2023).

Conclusion

The aim of this paper was to analyse the relationship between the unemployment rate and population ageing. Specifically, the research questions investigated the relationship between the unemployment rate and the average age of the population. The research question two dealt with the average age of the population and the level of career interest in the 50-64 age group in the Czech Republic. The methods such as Pearson and Spearman correlation coefficient and regression analysis were used to meet the research aim of this thesis.

The results revealed that relationships exist between the variables, but they are not completely linear and are affected by other factors. The research question one concerning the relationship between the average age of the ageing population and the unemployment rate showed a likely non-linear relationship between these variables. The research question two was aimed to examine the relationship between the average age of the population and the number of job seekers aged 50-64. The methods used for this question showed a moderate quality model assuming a linear relationship between the variables while the model quality improved significantly when a non-linear approach was applied. Similar to the research question one, the results indicate a more complex and likely non-linear relationship between the variables.

A summary based on the conducted research is that the aim of the thesis was fulfilled providing important insights about unemployment in the Czech Republic. The main contribution of the thesis is that a complex relationship was identified between the research variables.

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Appendix

Tab. 1 : RQ1 Input Data: Unemployment Rate and Average Age of the Population

Year	Unemployment Rate	Average Age
1993	4.30	36.80
1994	4.30	37.02
1995	4.03	37.28
1996	3.88	37.57
1997	4.81	37.86
1998	6.47	38.16
1999	8.75	38.46
2000	8.82	38.76
2001	8.17	39.00
2002	7.32	39.30
2003	7.84	39.52
2004	8.35	39.77
2005	7.97	39.99
2006	7.18	40.21
2007	5.38	40.30
2008	4.43	40.50
2009	6.76	40.63
2010	7.37	40.80
2011	6.79	41.08
2012	7.04	41.28
2013	7.04	41.50
2014	6.20	41.70
2015	5.14	41.87
2016	4.03	42.05
2017	2.94	42.20
2018	2.28	42.33
2019	2.07	42.48
2020	2.62	42.58
2021	2.88	42.78
2022	2.42	42.61
2023	2.673855	42.80

Source: Authors using the Czech Statistical Office data (2024).

Dynamics of Economic growth and Household Income Distribution

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Abstract

This research focused on the relationship between Gross Domestic Product (GDP) and household incomes in the Czech Republic in the period 2010 to 2022 was based on the need to understand how macroeconomic factors influence the standard of living during different phases of the economic cycle. The aim of this thesis was to evaluate the impact of GDP and other macroeconomic indicators such as inflation, unemployment, household expenditures, household net disposable income (HNDI) and average monthly pay on household income. Time series methods and regression analysis were used to identify the key factors influencing household income. The results revealed a strong dependence between GDP growth and household income, with household net disposable income emerging as the most significant factor. The study also highlighted the differing impacts of these factors during periods of economic growth and recession. The research was limited by the use of annual data and a focus on selected factors, providing opportunities for future analysis, encompassing more detailed data and a broader range of variables.

Keywords: GDP, household incomes, household expenditures, regression analysis, economic growth, unemployment

Introduction

In recent years, the relationship between economic growth as measured by GDP and household income has often been discussed. This relationship is key for understanding the impact of economic growth on living standards. Lupu et al (2023) point out that economic developments in 11 Eastern European countries demonstrate GDP growth as a key determinant of increasing wages, underlining the importance of this relationship to understand broader economic effects on household incomes. The choice of this topic is well timed because in the context of ongoing economic changes such as globalisation, automation and rising social inequality, these factors should be examined for effects both on the overall economy and individual households. Trzcinska (2022) argues that theoretical models such as the Zenga model are accurate tools for quantifying income inequality and provide a deeper understanding of differences in household income across different economies

The current social demand for analysis of this topic is based on the need to understand whether GDP growth actually leads to income growth for the majority of households, or whether only a narrow group of the population can benefit from it. Bilkova (2023) concludes that the trend of wages, GDP, inflation and unemployment in the Czech Republic since the beginning of the economic transformation shows a link between GDP growth and wage stagnation followed by wage recovery, with a delayed response of the labour market to economic crises. This issue not only affects economic but also social stability as rising inequality can result in adverse social consequences such as social tensions or political instability. Krajnakova et al., (2020) report that research on the employability of university graduates in the Czech Republic and the Slovak Republic shows a strong correlation between GDP growth and employment of persons with university degrees, suggesting a significant impact of economic growth on the labour market and household income.

The relationship between economic growth as measured by gross domestic product (GDP) and household income is one of the key issues in macroeconomics and social policy. Examining this relationship helps to understand the extent to which economic growth affects living standards and the distribution of income among different segments of the population. Hronova et al. (2022) point out that domestic consumption responds to economic recessions with a certain lag, thereby mitigating the effects of a crisis. In contrast, slower consumption growth during the recovery slows down the economic boom, confirming the key role of household consumption in economic development. Studies examining the effect of GDP on household income focus on both direct wage growth and indirect effects such as changes in unemployment, inflation or fiscal policy. Vochozka et al. (2023) point out that external economic shocks such as the Russian invasion of Ukraine, reveal the vulnerability of the financial system to external influences, and these shocks cause significant inflationary pressures that directly affect real household incomes.

Some studies argue that GDP growth has a greater income impact on higher income groups, resulting in an increase of income inequality. Tureckova et al. (2022) note that GDP growth often has a greater impact on the incomes of higher income groups, leading to an increase in income inequality. These inequalities can pose an obstacle to balanced economic development and cause tensions between social groups. On the other hand, other research suggests that GDP growth can also have a positive effect on middle-class incomes even if the growth of these incomes is not uniform. Bechny (2020) states in their study that Bayesian analysis shows that labour market shocks significantly affect GDP growth and real wage growth in the Czech Republic. Meanwhile domestic demand shocks have twice the effect on unemployment as foreign shocks, highlighting the role of the domestic economy in job creation and income growth.

These conclusions are the key to discussions about how economic growth should be distributed to make it more socially fair and economically efficient. Tsapko-Piddubna (2021) points out that the implementation of inclusive economic policies such as employment, infrastructure and business development policies are the key to achieving equitable economic growth and improved living standards in CEE, which in turn promotes social inclusion and competitiveness of these economics.

The methods and approaches used to examine the relationship between GDP and household incomes vary. Some studies apply macroeconomic models while others rely on regression analysis and time series to track effects such as inflation, unemployment or tax burden. Krizek et al (2022) says that government spending on education, especially secondary education, has a positive impact on future GDP growth, suggesting the importance of human capital investment for economic development. Time series show a strong correlation between GDP growth and wages in developed countries. Subova et al. (2024) claim that empirical analysis shows short run Granger causality between GDP and household saving rates, with household savings having a significant impact on economic activity in the Czech Republic and Hungary, especially during periods of crisis

Regression analysis often confirms that factors such as inflation and unemployment can slow wage growth during periods of economic growth. Chytilova & Frejlich (2020) report that regression analysis shows an adverse impact of GDP growth on unemployment rates while minimum wages and other macroeconomic factors such as inflation affect the labour market and household incomes.

Some research also points out that GDP growth does not always lead to a proportional increase of income for all households, especially in periods of recession. Kislingerova (2023) concludes that the slowdown in the growth of the Czech economy that was already observed before the pandemic, was associated with low labour productivity and significant capital outflows, which limited the potential for household income growth even as GDP continued to grow. The wage growth dynamics is dependent on the labour market, which may respond to economic changes with a certain delay. Paksi et al (2023) conclude that macroeconomic factors such as GDP growth, the number of job offers and housing completions are the key factors influencing migration behaviour, which indirectly affects the income distribution and economic conditions of households.

Income inequality is also an important factor which affects the relationship between GDP and household incomes. Stoilova (2023) points out that the analysis of tax revenues and their impact on economic growth in Central and Eastern European countries confirms the positive effect of tax revenues on GDP growth. At the same time, however, inefficient use of public spending can hinder inclusive growth and contribute to income inequality. Economics with higher levels of income inequality often show a weaker link between GDP growth and household income growth. Aydin et al. (2022) report that foreign direct investment combined with rising human capital largely affects economic growth in CEE countries. Skilled labour and technological development are the key factors of long-term economic expansion.

This effect can be amplified in periods of global economic changes such as economic crises or changes in technology sectors. Flek et al. (2022) point out that the differences in cyclical unemployment between the Czech Republic and Poland during economic cycles show the influence of global economic changes. Whileas a higher labour market fragmentation in the Czech Republic suggests more complex mechanisms affecting household income growth during economic expansions and crises.

The literature also analyses differences between sectors that respond differently to GDP growth. Stepanek (2022) says that demographic changes in the Czech Republic, including population ageing and migration, will have a significant impact on different sectors of the economy. Some sectors may experience an increase in labour costs and a decrease in competitiveness, which may affect long-term economic growth. Various sectors, especially those with higher levels of innovation and capital intensity, benefit from GDP growth more than traditional sectors such as agriculture. Pokorny (2023) concludes that population ageing in the Czech Republic has an adverse impact on economic growth from a regional perspective. Some regions such as the Moravian-Silesian Region show specific trends that may be influenced by factors other than demographic changes.

The results of these studies show that not only GDP growth itself, but also the structure of the economy, income inequality and the way different sectors and regions respond to macroeconomic changes are crucial for household income growth. Other factors such as foreign direct investment, demographic changes and government policies are also repeatedly mentioned in the literature and can affect the link between GDP growth and the distribution of income across households. Lomachynska et al. (2020) find that FDI inflows have a positive impact on export growth in Visegrad Group countries. However, further growth of their competitiveness will depend on increasing the share of highly technical sectors in national economics.

Based on results of these studies and a review of the available literature, data collection and processing methods were selected to analyse the relationship between GDP and household income, allowing for detailed monitoring of these variables in different phases of the business cycle. The data were obtained from secondary sources, namely the publicly available databases of the Czech Statistical Office (CSO), covering the time series in the period 2010-2022. A time series method will be used to provide an overview of long-term trends and changes in GDP growth and household income, and regression analysis will be used to identify the impact of specific factors such as unemployment, inflation and income inequality on this relationship. These methods were chosen because of their ability to capture both short-run and long-run dynamics, which is in line with the objectives of this thesis aimed at quantifying the economic growth impact on household incomes in the Czech Republic.

The aim of this thesis is to investigate and quantify a potential dependence between GDP growth and household income in different phases of the business cycle and analyse the factors that may influence this dependence / relationship.

The following research questions are set to achieve this goal:

The key for efficient economic policy is to understand the dynamics between GDP growth and household income in different phases of the business cycle. Changes in this relationship during periods of growth and recession can provide key information on the sensitivity of households to macroeconomic changes.

RQ1: How does the strength of the relationship between GDP growth and household income change in different phases of the business cycle (growth, recession) in the Czech Republic in the period 2010-2022?

To analyse the impact of specific macroeconomic factors such as unemployment, inflation and income inequality is the key to understanding differences in the redistribution of economic growth. This analysis will make it possible to identify why some households benefit more than others from GDP growth and what are the contributors.

RQ2: What impact do specific factors such as unemployment and inflation have on household income growth in the context of GDP growth in the Czech Republic in 2010-2022?

Methods and Data

This chapter provides a framework for analysis of the relationship between gross domestic product (GDP) and household income in the Czech Republic in the period 2010-2022.The first part presents the data and their sources, including the basic characteristics that ensure their relevance to the research questions. The second part shows data processing, describing the approaches and analytical techniques that will enable to answer the research questions. The structure of the chapter allows to fully understand how the information leading to the objectives of the thesis was obtained and analysed.

Data Collection Methods

Data for the analysis will be extracted from publicly available databases, specifically from the Czech Statistical Office (CSO). This source provides reliable and up-to-date data concerning GDP, average household income and household expenditure. The data collection method is based on the use of secondary data from published statistics and time series available in the CSO's online databases. These data will be included for the period from 2010 to 2022 and analysed at annual intervals. This approach allows for a detailed analysis of trends and developments in different phases of the business cycle such as growth and recession.

To answer RQ1, GDP and household income data will be used to analyse changes in the strength of their interdependence over different phases of the business cycle. For RQ2, GDP, household income and household expenditure data will be included to examine how GDP growth affects household income through household consumption behaviour.

For the purposes of analysis, a number of statistical characteristics will be used to better describe the structure of the data. For each variable, the basic statistics such as mean, median, mode, standard deviation and variance will be calculated which allows to better understand the distribution of data across years and within different macroeconomic indicators.

In respect of data collection methods, no experiment or observation will be required as these are secondary data already collected by official institutions. These data will then be adapted for use in statistical models for time series analysis and regression analysis.

Data Processing Methods

To answer the research questions, the following data processing methods will be used to enable detailed monitoring of the relationship between GDP, household income and selected macroeconomic factors in different phases of the business cycle.

Time Series Analysis

This method will be applied to GDP and household income data to analyse the long-run relationship between these variables and to identify changes in its intensity during different phases of the business cycle. The time series analysis will be based on year-on-year changes in GDP and household incomes and will use the ARIMA (AutoRegressive Integrated Moving Average) model. This model is defined by the equation (Box et al., 2015):

$$y_t = \phi_1 y_{t-1} + \phi_2 y_{t-2} + \cdots + \phi_p y_{t-p} + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \cdots + \theta_q \varepsilon_{t-q} + \varepsilon_t, \quad (1)$$

where:

- y_t *is the variable value (e.g. GDP or household income) at time t,*
- $\phi_1, \phi_2, \cdots, \phi_p$ *are autoregressive component coefficients ,*
- $\theta_1, \theta_2, \cdots, \theta_q$ *are moving average coefficients,*
- ε_t *is the random component (residuum).*

The data units will be expressed in Czech crowns (CZK) and the time unit will be set annually. This approach will make it possible to assess how the relationship between GDP and household income changes in periods of growth and recession.

Regression analysis

Regression analysis will be used to quantify the effect of individual factors on changes in household income as a GDP growth function. This method will allow to analyse in detail the structure and statistical significance of these relationships, using the following linear regression model (Draper & Smith, 1981):

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \varepsilon \quad (2)$$

where:

- y *is the dependent variable,*
- x_1, x_2, x_3 *are independent variables,*
- β_0 *is the intercept,* $\beta_1, \beta_2, \beta_3$ *are regression coefficients,*
- ε *is the random component (residuum).*

The results of regression analysis will make it possible to quantify the impact of selected macroeconomic factors on household income changes. The analysis will thus provide a comprehensive view of their relationship to GDP growth and their effects over the period under review.

Expected Results

The analysis is expected to show different intensity of the relationship between GDP and household income depending on the phases of the business cycle. During periods of economic growth, a strong positive relationship between GDP and household income is expected. This assumption is based on the Keynesian model, according to which economic growth leads to an increase in income and, consequently, in household consumption. In contrast, this relationship is expected to weaken in a recession period, which may be due to a decline in economic activity, increased unemployment and lower consumption demand. The impact of other factors such as inflation and unemployment will be analysed in detail using regression analysis. Inflation is expected to have an adverse effect on real household incomes while the unemployment rate is expected to have an impact on income growth, especially in a period of economic recession.

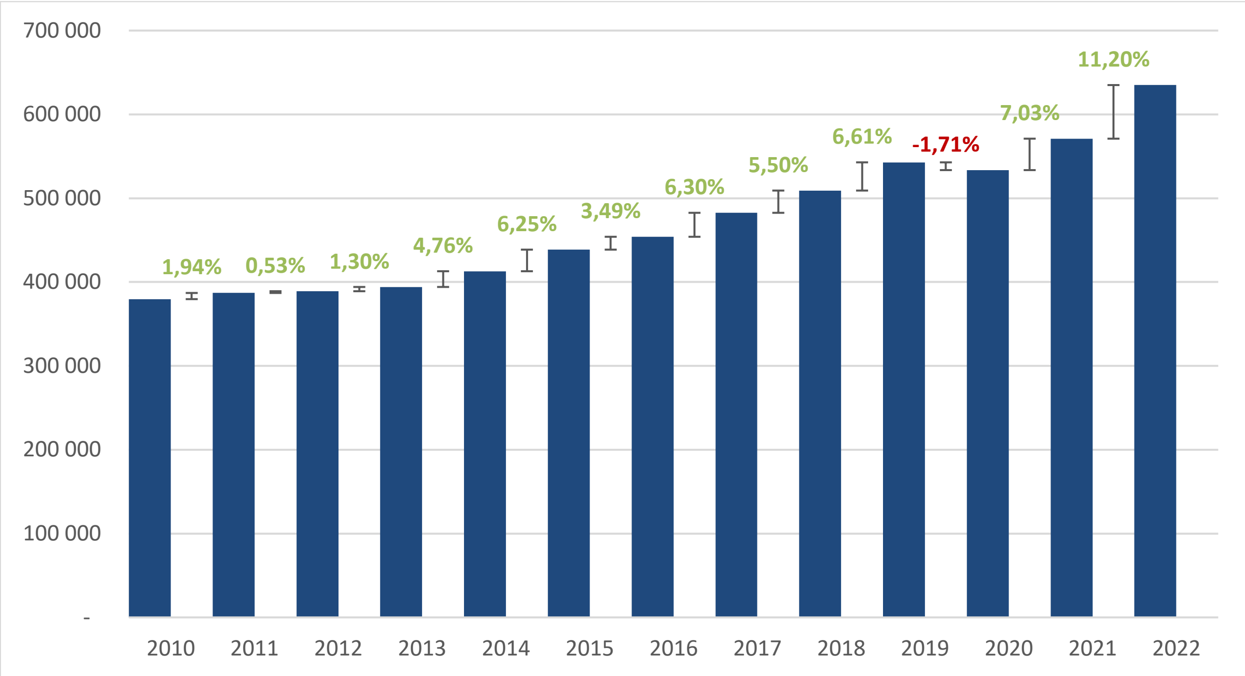
Results

This chapter presents the results of the data analysis conducted to answer the research questions. The analysis is focused on the relationship between GDP growth and household income in different phases of the business cycle in the Czech Republic in the period 2010-2022. The methods used include time series analysis and correlation analysis and their results are presented below.

Relationship between GDP Growth and Household Income during Business Cycle

In order to answer this research question, the annual changes in GDP and household income were analysed based on data available from the Czech Statistical Office. Time series, statistical calculations and trend visualizations were used for the analysis (see Graph 1).

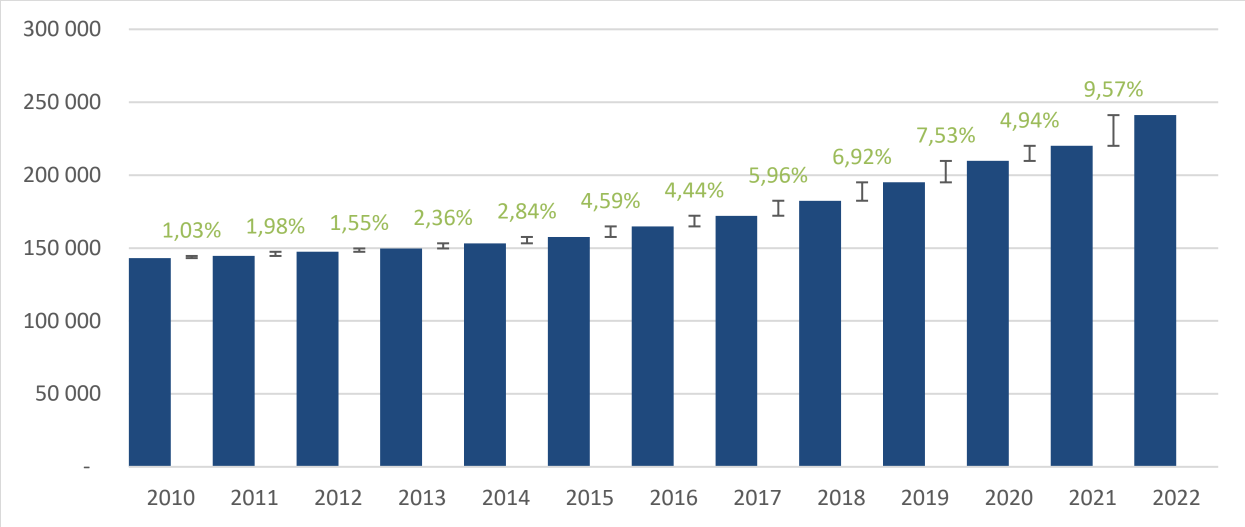
Graph 1: Year-on-year GDP changes



Source: Authors.

The GDP and household income trends in the period 2010-2022 were assessed using time series and graphical representation of year-on-year changes. Graph 1 shows the GDP trend in each year along with the year-on-year percentage variation. The results show long-term GDP growth with some periods of slowdown or recession. The most significant growth was recorded in 2022 when GDP grew by 11.20%. This rapid increase was in response to the economic recovery after the downturn in 2020 (-1.71%). A steady GDP growth was observed between 2013-2018, with slight fluctuations from year to year.

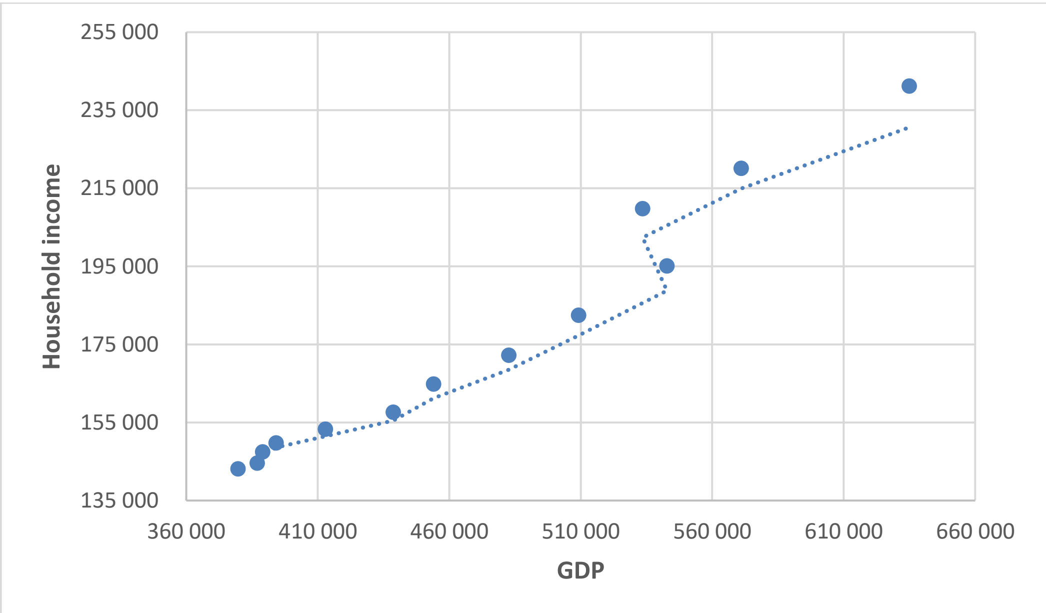
Graph 2: Year-on-year changes in household income



Source: Authors

Graph 2 shows the trend of household incomes, which indicates an overall increasing trend in the period under review. While GDP growth has been accompanied by larger fluctuations in some years, household income has been more stable. The highest annual increase in household income was achieved in 2022 (9.57%), which is related to the post-pandemic economic recovery and the strengthening of the labour market. In contrast, growth slowed to 4.94% in 2021, corresponding to the overall GDP slowdown in the same year. Thus, household income growth dynamics follow GDP trends, but with less volatility, indicating the resilience of household income to short-term economic fluctuations.

Graph 3: Time series with moving averages (ARIMA model) for the relationship between GDP and household incomes



Source: Authors.

In order to examine the long-term relationship between GDP and household income in more detail, a time series graph with moving averages was created based on the ARIMA model. Graph 3 provides a smoothed overview of the trends of both variables and eliminates short-term fluctuations, which allows to better identify the main trends in the period under study.

The results illustrated in the Graph show that a moderate GDP growth was experienced between 2010 and 2013, accompanied by a gradual increase in household incomes. Both time series show synchronous growth, with moving averages confirming a stable positive trend. In the following years, namely between 2014 and 2018, there was a stronger increase in GDP, to which household income also responded with positive growth. Moving averages over this period suggest a strengthened relationship between the two variables, which can be attributed to the economic recovery and stabilization of the labour market.

The economic downturn in 2020 is also visible from the Graph, with GDP showing a slight decline due to the economic recession. Household incomes respond to this decline with a lag, which is reflected in the slowdown of their growth in the Graph. The impact of the economic recession is therefore mainly visible in the short term, while the long-term trend remains positive. In the last phase of the period under review, i.e. 2021 and 2022, the economy was recovering, which is reflected in a sharp GDP increase. This trend is accompanied by a significant increase in household incomes, with moving averages confirming a return to a positive relationship between GDP and income.

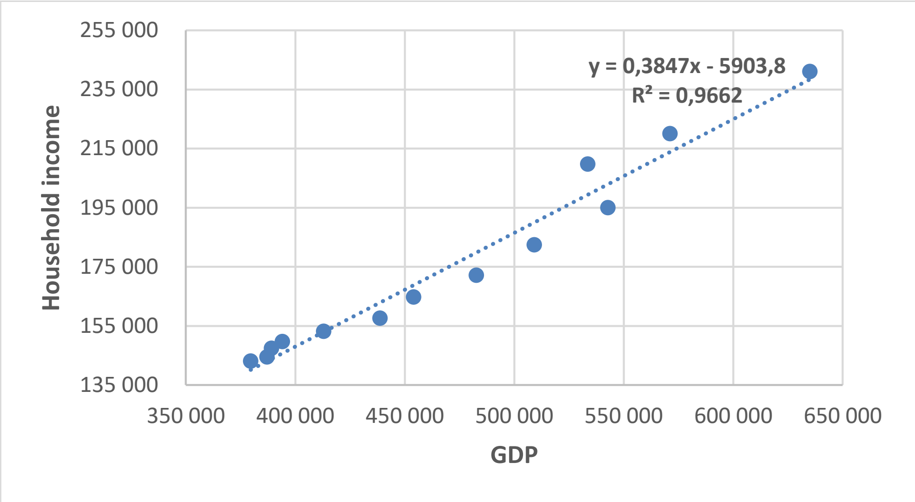
Graph 3 of the time series with moving averages shows that household incomes are responding to GDP changes in a stable and positive manner, but with a slight time lag. The use of the ARIMA model and moving averages has made it possible to better capture the long-term dynamics of the relationship between the two variables and to eliminate short-term fluctuations that could distort the overall trend. This approach confirms that GDP growth is an important factor affecting household incomes, especially in periods of economic growth while this relationship can be temporarily weakened by recessions.

Impact of Selected Factors on Household Income Growth in Context of GDP Growth

This chapter presents the results of regression analysis which studies the impact of selected macroeconomic factors on household income growth in the Czech Republic in the period 2010-2022. The factors analysed include gross domestic product (GDP), household expenditure, inflation, unemployment, the average monthly individual pay and household net disposable income (NDI). The results are presented in Graphs and regression coefficients that illustrate the strength and significance of the relationships.

The results of regression analysis showed that GDP has a strong positive relationship with household income growth. The graphical representation clearly shows a linear relationship between the two variables. Rising GDP increases the economic activity and production, which leads to increasing employment, wages and total household income. This result confirms that GDP is the key indicator of economic growth, which in turn is reflected in the financial situation of households (see Graph 4).

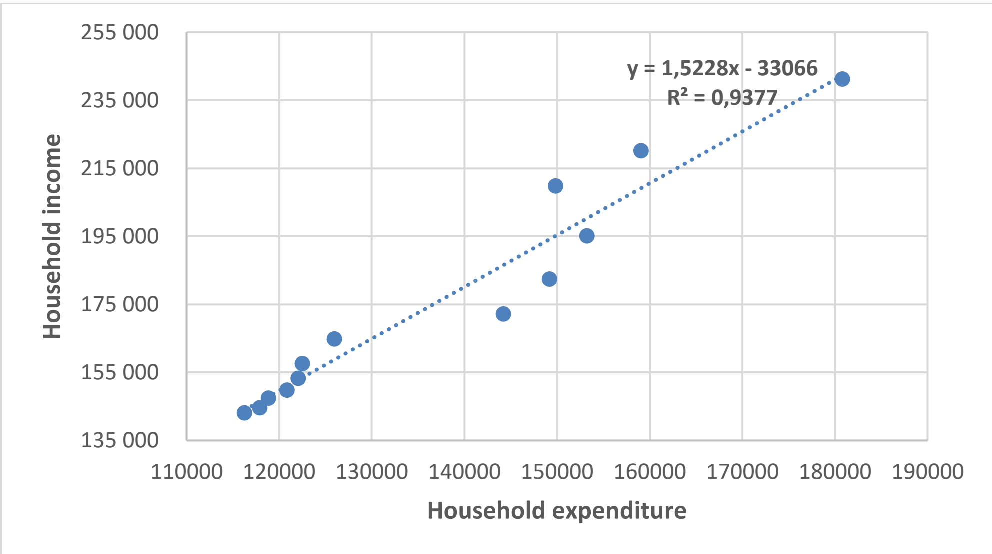
Graph 4: Relationship between GDP and household income



Source: Authors.

Household expenditure is another important factor affecting household income. The analysis showed a strong linear relationship, with higher household expenditures leading to higher incomes. This relationship is logical - rising consumption promotes economic growth, which is reflected in rising employment and wages. Higher spending may reflect households' growing confidence in the economy, which encourages their willingness to invest and spend (see Graph 5).

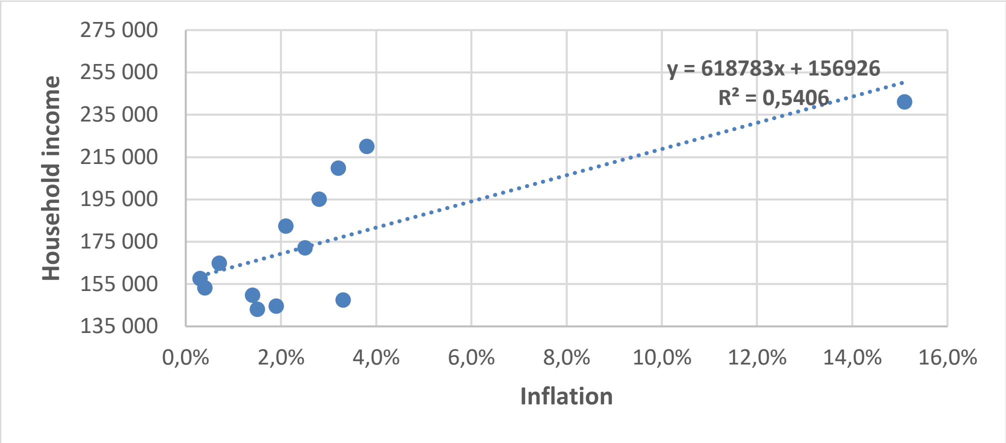
Graph 5: Relationship between expenditure and household income



Source: Authors.

The relationship between inflation and household income was slightly positive. Rising inflation can increase nominal household incomes, which is particularly visible in the short term. However, it is important to note that real incomes may be depressed by inflation. This result suggests that inflation affects incomes rather indirectly, through wage adjustments and the price level (see Graph 6).

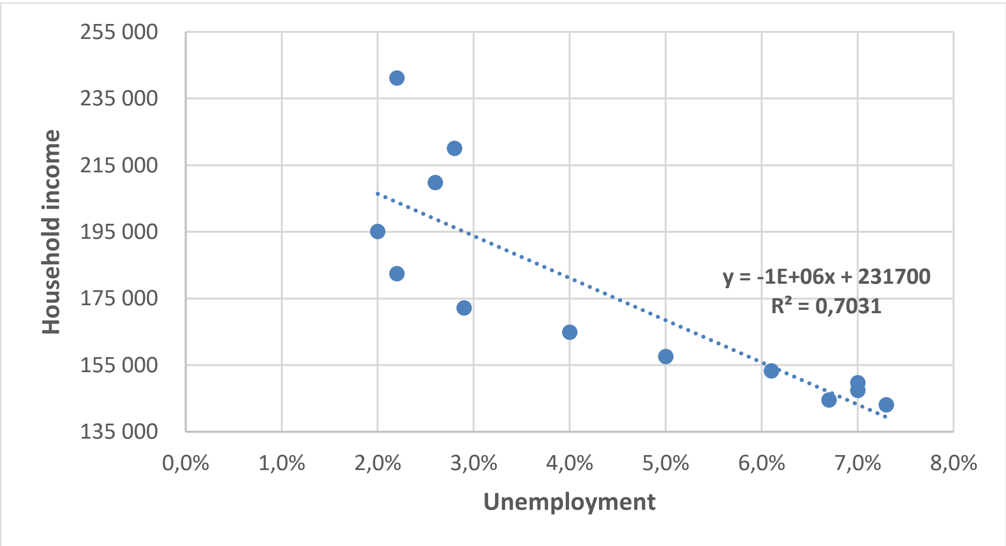
Graph 6: Relationship between inflation and household income



Source: Authors.

Unemployment shows a negative relationship with household incomes as shown in Graph 7. As the unemployment rate increases, household incomes decline as a result of limited job availability and lower incomes. This result is consistent with the economic theory where unemployment reduces aggregate demand and household income.

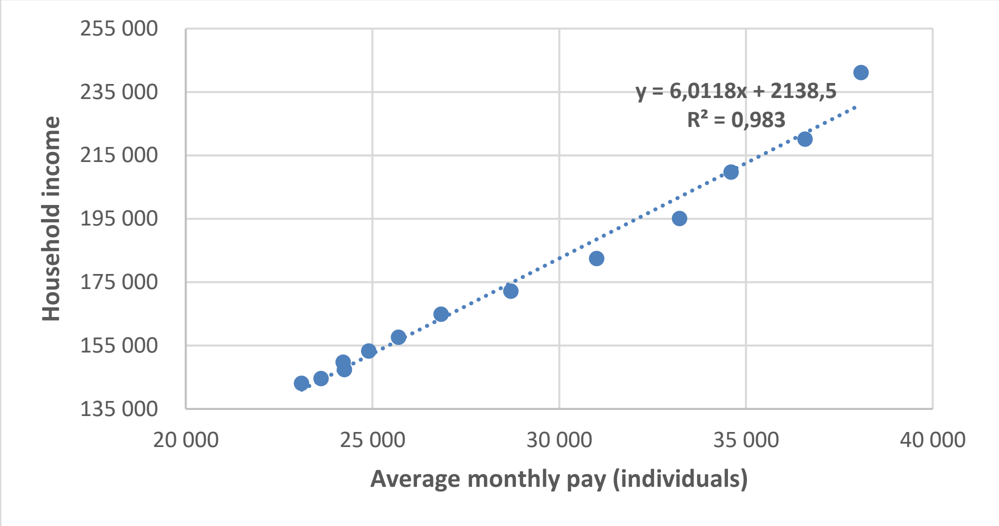
Graph 7: Relationship between unemployment and household income



Source: Authors.

The average monthly pay of individuals showed a very strong positive relationship with household incomes. Higher wages increase the total household income and support their financial stability. This result confirms that wage growth is the key factor improving the economic situation of households (see Graph 8).

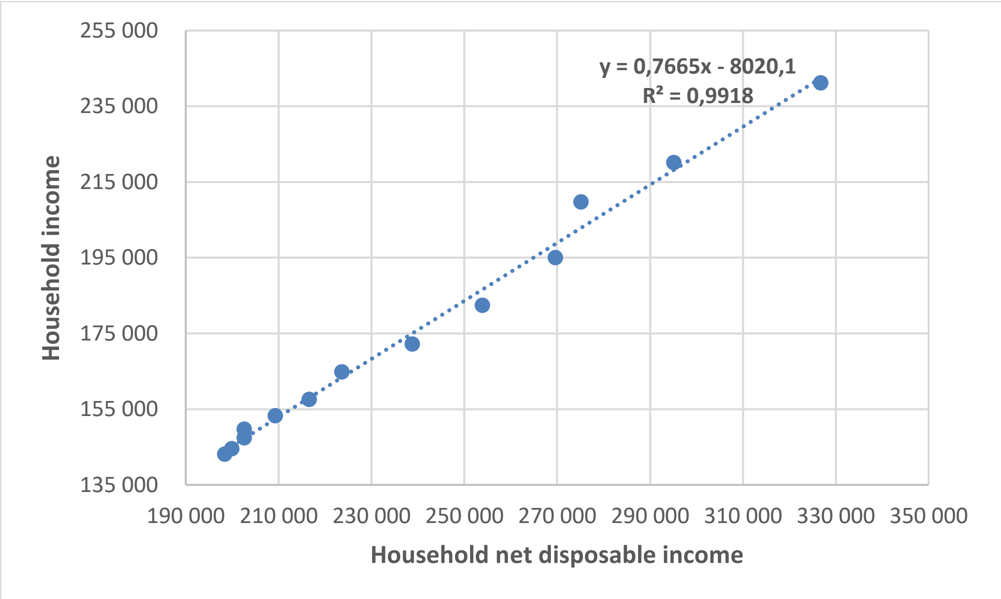
Graph 8: Relationship between the average monthly pay (individuals) and household income



Source: Authors.

The most significant relationship was found between household net disposable income and household income. Net disposable income represents the resources available to households after deducting taxes and social contributions. The analysis results confirm that rising household net disposable income directly increases household income, which is logical as this factor reflects the real disposable resources of households (see Graph 9).

Graph 9: Relationship between household net disposable income and household income



Source: Authors.

It was concluded from the regression analysis and graphical illustration that household income growth is affected by several key macroeconomic factors, with varying degrees of significance and influence. Household net disposable income (HNDI) proved to be the most significant factor, showing a strong linear relationship with household income. This result is logical as NDHI represents the resources available to households after deducting tax and insurance liabilities. The high R^2 value and visual analysis of the graph confirm that this factor most precisely predicts income growth and provides a stable basis for assessing the financial situation of households.

A similar significant effect was observed for average monthly pay of individuals, which is another key indicator of income growth. This factor directly reflects the payroll policy trend and labour market situation. Higher average pay supports the households' financial stability and increases their purchasing power, which can further stimulate the economy through higher consumer demand.

GDP which is often considered the main indicator of economic growth also showed a significant positive relationship with household incomes. The analysis results confirm that GDP growth increases economic activity, consequently resulting in growth of employment, production and income. For this reason, GDP can be used as a general indicator of long-term household income growth.

Household expenditure has also proven to be an important factor affecting household income. The graphical illustration and analysis results showed a strong correlation between higher expenditure and rising incomes. This phenomenon can be interpreted as a result of higher consumer confidence and rising economic activity, supporting income growth through increased demand and production.

On the other hand, inflation has showed a slightly positive relationship with household income, but with a lower level of statistical significance. This may be due to the fact that inflation mainly affects nominal incomes, while real incomes may be devalued by the rise in prices. Nevertheless, the results suggest that moderate inflation may be associated with payroll adjustments and subsequent income growth.

On the other hand, the unemployment rate has proven to be a negative factor affecting household incomes. The results of regression analysis and graphical processing show that household income decreases as unemployment increases, which reflects the theoretical assumptions. Higher unemployment rates limit the availability of jobs and reduce aggregate household incomes.

Discussion

In this chapter, the results from the previous chapters will be analysed and discussed with respect to the research questions. Furthermore, the results will be compared with the existing knowledge and insights that have been presented in the literature review as well as any limitations of the research that was conducted will be identified.

How does the strength of the relationship between GDP growth and household income change in different phases of the business cycle (growth, recession) in the Czech Republic in the period 2010-2022?

The analysis of the results confirmed that the relationship between GDP growth and household income varies significantly depending on the business cycle. In periods of GDP growth such as 2013-2018, household incomes were positively affected, which was especially evident in the steady growth of real incomes and the strengthening of household purchasing power. This phenomenon can be attributed to the economic expansion, resulting in employment growth and increasing household disposable incomes.

In contrast, during periods of recession such as 2020 when GDP fell by 1.71%, household incomes were relatively stable, indicating the effect of government interventions and social programmes for maintaining household living standards. This finding is in line with the argument of Hronov et al. (2022), who emphasize the stabilizing role of domestic consumption during crisis periods. The use of the ARIMA model allowed to identify long-term trends and eliminate short-term fluctuations, providing a more comprehensive view of this relationship dynamics.

Furthermore, the analysis showed that the strength of the relationship between GDP and household income changes during recessions. The GDP effect on incomes is weakening while other factors such as government support and transfers are becoming more important. These results are consistent with the assumptions of Bilkov (2023), who emphasizes a delayed response of the labour market to economic crises.

These findings suggest that GDP plays a key role during periods of growth while other instruments stabilizing household incomes are more important during recessions. This knowledge is crucial for making policies, which should not only reflect growth phases but also the needs of households during economic downturns.

What impact do specific factors such as unemployment and inflation have on household income growth in the context of GDP growth in the Czech Republic between 2010 and 2022?

Regression analysis revealed that the selected macroeconomic factors have different degrees of influence on household income. The most significant factor was household net disposable income (HNDI), which showed a strong positive dependence on household income. This relationship can be supported by the fact that HNDI means the real resources that households can use for consumption or investment. This finding is consistent with the results of Subov et al. (2024), who points out the key role of HNDI in predicting household economic behaviour.

The unemployment rate had an adverse effect on household incomes, which is consistent with economic theory. Higher unemployment rates reduce the availability of jobs and aggregate income, which was especially evident in a crisis period. This relationship is supported by the conclusions of Chytilova and Frejlich (2020), who highlight the importance of a stable labour market for ensuring household financial stability.

Inflation only had a slightly positive effect on household incomes, which may be due to payroll adjustments in response to the rise in prices. This result underlines that payroll policy is important to protect real household incomes from the impacts of inflation. However, the long-term effects of inflation can be adverse if wage growth does not keep pace with price increases.

The analysis also showed that household expenditure and the average monthly pay have a strong impact on household income. Higher spending indicates rising household confidence in economics, which supports consumption and income growth. The average monthly pay has proven to be a key indicator of economic stability as it supports households' purchasing power and their ability to cope with economic fluctuations.

This analysis was limited by the use of annual data, which cannot capture short-term fluctuations. Furthermore, some important factors such as the impact of foreign investment or regional differences were not considered, which creates the opportunity for future research. Nevertheless, the results provide important insights into the impacts of macroeconomic factors on household incomes in the Czech Republic.

Conclusion

The aim of this thesis was to analyse the relationship between GDP growth and household income in the Czech Republic in the period 2010-2022 and review the impact of selected macroeconomic factors on this relationship. Time series methods and regression analysis were used to achieve this goal.

The results showed that GDP growth had a strong and positive effect on household incomes, with this relationship being most pronounced during periods of economic growth. The use of the ARIMA model allowed to capture long-term trends and eliminate short-term fluctuations, which provided a more comprehensive view of the relationships being analysed. Moreover, the regression analysis revealed that household net disposable income (HNDI) and average monthly pay were the key determinants of household income growth. These factors helped to better understand the dynamics between economic growth and households' financial situation.

Economic factors such as inflation and unemployment affected household incomes more indirectly and their impact was less pronounced. Inflation had a slightly positive impact, which could be linked to payroll adjustments. On the other hand, unemployment was adversely related to household income, which is consistent with theoretical assumptions of lower aggregate demand during an economic crisis.

The thesis also showed that household income dynamics were sensitive to the phases of the business cycle. During periods of recession, stabilizing factors such as government intervention played a key role while during periods of growth, economic expansion was reflected in increased consumption and income growth. This finding is crucial for making policies aimed at promoting household economic stability.

The limitation of this thesis was that the analysis covered annual data that do not capture short-term fluctuations. Also, a broader set of macroeconomic factors such as the impact of foreign investment or regional differences was not included, which creates the opportunity for future research.

Based on the results of this thesis, it can be concluded that the objective of research was fulfilled. The thesis answers the research questions and provides an overview of the key factors affecting household incomes in the Czech Republic. The results underline the importance of GDP as a key indicator of economic growth and confirm GDP relevance for improving households' living standards. These findings can be used for practical making of economic policy aimed at ensuring the long-term financial stability of households.

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Pollution and its Fiscal Echo: Quantifying the Impact of Environmental Factors on Government Debt

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Abstract

In Mongolia, the postal and telecommunications sector is transitioning from a state service monopoly to a market characterized by perfect competition. Following the Covid-19 pandemic, there has been a surge in demand for delivery and dispatch services. Specifically, revenue within the postal industry witnessed a notable upswing, with increases of 26 percent in 2020, 39 percent in 2021, and 37 percent in 2022, respectively. This surge underscores a sharp rise in demand for parcel, shipping, and delivery services within the postal sector. Hence, within the postal sector of Mongolia, there exists a challenge to the expansion of e-commerce delivery services, the integration of novel electronic technologies, the enhancement of logistical service standards, and the systematic elevation of sectoral competitiveness. The primary objective of this research is to examine the factors influencing the competitiveness of companies within the postal sector by employing M. Porter's Diamond model. Additionally, the study aims to identify the pivotal success factors crucial for enhancing the competitiveness of the postal sector in Mongolia. In assessing competitiveness, the study employs the comprehensive methodology of the Diamond model, which encompasses resource factors, demand factors, company strategy, structure, and organization, as well as related and supporting industry factors. Through this framework, the competitiveness of Mongolia's postal industry is analyzed across seven dimensions, comprising a total of 119 indicators. These dimensions include government support, human resources, and opportunities, among others. Subsequently, the findings are disseminated to reveal the outcomes of the assessment. The results revealed that the opportunity factor is the major important factor, on the other hand, the government factor was the less important factor for boosting the competitiveness of the postal company.

Keywords: air pollution, PM10, government debt, public healthcare expenditures, correlation analysis.

Introduction

Pollution in the form of greenhouse gas emissions, chemical substances, or other contaminants is emerging as an increasingly pressing global issue, which has significant negative impacts on our planet. In recent years, this issue has become one of the most discussed topics at the global level, especially due to the growing awareness of the detrimental impacts on both public health and economic stability.

Deteriorating air quality, for example higher concentration of particulate matter (PM2.5) and nitrogen oxide (NOx) emissions, leads to increased morbidity and mortality rates. This results in higher healthcare expenditures and reduced labour productivity, thereby undermining the fiscal stability of countries (Gao et al., 2021). Moreover, these costs associated with air pollution may exacerbate public debt, as governments are often required to finance mitigation efforts and address pollution-related health issues (Han et al., 2023). The expenditures include e.g. the treatment of respiratory and cardiovascular diseases, which are directly attributable to the exposure of pollutants (Wang et al., 2022). Empirical studies show that rising pollutant concentration can elevate public spending by several percentage points per year, contributing to a growth in public debt (Fareed et al., 2022).

Governments are increasingly compelled to allocate substantial funds to environmental measures, which often contributes to the escalation of public debt, especially in countries under pressure to meet the emission goals of the European Union. The EU has outlined ambitious objectives, including the transition to a carbon-neutral economy by 2050, which necessitates large-scale investments in renewable energy resources and infrastructure modernization (European Environment Agency, 2022). The primary goal of these investments is to reduce air pollution and improve citizens´ quality of lifel (Irfan et al., 2021). However, this financial burden can further strain public finances, especially when they are not effectively managed and if these projects are debt-financed by the state (Kickhöfer et al., 2018).

Elevated levels of sovereign debt increase economic vulnerability to external shocks and crises, which limits the effectiveness of both fiscal and monetary policy. Governments borrowing in order to fund green investments may often face the risk that in times of economic downturn or unforeseen crisis, they will have to raise taxes or cut spending in other areas to meet debt servicing obligations (Ogbeifun & Shobande, 2020).

Like other EU member states, the Czech Republic has been investing annually in projects aimed at reducing dependence on fossil fuels and promoting renewable energy sources. However, these measures represent a significant financial burden, which may have long-term implications for the country´s economic stability.

The issue of environmental pollution began to gain prominence when people started to intensively use natural resources for personal and industrial needs, often without regard for the consequences on ecosystems (Pattanaik, 2024). This leads to significant degradation of the natural environment and poses a serios threat to the quality of life on our planet.

Environmental pollution encompasses the presence of harmful substances in air, water, and soil, primarily resulting from human activities such as industrial production, transportation, agriculture, or improper waste management (Atavullayeva, 2024; Fowler et al., 2020). These activities contribute not only to biodiversity loss but also lead to the emergence of new health issues within human population. According to Omer (2024), developing countries are particularly vulnerable to these impacts, as weak regulatory frameworks and rapid industrialization often result in uncontrolled release of pollutants in the environment. Dibley et al. (2021) also point to the fact that wealthier states frequently externalize their environmental burdens by shifting them to poorer countries, thereby exacerbating global environmental inequalities.

Air pollution represents a serious contemporary environmental problem. It involves the presence of harmful substances in the atmosphere, including particulate matter (PM2.5, PM10), nitrogen oxides (NOx), sulphur dioxide (SO_2), and ozone (O3), which are primarily generated through the combustion of fossil fuels, industrial activities, transportation, and other anthropogenic sources (Atavullayeva 2024; Bahrami et al., 2024).

For instance, a study by Sakib et al. (2023), employing time series analysis with ARIMA and SARIMAX models, identified seasonal trends and long-term trends in PM10 and PM2.5 concentrations in the capital of Bangladesh. The results revealed a significant decline in air quality during periods of elevated industrial and transport-related emissions. Similarly, Istiana et al. (2023) examined the relationship between PM2.5, other air pollutants (PM10, CO, NO2), and meteorological factors in Jakarta. Pearson correlation coefficient revealed the existence of linear relationship, while the application of the Convergent Cross Mapping (CCM) identified stronger non-linear causal relationships, particularly during the period December-February and March-May, with PM10 ($\rho = 0.74$) and wind speed ($\rho = 0.52$), exerting the strongest influence on PM2.5 levels. Similarly, Liang et al. (2021) analysed the impact of meteorological conditions on air quality in Beijing using Pearson correlation. Their findings showed that PM2.5 levels were negatively correlated with the temperature and wind speed but positively correlated with relative humidity. These studies underscore the significant role of seasonal dynamics, meteorological variables, and the complexity of interactions affecting air pollution levels. Li et al. (2021) found that public interest in air pollution measured using the Baidu Index, correlates with the concentrations of PM2.5, particularly during smog-heavy winter months. The study highlighted that while the public is highly responsive to current pollution levels, there is comparatively lower awareness or interest in long-term prevention strategies. However, since Pearson correlation assumes both linearity and normally distributed data, these assumptions must be tested using Shapiro-Wilk test prior to application. The test was used e.g. by Papadaki et al. (2023), who examined water pollution and found that most water quality indicators, such as dissolved oxygen (DO), total nitrogen (TN), and E. coli concentrations, did not follow a normal distribution ($p < 0.05$).

One of the most significant consequences of air pollution is the rise in healthcare expenditures. Prolonged exposure to elevated concentrations ofPM2.5 and PM10 is associated with chronic respiratory and cardiovascular diseases, which require substantial and ongoing medical treatment (Bahrami et al., 2024; Zhang et al., 2022). Globally, air pollution ranks as the fourth leading risk factor for mortality among all health threats (Murray et al., 2020). In Europe, air pollution is responsible for up to 790,000 premature deaths annually, with 40% to 80% of these deaths attributed to cardiovascular diseases (Lelieveld et al., 2019). A study conducted by Xia et al. (2022), employing Spearman correlation analysis alongside the GeoDetector method, examined the impact of air pollution on public healthcare expenditures in China. The results revealed that a 1 $\mu g/m^3$ increase inPM2.5 o 1 $\mu g/m^3$ concentration can lead to a rise in healthcare spending of up to 2.94%.

Velásquez & Lara (2020) employed Gaussian process regression to examine the relationship between air pollution (NO2, PM2.5) and the incidence of COVID-19 in Lima. Their findings indicated that pollution levels in industrial zones were significantly associated with higher infection rates, highlighting the influence of environmental actors on public health.

Jalaludin et al. (2021) applied basic statistical methods (mean, median, and standard deviation) to describe the level of air pollution during pregnancy, focusing on PM10, PM2.5 and O3 concentrations. These descriptive statistics provided an overview of pollutant exposure and serve as a foundation for a regression analysis assessing the impact of air pollution on prenatal health risks. However, the results of the study did not reveal a statistically significant association.

In the Czech Republic, air pollution is particularly severe in industrial regions, such as the Ostrava region. According to research by Volná et al. (2024), the primary sources of pollution include household emissions from burning solid fuels such as coal and emissions from industrial facilities, both of which contribute to increased morbidity and rising healthcare costs. Another major contributor is transport, with particularly older vehicles posing a significant problem. These factors collectively impact not only health but also economy. Although the CR remains one of the least indebted countries in the European Union, government debt has increased in recent years, particularly during the COVID-19 pandemic, which contributed to a rise in the structural deficit (Tomášková, 2023).

Research by Wang et al. (2022) also demonstrated that morbidity related to air pollution leads to a decline in labour productivity. Han et al. (2023) found that higher concentrations of particulate matter in the air are associated with an increase in local government debt. Their study revealed that a rise in PM2.5 concentration resulted in approximately a 3% increase in local government debt, primarily due to higher costs of healthcare and environmental measures. Similarly, Tan et al. (2021) showed that elevated levels of air pollution increase the cost of financing corporate debt. Specifically, they found that an increase in pollution intensity by one standard deviation led to a 16% rise in bond yield spreads. These findings were based on panel regression analyses that involved more than 200 enterprises in China.

Socioeconomic factors, such as GDP, the level of industrialization, and government policy, play an important role in the issue of air pollution and government debt. Xia et al. (2022) found that GDP, in combination with SO_2 emissions, contributes to increased healthcare expenditure, thereby putting pressure on public finances. According to Boly et al. (2022), a 1% increase in the public debt-to-GDP ratio leads to 0.74% increase in CO_2 emissions per capita, which highlights the conflict between fiscal and environmental goals. In a study by Bréon et al. (2017), the annual growth rate was used to analyse year-on-year changes in CO2 emissions. The results showed that GDP was one of the main drivers of emission growth, while annual meteorological factors (e.g., heating and cooling demand) had a smaller but notable effect, particularly in mid-latitude countries.

Within economic policy, environmental regulation and the allocation of public finances play a key role in combating pollution. Xie et al. (2023) found that local governments in China with high levels of debt often refrain from implementing stricter environmental regulations, leading to higher emissions from factories. Zhao et al. (2024) also state that rising local debt hampers the development of the green economy, distorts resource allocation, and limits investment in green technologies.

An effective solution to reduce air pollution is investment in green technologies. As stated by Li & Qiu (2024), the introduction of green innovations offers an effective way to address environmental issues by promoting economic growth while minimizing emissions and waste. Studies by Chen et al. (2022) and Han et al. (2023) also show that investment in industrial modernization can reduce greenhouse gas emissions, improve air quality, and contribute to long-term public finance stability. However, the implementation of such measures must be carefully managed to avoid a disproportionate increase in public debt (Nordhaus, 2017). Another effective solution is the investment in green technology. Further research using machine learning methods, such as artificial neural networks (ANN), was conducted by Chang & Tseng (2017), who accurately identified the impact of industrial and agricultural activities on PM2.5 levels. According to Halkos & Papageorgiou (2018), one of the key tools to mitigate the negative impacts of air pollution on public finances is the introduction of environmental tax reforms. For example, the introduction of a carbon tax in countries such as Sweden has shown that a tax increase by 1EUR per tonne of CO_2 can reduce annual emission per capita by up to 11.58 kg, while also supporting long-term fiscal stability (Hájek et al. 2019). Fodha et al.

(2018) also examined the impact of environmental tax reforms (ETR) on government debt levels. Using the overlapping generations (OLG) model, they found that revenues generated from such taxes can cover the higher healthcare costs of pollution-related diseases while helping to reduce public debt. Similar conclusions were made by Barrage (2020), who analysed optimal carbon tax in combination with fiscal policy. Using the COMET model and data from the International Monetary Fund, the study found that the optimal carbon tax could be up to 24% lower if other distortionary taxes are already in place.

The current goals of the Czech government include reducing the budget deficit and supporting eco-innovations that could improve air quality and reduce long-term healthcare costs. According to Hájek et al. (2019), introducing a higher carbon tax in the CR could help lower CO_2 emissions and encourage investment in renewable energy sources.

Nevertheless, quality research requires accurate and relevant data. Content analysis, both inductive and deductive, is particularly useful due to its effectiveness in secondary data processing (Kibiswa, 2019). Secondary data provide a comprehensive view of the issue; however, their reliability depends on the quality of the original resources. Their main advantages are availability and time efficiency compared to primary data collection (Renbarger et al., 2019), which makes them particularly suitable for this purpose. As stated by Kleinheksel et al. (2020), such data enable the identification of key patterns and relationships, thus improving planning and decision—making. Despite this, the data can be limited by inaccuracy.

For the purposes of this paper, secondary data will be used and processed through content analysis in order to identify relevant information related to air pollution and public healthcare expenditures in the Czech Republic. Time series, along with linear regression and basic descriptive statistics such as mean, median, and standard deviation, will provide a general overview of the data. The year-on-year growth rate will also be used to gain insight into the dynamics of key indicators. To analyse the relationships between variables and verify data normality, the Shapiro-Wilk test will be applied. Pearson correlation will be used for normally distributed data, while Spearman correlation will be applied in the case of non-linear relationships. Based on the results, the formulated research questions will be gradually addressed.

The objective of the paper is to assess the impact of air pollution and investments in its mitigation on the public finances of the Czech Republic during the period 2012–2022. The analysis focuses on pollution trends, developments in healthcare expenditures, and the impact of government investment on fiscal stability.

Based on this objective, the following research questions are formulated:

The first question will analyse the overall trends of air pollution in the CR in the period from 2012 to 2022. These data will be further used for the third research question.

- RQ1: What were the trends in air pollution (PM10) in the Czech Republic during the period 2012–2022?

The second question aims to analyse the overall development of public healthcare spending in the CR over the monitored period. The data will also be used for the third research question.

- RQ2: How did public healthcare expenditures evolve in the Czech Republic during the period 2012–2022?

By answering this question, it will be determined whether there is a relationship between the level of pollution (PM10) and public spending on healthcare, or how the increase in pollution affects spending in this sector.

- RQ3: Is there a relationship between air pollution levels (PM10) and public healthcare expenditures in the Czech Republic during the period 2012–2022?

The aim of the following question is to explore how PM10 pollution affects the development of government debt in the period 2012–2022. The obtained data will be used for a deeper understanding of the economic implications of environmental challenges on public finances and informing policy aimed at mitigating these negative effects.

- RQ4: What is the impact of PM10 air pollution on the public debt of the Czech Republic during the period 2012–2022?

Methods and Data

For all formulated research questions, content analysis will be used, which will enable an in-depth analysis of the secondary data.

Research question RQ1

To answer the first research question (RQ1), data on air pollution in the CR obtained from the Czech Hydrometeorological Institute (ČHMÚ, 2023) will be analysed, specifically, average annual concentrations of PM10 for the period from 2012 to 2022. The data will be examined using time series analysis, basic descriptive statistics, and the year-on-year growth rate.

First, a time series analysis will be conducted to identify the long-term development of pollution levels. The data will be visualized in the form of a line graph, with individual years displayed on the X-axis and the average annual PM10 concentrations (μg/m^3) on the Y-axis. This graph will provide a general overview of whether the PM10 concentration levels in the CR showed an increase, decrease, or remained stable.

For a more detailed analysis, linear regression will be applied, modelled according to the following equation (Zvára, 2019):

$$PM_{10}(t) = \beta_0 + \beta_1 t + \epsilon_t \tag{1}$$

where:
β_0 – is the constant indicating the initial level of pollution at the beginning of the monitored period [µg/m^3]
β_1 – the trend coefficient indicating whether pollution increases or decreases over time [µg/m^3 per year]
ϵ_t – random error accounting for unpredictable deviations [µg/m^3]
t – time variable [year]

The coefficient β_1 indicates how the level of pollution changes over time. If $\beta_1 > 0$, it suggests that pollution is increasing each year, which reflects a deterioration in air quality. Conversely, if $\beta_1 < 0$, pollution levels are decreasing, indicating an improvement in air quality. A time series graph created in MS Excel will be used to visualize these trends.
In the next stage, a basic statistical analysis of the data will be conducted in order to provide a more accurate description of their characteristics. First, the average value of PM10 concentrations for the entire observed period will be calculated using the following formula (Hindls, 2018):

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} \tag{2}$$

where:
n – number of years
X_i – average PM_{10} concentration in individual years.
¨Subsequently, the variance (σ^2) will be calculated to determine the extent to which annual values deviate from the mean. The following formula will be applied:

$$\sigma^2 = \frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n} \tag{3}$$

Standard deviation (σ) will be calculated as a square root of the variance:

$$\sigma = \sqrt{\sigma^2} \tag{4}$$

The standard deviation reflects the average deviation of annual values from the mean, providing an indication of the stability of PM_{10} concentration values over time. Finally, the minimum and maximum values of PM_{10} values will be identified to determine the range of fluctuations throughout the monitoring period.

Following the descriptive analysis, the year-on-year growth rate will be calculated using the formula below (Majaski, C., 2024):

$$Growth = \left(\frac{Value_t - Value_{t-1}}{Value_{t-1}}\right) \times 100 \tag{5}$$

where:
$Value_t$ – concentration of air pollution (PM_{10}) in the current year [µg/m^3]
$Value_{t-1}$ – concentration of air pollution (PM_{10}) in the preceding year [µg/m^3]
$Growth$ – percentage change in pollution concentration between two consecutive years [%]

The results of the year-on-year growth rate will be visualised using a bar graph, with the individual years displayed on the X-axis and percentage change in the Y-axis.

If the result is positive, i.e., $Growth > 0$, it indicates that the pollution concentration increased compared to the preceding year. A negative result, i.e., $Growth > 0$, suggests a decrease in pollution levels. If the result is zero, the concentration remained unchanged year-on-year. The results will be visualised using a bar graph in MS Excel. With individual years shown on the X-axis and the percentage change in concentrations displayed on the Y-axis.

This research question will further contribute to addressing the third and fourth research questions (RQ3 and RQ4).

Research question RQ2

To address the second research question (RQ2), which focuses on monitoring the year-on-year trend of healthcare expenditures in the CR in the period from 2012 to 2022, data obtained from the Czech Statistical Office will be analysed (CSO, 2023). The data will be processed using content analysis, which allows for the systematic evaluation of available secondary information.

The analytical approach will mirror the methods applied in response to RQ1. Initially, a time series analysis will be conducted to identify long-term trends in public healthcare expenditures. The data will be visualised using a line graph, where individual years will be displayed on the X-axis and annual healthcare expenditures (in billions of CZK) represented on the Y-axis.

Next, a linear regression model will be used in the same form as in RQ1.

As in the case of RQ1, basic statistical analysis will be conducted, including the calculation of the mean annual expenditures, variance, and standard deviation, as well as identification of minimum and maximum expenditures during the monitored period.

To compare the year-on-year changes, the annual growth rate will be applied to determine the percentage change in expenditures between two consecutive years. The calculation will be carried out in the same way as in RQ1. All results will be presented using MS Excel. The second research question will serve as the basis for addressing the third research question (RQ3).

Research question RQ3

The third research question will be addressed through correlation analysis, using the data obtained in RQ1 and RQ2, i.e., the data on annual mean concentrations of PM10 and annual public healthcare expenditures in CR for the period 2012–2022 (ČHMÚ, 2023; CSO, 2023).

First, Shapiro-Wilk test will be performed to verify data normality (Hanusz et al. 2016):

$$W = \frac{(\sum_{i=1}^{n} a_i x_{(i)})^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{6}$$

where:
$x_{(i)}$ – *data values arranged in ascending order (from the smallest to the larges)*
x_i – *initial values*
$\bar{x}$ – *arithmetic mean of the data set*

n – number of observations
a_i – weighting coefficients derived from the expected values of ordered samples from a normal distribution

To assess the statistical significance of the observed relationship, the null hypothesis regarding the distribution of annual mean concentrations of PM_{10} for the period 2012 – 2022 will be tested as follows:

H0: The data on annual mean concentrations of PM_{10} for the period 2012 - 2022 are drawn from a normal distribution.

H1: The data on annual mean concentrations of PM_{10} for the period 2012 - 2022 are not drawn from a normal distribution.

To assess the statistical significance of the relationship, the null hypothesis regarding public healthcare funding will be tested as follows:

H0: The data on healthcare funded by public budgets for the period 2012–2022 are drawn from a normal distribution.

H1: The data on healthcare funded by public budgets for the period 2012–2022 are not drawn from a normal distribution.

The level of statistical significance p was determined at 5% for both samples.

If both datasets follow a normal distribution, Pearson correlation will be employed to quantify the linear relationship between the concentrations of PM_{10} and public healthcare expenditures. If the assumption of data normality is not met for one or both datasets, Spearman correlation will be utilized, as it more effectively captures potential non-linear relationships.

Pearson correlation coefficient will be calculated as follows (Okoye, 2024):

$$r = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2}\sqrt{\sum_i (y_i - \bar{y})^2}} \tag{7}$$

where:
x_i –PM_{10} pollution concentration in a given year [μg/m^3]
y_i – healthcare expenditures in a given year [billion CZK]
$\bar{x}$ – mean PM_{10} pollution concentration for all years
$\bar{y}$ – mean healthcare expenditures for all years

The value of the Pearson correlation coefficient ranges from -1 to +1. Values approaching +1 indicate a strong positive linear relationship between the variables (e.g., an increase in pollution levels is associated with an increase in healthcare expenditures), whereas values approaching -1 suggest a strong negative correlation. A coefficient value of 0 indicates no linear relationship between the variables. The significance level (α) is set at 5% (Akoglu, 2018).

To verify the statistical significance of the relationship, the null hypothesis will be tested as follows:

H0: There is a linear relationship between air pollution concentrations (PM_{10}) and public healthcare expenditures in the selected decade.

H1: There is no linear relationship between air pollution concentrations (PM_{10}) and public healthcare expenditures in the selected decade.

Spearman correlation coefficient will be calculated as follows (Hendl, J., 2012):

$$\rho = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)} \tag{8}$$

where:
d_i – is the difference between the ranks of the PM_{10} concentration values (x) and the healthcare expenditure values (y) for each pair of observations
n – number of observations (number of pairs of values)

The value of the Spearman correlation coefficient ranges between -1 and +1. Values approaching +1 suggest a strong positive monotonic correlation, which means that as the value of one variable (e.g., PM_{10} concentration) increases, the value of the other variable (healthcare expenditures) increases as well. Conversely, values approaching -1 indicate a strong negative monotonic correlation, where an increase in one variable corresponds to a decrease in the other. A Spearman correlation coefficient of zero implies no monotonic relationship between the variables. The level of statistical significance (α) is set at 5% (0.05).

To verify the statistical significance of the relationship, the following null hypothesis will be tested:

H0: There is no monotonic relationship between air pollution concentrations (PM_{10}) and public healthcare expenditures in the selected decade.

H1: There is a monotonic relationship between air pollution concentrations (PM_{10}) and public healthcare expenditures in the selected decade.

If a statistically significant Pearson correlation is identified, linear regression will be performed as in the case of RQ1 and RQ2. All results will be presented in MS Excel charts.

Research question RQ4

To address the fourth research question, a content analysis of data on public healthcare expenditures (as identified in RQ2) and their relationship to the annual government debt levels of the Czech Republic for the period 2012–2022 will be conducted. The data on government debt will be obtained from the official statistics of the Ministry of Finance of the CR (MFČR, 2023). The analysis aims to determine whether higher healthcare expenditures contribute to the increase in government debt.

First, a time series analysis of government debt will be carried out, following the same procedure as applied in RQ1 and RQ2. The data will be visualized using a line graph, where the X-axis represents individual years, and the Y-axis displays the absolute value of government debt in billions of CZK. Linear regression will also be applied in accordance with the methodology used in RQ1 and RQ2

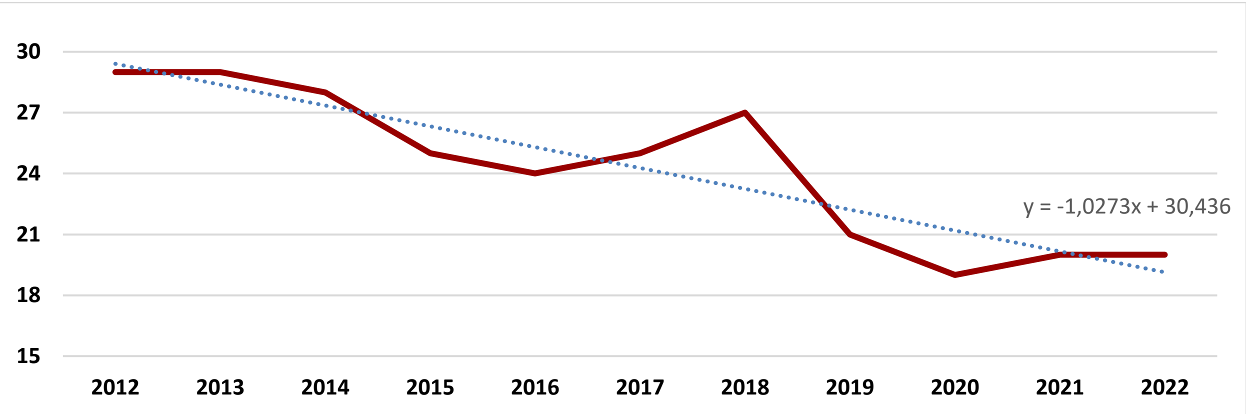
Subsequently, a descriptive analysis of government debt will be conducted, including the calculation of the mean, variance, and standard deviation, as previously done in RQ1 and RQ2. These descriptive statistics will help to better characterize the variability of debt over the observed period.

Following this, the Shapiro–Wilk test will be used to assess the normality of the data on public healthcare expenditures and government debt in the Czech Republic for the period 2012–2022. If the data meet the assumption of normality (p-value > 0.05), Pearson correlation will be used to determine the linear relationship between these variables. If the assumption of normality is not met (p-value ≤ 0.05), Spearman correlation will be employed, as it more accurately captures potential monotonic relationships. Based on the results of the correlation analysis, it will then be evaluated whether increased public healthcare expenditures potentially associated with air pollution may have contributed to the growth of government debt in the Czech Republic during the analysed period. The results will be presented in tables and charts generated using Microsoft Excel.

Results

Data on air pollution in the CR were collected on an annual basis for the period from 2012 to 2022. Information on PM_{10} concentrations was obtained from the Czech Hydrometeorological Institute (ČHMÚ, 2023).

Graph 6: Trend in yearly average concentrations of PM10 in the CR [μg/m3]



Source: Authors based on (ČHMÚ, 2023).

Graph 1 illustrates the annual trend in average concentrations of PM_{10} in the Czech Republic over the period 2012–2022. The data reveal a clear overall downward trend in air pollution, with average concentrations decreasing by approximately 1.03 μg/m^3 per year, as indicated by the linear regression equation. The highest concentrations were observed at the beginning of the monitored period (in 2012 and 2013), reaching 29 μg/m^3, while the lowest value (19 μg/m^3) could be seen in the years 2020 and 2021. This reduction may be partially attributed to exceptional measures implemented during the COVID-19 pandemic, which involved restrictions on transport, industrial production, and other activities affecting air quality. In the final years of the observed period (2021 and 202), the concentrations of PM_{10} stabilized at 20 μg/m^3.

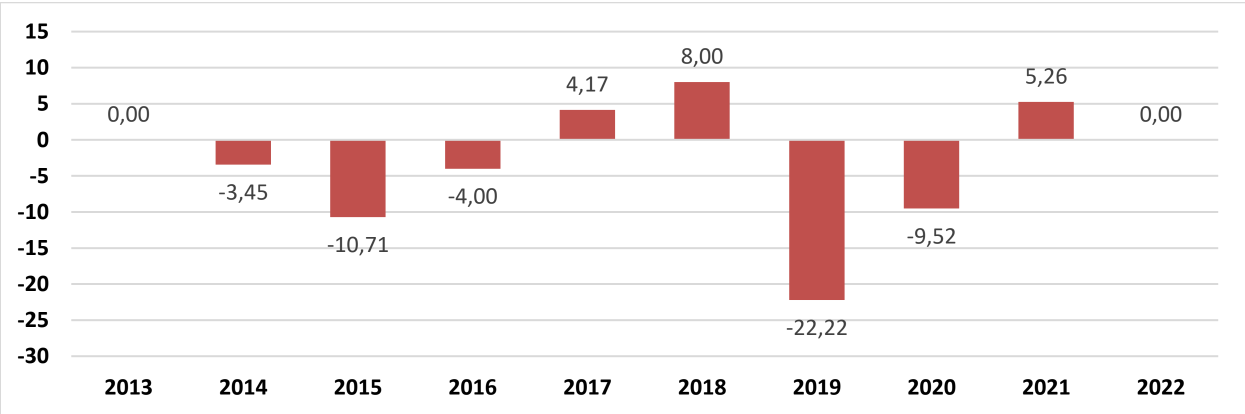
Tab. 1: Basic statistical analysis of PM10 concentrations in the CR (2012-2022)

Statistics	Value
Mean value ($\bar{X}$)	24.27 μg/m^3
Variance (σ^2)	12.93
Standard deviation (σ)	3.60 μg/m^3
Minimum value	19 μg/m^3
Maximum value	29 μg/m^3

Source: Authors based on (ČHMÚ, 2023).

Table 1 provides a basic statistical data analysis of PM10 concentrations in the Czech Republic for the period 2012–2022. The results indicate a mean value of 24.27 μg/m^3, with a variance of 12.93, and a standard deviation of 3.60 μg/m^3, suggesting relatively low variability in annual values. The lowest concentration (19 μg/m^3) was recorded in 2020 and 2021, while the highest value (29 μg/m^3) occurred in 2012 and 2013. These findings support the observed downward trend in air pollution levels in the CR.

Graph 7: Annual growth rate of PM10 concentrations (2012–2022)

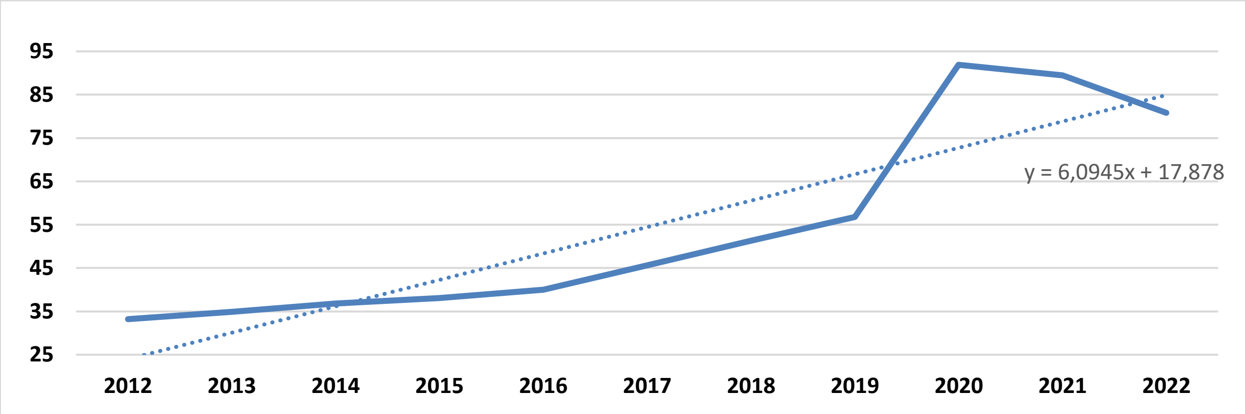


Source: Authors based on (ČHMÚ, 2023).

Graph 2 illustrates the annual percentage changes in PM10 concentrations in the Czech Republic. As the graph indicates, most of the year-on-year changes are negative, confirming the overall decline in PM10 levels over the observed period. The most significant decrease occurred between 2019 and 2020, when concentrations dropped by more than 22%, largely due to restrictions on emission-generating activities implemented during the COVID-19 pandemic. These findings are consistent with the results of previous analyses.

Data on public healthcare expenditures in the Czech Republic were also monitored on an annual basis during the period 2012–2022. This information was obtained from the Czech Statistical Office (ČSÚ, 2023).

Graph 8: Trend in public healthcare expenditures in CR [CZK billion]



Source: Authors based on (ČSÚ, 2023).

Graph 3 illustrates the annual public healthcare expenditures in the CR from 2012 to 2022. The data reveal a clear upward trend, with spending rising from CZK 33,2 billion in 2012 to CZK 80,8 billion in 2022. The most pronounced increase occurred between 2019 and 2020, likely reflecting additional costs related to the COVID-19 pandemic, including investments in healthcare infrastructure and preventive measures. Although a slight decline in expenditure followed after 2020, the overall level remained significantly higher than in the pre-pandemic years, suggesting a long-term policy shift towards increased investment in public healthcare. The linear regression depicted in the graph confirms this long-term upward trend in expenditure throughout the observed period.

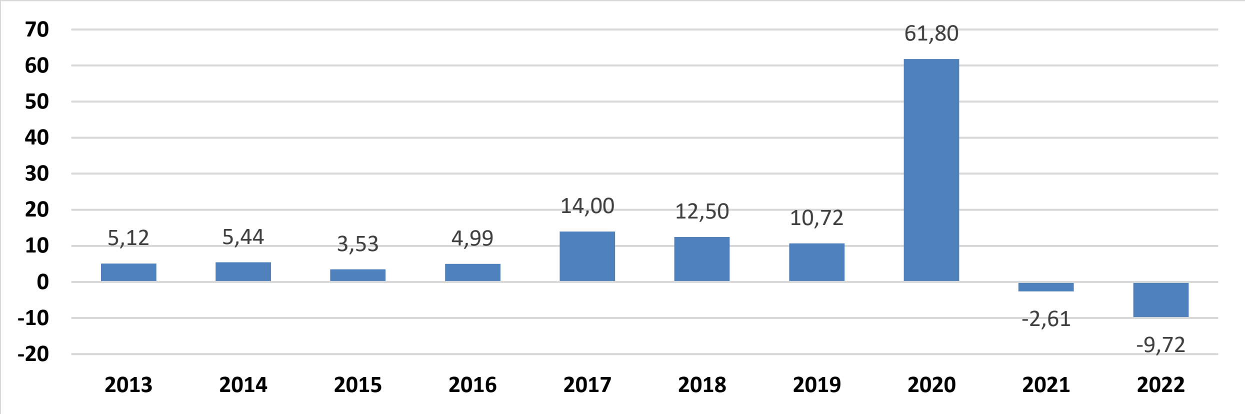
Tab. 2: Basic statistical analysis of public healthcare expenditures in the CR (2012–2022)

Statistics	Value
Mean value ($\bar{X}$)	CZK 54.45 billion
Variance (σ^2)	CZK 458.23 billion
Standard deviation (σ)	CZK 21.41 billion
Minimum value	CZK 33.20 billion
Maximum value	CZK 91.90 billion

Source: Authors based on (ČSÚ, 2023).

Table 2 provides a basic statistical analysis of public healthcare expenditure in the Czech Republic for the period 2012–2022. The results indicate that the average annual expenditure amounted to CZK 54.45 billion, reflecting substantial investment in the healthcare sector. The variance of CZK 458.23 billion^2 suggests a high degree of variability in annual spending, while the standard deviation of CZK 21.41 billion illustrates the average deviation from the mean. The lowest expenditure was recorded in 2012 (CZK 33.2 billion), whereas the highest occurred in 2020 (CZK 91.9 billion), likely due to the exceptional costs associated with the COVID-19 pandemic. These findings support the observed long-term increase in public healthcare investment in the Czech Republic.

Graph 9: Annual growth rate of public healthcare expenditures (2012-2022)



Source: Authors based on (ČSÚ, 2023).

Graph 4 illustrate the year-on-year changes in public healthcare expenditures in the CZ, expressed as percentages. The data show that until 2019, the annual growth in expenditures remained relatively stable, ranging from 3.53% to 14%, with the highest increase observed in 2017. A dramatic surge occurred in 2020, when expenditures rose by 61.80%, largely due to the extraordinary measures implemented during the COVID-19 pandemic. This period was followed by a decline in the growth rate. In 2021 and 2022, year-on-year expenditures decreased, with the most pronounced decrease by 9.72% being recorded in 2022. These findings confirm the exceptional impact of the pandemic on healthcare expenditure, followed by a return to more typical growth rate, although interrupted by short-term fluctuations.

Tab. 3: Results of Shapiro-Wilk test of data normality

Data	**Test statistics (W)**	**p-value**	**Data normality**
Average concentrations of PM_{10}	0.901470184	0.192638814	Yes
Public healthcare expenditures	0.822440207	0.018570257	No

Source: Authors based on (ČHMÚ, 2023; ČSÚ, 2023).

Table 3 presents the results of the Shapiro-Wilk normality test conducted on the data for average PM_{10} concentrations and public healthcare expenditures for the period 2012–2022. The test indicated that the PM_{10} concentration data follow a normal distribution, as evidenced by the test statistic $W = 0.9014$ and p-value of 0.193, which exceeds the 5% significance level ($p > 0.05$). Conversely, the data on public healthcare expenditures did not meet the assumption of normality, as shown by the test statistic $W = 0.0186$ and p-value 0.019 ($p < 0.05$).

In light of these results, the Spearman correlation analysis was selected for further investigation, as it is appropriate for data sets that do not meet the assumption of normality.

Tab. 4: Correlation of average PM10 concentrations and public healthcare expenditures

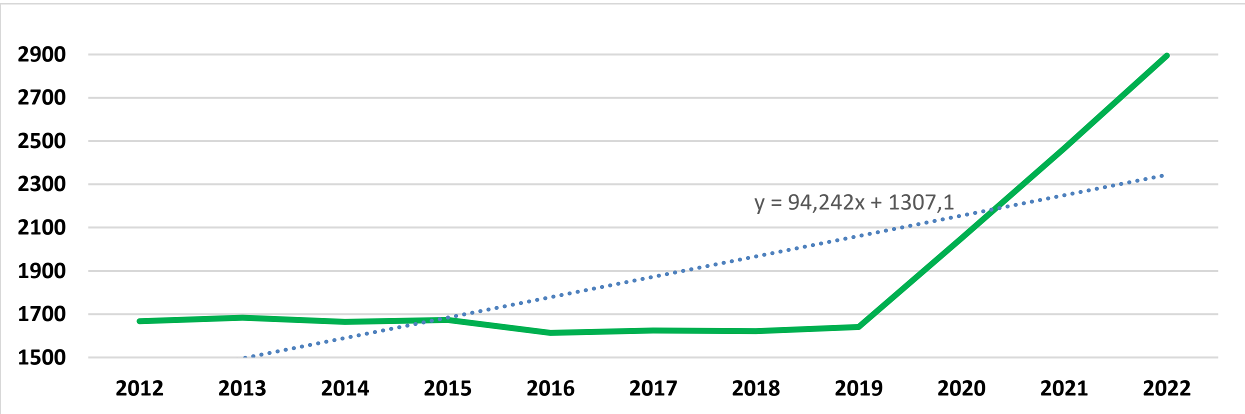
	Average concentrations of PM10	**Public healthcare expenditures**
Average concentrations of PM10	1	-0.91136364
Public healthcare expenditures	-0.91136364	1

Source: Authors based on (ČHMÚ, 2023; ČSÚ, 2023).

Table 4 presents the Spearman correlation coefficient, which was approximately -0.9114, indicating a strong negative monotonic relationship. This relationship suggests that as PM10 concentrations decreased, public healthcare expenditures tended to increase. The significance level was set at 5%, and the p-value obtained was considerably lower than this threshold, confirming the statistical significance of the relationship. Consequently, the null hypothesis H0, which assumed no monotonic relationship between the two variables, was rejected.

Additionally, data on government debt in the CR were monitored on an annual basis for the period 2012–2022. The data were obtained from the Ministry of Finance of the Czech Republic (MFČR, 2024).

Graph 10: Trend in government debt in the CR [CZK billion]



Source: Authors based on (MFČR, 2024).

Graph 5 illustrates the development of government debt in the Czech Republic between 2012 and 2022. The data reveal a substantial increase in government debt, rising from CZK 1667,6 billion in 2012 to CZK 2894,8 billion in 2022. The most significant increase occurred between 2019 and 2020, when the debt surged by over CZK 400 billion, followed by continued growth between 2020 and 2022. These increases can be largely attributed to extraordinary circumstances, particularly the economic consequences of the COVID-19 pandemic. The linear regression displayed in the graph confirms a long-term upward trend, with the average annual increase in government debt estimated at approximately

CZK 94,24 billion.

Tab. 5 Basic statistical analysis of government debt in the CR (2012–2022)

Statistics	Value
Mean value ($\bar{X}$)	CZK 1872.55 billion
Variance (σ^2)	CZK 183481.29
Standard deviation (σ)	CZK 428.35 billion
Minimum value	CZK 1613.4 billion
Maximum value	CZK 2894.8 billion

Source: Authors based on (MFČR, 2024).

Table 5 presents a basic statistical analysis of government debt in the Czech Republic for the period 2012–2022. The mean value of the government debt during this period was CZK 1872,55 billion, reflection the long-term level of indebtedness. The variance, amounting to CZK 183481,29, indicates considerable year-on-year fluctuations in debt levels. The standard deviation of CZK 428.35 billion further illustrates the average deviation from the mean. The lowest level of debt was recorded in 2016, at CZK 1,613.4 billion, while the highest value (CZK 2,894.8 billion) was reached in 2022. These findings confirm a rising trend in public debt, particularly in the latter years of the period, likely influenced by extraordinary events such as the COVID-19 pandemic.

Tab. 6: Shapiro-Wilk normality test

Data	Test statistics (W)	p-value	Data normality
Government debt	0.659685373	0.000142914	No
Mean concentrations of PM_{10}	0.901470184	0.192638814	Yes

Source: Authors based on (ČHMÚ, 2023; MFČR, 2024).

Table 6 presents the results of the Shapiro-Wilk normality test conducted on the data on government debt and PM10 air pollution in the CR for the period 2012–2022. The results indicate that the distribution of government debt data deviates significantly from normality, as confirmed by the test statistic W = 0.6597 and a p-value of 0.00014, which is well below the 5% significance threshold. In contrast, the data on average PM10 concentrations satisfy the assumption of normality, making them suitable for parametric statistical analyses.

Based on these results, Spearman's rank correlation analysis was selected for further examination, as it is appropriate for data that do not meet the assumption of normality.

Tab. 7: Correlation between PM10 concentrations and government debt in the CR

	Government debt	**Average concentrations of PM_{10}**
Government debt	1	-0.36136364
Average concentration of PM_{10}	-0.36136364	1

Source: Authors based on (ČHMÚ, 2023; MFČR, 2024).

Table 7 presents the resulting Spearman correlation coefficient, which reached approximately -0.3614, indicating a weak negative monotonic relationship between the two variables. This suggests that a decrease in PM_{10} concentrations may be accompanied by a slight increase in national debt; however, the relationship is not statistically significant. The significance level was set at 5%, and the obtained p-value of 0.26171 exceeds this threshold ($p > 0.05$). Therefore, the relationship between PM_{10} concentrations and national debt cannot be considered statistically significant.

Discussion

Based on the obtained findings, the formulated research questions can be answered:

RQ1: What were the trends in air pollution (PM_{10}) in the Czech Republic during the period 2012–2022?

The results of the analysis revealed a downward trend in PM_{10} concentrations in the CR in the selected period. This decline can largely be attributed to technological modernization, improvements in industrial processes, and the implementation of stricter environmental regulations, including adherence to European emission standards. These findings are consistent with the conclusions of Chen et al. (2022), who underscore the role of technological innovation and investments in environmental protection as key factors in improving air quality. However, the sustainability of this downward trend remains uncertain. As noted by Halkos & Papageorgiou (2018), systemic reforms, such as the introduction of environmental taxes, could be essential for achieving log-term reduction in pollution and mitigating its economic impacts.

An interesting and unexpected development during this period was the influence of the COVID-19 pandemic, which had a significant effect on air quality. A sharp drop in PM_{10} concentrations was observed in 2020, coinciding with the peak of pandemic-related restrictions. Reduced transportation and industrial activity during lockdowns highlighted the sensitivity of air pollution levels to changes in human behaviour and economic operations. A similar pattern was reported by Sakib et al. (2023), who documented a comparable decline in emissions in Bangladesh during the pandemic.

However, the data also show notable fluctuations in PM_{10} concentrations, particularly in 2017 and 2018. These fluctuations may be due to seasonal factors and climatic conditions. Liang et al. (2021) emphasize that factors such as humidity, temperature, and wind speed can have a significant influence on air quality. Such variability indicates that both short-term and long-term dynamics must be considered when designing environmental policies, in order to ensure their effectiveness under a range of conditions.

RQ2: How did public healthcare expenditures evolve in the Czech Republic during the period 2012–2022?

Public healthcare expenditures in the CR in the selected period showed a downward trend, with the sharp increase between 2019 and 2020, which can be attributed to the COVID-19 pandemic. Overall, this trend reflects substantial investment in medical supplies, healthcare infrastructure, and preventive measures. Notably, even after the acute phase of the pandemic subsided, expenditure levels remained above the pre-pandemic ones in 2019. This may suggest structural shifts within the Czech healthcare system.

Similar trends were observed in other studies. For example, Velásquez & Lara (2020), who deal with the impact of the COVID-19 pandemic on healthcare systems in Lima, described how the pandemic prompted a considerable strengthening of healthcare infrastructure and preventive measures. Xia et al. (2022) explored the relationship between air pollution (particularly $PM_{2.5}$) and rising healthcare costs. Their findings suggest that improvements in air quality could contribute to long-term reduction in public healthcare expenditure.

These insights underscore the importance of long-term strategies that extend beyond short-term crisis management to include prevention, preparedness, and sustainable financing of the healthcare system. The observed growth in healthcare expenditure may therefore reflect broader policy shifts, with public health increasingly viewed as a central pillar in political decision-making.

RQ3: Is there a relationship between air pollution levels (PM_{10}) and public healthcare expenditures in the Czech Republic during the period 2012–2022?

Spearman correlation analysis revealed a strong negative monotonic relationship between PM_{10} concentrations and healthcare expenditures, suggesting that the decrease in PM_{10} levels was associated with an increase in healthcare expenditures. This finding is initially surprising, as a reduction in healthcare costs could be expected with improved air quality.

One possible explanation is the "delayed effect" of air pollution, where health issues associated with long-term exposure to poor air quality persist even after environmental conditions improve. Bahrami et al. (2024) emphasize that chronic diseases, such as respiratory and cardiovascular diseases, incur long-term costs that may not immediately decrease, even with a reduction in pollution levels.

The increase in healthcare spending may also be attributed to structural changes within the healthcare system. Improved air quality could have enabled governments to reallocate resources toward modernizing healthcare infrastructure or supporting preventive programs, which would contribute to long-term improvements in public health. Nevertheless, these findings align with the conclusions of Xia et al. (2022), who highlight the enduring health impacts of pollution that can persist even after air quality improves.

However, the COVID-19 pandemic likely played a crucial role, as the surge in healthcare spending during 2020 and 2021 may have contributed to the apparent negative correlation with declining PM_{10} levels. Velásquez & Lara (2020) suggest that the combination of reduced air pollution and increased healthcare expenditure during the pandemic could have distorted the perceived relationship between these variables. Paradoxically, while air quality improved during the lockdown, potentially lowering healthcare costs, the pandemic itself led to increased healthcare costs related to COVID-19 treatment and enhanced preventive measures.

This result underscores the complexity of the relationship between air quality and public healthcare spending. While lower PM_{10} concentrations may ultimately reduce healthcare costs in the long run, it should be considered that healthcare systems respond not only to current challenges but also to cumulative impacts from the past and broader societal changes.

RQ4: What is the impact of PM_{10} air pollution on the public debt of the Czech Republic during the period 2012–2022?

In the Czech Republic, government debt exhibited an upward trend over the analysed period, rising from CZK 1667,6 billion in 2012 to CZK 2894,8 billion in 2022. However, the Spearman correlation between PM_{10} concentrations and government debt indicated a weak negative monotonic relationship, which was statistically insignificant. These results suggest that, within the Czech context, the primary drivers of public debt were macroeconomic factors—such as pandemic-related healthcare expenditures, social support measures, and other crisis-related interventions—rather than the direct environmental impacts of air pollution.

Although the analysis did not show a statistically significant direct relationship between air pollution and government debt, studies such as Boly et al. (2022) point to possible indirect links. Their findings highlight that rising public debt may hinder the financing of environmental policies, while insufficient investment in environmental protection can, over time, lead to higher emissions and increased healthcare costs. Conversely, Han et al. (2023) argue that although investments in green technologies may raise public debt in the short term, they can deliver long-term economic and health benefit.

These insights underscore the complexity of the interplay between environmental and economic factors. While the impact of air pollution on government debt appears weak, indirect effects should not be disregarded. It is therefore essential that environmental policies be crafted in a manner that simultaneously promotes sustainable development and maintains fiscal responsibility.

Conclusion

The objective of this paper was to assess the impact of air pollution and investment in its mitigation on public expenditures in the Czech Republic in the period 2012–2022, with a focus on analysing air pollution trend, development of public healthcare expenditures, and the impact of government investment on financial stability. The set objective was achieved.

The analysis revealed that PM_{10} concentrations generally followed a decreasing trend over the observed period. At the beginning of the period, concentrations reached 29 μg/m^3, while by the end they had stabilized at 20 μg/m^3. The most significant decline occurred during the COVID-19 pandemic, likely due to restrictions on emissions from transport and industrial activities. Overall, the findings confirm an improvement in air quality during the decade, with the most notable progress occurring after 2019.

In contrast, public healthcare expenditures in the Czech Republic demonstrated a steadily increasing trend. Starting at CZK 33.2 billion at the beginning of the observed period, they peaked at CZK 91.9 billion in 2020. Although a slight decline followed, expenditures remained above pre-pandemic levels.

Correlation analysis revealed a strong negative monotonic relationship between PM_{10} concentrations and public healthcare expenditures over the selected decade. Spearman's correlation coefficient indicated that as air pollution decreased, health-related public spending increased. This relationship underscores the complex and possibly delayed impact of air quality on healthcare costs.

Government debt showed an upward trend in the observed period, rising from CZK 1667,6 billion in 2012 to CZK 2894,8 billion in 2022. The relationship between PM_{10} concentrations and the government debt was weaker. Spearman correlation coefficient showed a mild negative monotonic relationship, which was not statistically significant. These findings suggest that the impact of air pollution on government debt is rather indirect and may be influenced by other factors, such as economic shocks, pandemics, and structural changes in fiscal policy.

The main limitation of this study was the relatively short observation period and the restriction of available data to average annual values. Another limitation is the absence of direct measurements of health consequences of air pollution and their impact on individual components of government debt.

Further research could include analysis of extended period and incorporating data with greater temporal resolution. Moreover, it would be recommendable to consider regional differences in air quality, public healthcare expenditures, and government debt.

The results of this paper may support the development of policies aimed at improving air quality, enhancing the efficiency of healthcare spending, and promoting the long-term stability of publicfinances.

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The price dynamics of selected herbal and animal raw materials

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Abstract

The Federal Republic of Germany is one of the leading producers of milk and milk products as basic elements of the human diet within the European Union. Knowledge of the market prices of milk and milk products and the factors influencing them is important for a number of market operators not only in the Federal Republic of Germany, but also worldwide, when making everyday and major decisions. The aim of this work was to define the development of market prices of selected commodities, namely milk, butter, Gouda cheese, whey, and skimmed milk powder, in the Federal Republic of Germany for the years 2019-2023 and to specify the price correlation between milk and other selected commodities. By analyzing the time evolution using descriptive statistics tools, the development of the market prices of selected commodities was defined, which varied for individual commodities during the period under review. The most stable development was observed for milk market prices, while the most uneven development was identified for butter market prices. The coronavirus pandemic, the war in Ukraine and the high inflation rate had a significant impact on the evolution of prices of selected commodities, with commodity prices rising from their low in 2020 to their high in 2022, but even so, there was no major deviation of prices of selected commodities from their average. The price correlation between milk and other selected commodities was specified using Pearson correlation coefficient and regression analysis. A positive linear relationship was found between market prices of milk and market prices of all other selected commodities. In particular, a very strong linear relationship was registered for the prices of the commodities milk and butter as well as milk and Gouda cheese. During the period under review, the market prices of the selected commodities in the Federal

Republic of Germany were influenced by the price of milk 89 % for butter, 81 % for Gouda cheese, 28 % for whey and 49 % for skimmed milk powder. Thus, in addition to the price of milk, other factors influenced the price of other dairy products, including the size of processors' costs, the volume of production in the period, world market conditions and others.

Keywords: Dairy industry, Federal Republic of Germany, time evolution, price relation, linear regression

Introduction

Milk and dairy products may be included in staple foods consumed by households in Slovakia, as well as in the V4 countries. The inevitability of milk consumption is proven by its positive health effects, above all the prevention of osteoporosis. Currently, the lifestyle of consumers is emphasised, and constant changes positively affect the growing consumption of dairy products. In connection with the situation resulting from the COVID-19 pandemic, consuming milk has been vital as it turned out to have a positive impact on consumers' immunity, which is strengthened by it. The positive effects of milk and dairy products are becoming a precondition for their regular consumption (Kubicová et al., 2021). Headey et al. (2024) also add that dairy products have an extraordinarily rich nutritional profile and have long been promoted to mitigate child malnutrition in high-income countries. Dairy products have a number of nutritional and physical qualities, which make them almost ideal supplemental food for infants, however, they are also nutritionally beneficial even for older children and adults, if they tolerate a certain quantity of lactose.

Milk is one of the most produced, consumed, and protected agricultural commodities in the world (Zolin et al., 2021). The European Union is a huge producer of milk and dairy products. It is also a significant market for their consumption, which is characterised by effective demand and significantly influences the markets of other food products (Klapkiv et al., 2023). In 2022, the EU dairy production reached rounded 160.8 million tonnes, and 10.6 million tonnes of cheese, 2.3 million tonnes of butter and other dairy fats, 55.2 tonnes of whey, and 2.9 million tonnes of skimmed milk powder were produced (Eurostat, 2024). The main producers of milk in the EU are Germany, France, Poland, Italy, and Spain (Klapkiv et al., 2023). The dairy industry is sensitive to seasonal variable factors, such as temperature, cold climatic conditions, and rainfall. They influence the productive and reproductive qualities of dairy animals. Seasonal variability also significantly impacts the quantity of milk consumption and launching milk into the market (Mari et al., 2021).

The conditions of the dairy market both in Czechia and the EU are unstable, especially due to the volatility of milk prices, and they increase pressure on dairy farmers to maximise production with the lowest possible production costs (Syruček et al., 2022). The prices of raw milk are important for the competitiveness of the dairy market and impact the prices of other dairy products and the export (Bórawski et al., 2021). Companies, from small producers to market leaders, are further investing in differentiating their product series and their production choices are being increasingly oriented to specialities related to sustainability and health benefits. Not only is this trend meeting the needs of consumers, who are increasingly caring for sustainable and healthy food, however, it also has an important impact on the production and profitability of dairy companies (Merlino et al., 2022).

The price volatility of agricultural products is a critical problem for countries with a large agricultural sector. Price changes destabilise the economic market and influence the managerial decisions of producers, mediators, and consumers. The fluctuation of prices is a consequence of factors such as weather, inflation, changes in supply and demand, consumer income, and governmental policy. Prices are also determined by the taste and preferences of consumers. Income prices are significant for market participants in the course of the determination of prices and the assessment of the effectiveness of various types of economic activity. Price research provides detailed and topical information for producers, consumers, and managers. Market institutions can adopt decisions, and scientific institutions can assess the effectiveness of market mechanisms and regulatory instruments on this basis (Rembeza & Seremak-Bulge 2010; Borawski et al., 2020).

This chapter will present other authors' current knowledge, with the help of which data sources and research methods leading to answering the RQ and fulfilling the aim of the work will be sought and considered.

A number of researchers refer to secondary data obtained from various databases to examine the milk market. Roman & Kroupová (2022) obtained information about the monthly prices of fresh milk, butter, Eidam cheese, and dried skimmed milk in the entire country from the CLAL (Italian dairy economic advisory) webpages and from the FAO (Food and Agriculture Organisation of the United Nations). The FAO database, in accordance with Klapkiv et al. (2023), provides appropriate figures for production, consumption, commerce, and prices; the advantage of the Eurostat database is its wide coverage and single data methodology. Syruček et al. (2022) used an available database of the European Commission to determine the average sale prices of dairy products. The database collects the weekly prices of dairy products in the entire EU; they are calculated as the averages of national prices, and the prices of individual countries are not available (Beldycka-Bórawska et al., 2021).

This sub-chapter is further divided into two parts determined by the RQ.

The price development of milk and dairy products

The price development of dairy products in Germany was influenced by a number of factors. The year 2019 was not easy for the dairy industry in Germany, as there was increased evidence about a slowing economy and various political uncertainties appeared; the issue of sustainability especially captured public attention, obviously, the sustainability discourse impacts the dairy industry in several respects (Hunecke et al., 2020). Meyerding & Seidemann (2024) revealed that, although the previous studies determined price as a primary decisive factor, the preferences of German consumers for purchasing milk are especially influenced by the type of cattle breeding and the type of wrapping material. The coronavirus pandemic changed the total consumption of dairy products in Germany. Although the activity in the dairy market was initially relatively stable and it was primarily influenced by delays in supply chains, the household demands increased, and a significantly higher demand for almost every dairy product was recorded (Mehlhose et al., 2021). In 2021, in accordance with Busch et al. (2022), the volume of milk deliveries decreased, and the prices of dairy products significantly rose, especially at the end of the year, together with the costs for production factors. Nevertheless, the highest quantity of raw milk per farm in the entire EU was recorded in Germany this year, which amounted to 21% of the total quantity within the EU. In 2022 the total economic conditions were significantly changed in Germany in comparison to the previous years, it was the consequence of extraordinary events including pandemic, Russian aggression against Ukraine, and the high degree of inflation, which influenced the development in the dairy market resulting in a sharp rise as well (Langer et al., 2023).

While the aforementioned authors primarily dealt with the causes of price changes, and the general development of dairy market in Germany, Borawski et al. (2020) used the methods of descriptive statistics, involving the calculation of mean, median, minimum, maximum, coefficient of variation, degrees of skewness and kurtosis, for evaluating the changes in the purchasing prices of raw milk in the EU. The same methods were used in the case of measuring the development of butter prices, Edam, gouda, cheddar, dried whey, dried skimmed and whole milk in the EU by Beldycka-Bórawski et al. (2021), who found out that, from 2001 to 2019, the highest average prices were reached by Emmental cheese, and the biggest changes measured by coefficient of variation took place in dried whey (34%), butter (24%), and dried skimmed milk (22%), while smaller changes were observed in dried whole milk (16%), and cheddar (12%). The descriptive method of statistical analysis for describing the development of the dairy sector is also used by Mikelionyte & Eicaite (2023) or Popescu et al. (2020), who determine the average annual growth rate within the methods.

The relation between milk prices and dairy product prices

It is crucial for decision-making in uncertain conditions to understand price interactions that are a pre-condition for understanding the consumer prices of animal products, which is essential for producers, governments, and industrial sectors that are based on livestock farming (Mat et al., 2023).

Statistical instruments called correlation coefficients (CC) measure the strength of the mutual relation between two variables (Sadeghi, 2022). Correlation coefficients quantify the degree and direction of influences in certain characteristics (Mariña, 2021). Correlation is a widespread instrument in statistics to determine how two entities interchange at the same time (Bramante et al., 2020). The tests based on Pearson, Kendall, and Spearman correlation coefficients are usually used during research to find out whether there is a relation between two variables (Karch et al., 2024).

The Karl Pearson's correlation coefficient is one of the most common measurements of linear dependence (Ly et al., 2018). It describes the degree of relation between two quantitative categorial variables. Variables change in tandem; when one is changed, the other changes in the same direction or takes the opposite direction (Alsaqr, 2021). The correlation between variables is marked by the letter r, and is quantified by a number oscillating between -1 (indicating inverse proportion) and +1 (indicating direct proportion). These numerical values serve as indicators determining the strength of the relation (Sathasivam et al., 2022). Naught represents non-correlation, therefore, there is no dependence between variables (Akoglu, 2018). The Pearson's correlation coefficient may be regarded as a strong indicator if the linear dependency relationship and deviation are normally distributed; if this is not the case, it is recommended to use other dependency indicators such as Kendall's Tau or Spearman's rank correlation coefficient (Bentoumi et al., 2019). Since Pearson's correlation coefficient may be seen as the most frequently used, increased attention should be paid to whether the data are two-dimensionally normal, except the linearity of the relation between variables, and r represents a significant part of Y dispersion, further, the existence of outliers, grouping or limited range of data, appropriate sample size, and whether significant correlation at least indicates causality (Armstrong, 2019). However, it is impossible to interchange the concept of causality with correlation, which is significantly different as it merely concentrates on the connection of trends or formulas (Kathpalia, Nagaraj, 2021). However, Prion & Haerling (2020) note that the stronger the relation between quantities displayed by a correlation coefficient, the better our ability to predict one value from the information about the other one. Furthermore, they point to the appropriateness of using simple linear regression as a 'cousin' of correlation.

The correlation analysis for the mutual relation between milk prices, and dairy products in the EU was used by Beldycka-Bórawska et al. (2021) and revealed that, in most cases, the correlation of prices was positive, the corelation was negative only between butter and Emmental, between butter and dried skimmed milk, and between dried whey and Emmental, which indicates that, as an example, if the price of dried whey rises, the price of Emmental drops, and vice versa.

The regression analysis may be regarded as one of the key analyses that may be used for determining the relation between variables (Attanayake, 2021). In accordance with Etemadi and Khashei (2021), regression modelling is one of the most widespread statistical processes used for estimating relations, and is successfully applied in a wide range of applications. Regression may be divided into three categories: linear, polynomial, and logistic.

Linear regression deals with the relation between a dependent variable and independent variables (Ugwuowo et al., 2023). The name itself reveals that this relation is linear, and is modelled with a linear function (Abu-Faraj et al., 2022; Qiu et al., 2020). Despite linear regression being one of the most important and abundantly used techniques, it is often applied under the assumption that entire information about errors is known, which is impossible in practice (Gong et al., 2019).

Simple linear regression is a statistical technique that is able to estimate the relation between two variables, i.e., between the prediction variable labelled as x and a resulting/response variable labelled as y (Prion & Haerling, 2020). Meijer, Oczkowski, Wansbeek (2021) add that an error in measurement distorts the results of simple linear regression; however, if we know the errors in the absolute or relative form, the adjustment is simple.

Multiple linear regression is a perfect instrument to explain the relation between one dependent variable y and two or more independent variables x1, x2, x3 …, xp, although widely used in practice, it is not recommended in many cases due to its oversimplification of the reality by assuming a linear relation between all independent variables and a dependent variable (Genç & Mendes, 2024). Zhang et al. (2023) point to the issue of selecting explanatory variables x as we will deal with a large quantity of candidates, when many of them have to be purchased, in certain cases, at significant costs.

In connection to dairy industry, linear regression was used, for example, to measure factors influencing the dairy market by the following researchers, Klapkiv et al. (2023), or to reveal the structure of indicators influencing the consumer price of milk by Mat et al. (2023), or to analyse the influence of imported skimmed milk powder and secondary dairy products on the real production price of milk by Espinoza-Arellano et al. (2019), and to identify the relation between factors determining production costs and the prices paid to milk producers by researchers Cristo-Diniz, Neto, & Tavares (2022).

The knowledge of other authors indicates obtaining secondary data with the help of content analysis from public databases for their easy availability and wide coverage to answer both RQ to fulfil the aim of the work. Also, to describe the development of the market prices of milk, butter, Gouda cheese, whey, and dried skimmed milk in the Federal Republic of Germany from 2019 to 2023, which is the subject of RQ1, with the use of the instruments of descriptive statistics, specifically with mean, median, minimal and maximal values, coefficient of variation, and degrees of skewness and kurtosis, for the reason of understanding the qualities of examined data, and their structure. Moreover, to analyse the relation of the market prices of milk and the other aforementioned selected commodities in the Federal republic of Germany from 2019 to 2023, which is the subject of RQ2, with the help of the correlation analysis based on Pearson's correlation coefficient, and with the help of the regression analysis with the use of linear regression, i.e., the most appropriate methods analysing the mutual relation between two variables.

The aim of the work is to define the development of the market prices of selected commodities, specifically milk, butter, Gouda cheese, whey, and dried skimmed milk, in the Federal Republic of Germany from 2019 to 2023, and to specify the mutual price relation between milk and other aforementioned selected commodities.

The following research questions (RQ) are determined in relation to the:

RQ1: How did the market prices of milk, butter, Gouda cheese, whey, and skimmed milk powder develop in the Federal Republic of Germany in the years 2019-2023?

The development of selected market commodities, whose knowledge is indispensable for understanding the interactions of commodity prices, will answer this question. Further, it will provide a wider insight into the market rules of the dairy market in Germany and reveal its seasonal and other oscillations.

RQ2: What was the price relation between milk, butter, Gouda cheese, whey, and skimmed milk powder in the Federal Republic of Germany in the years 2019-2023?

The answer to this question will determine whether milk price impacts the selected dairy products. In the case of price dependence, it will clarify the size of this influence as well.

Methods and Data

The chapter 'data and methods' is divided into two sub-chapters, where data and methods that will be used in the work are introduced.

Data

In this work, secondary data will be used from the web pages of CLAL company (Italian dairy economic advisory, 2024, www.clal.it), providing the average monthly market prices of all selected commodities collected in the Federal Republic of Germany. On the web pages, they are to be found under the card of milk market – instruments – prices. In the case of milk, the gross price of raw milk is from a farm. The prices of butter correspond to a previously formed butter package of up to 250g. The prices of Gouda cheese represent German Gouda cheese containing 45% - 48% fat. Furthermore, only skimmed milk powder and whey powder suitable for human consumption will be counted. For research purposes, the data will be adjusted by converting to the same unit of measurement, €/1000 kg, for each commodity and rounded to 2 decimal places. The adjusted data can be found in Annex No. 1 under the heading: Average monthly market prices of milk, butter, Gouda cheese, whey, and skimmed milk powder in the Federal Republic of Germany from 2019 to 2023.

Methods

As the first one, the time development of the individual monthly market prices of selected commodities (milk, butter, Gouda cheese, milk whey, dried skimmed milk) in the Federal Republic of Germany in 2019 - 2023 will be introduced, and analysed, it will contribute to defining their development, and demonstrate the examined data. The time development of prices will be shown using a line graph. Subsequently, descriptive statistics tools (simple arithmetic mean, median, minimum, maximum, coefficient of variation and measures of skewness and kurtosis) will be used to define the evolution of prices of milk, butter, Gouda cheese, whey and skimmed milk powder in the Federal Republic of Germany for the years 2019-2023 leading to the answer to RQ1. The values will be calculated for each commodity (i.e., for milk, butter, Gouda cheese, whey, skimmed milk powder) separately. The calculations will be performed using MS Excel. The resulting values will be recorded in a table.

It will be followed by correlation analysis based on Pearson's correlation coefficient and regression analysis with the use of simple linear regression. The relationship between the average monthly prices of: 1. milk and butter, 2. milk and Gouda cheese, 3. milk and whey, 4. milk and skimmed milk powder, for the period 2019-2023 in the Federal Republic of Germany will be examined. In the case of correlation analysis, the individual results of the calculation of the Pearson correlation coefficient for each examined pair will be recorded in a summary table. According to the resulting values of the Person coefficient, it will be understood whether the prices are in a certain relationship and whether this relationship is positive or negative. The relationship of the prices of the individual pairs will be examined in more detail using simple linear regression. A linear equation will be defined for each pair, which will then be recorded in a scatter plot. The values of the coefficient of determination will be recorded in a table, and it will be determined how much the price of butter, Gouda cheese, whey, and skimmed milk powder can be explained by the price of milk.

The results of correlation and regression analysis and their interpretation will show whether there is any relationship between the price of milk and the prices of other dairy products and, if so, what kind, which will gradually lead to answering RQ2 and ultimately to fulfilling the objective of the work.

The following methods will be used for calculations:

1) **Simple arithmetic mean –** calculated as the aggregate of all its individual monthly prices for the years 2019-2023 in the specified category and divided by the quantity. The following formula, which is integrated in the MS Excel function under the name *MEAN,* will be used to calculate the simple arithmetic mean.

$$\bar{x} = \frac{x_1 + x_2 + \cdots + x_n}{n} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{1}$$

Where: $\bar{x}$ … the simple arithmetic mean of monthly market prices

$x_1, x_2, \ldots, x_n$ … individual market commodity prices

n … the number of individual monthly market prices equal to the number of months in the monitored period

2) **Median –** the individual monthly market prices for the years 2019-2023 will be organised in an ascending way in the specified category, and the middle element will be determined with the help of the following formula for n even, which is

$$\tilde{x} = \frac{1}{2} \times \left(x_{\left(\frac{n}{2}\right)} + x_{\left(\frac{n}{2}+1\right)} \right) \ldots \text{ for } n \text{ even} \tag{2}$$

integrated in the MS Excel function under the name *MEAN.*
Where: $\tilde{x}$ … the median of monthly market prices

$x_1, x_2, \ldots, x_n$ … individual monthly market commodity prices

n … the number of individual monthly market prices is equal to the number of months in the monitored period

3) **Minimal values** – the lowest average monthly price for the years 2019-2023 in the specified category will be determined by the *MIN* function in the MS Excel program.
4) **Maximal values** – the highest average monthly market price for the years 2019-2023 will be determined by the *MAX* function in the MS Excel program.
5) **Variation coefficient** – the degree of relative dispersion will be calculated as the standard deviation ratio of monthly market prices for the years 2019-2023 in the specified category determined by the *SMODCH* MS Excel function, and the absolute values of the earlier calculated simple arithmetic mean. The results of the

$$CV = \frac{\sigma_x}{|\bar{x}|} \times 100 \tag{3}$$

Calculation of the variation coefficient will be given in percentage.
Where: CV … variation coefficient

σ_x … the standard deviation of monthly market prices

$\bar{x}$ … the simple arithmetic mean of monthly market prices

It is valid for the variation coefficient:

CV > 50 % … the set is heterogeneous, the values are scattered further from the centre,

CV < 50 % … the set is homogeneous, the values are close to the average value.

6) **Degree of skewness** – the symmetry of monthly prices in the specified category for the years 2019-2023 around its mean value will be determined with the help of the selection coefficient integrated in the *SKEW* MS Excel function.

$$= \frac{n}{(n-1)\,(n-2)} \times \sum_{i=1}^{n} \left(\frac{x_i - \bar{x}}{\sigma_x}\right)^3 \tag{4}$$

Where: γ … skewness coefficient

x_i… individual monthly market commodity prices

n … the number of the individual monthly market prices equal to the number of months in the monitored period

σ_x … standard deviation of market monthly prices

$\bar{x}$ … the simple arithmetic mean of monthly market prices

It is valid for the skewness coefficient:

$\gamma = 0$ … zero skewness – symmetric distribution,

$\gamma > 0$ … positive skewness – asymmetric distribution, median has a lower value than the mean,

$\gamma < 0$ … negative skewness – asymmetric distribution, median has a higher value than the mean.

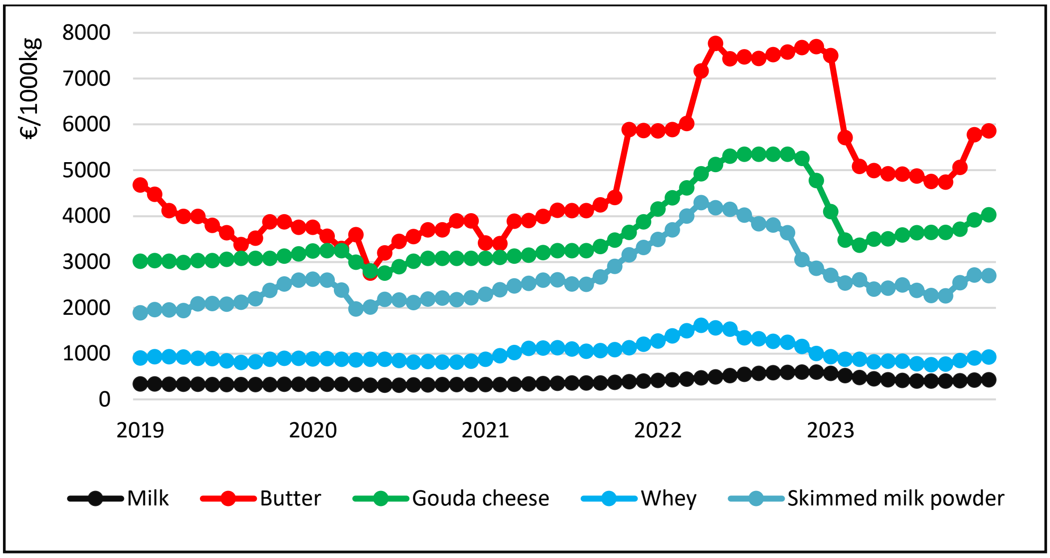
Results

This chapter presents the results of the application of individual selected research methods, on the basis of which the development of market prices of selected commodities, namely milk, butter, Gouda cheese, whey and skimmed milk powder, is defined, and the mutual price relationship between milk and the other selected commodities listed above in the Federal Republic of Germany in 2019–2023 is specified. This chapter is divided according to the specified RQ. The first subchapter presents the time development of individual market monthly prices of the examined commodities in the Federal Republic of Germany for the years 2019–2023, and the results of individual descriptive statistics methods are presented, with the help of which RQ1 will be answered. The second subchapter presents the results of correlation and regression analysis, on the basis of which RQ2 will be answered.

Description statistics methods

Figure 1 shows the time development of the monthly market prices of milk, butter, Gouda cheese, whey, and skimmed milk powder in the Federal Republic of Germany in the years 2019-2023.

Figure 1: The time development of selected commodities in the Federal Republic of Germany in the period 2019-2023.



Source: Authors on the basis of the data (Appendix No.1) retrieved and modified from www.clal.it.

In the table, there are the recorded resulting values obtained by using the individual methods of descriptive statistics, i.e., simple arithmetic mean, median, minimum, maximum, coefficient of variation, and degrees of skewness and kurtosis.

Tab. 1: Statistical characteristics of the monthly prices of examined commodities in the period 2019-2023 in the Federal Republic of Germany.

	Milk	**Butter**	**Gouda cheese**	**Whey**	**Skimmed milk powder**
Simle arit. mean	396,29 €/1000kg	4845,43 €/1000kg	3620,00 €/1000kg	1003,52 €/1000kg	2665,53 €/1000kg
Median	356,60 €/1000kg	4191,00 €/1000kg	3250,00 €/1000kg	903,50 €/1000kg	2519,50 €/1000kg
Minimal value	310,20 €/1000kg	2760,00 €/1000kg	2760,00 €/1000kg	760,00 €/1000kg	1893,00 €/1000kg
Maximal value	600,40 €/1000kg	7770,00 €/1000kg	5350,00 €/1000kg	1623,00 €/1000kg	4299,00 €/1000kg
Coefficient of variation	21,73%	29,55%	21,15%	21,29%	23,91%
Skewness coefficient	1,12	0,87	1,27	1,33	1,20
Kurtosis coefficient	0,07	-0,50	0,34	0,95	0,45

Source: Authors on the basis of the data (Appendix No.1) retrieved and modified from www.clal.it.

The monthly market price of milk developed very evenly compared to other commodities during the monitored period, as can be seen in Figure 1. A certain increase was recorded at the turn of 2022 and 2023, which weakened as 2023 progressed. The average monthly market price of milk during the monitored period was €396.29 per 1,000 kg and was very close to the median price (€356.6 per 1,000 kg), as can be seen from Table 1. Milk was the cheapest in June 2020, when its price reached €310.20 per 1,000 kg, but the most expensive milk could be purchased in November 2022, when the price climbed to €600.40 per 1,000 kg, almost double. However, prices remained closer to the average price during the monitored period, as the variation coefficient was 21.73%. Nevertheless, it can be stated that during the monitored period an asymmetric price distribution was recorded, both in the form of positive skewness, which means that the average price was higher than the median price (the skewness coefficient took the value of 1.12), and in the form of higher kurtosis, but very close to the normal distribution, when the kurtosis coefficient took the value of 0.07.

The market price of milk developed very evenly during the monitored period in comparison to other commodities, as seen in Figure 1. Certain growth was recorded at the turn of 2022 and 2023, it gradually turned weaker in the course of 2023. The average monthly market price of milk during the period under review was €396.29 per 1,000 kg and was very close to the median price (€356.6 per 1,000 kg), as can be seen from Table 1. Milk was the cheapest in June 2020, when its price reached €310.20 per 1,000 kg, but it was the most expensive in November 2022, when the price climbed to €600.40 per 1,000 kg, almost double. However, prices remained closer to the average price during the period under review, as the coefficient of variation was 21.73%. Nevertheless, it can be stated that during the monitored period an asymmetric price distribution was recorded, both in the form of positive skewness, which means that the average price was higher than the median price (the skewness coefficient took the value of 1.12), and in the form of higher kurtosis, but very close to the normal distribution, when the kurtosis coefficient took the value of 0.07.

Unlike the price of milk, the price of butter developed very unevenly, and there was a marked turn between, which is shown in figure 1, between its growth and drop. From the beginning, the monthly market price of butter fell until the beginning of 2020, when the trend reversed and began to rise significantly. A sharp increase was recorded at the end of 2021 and during 2022. It began to fall again at the beginning of 2023. The decline reversed into growth in November 2023. From Table 1, it can then be seen that the average monthly market price of butter in the monitored period was €4,845.43 per 1,000 kg, and its median was €4,191.00 per 1,000 kg. The monthly market price of butter reached its maximum in May 2022 and its minimum in the same month of 2020. The value of the variation coefficient of 29.55% reveals that the individual prices observed were close to the average price. Asymmetry was noted, both the right-sided skewness of prices and their flatness, as can be seen from the values of the coefficient of skewness (0.87) and kurtosis (-0.50).

It is noticeable from Figure 1 that the market price of Gouda cheese slightly rose till the beginning of 2020, when the trend temporarily changed. Further growth was recorded from the half of the year 2020. The growth was mild at the beginning, it gained pace from the half of the year 2021. In mid-2022, there was a stabilization and then a significant decrease, which stopped only in March 2023. From March 2023, there was a further increase. On average, the monthly market price of Gouda cheese in the monitored period was €3,620.00 per 1,000 kg and did not deviate too much from the median price (€3,250.00 per 1,000 kg), as recorded in Table 1. The monthly market price reached its bottom in June 2020 (€2,760.00 per 1,000 kg) and was at its peak from June to October 2022 (€5,350.00 per 1,000 kg). It can also be stated that the individual recorded prices did not deviate too much from the average price, when the variation coefficient becomes 21.15%. Prices were slightly asymmetric. A skewness coefficient of 1.27 indicates right-sided asymmetry, and a kurtosis coefficient of 0.34 indicates that the peaks were low and broad.

The monthly market price of whey did not record such oscillations in the monitored period, as displayed in Figure 1. Till the beginning of spring 2021, it oscillated between €810.00 and €953.00 per 1,000 kg, the growth began afterwards. The biggest growth was noticeable in spring 2022, then the price gradually decreased. On average, in the monitored period, we would pay €1,0003.52 per 1,000 kg for whey in the market in the Federal Republic of Germany, which is €100.02 per 1,000 kg less than the median price. The most expensive price would be €1,623.00 per 1,000 kg in April 2022. The cheapest price for whey in the market was in August 2023 (€760.00 per 1,000 kg). Table 1 also shows that the monthly market prices of whey during the monitored period were close to the average price (the coefficient of variation is 21.29%). The average price was higher than the median price, which indicates that there was a right-sided skewness (the coefficient of skewness is 1.33). The peaks formed were then higher and narrower than in the normal distribution (the kurtosis coefficient reached a value of 0.95).

Figure 1 shows that the monthly market price of skimmed milk powder grew from February 2020, then it sharply dropped, and it rose again from April of that year. The growth was gradual at first, then it peaked till April 2022, when there was a turning point, and the market price of skimmed milk powder began to decrease. Their further growth came with the end of the year 2023. Table 1 shows that the average price of €2665.53 per 1,000 kg was close to the median price (€2519.50 per 1,000 kg), and the prices did not depart from the mean too much (VC = 23,91 %), as well as in the case of other commodities. The higher value of the average monthly market price of skimmed milk powder than the median indicates positive skewness (the skewness coefficient is 1.20). The kurtosis coefficient of 0.45 indicates that prices were not symmetrical. The monthly market price of skimmed milk powder reached its minimum (€1,893.00 per 1,000 kg) at the beginning of the observed period and its maximum (€4,299.00 per 1,000 kg) in April 2022.

Correlation and regression analysis

This sub-chapter was divided into two parts in accordance with the individual applied analysis to improve orientation in the results of the correlation and regression analysis, which are presented in this sub-chapter. Within the correlation and regression analysis, the relation between the market prices of these commodity pairs was analysed: 1. Milk and butter, 2. Milk and Gouda cheese, 3. Milk and whey, 4. Milk and skimmed milk powder in the Federal Republic of Germany for the period 2019-2023.

Correlation analysis
In Table 2, the obtained values of the Pearson's (selective) correlation coefficient for each of the examined pairs of commodities were presented.

Tab. 2: The resulting values of the Pearson's correlation coefficient

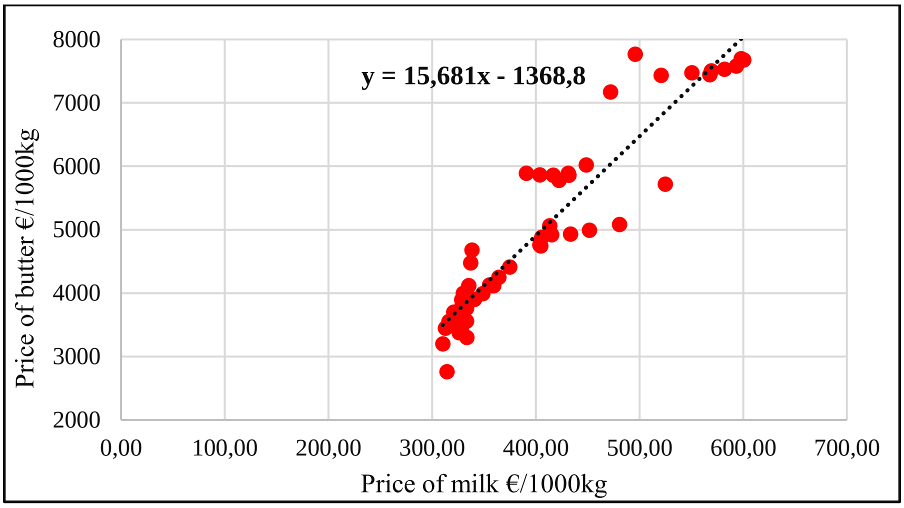
Variable (x)	Variable (y)	Pearson´s correlation coefficient
Milk	Butter	0,94
Milk	Gouda cheese	0,90
Milk	Whey	0,53
Milk	Skimmed milk powder	0,71

Source: Authors on the basis of the data (Attachment No.1) retrieved and modified from www.clal.it.

It is noticeable in Table 2 that the values of Pearson's correlation coefficient are positive in all the examined pairs of commodities, i.e., there is a relation in each pair of commodity prices, and it is positive. In other words, the positive linear dependence was registered in every pair of commodities in the monitored period, and the increasing price of the first commodity resulted in the increasing price of the other commodity. In the pair of the monthly market prices of milk and butter, the value of the Pearson's correlation coefficient (0.94) gets close to 1, which means a nearly perfect correlation, hence, almost the relation in the form of direct proportion. The high value of Pearson's correlation coefficient in the pair of the monthly market commodity prices of milk and Gouda cheese (0.90) indicates a very strong linear relation. In the pair of the monthly market commodity prices of milk and whey, the correlation was not very strong, but medium, when the Pearson's coefficient acquired the value 0.53. The monthly market prices of milk and skimmed milk powder were in a strong mutual relation. The value of the Pearson's correlation coefficient was 0.71 in this pair.

Regression analysis
The relation between the market price of milk and the market price of butter can be described by the equation $y = 15,681x - 1368,8$. Figure 2 presents the form of the linear regression line and the strength of the dependence of the market prices of butter on the market prices of milk, which reveals that there is a significant positive relation between the dependent variable and the independent variable.

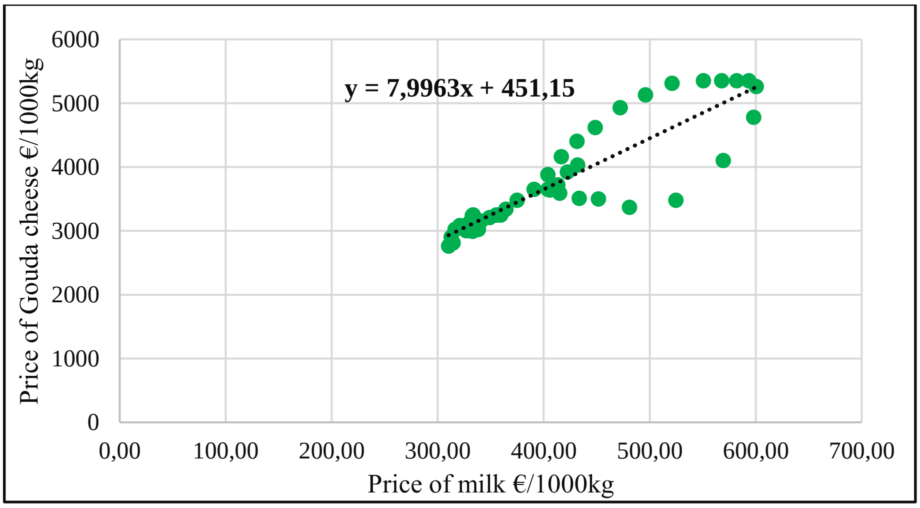
Figure 2: The graph of the regression line – the relation between the market prices of butter and milk



Source: Authors on the basis of the data (Attachment No.1) retrieved and modified from www.clal.it.

Figure 3 makes it noticeable that there existed a significant positive relation between the market price of milk and the market price of Gouda cheese, as the prices of these commodities tended to be on the same line. This relation may be expressed by the equation y = 7,9963x + 451,15.

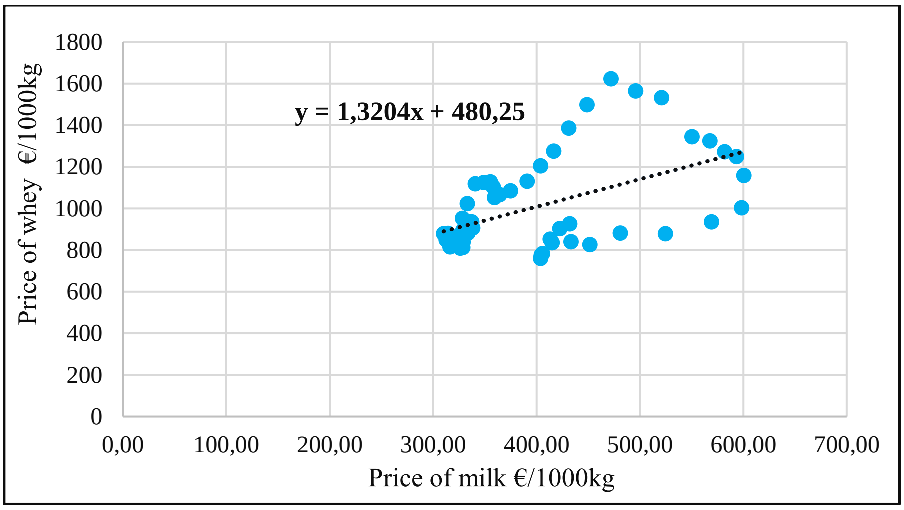
Figure 3: The graph of the regression line – the relation between the market prices of milk and Gouda cheese



Source: Authors on the basis of the data (Attachment No.1) retrieved and modified from www.clal.it.

Medium strength dependence can be noticed between the market prices of milk and whey, as the prices of these commodities had higher dispersion. The mutual relation of these commodities may be presented as y = 1,3204x + 480,25. The form of the regression line was not so steep as a result of the higher proximity of milk prices and whey prices per 1, 000 kg, subsequently shown in Figure 4.

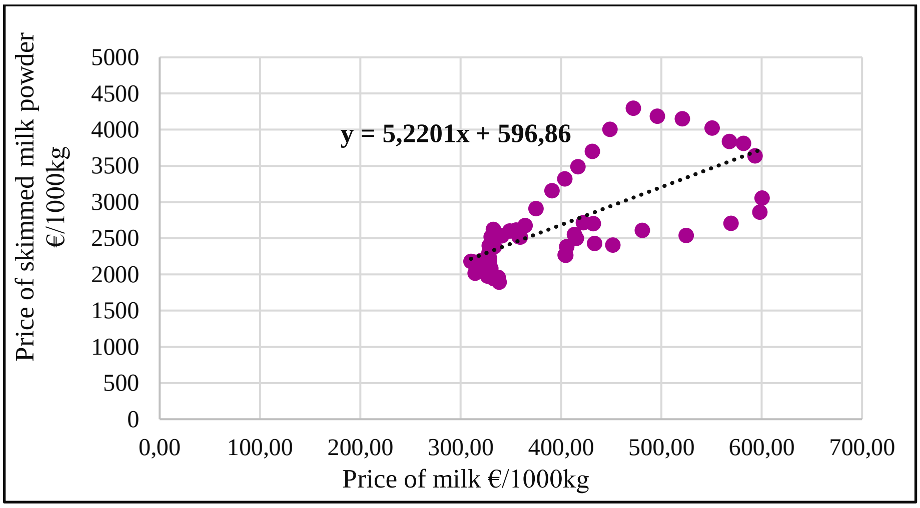
Figure 4: The graph of the regression line – the relation between the market prices of milk and whey



Source: Authors on the basis of the data (Attachment No.1) retrieved and modified from www.clal.it.

It is noticeable from Figure 5 that there was a positive relation between the market price of milk and the market price of skimmed milk powder. These commodities recorded a higher dispersion as well, however, the prices had a linear dependency, and their relation can be represented by the equation y = 5,2201x + 596,86.

Figure 5: The graph of the regression line – the relation between the market prices of milk and skimmed milk powder



Source: Authors on the basis of the data (Attachment No.1) retrieved and modified from www.clal.it.

Table 3 shows the values of the coefficient of determination for each of the examined pairs of commodity prices. All the measured values of the coefficient of determination were higher than 0, therefore, it may be assumed that the regression analysis served to better understand the relation between the independent variable (price of milk) and the dependent variable (prices of butter, Gouda cheese, whey, and skimmed milk powder).

Tab. 3: The resulting values of the coefficient of determination

Variable (x)	Variable (y)	Coefficient of determination
Milk	Butter	0,89
Milk	Gouda cheese	0,81
Milk	Whey	0,28
Milk	Skimmed milk powder	0,49

Source: Authors on the basis of the data (Attachment No.1) retrieved and modified from www.clal.it.

The value of the determination index (0.89) in the pair of milk, butter came very close to 1, as recorded in Table 3. The market price of butter was under a 89% influence of the market price of milk in the monitored period, and it can be mostly explained with the help of the prices of milk. The market price of Gouda cheese can be explained with an 81% accuracy rate with the help of the market price of milk, as it is shown by the value of the coefficient of determination 0.81. The possible prediction of the price of whey requires other independent variables, as the price of milk is not sufficient. The coefficient of determination acquired the value 0.28, which indicates the mutual linear relation between commodities, however, it is not too big, and the price of whey can be determined with a mere 28% accuracy rate. The price of skimmed milk powder cannot be explained on the basis of the price of milk, even with a 50% accuracy rate. In this case, the regression model determines only 49% of the proportion of the dependent variable, as the coefficient of determination was 0.49.

Discussion

RQ1: How did the market prices of milk, butter, Gouda cheese, whey, and skimmed milk powder develop in the Federal Republic of Germany in the years 2019-2023?

In the course of defining the market prices of selected commodities in the Federal Republic of Germany in the years 2019-2023, the time development of selected monthly market prices was characterised first, and subsequently it was analysed with the help of the instruments of descriptive statistics. The most even development was recorded in the price of milk, however, the market price of butter went through oscillations between growth and decrease in the course of the monitored period. The commodity prices reached their minimum at the beginning of spring 2020, only whey did in autumn 2023, and skimmed milk powder in winter 2019. It is necessary to mention that Covid-19 pandemic hit negatively all sectors of the economy, including the dairy sector (Das, Sivaram and Thejesh, 2021). After the outbreak of the coronavirus pandemic, in accordance with Mehlhose et al. (2021), the total consumption of dairy food changed, although it did not appear at first as the activity had been relatively stable. The pandemic resulted in increasing the input costs of dairy producers, who focused on maintaining the operation of plants, and re-channelling the products from food services to retail, which was connected to processing, packaging, and distribution (Acosta et al., 2021). The price increase recorded in 2021 can be explained, in accordance with Bushe et al. (2022), by decreasing the volumes of milk and increasing the costs of production factors. The prices of all commodities in the market culminated in the course of 2022, without exception. The sharp increase in prices was observed by Langerem et al. (2023), who add that the cause was the change of general economic conditions in Germany, which had been caused by the coincidence of the corona pandemic, the war in Ukraine, and high inflation. The prices of commodities in the individual months did not move too far from their average prices, which were close to median prices. On average, it was possible to buy the monitored commodities in Germany for: €396.29 for 1, 000 kg (butter), €3, 620.00 for 1, 000 kg (Gouda cheese), €10, 003.52 for 1, 000 kg (whey), and €2, 665.53 for 1, 000 kg (skimmed milk powder). The distribution of commodity prices was slightly asymmetric, with observable right-sided skewness and, except for butter, high kurtosis.

RQ2: What was the price relation between milk, butter, Gouda cheese, whey, and skimmed milk powder in the Federal Republic of Germany in the years 2019-2023?

The price relation of the selected commodities was specified on the basis of the Pearson's correlation coefficient and the regression analysis. The positive linear dependence was registered in every examined pair in the monitored period, which may lead to the conclusion that the prices of other commodities grew with the rise of the milk price. A very strong linear relation between the prices of milk and butter, and between the prices of milk and Gouda cheese, was discovered. A medium dependency was between the prices of milk and whey. A strong, but not very strong, dependency was registered in the prices of milk and skimmed milk powder. The market price of milk influenced the market price of butter at the rate of 89%, Gouda cheese of 81%, whey of 28%, and skimmed milk powder of 49%. The conclusion that the price of milk influences the price of other dairy products was reached by Beldycka-Bórawska et al. (2021) as well, however, they add that the prices of milk are impacted by a wide range of factors, such as the conditions in the world market, the size of the costs of producers, the volume of production in the specific period, food safety measures, etc. The relation between the market prices of milk and other dairy products in the same area over at least an approximate period of time was not examined in more detail by other authors.

Conclusion

Milk and dairy products are essential foodstuffs that offer numerous nutritional and economic benefits. The Federal Republic of Germany is one of the major producers of milk and dairy products within the European Union, which ranks among the world´s leading producers. Fluctuations in dairy product prices affect the profitability of processing companies, influence consumer decision-making, and may even destabilize the economic market. Accurate information on the market prices of milk and dairy products, as well as the factors influencing them, is crucial for stakeholders when making both routine and strategic decisions. The objective of this paper was therefore to define the development of market prices of selected commodities, namely milk, butter, Gouda cheese, whey, and skimmed milk powder, in the Federal Republic of Germany over the period 2019-2023, and to identify the price relation between milk and the aforementioned commodities. This objective was successfully achieved.

The development of market prices for selected commodities was analysed using time series analysis supported by descriptive statistics. The most stable price development throughout the observed period was observed in milk, whereas butter experienced the most frequent fluctuations between periods of growth and decline. At the beginning of summer 2020, the market prices of most analysed commodities in the Federal Republic of Germany reached their lowest levels. Their subsequent increase was influenced by the COVID-19 pandemic, which had a negative impact on the dairy market by disrupting both supply and demand. A significant escalation in prices occurred in 2022, driven by the combined effect of the ongoing pandemic, the war in Ukraine, and a high inflation rate, all of which contributed to substantial changes in the overall economic environment in Germany. Despite the fluctuations, the market prices of the selected commodities remained close to their mean values, which were close to the median. The distribution of prices was asymmetric, with right-skewed distributions observed for all commodities, and kurtosis for all commodities except butter.

The mutual price relation between the pairs: milk and butter, milk and Gouda cheese, milk and whey, milk and skimmed milk powder was specified with the help of the correlation analysis based on the Pearson's correlation coefficient, and the regression analysis. A positive linear dependence was identified with every examined pair, when a very strong linear relation was registered between the prices of milk and butter, and between the prices of milk and Gouda cheese. The prices of milk and whey were mutually medium-strong dependent, and the relation of the price of milk and skimmed milk powder was linear strong, however, not very strong. The prices of the selected commodities in the market in the Federal Republic of Germany were influenced by the price of milk at the rate of 89% in butter, 81% in Gouda cheese, 28% in whey, and 49% in skimmed milk powder in the course of the monitored period. Apart from the price of milk, the price of other milk products was also impacted by other factors, such as the size of the costs of producers, the production volume in the specific period, the conditions in the world market, etc.

Since it is necessary to base an appropriate decision on adequate information, the knowledge of the market prices of milk and dairy products, their development, and their mutual interaction is necessary for many subjects. The management of enterprises operating in the dairy sector, all their stakeholders, however, also final consumers, and the state, can be such subjects. Furthermore, this work is beneficial for the scientific community as it provides a basis for further research in this area.

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Appendix

Tab 1: The average monthly market prices of milk, butter, Gouda cheese, whey, and skimmed milk powder in the Federal Republic of Germany in the years 2019-2023.

		Milk	Butter	Gouda cheese	Whey	Skimmed milk powder
	01.01.2019	338,30	4680	3020	906	1893
	01.02.2019	337,20	4480	3030	935	1963
	01.03.2019	335,10	4120	3020	936	1958
	01.04.2019	332,90	4000	2990	926	1944
	01.05.2019	329,90	4000	3030	903	2085
	01.06.2019	328,70	3800	3030	894	2094
	01.07.2019	327,10	3640	3060	841	2079
	01.08.2019	326,10	3380	3080	810	2121
	01.09.2019	327,10	3520	3080	826	2203
	01.10.2019	329,20	3880	3080	877	2383
	01.11.2019	330,20	3880	3130	899	2523
2019	01.12.2019	333,10	3760	3180	903	2607
	01.01.2020	332,40	3760	3240	884	2623
	01.02.2020	333,00	3560	3250	894	2603
2020	01.03.2020	333,50	3300	3250	881	2386

	01.04.2020	326,70	3600	3000	867	1978
	01.05.2020	314,40	2760	2810	880	2020
	01.06.2020	310,20	3200	2760	878	2183
	01.07.2020	312,60	3448	2900	850	2172
	01.08.2020	316,20	3556	3020	816	2119
	01.09.2020	320,80	3700	3080	833	2195
	01.10.2020	326,70	3700	3080	818	2213
	01.11.2020	328,60	3900	3080	813	2180
	01.12.2020	328,80	3900	3080	838	2223
	01.01.2021	328,10	3413	3080	878	2298
	01.02.2021	328,20	3401	3100	953	2398
	01.03.2021	333,00	3891	3130	1023	2478
	01.04.2021	340,70	3903	3150	1118	2535
	01.05.2021	348,90	3994	3210	1125	2603
	01.06.2021	355,20	4131	3250	1128	2613
	01.07.2021	358,00	4120	3250	1103	2521
	01.08.2021	359,30	4120	3250	1053	2518
	01.09.2021	364,20	4251	3340	1067	2676
	01.10.2021	374,80	4411	3480	1085	2909
	01.11.2021	390,90	5890	3650	1131	3160
2021	01.12.2021	403,80	5868	3880	1205	3320
	01.01.2022	416,60	5860	4160	1275	3490
	01.02.2022	431,20	5890	4400	1386	3701
	01.03.2022	448,60	6022	4620	1498	4006
	01.04.2022	472,00	7174	4930	1623	4299
	01.05.2022	495,90	7770	5130	1565	4188
	01.06.2022	520,80	7437	5310	1533	4150
	01.07.2022	550,40	7478	5350	1345	4025
	01.08.2022	567,70	7445	5350	1324	3839
	01.09.2022	581,90	7530	5350	1273	3811
	01.10.2022	593,40	7583	5350	1250	3641
	01.11.2022	600,40	7680	5260	1159	3056
2022	01.12.2022	598,10	7700	4780	1003	2863
	01.01.2023	569,30	7504	4100	935	2709
	01.02.2023	524,70	5718	3480	879	2540
	01.03.2023	480,80	5086	3370	882	2610
	01.04.2023	451,50	4995	3500	826	2408
	01.05.2023	433,30	4930	3510	840	2428
	01.06.2023	415,10	4920	3590	835	2500
	01.07.2023	405,70	4880	3640	783	2385
	01.08.2023	403,90	4760	3650	760	2271
	01.09.2023	404,60	4745	3650	776	2265
	01.10.2023	413,20	5064	3720	853	2551
	01.11.2023	422,30	5778	3920	904	2716
2023	01.12.2023	432,00	5860	4030	927	2703

Source: Authors on the basis of the data (Attachment No.1) retrieved and modified from www.clal.it.

Historical Analysis and Forecasting of Gold Price as an Economic Indicator

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Abstract

The aim of this study was to analyse the gold price development during the period 2020–2024 and subsequently to forecast the gold price development for the period 2025–2030. To achieve this objective, the content analysis and data description method was used to process historical data, and the Exponential Smoothing forecasting model was used to estimate future trends. The analysis of historical data was conducted on the basis of daily closing prices of gold, while the predictions relied on trend and seasonal components of time series. The results showed that in 2020–2024, the gold price was affected by major global events such as the COVID-19 pandemic, geopolitical conflicts and monetary policies. The most notable rise occurred in 2020, when the price peaked at USD 2,075 per troy ounce. The forecast for 2025–2030 indicated a continuous rise in the price of gold, which is expected to reach approximately USD 5,500 by the end of 2030. This growth reflects anticipated global economic conditions, in particular rising inflation and the demand for gold as a safe-haven investment. Although the Exponential Smoothing model provided accurate results, the research remains limited by its dependence on historical data, which cannot account for unexpected future events such as geopolitical changes or technological innovations. Nonetheless, the findings of this study offer valuable information for investors and analysts that can be further used to better understand the gold market's dynamics and to formulate long-term investment strategies.

Keywords: gold price evolution, forecast, investment strategy, time series, economic analysis, Exponential Smoothing model, market volatility.

Introduction

Today, commodities are a standard part of investment portfolios. They constitute a fundamental pillar for modern society, and their price fluctuations can have a major impact on macroeconomic stability, production processes and the security and well-being of the population. They can be characterised as primary raw materials or commodities that serve commercial purposes. They can be purchased in several ways. An average consumer chooses between partial one-time and long-term purchases or mass purchases. Commodity trading occurs most often on commodity markets which are strictly meant for trading raw or basic materials, not finished products. At the same time, commodity markets play a crucial role in the international competitiveness of industries and their sustainable development (Zhang et al., 2022a). Forecasting prices of precious metals is crucial for a wide range of stakeholders, including investors, traders, policy makers, and researchers. This discipline poses a major challenge due to significant price fluctuations and irregular cycles, which in turn affect the price development of these metals (Liu et al., 2020).

Commodities can be divided into two basic groups, namely soft and hard. Soft commodities include agricultural products such as wheat, cattle, coffee, cocoa, and sugar. Hard commodities, on the other hand, are obtained through mining or other extraction processes and include, for example, gold, rubber, natural gas and oil. In addition, the range of commodity markets has recently expanded to include new items such as emission allowances, electricity, and even mobile phone minutes (Teall, 2023).

The position of commodities within investment portfolios is one of the most effective inflation protection tools because their prices usually rise during inflationary periods, which brings advantages for investors. In the context of portfolio management, hedging constitutes a proactive risk management strategy designed to protect the portfolio from undesirable market fluctuations by incorporating assets whose values tend to move in the opposite direction to the market. While efforts to minimize risk can reduce losses, they can also reduce potential gains (Uzik et al., 2023). Spikes in commodity markets are rare. Extreme events occur less frequently than in equity markets (Nguyen & Prokopczuk, 2019).

In times of economic uncertainty, when inflation is rising and trust in the traditional banking system is falling, people are looking for alternatives to protect their assets. One often mentioned option is gold as a means of payment. With its thousand-year history as a store of value, gold is regarded as a stable investment. Its use as money dates back to antiquity and it still plays an important role in the global economy. One of the main advantages of gold is its limited quantity, which means it does not succumb to inflation as quickly as paper money. Additionally, gold cannot be "printed" by the government, making it a reliable investment and protector of value in uncertain times (Uzik et al., 2023).

Gold, as a commodity of substantial economic value, experiences price volatility driven by a range of factors such as macroeconomic conditions, political shifts, and market sentiment. The interplay of these factors makes the future trend of the gold price complex and difficult to forecast. However, for investors, the ability to accurately estimate the future trend of gold prices is essential to making sound investment decisions and achieving desirable returns. Therefore, forecasting gold market price trends remains a key and critical issue in finance.

The study of gold prices prediction for better financial risk management has recently focused on the application of advanced hybrid models that combine deep learning techniques and time series analysis. Amini et al. (2024) use CNN-Bi-LSTM hybrid model with automatic parameter tuning, which, by combining convolutional neural networks (CNN) and long short-term memory (LSTM), achieved high accuracy in predicting the closing gold prices over the period 1978–2021. In this model, CNN identifies key patterns in the data, while LSTM is able to preserve the sequential relationships needed for more accurate long-term forecasting. This approach was effective in improving financial forecasts and managing the risk associated with gold volatility.

A recent study investigated the capabilities of the hybrid VMD-RES.-CEEMDAN-WOA-XGBoost model (Guo et al., 2024), which uses the Complete Ensemble Empirical Mode Decomposition with Adaptive Noise (CEEMDAN) to decompose complex information. Here, the XGBoost algorithm, optimized by the Whale Optimization Algorithm (WOA), yields better performance than traditional forecasting models. The results show that this hybrid model provides better gold prices predictions based on COMEX data and confirms the effectiveness of combining optimization and analytical tools that can work with complex market data structures.

In another study, Garcia-Gonzalo et al. (2024) discuss the construction of time series datasets using three techniques: direct multi-step, recursive multi-step and direct-recursive hybrid scheme. This research introduces new methods, nonlinear autoregression with exogenous variables (NARX SVR) and Gaussian process regression (GPR) optimized by differential evolution (DE), which leads to higher accuracy in forecasting gold spot prices from COMEX. The NARX DE/SVR method has proven to deliver the best results, highlighting the importance of new regression methods and hyperparameter optimization in prediction of price time series.

The forecast of monthly gold prices from 1978 to 2023 using ARIMA and multilayer perceptron (MLP) models was analysed in Gbadamosi et al. (2024). The study showed that the optimized hyperparameter setting significantly improves the forecasting abilities of MLP while reducing the mean squared error and mean absolute error (MSE and MAE). The results clearly show that MLP outperforms the ARIMA model, confirming the advantages of using neural networks in financial analysis.

Qiu et al. (2024) come up with an innovative two-stage hybrid model that combines feature extraction and residual correction techniques in order to predict gold prices. In this model, a variational modal decomposition is used to categorize the time series data, while convolutional neural networks (CNN) and long short-term memory (LSTM) provide higher accuracy of the analysis. The model has proven that the two-stage approach not only improves prediction results but also provides valuable insights into the dynamics of gold markets.

Further research by Quan and Shi (2024) focuses on improving the predictive ability of LSTM in forecasting gold futures prices. By integrating the CEEMDAN technique to decompose complex time series, the data can be separated into different components of intrinsic mode function (IMF), which are then independently modelled by LSTM. The use of the Random Forest algorithm for weighted aggregation of individual component predictions reduces the prediction error by 30–50%, highlighting the importance of combining CEEMDAN and LSTM in more accurate analyses.

Economic shocks such as trade wars or the COVID-19 pandemic cause significant gold prices fluctuations. In response to this volatility, Yang et al. (2024) propose a hybrid model that combines Hurst-oriented reconfiguration with machine learning. The model analyses decomposed time series and identifies a negative correlation between the Hurst exponent and prediction error, thereby outperforming traditional methods in terms of directional forecasting accuracy.

Manickam et al. (2023) propose a hybrid Grey-Fourier-Markov model that combines Grey models, Fourier series, and Markov state transition to predict daily changes in gold prices in Indian rupees. The three-step prediction process involves data simulation by Grey models, trend analysis of residual error using Fourier series, and final correction, which shows that this approach achieves more accurate results than conventional prediction strategies.

In the study by Zhang et al. (2022b), a wavelet transform was applied to bitcoin and gold data to reduce noise, resulting in increased prediction accuracy using the LSTM-P model. The high-frequency noise components were eliminated, which allowed significant accuracy for both bitcoin and gold, and outperformed traditional LSTM models.

Wavelet analysis was also applied in the study of Lee et al. (2021), where its combination with LSTM provided a more efficient prediction of gold futures even for non-stationary data. The results show that wavelet analysis combined with LSTM significantly improves the prediction accuracy under volatile market conditions.

Chen and Zhang (2019) employed a combinatorial model using a pursuit algorithm and BP neural network to select relevant factors and incorporate them into a gold price forecasting model. This approach simplified the network structure and increased the learning rate, leading to more accurate predictions.

Khan and Bhardwaj (2019) investigated the prediction of gold prices in India using data mining and RapidMiner modelling tool to analyse the MCX Gold time series from Quandl database. Data mining enabled efficient extraction of relevant patterns and factors, leading to accurate predictions of gold prices in INR.

In their paper, Xie et al. (2019) examine the Dilated Convolution Long Short-Term

Memory (DCLSTM) model, which integrates CNN and LSTM and includes multiple prediction variables. The results show that this model significantly outperforms traditional approaches such as ARIMA and CNN, demonstrating the high potential of advanced neural networks in forecasting.

E et al. (2019) present ICA-GRUNN technique that combines independent component analysis (ICA) and Gated Recurrent Unit Neural Network (GRUNN) for accurate gold price prediction. The results show that ICA-GRUNN outperforms commonly used methods such as ARIMA or RBFNN and provides higher accuracy, making it an effective tool for financial forecasting.

For the first research question, the method of content analysis and data description will be utilized to determine the development of gold prices in the period 2020–2024.

For the second research question, Python is used to forecast gold prices for the period 2025–2030.

The aim of the paper is to evaluate the development of gold prices and predict their future trends in the next five years.

To achieve this objective, the following research questions were defined:

RQ1: What was the development of the gold price in the period 2020–2024?

This question focuses on the analysis of the gold price trend from 2020 to 2024, a time period heavily influenced by global events such as the COVID-19 pandemic, subsequent economic uncertainty and geopolitical conflicts. An examination of the gold price during this period will offer insight into how gold responded to the increased volatility in the markets. This analysis will result in the identification of the main trends and influential factors that have contributed to the rise or fall in the value of gold.

RQ2: How will the gold price evolve in the period 2025–2030?

This question focuses on forecasting the future price of gold over the period 2025–2030 based on an analysis of past trends and patterns of market behaviour. Answering this question will allow a better understanding of the potential influences and trends that could shape the gold market in the coming years. Forecasting gold price developments over this horizon will contribute to better planning of investment strategies and provide useful information for risk management and long-term financial decision-making.

Methods and Data

To answer the first research question - "What was the development of the gold price in the period of 2020–2024?" - secondary data obtained from the Stooq platform, which provides freely available financial and economic data, were used. Historical data on gold prices was downloaded directly from the website www.Stooq.com. The data download was set from 1 January 2020 to 31 November 2024 with a frequency of daily records. The file contained the following variables: date (Date), opening price (Open), high and low price (High, Low), closing price (Close) and trading volume (Volume).

The downloaded CSV file was subsequently converted to Excel format named Vyvoj_zlata.xlsx and saved in the same directory, where further data processing was carried out using Python. The analysis primarily utilised the closing price of gold (Close), which provides key information on the daily market trend.

Methods

For the analysis of the historical development of gold prices in 2020–2024, the method of content analysis and data description was chosen. This method allowed to analyse the characteristics of the price development on the basis of summary statistics and visual representations of the data. The data were processed in Python (version 3.12) using the pandas and matplotlib libraries. First, the data were read from an excel file and filtered for the period from 1 January 2020 to 12 December 2024. Subsequently, basic indicators such as mean, median, standard deviation and variance of closing prices were calculated. The results were visualized using a chart that provided an overview of the trends and volatility of gold prices over the period analysed.

For the second research question - "How will the gold price evolve in the period 2025–2030?" - the Exponential Smoothing forecasting model was employed and implemented via the statsmodels library. This method, which is suitable for time series with a trend and seasonal component, was applied to historical data from 2020–2024. First, a model with an additive trend and a seasonal component with a period of 365 days was created, which corresponds to annual cycles in the time series. The model was fitted to historical data that were used to produce a forecast up to 31 December 2030. A corresponding date was generated for each predicted value, allowing the forecasted prices to be linked to specific days.

The result of the analysis was Table 2, which includes the forecasted data. The table contained columns with the dates, the closing prices for the historical data and the forecasted prices for the period 2025–2030. The outputs also included a graph that combined the historical data with the forecast. This graph illustrated the trend in gold prices over the period analysed and facilitated the interpretation of the results.

Results

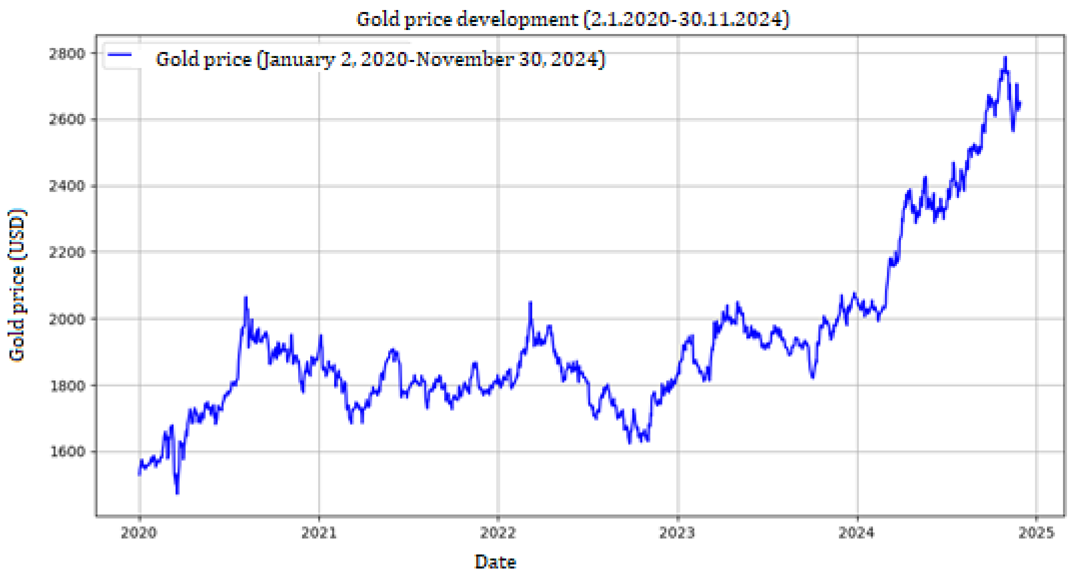
This chapter presents the results of the analysis of the historical development of gold prices in 2020–2024 as well as forecasts for the period 2025–2030. The description of the results is based solely on the methods presented in the chapter Data and Methods, thus ensuring a factual and logical structure. The presentation of the results includes graphs and tables that provide a more detailed view of the data analysed.

The Evolution of Gold Prices in 2020–2024

The gold price trend from 2020 to 2024 was analysed based on historical data obtained from the Stooq platform, which included daily closing gold prices in USD per troy ounce, with the reported period beginning on 2 January 2020 and ending on 30 November 2024. This data provide a detailed overview of the daily gold price development and form the basis for trend analysis and predictive modelling. Data processing was done in Python, using the pandas library for time series analysis and the matplotlib library for visualization.

Figure 1 shows the evolution of the gold price over the period under analysis. The graph illustrates the significant volatility of the gold price, which reflects the major events of the period.

Figure 1: The evolution of gold prices in 2020–2024



Source: Authors (via Python)

Year 2020

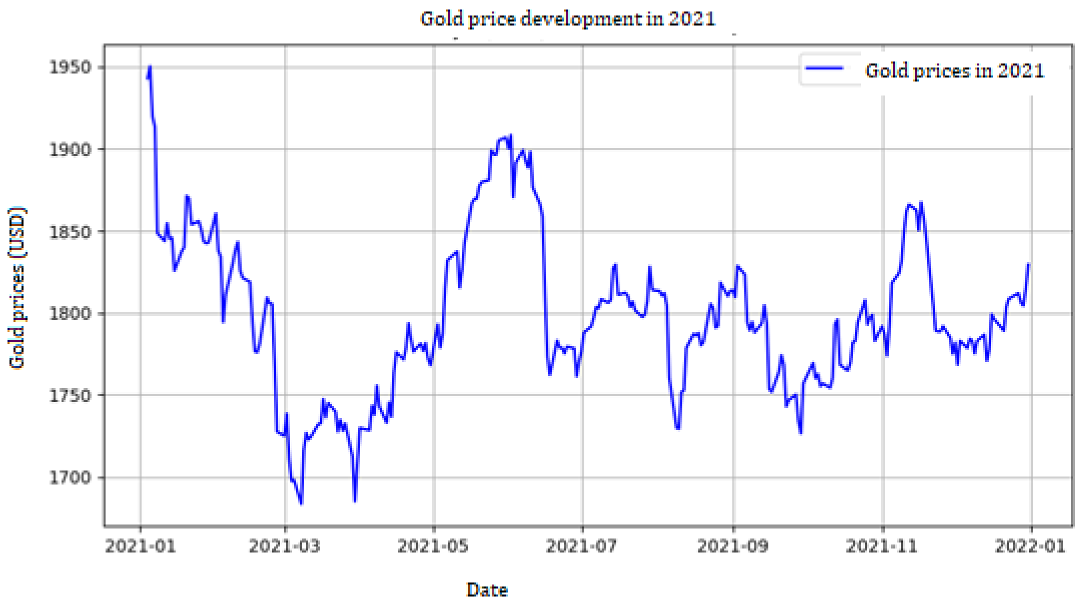
Figure 2: The evolution of gold prices in 2020

Source: Authors in Python

The year 2020 was characterised by a dramatic rise in the price of gold, with the horizontal axis showing each day in 2020, while the vertical axis shows the gold price in USD per troy ounce. Each point on the graph represents the daily closing gold price. The gold price ranged from USD 1,550 to USD 2,075. This growth was driven by the COVID-19 pandemic, which caused uncertainty in financial markets and increased demand for safe investments. Gold reached its highest value in August 2020, when it exceeded USD 2,075 per troy ounce. This peak was followed by a slight decline and a stabilisation of the price around USD 1,900 towards the end of the year.

Year 2021

Figure 3: The evolution of gold price in 2021

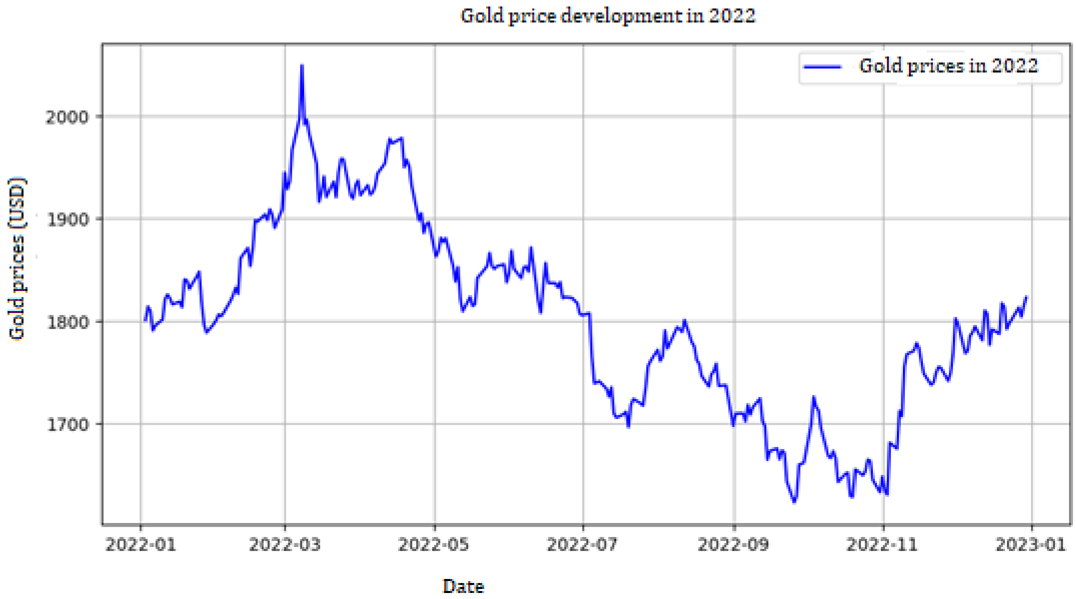


Source: Authors (via Python)

The year 2021 shows a stabilization of the gold price after a sharp rise in the previous year. The horizontal axis shows days in 2021, and the vertical axis shows the gold price in USD per troy ounce. Each point on the graph corresponds to the daily closing price of gold. That year, the gold price ranged between USD 1,750 and USD 1,900. The year was characterised by relative stability as economies began to recover from the pandemic. Inflation helped to keep the gold price higher, but its growth was limited by expectations of rising interest rates.

Year 2022

Figure 4: The evolution of gold price in 2022

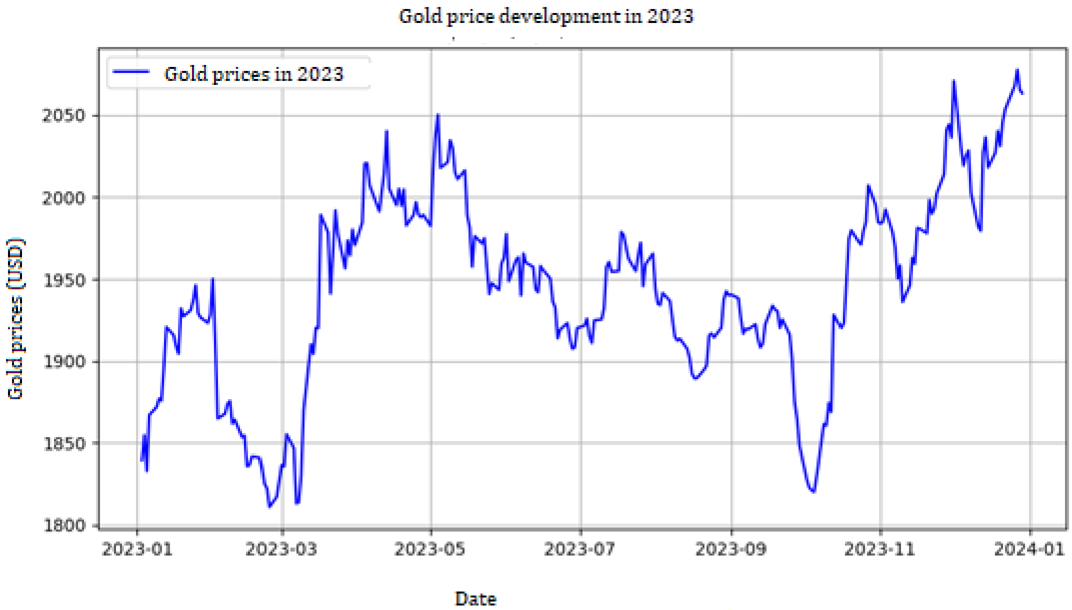


Source: Authors (via Python)

In 2022, the impact of geopolitical events was reflected in the price of gold. The horizontal axis shows days in 2022, and the vertical axis shows the gold price in USD per troy ounce. Each point represents the daily closing price of gold. The gold price ranged from USD 1,800 to USD 2,000. The highest levels were reached at the beginning of the year when the gold price rose sharply due to geopolitical uncertainty related to the conflict in Ukraine. However, the price went down in the second half of the year and stabilised at around USD 1,800.

Year 2023

Figure 5: The evolution of gold price in 2023

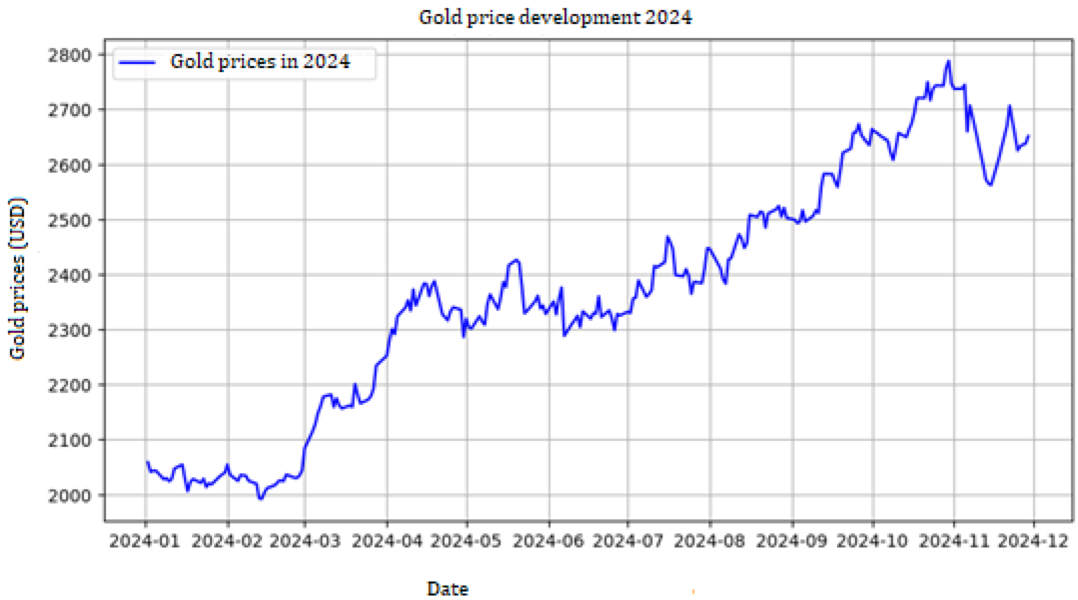


Source: Authors (via Python)

In 2023, the growing trend resumed mainly due to the weakening of the US dollar and rising inflation, which boosted demand for gold as a store of value. At the end of the year, the gold price reached approximately USD 2,050 per troy ounce. This rise was also influenced by increased demand from central banks, which continued to diversify their reserves.

Year 2024

Figure 6: The evolution of gold prices in 2024



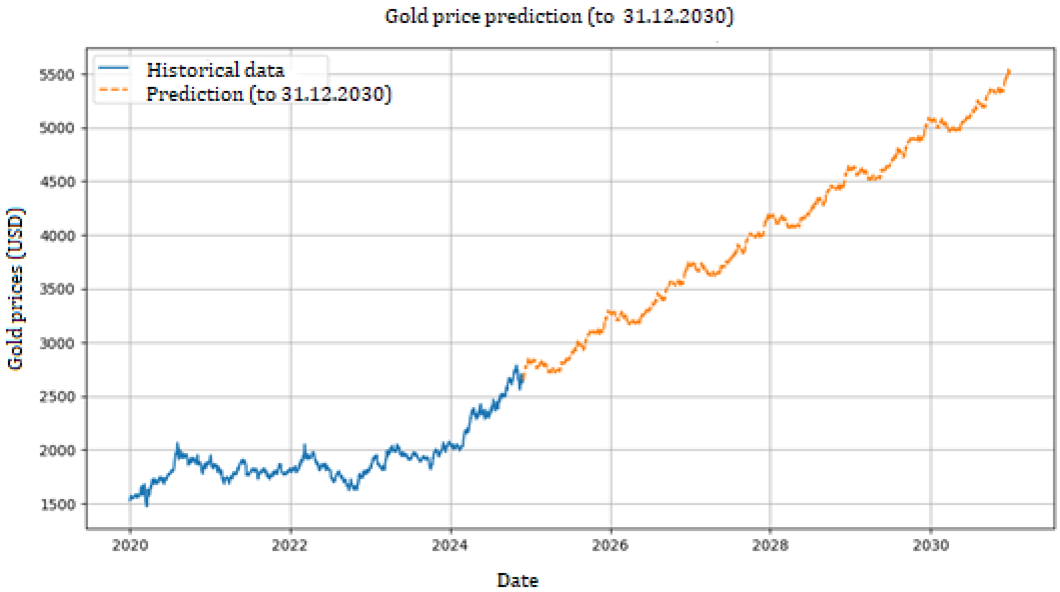
Source: Authors (via Python)

This year shows one of the most significant increases in the gold prices over the period under consideration. The horizontal axis represents days in 2024, and the vertical axis represents the gold price in USD per troy ounce. Each point on the graph corresponds to the daily closing price. In 2024, the gold price ranged from USD 2,000 to USD 2,800. The largest increase was recorded in the second half of the year, when demand for gold as a safe investment increased due to geopolitical uncertainty and inflation.

Gold Price Forecast for the Period 2025–2030

Forecasting gold prices was performed using the Exponential Smoothing model, which was implemented via the statsmodels library in Python. The model included an additive trend and a seasonal component with a period of 365 days, which corresponds to the annual gold price cycle. The input data included historical data from 2020–2024, as recorded in Table 1.

Figure 7: Gold price forecast for 2025–2030



Source: own processing from Python

The forecast graph for 2025–2030 includes the evolution of the gold price. There are two curves in the graph, the blue curve shows historical data on the gold price in 2020–2024, the orange curve shows the gold price forecast in 2025–2030. The horizontal axis represents the period from 2025 to 2030, and the vertical axis shows the predicted gold price in USD per troy ounce. Each point on the graph corresponds to the predicted daily price. The forecast suggests a gradual rise in the gold price from USD 2,800 at the beginning of 2025 to around USD 5,500 at the end of 2030. This growth reflects the long-term trend of increasing demand for gold as a store of value, particularly in emerging markets. The biggest jump in the price is expected between 2027 and 2030 when gold will exceed USD 5,000.

Year 2025

In 2025, the predicted gold price starts at around USD 2,800 per troy ounce. A steady increase is seen during the year, with the price reaching approximately USD 3,000 by the end of the year.

Year 2026
In 2026, the gold price will continue to rise. At the beginning of the year, it will be around USD 3,000 and at the end of the year it will reach approximately USD 3,500.

Year 2027
The forecast for 2027 suggests a stronger increase in the gold price. During this year, the price will exceed USD 4,000 per troy ounce and reach about USD 4,200 at the end of the year.

Year 2028
In 2028, gold is forecasted to continue to rise, with the price at the beginning of the year around USD 4,200 and around USD 4,500 at the end of the year.

Year 2029
In 2029, the gold price will exceed the important threshold of USD 5,000 per troy ounce. At the beginning of the year, the price will be approximately USD 4,500. By the end of the year, it will reach approximately USD 5,200.

Year 2030
The year 2030 is closed at around USD 5,500 per troy ounce. The gold price at the beginning of the year will be around USD 5,200.

The results of the forecast suggest that gold will continue its upward trend due to its stable position in the market as a safe investment instrument. The expected values suggest a gradual increase in price from around USD 2,800 at the beginning of 2025 to around USD 5,500 at the end of 2030. This evolution reflects anticipated global economic conditions such as rising inflation and increasing demand for precious metals, particularly in emerging markets. Although the forecast shows a consistent upward trend, it should be borne in mind that the results may be affected by unexpected factors such as geopolitical changes or economic shocks. However, this analysis provides valuable insights for investors and other stakeholders interested in the future development of the gold market.

Discussion

RQ1: What was the development of the gold price in the period 2020–2024?
The results of the analysis showed that the gold price was subject to significant fluctuations between 2020 and 2024, which were influenced by key global events. 2020 saw a sharp rise in the gold price, which peaked at USD 2,075 per troy ounce in August. This increase was a direct result of the COVID-19 pandemic, which caused uncertainty in the financial markets. This period was followed by price stabilisation around USD 1,900. The years 2021 and 2022 were characterised by lower volatility and stabilisation of prices within the range of USD 1,750-2,000. Major geopolitical events, such as the conflict in Ukraine in 2022, led to a temporary increase in prices, which later stabilised. In 2023 and 2024, the gold price rose again due to the weakening of the dollar, inflation and increased demand from central banks.

The identified trends are consistent with the findings of studies such as Guo et al. (2024), which highlights the influence of geopolitical and economic factors on gold price volatility. Similarly, the results corroborate the findings of Liu et al. (2020), who identified the pandemic as a significant factor in the rise of precious metal prices.

RQ2: How will the gold price evolve in the period 2025–2030?

The predictive analysis shows a continuous rise in the gold price between 2025 and 2030. At the beginning of 2025, the price is around USD 2,800 per troy ounce, reaching approximately USD 5,500 at the end of 2030. This growth reflects the long-term trend also identified in Amini et al. (2024), which shows that demand for gold as a store of value remains strong. The greatest acceleration in rise was predicted for the period 2027–2030, consistent with the anticipated uncertainty in global markets and growing demand from developing markets, particularly in Asia.

The prediction model used in this paper proved to be a suitable tool for time series analysis with trend and seasonal components. This approach enabled more accurate results than traditional methods such as ARIMA, which was also confirmed in the studies of Gbadamosi et al. (2024).

Although the chosen methods provided detailed insights into the development and prediction of gold prices, several limitations should be considered. The prediction is based on historical data which cannot take into account unexpected events such as new geopolitical conflicts, economic crises or technological changes that may significantly affect the gold market. In addition, the Exponential Smoothing model does not include all possible exogenous factors, such as demand and supply dynamics at the micro level.

The results of this study are in line with previous research that emphasizes the importance of macroeconomic and geopolitical influences on gold prices. However, the paper provides a better prediction due to the applied model and detailed analysis. Unlike studies using simpler forecasting approaches such as ARIMA, the model employed here provides higher accuracy and better captures seasonal trends. This result is consistent with the findings of Guo et al. (2024) and confirms the efficiency of advanced hybrid models in forecasting.

The results of this analysis provide not only answers to the research questions posed, but also useful insights for investors and analysts interested in the evolution of the gold price in the context of changing global conditions.

Conclusion

The aim of this study was to analyse the gold price evolution in 2020–2024 and to forecast the gold price for the period 2025–2030. To achieve this objective, content analysis and data description methods were used for historical analysis and the Exponential Smoothing prediction model was applied to forecast future trends. The results of the study thus answer both research questions and provide a comprehensive view of gold price evolution.

The analysis of historical data showed that, in 2020–2024, the gold price was affected by key global events such as the COVID-19 pandemic, geopolitical conflicts and economic uncertainties. The gold price reached its highest level in 2020, when it exceeded USD 2,075 per troy ounce. This sharp rise was driven by high uncertainty in financial markets and demand for safe investments. Subsequently, the price stabilised within a range of USD 1,750-2,000, with an upward trend again observed in 2023 and 2024. During these years, there was an increase in demand for gold as a store of value, particularly in response to inflation and growing economic uncertainty. These findings confirm the importance of gold as a safe investment in times of economic uncertainty.

The Exponential Smoothing forecasting model used historical data to create a forecast for 2025–2030. The results of the forecast suggest a continuous rise in the gold price from approximately USD 2,800 at the beginning of 2025 to USD 5,500 at the end of 2030. This growth reflects anticipated global economic conditions such as rising inflation, geopolitical uncertainty and continued demand for gold, particularly in emerging markets. The analysis shows that gold will retain its role as a strategic investment in the future. Additionally, the model has shown the ability to accurately predict long-term trends and identify seasonal influences, which increases its utility for forecasting purposes.

One of the main contributions of this paper is the emphasis on combining historical analysis and forecasting, which together provide a comprehensive view of the gold market. The historical analysis revealed key factors influencing the gold price, such as macroeconomic stability, geopolitical events and monetary policy. The forecast for 2025–2030 offers specific outcomes that can be useful for investors and analysts. Moreover, the identification of a stable growth trend underlines the importance of gold as a store of value in an environment of rising inflation.

The findings meet the stated objective of the study and contribute to the understanding of gold market dynamics. The results answer both research questions, showing not only the historical evolution of the gold price but also its potential development in future years. Apart from enabling the retrospective analysis of historical events, this approach also provides tools for future decision-making. The applied methodology, particularly the use of the Exponential Smoothing model, proved to be suitable for this type of analysis as it helped to capture both long-term trends and seasonal fluctuations.

However, some limitations of the research need to be considered. Forecasting is based on historical data, which means that unexpected events such as new geopolitical crises, technological innovations or major changes in supply and demand can affect the results. Also, the Exponential Smoothing model does not include all possible exogenous factors, such as dynamics in other precious metals markets or the impact of emerging economies' monetary policies. Nevertheless, these limitations do not diminish the contribution of the paper, but they rather suggest directions for future research.

Historical analysis and forecasts provide valuable information for investors looking for safe and stable investment opportunities. Furthermore, the results can be used by analysts to develop investment strategies and manage risk. In addition, identifying key trends and factors influencing the gold price contributes to a better understanding of the market and its dynamics. This approach may inspire future studies aimed at analysing other commodities or currency markets.

In conclusion, the aim of the thesis was fulfilled. The historical analysis has provided a comprehensive view of the gold price evolution in 2020–2024, while the forecasting model has made it possible to create a specific forecast for the period 2025–2030. This study not only answered the research questions posed, but also provided useful findings that can benefit a wide range of stakeholders from investors to academics. Despite some limitations, the results clearly confirm that gold remains a key commodity with a significant role in global markets, both in terms of current analysis and future forecasts.

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Demographic Trends Reflecting Unemployment Rates

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Abstract

The aim of this study was to evaluate the trends in population ageing and assess its impact on unemployment in the Czech Republic from 2014 to 2023. Another objective was to determine whether there is a correlation between the ageing index and the unemployment rate and to analyze how generational ageing affected unemployment in selected age groups in the Czech Republic. Data collection was conducted using content analysis, and the obtained values were presented in graphs using graphical methods. It was found that, despite the gradual ageing of the population, the unemployment rate declined over the same period. Consequently, a correlation analysis was performed using Pearson's correlation coefficient, preceded by data normalization using the Min-Max method. The result was a negative correlation coefficient, indicating a strong to very strong correlation. It was also observed that younger age groups had fewer registered job seekers compared to older age groups in the records of the Labor Office. A limitation of this study is the impact of the Covid-19 pandemic and the war in Ukraine, which necessitate interpreting certain findings with caution.

Keywords: Population ageing, unemployment, trends, correlation, age groups, ageing index, data normalization

Introduction

Population ageing is currently one of the most significant demographic phenomena, affecting the whole world, including the Czech Republic. Long-term predictions do not bode well either (Šídlo et al., 2020). The number of people over 59 dramatically increases, while the percentage of adolescents under 16 drastically plummets. Birth rates also witness a marked decline, while people live to see a more advanced age. This rare occurrence currently poses a radical demographic challenge to the developed countries, housing the largest number of the global pensioners (Xue et al., 2022).

This accelerating trend provokes massive social and economic upheavals, calling for the attention of experts and politicians (Chen et al., 2022). The transformation of the population age distribution deeply influences macroeconomic indicators, including GNP, inflation, fiscal equilibrium, labour market and unemployment (Goh et al., 2020). Population ageing also affects the workforce, labour demand and job opportunities. Unemployment rates are a key indicator reflecting the economic stability and performance, governing the decisions of the government, enterprises and individuals (Monušová, 2020). Although the issue is vital on a global scale, domestic labour markets and national economies will face a massive increase of the older generation, indicating a chance smaller by 25% to find a job (Flek et al., 2020).

This demographic phenomenon boosts a demand for effective solutions in the employment policy, compelling the government and employers to ensure a steady and thriving labour market despite a marked decline in working population (Chu et al., 2021). Our research outcomes may clarify the relationship between population ageing and changes in unemployment rates, suggesting practical measures that will stimulate the labour market and economic stability.

As global population has considerably aged, expert communities try to map this worldwide phenomenon and assess its impact on the key indicators of economic performance, including unemployment, and offset, or at least mitigate, its negative effect on society. Many articles, studies, methods or pieces of research from the whole world have contributed to this problem.

Impacts of population ageing

Population ageing sways many economic and social indicators, including pension, healthcare and social security expenses (Stahmeyer et al., 2021). This demographic trend shakes the labour market structure, slashing the workforce and causing an economic slow-down. Population ageing also burdens younger generations with increased taxes to fund pension systems. Wang et al. (2022) explored the impacts of this phenomenon on Chinese society between 1990 and 2020 using Autoregressive Distributed Lag. Their results indicate a strong negative effect of the ageing population growth on human welfare. Ranking No. 1 problem in China, tackling this issue should improve the health of local population. Liu et Zhao (2023) analysed the impact of population ageing on Chinese financial sustainability between 2010 and 2019 using two-way fixed-effect models, showing inverse proportion between population ageing and fiscal sustainability. The suggested measures involve increasing the birth rate, protect fiscal expenses and efficiently using funds for healthcare and social security. Li et al. (2022) devised an OLG (Overlapping Generations) model and CGE (Computable General Equilibrium) model to apply two-child and postponed retirement policies and to cushion the adverse impacts of rapidly ageing Chinese population.

Balachandran et al. (2020) compared population ageing in Europe and Asia using time consistency and comparative methods, revealing faster population ageing in Asian countries than in the EU. This confirms the findings of the previous authors.

Consistent population ageing profoundly affects national economic growth, energy consumption, CO_2 emissions and sustainable development. Pais-Magalhaes et al. (2022)

confirmed this theory by analysing the impact of accelerated population ageing on households in 28 EU countries between 2005 and 2018 using econometric methods.

Population ageing radically affects many countries, including the Czech Republic. Štěpánek (2022) analysed macroeconomic and sectoral impacts of rapid population ageing and migration on the demography of the Czech Republic. He applied content analysis and an OLG-CGE model to various age groups with varied education and occupation and revealed that national economy will face restricted labour supply and changes in the aggregate and sectoral demand, leading to a slow-down in the economic growth (GNP reduced by 4.4% by 2050), increased labour costs (wages raised by 5.2%) and weakened competitiveness of the economy. Gawthrope (2022) used content analysis and simulation methods to assess the effectiveness of fiscal policy measures for mitigating the impact of ageing on the income and welfare, recommending an extended version of the Czech model regulated by the Ministry of Finance. The model involves adopting postponed retirement policies, increasing pensions and reducing social security payments while raising GNP rates and other transfers to overcome the deficit. Pension schemes endorsing postponed retirement are more sustainable thanks to reduced pension costs, reinvigorating depressed national economy and sluggish labour market. Krpán et al. (2020) confirm this theory, analysing the differences between pension schemes of selected EU countries using Ward's clustering method.

Population ageing and unemployment

The impact of population ageing on unemployment has recently been subject to many scholarly studies and articles, exploring how demographic changes (accelerated population ageing) affect the labour market. Although many experts dread the adverse effects of this phenomenon like declining workforce and mounting pressure on younger generations, other scholars emphasize advantages, including job security for seniors and their deeper involvement in the working process. What also varies are opinions to which extent population ageing influences unemployment rates.

Ochsen (2021) argues that accelerated active population ageing cuts the unemployment rate by 1%, using a panel data model on the US districts between 2000 and 2014.

Rozen-Bakher (2020) measured the influence of postponed retirement on unemployment according to age groups in 30developed countries, comparing the unemployment rates between young people and pensioners. Using comparative correlation analysis, the author revealed that although postponed retirement leads to a lack of job openings for younger generations (including adults) in an already-crowded labour market, it reduces senior unemployment rates. The study recommends offsetting the labour shortage with postponed retirement to expand the workforce and resolve pension scheme issues. Lee et al. (2021) analysed a similar problem in Korea, where people feared that postponed retirement would result in exorbitant unemployment rates in younger generations. By processing the data from a Korean panel study on jobs and incomes from 1998-2017 and Korean census from 2000, 2005, 2010 and 2015 and applying a logit model, the authors revealed no correlation between postponed retirement and job vacancies for young people. They also recommend opening new jobs for older generations to alleviate poverty and strengthen economic security. Apello (2024) examined whether postponed retirement will leave young people unemployed, i.e. if the older workforce will replace young workers by analysing job openings in Latin America. Rather than proved, their correlation analysis rejected this hypothesis, revealing a positive correlation between the employment rates of older and younger generations. The results also show a direct relationship between the wages of older and younger workers. These findings suggest that employing older people stimulates economic growth and increases the labour demand of young candidates.

Katagiri (2021) explored how population ageing influences unemployment in Japan using a multisector New Keynesian model to analyse job cuts and openings. They revealed that population ageing curbed inflation by 0.3%, increased unemployment rates by 0.3% - 0.4% and reduced GNP by 1.8% from 1990s to 2000, indicating a profound impact on local economy.

We use content analysis for the data collection, using correlation analysis to process our findings. We also apply data normalization using Min-max method and graphical analysis to answer the research questions.

The study aims to explore the population ageing trend and assess its influence on unemployment in the Czech Republic in 2014-2023.

The research questions are as follows:

RQ1: What was the population ageing trend and unemployment rates in the Czech Republic in 2014-2023?

We explore the relationship between population ageing trends and unemployment rates in 2014-2023, showing possible correlations between population ageing indicators and unemployment.

RQ2: Is there a correlation between the ageing index and unemployment rates?

We examine whether a correlation between the ageing index and unemployment rate exists in the Czech Republic between 2014 and 2023 and, if so, what its nature is.

RQ3: How did population ageing influence unemployment rates in selected age groups in the Czech Republic between 2014 and 2023?

We inspect how population ageing influenced unemployment rates in selected age groups in the Czech Republic between 2014 and 2023.

Methods and Data

The methodology involves three main parts, including data collection, used methods and results containing answers for the research questions.

Data

We used content analysis to collect secondary data for the first research question, analysing the statistics from a public database and of official websites of the Czech Statistical Office (CSO, 2024). We process data about population and its age distribution, birth rates, death rates, active ageing index and unemployment rates in the Czech Republic from 2014 to 2023. We summarize the data to the end of the year, i.e. 31st December, compiling a graphical table in MS Excel.

The second research question also involves data from a public database and official websites of the Czech Statistical Office (CSO, 2024), emphasizing the figures relating to active ageing indices and unemployment rates over the same monitored period.

The third research question includes secondary data gathered by content analysis from the official websites of the Ministry of Labour and Social Affairs (MLSA, 2024), analysing the data about the numbers of job applicants registered in the Unemployment Office according to the age. The monitored period and data observation remain the same as in the previous cases.

Methods

The first research question includes content and graphic analysis, mapping and assessing the selected indicators of population ageing and unemployment rates in the Czech Republic over the monitored period.

The second research question involves correlation analysis, whose prerequisite is data normalization due to their various nature and magnitude. We use Min-max method for data normalization, converted into the interval from 0 to 1.

This data normalization method is as follows (Shantal et al., 2023):

$$x' = \frac{x - \min(x)}{\max(x) - \min(x)} \quad (1)$$

where:
x = original value to normalize
x_{min} = minimum variable value in the whole dataset
x_{max} = maximum variable value in the whole dataset
x' = normalized value

We use correlation analysis and Pearson's correlation coefficient to explore the relationship between population ageing and unemployment, defined as follows (Eldomiaty et al., 2020):

$$r = \frac{\sum(x - \bar{x})(y - \bar{y})}{\sqrt{\sum(x - \bar{x})^2 \sum(y - \bar{y})^2}} \quad (2)$$

where:
x = ageing index value
$\bar{x}$ = average ageing index value

y = unemployment rate [%]
$\bar{y}$ = average unemployment rate [%]
α = significance level [%]

The significance level α is set to 5%.

We use MS Excel to calculate r correlation coefficient, classifying the results into five categories:

Very strong	r > = 0.8
Strong	r = 0.6 – 0.8
Medium	r = 0.4 – 0.6
Weak	r = 0.2 – 0.4
Very weak	r = 0 – 0.2

The zero-coefficient r does not indicate any relationship between the ageing index and unemployment rate, whereas the coefficient close to 1 or -1 shows a very strong correlation. Positive values imply a direct proportion between the ageing index ad unemployment rate, while negative numbers indicate the inverse relationship between the measured variables.

We formulated a zero hypothesis H0 to validate data normality. Depending on the rejection or confirmation of the former, we also constructed an alternative hypothesis H1.

H0: There is a correlation between the ageing index and unemployment rates.

H1: There is no correlation between the ageing index and unemployment rates.

The third research question also involves content analysis.

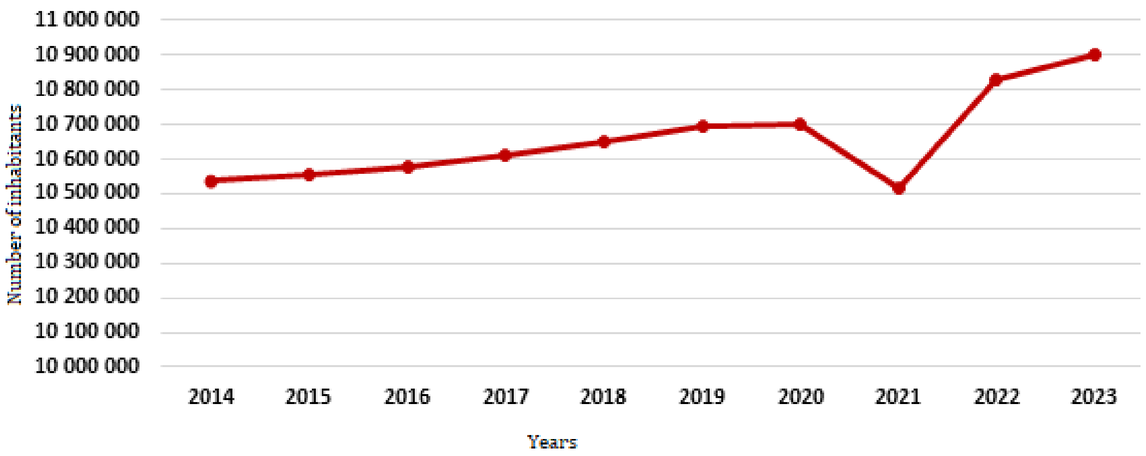
The adopted methodology allows us to fulfil our research aim and answer the research questions.

Results

This chapter presents our findings based on the collected data using the methodology from the previous part. The chapter suggests a chronological overview including three parts that respectively answer our hypotheses, allowing a practical and systematic assessment of the relationship between demographic population ageing and unemployment rates.

Population ageing and unemployment trends in the Czech Republic
The evaluation of the population ageing trend in the Czech Republic within 2014 – 2023 is shown on the selected indicators.

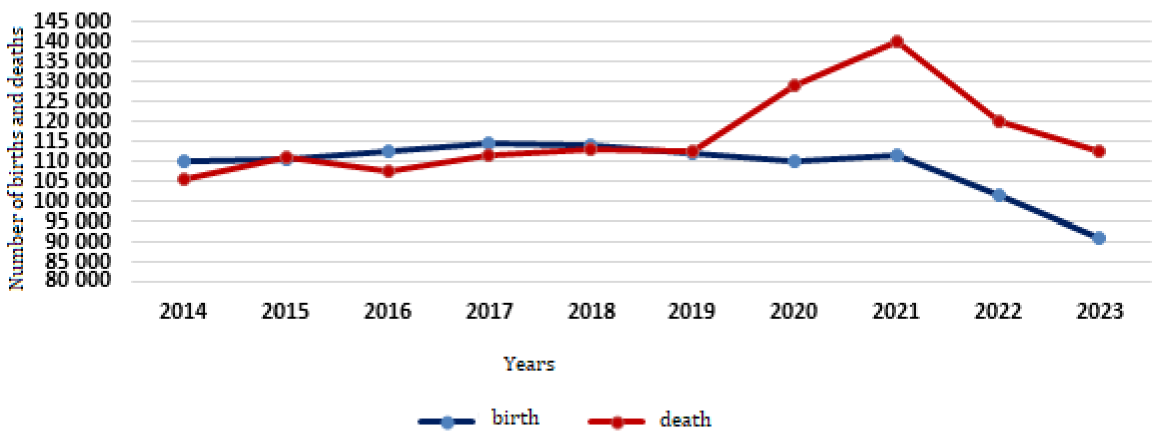
Graph 1: Total population trend in the Czech Republic



Source: Author from CSO data (2024).

The total population trend in the Czech Republic is a key factor for assessing its ageing trend, depicted in Graph 1 over 10 years from 2014 to 2023. The data were gathered from the public database of the Czech Statistical Office to 31st December of each year. The graph depicts a continuous increasing population trend, indicating the strongest year-to-year rise in history in 2022 when the Czech population grew by 310.8 people. However, the CSO (2024a) suggests that this population explosion reflected mass immigration caused by the armed conflict in Ukraine. The Office further states that the growing trend indicates a predominantly positive balance of the massive migration wave; otherwise, birth and death rates in the Czech Republic decline as of 2019, as illustrated in Graph 2.

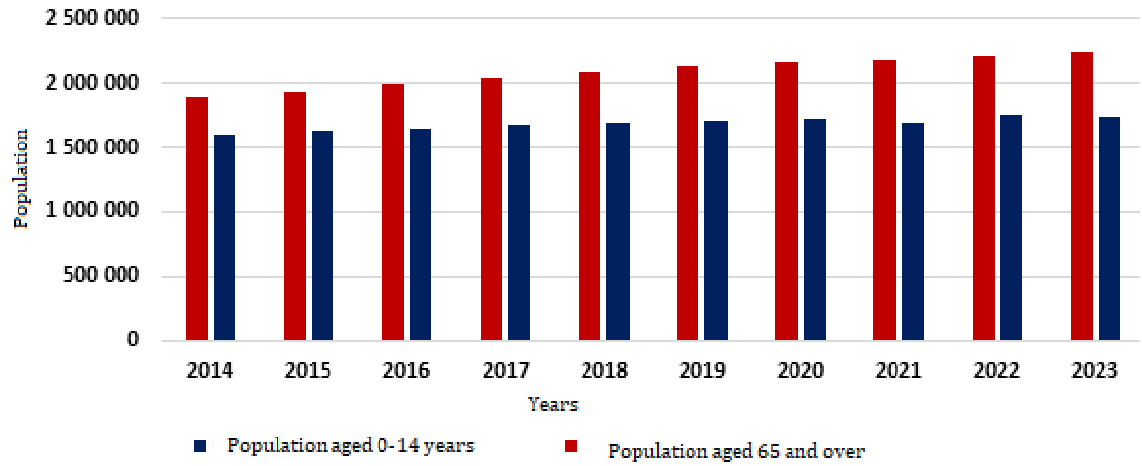
Graph 2: Birth and death rate trends



Source: Author from CSO data (2024b).

Graph 2 depicts birth and death rate trends in the Czech Republic over the monitored period from CSO data to 31st December, suggesting a steady decline in the birth rates. In 2014, 109,860 babies were born, seeing a downturn to 91,149 newborns in 2023. Death rates witness a constant or a slightly increasing trend, supposing we rule out Covid-19 pandemic death tolls from 2020, 2021 and 2022.

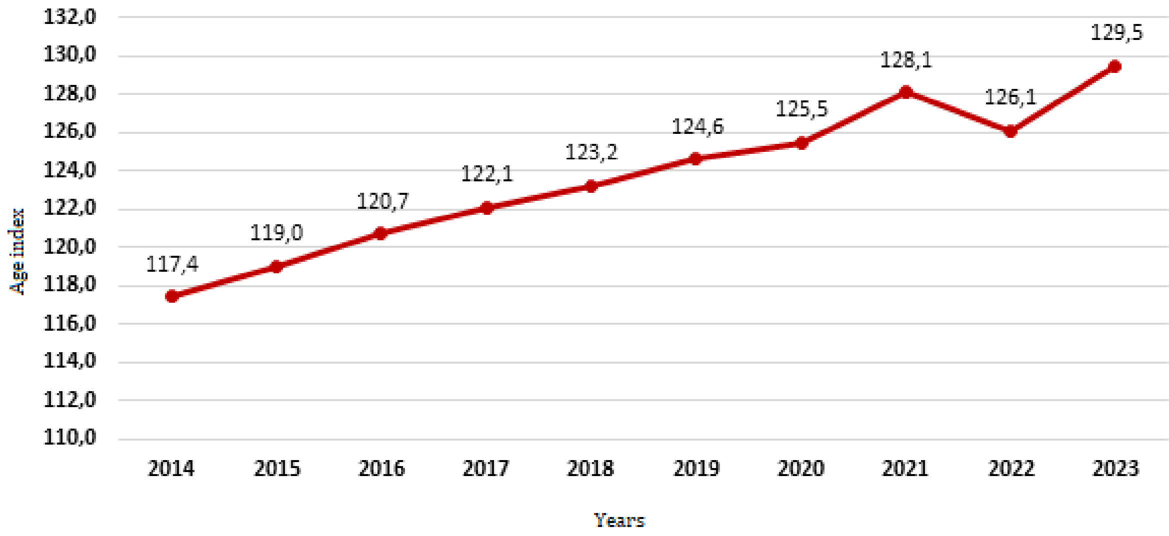
Graf 3: Population trends for 0-14 years and over 64



Source: Author from CSO data (2024).

Other indicators showing population ageing trends are population levels within 0-14 and over 64 years, depicted in Graph 3 based on the publicly available of the CSO to 31st December over the same period. The graph illustrates a massive upsurge in population over 64 years, contrasted to an imperceptible increase in young people between 0 and 14 years. A numerical overview suggests that 2014 recorded 1,880,406 people in the pensionable age, while 2023 saw this age group soar to 2,237,322 people, indicating a growth in pensioners by 356,916 inhabitants. According to CSO (2024c) retirees have continuously been outnumbering children up to 15 years in a ratio of 100 children to 130 pensioners to 31st December 2023. This ratio is expected to surpass 200 by 2040.

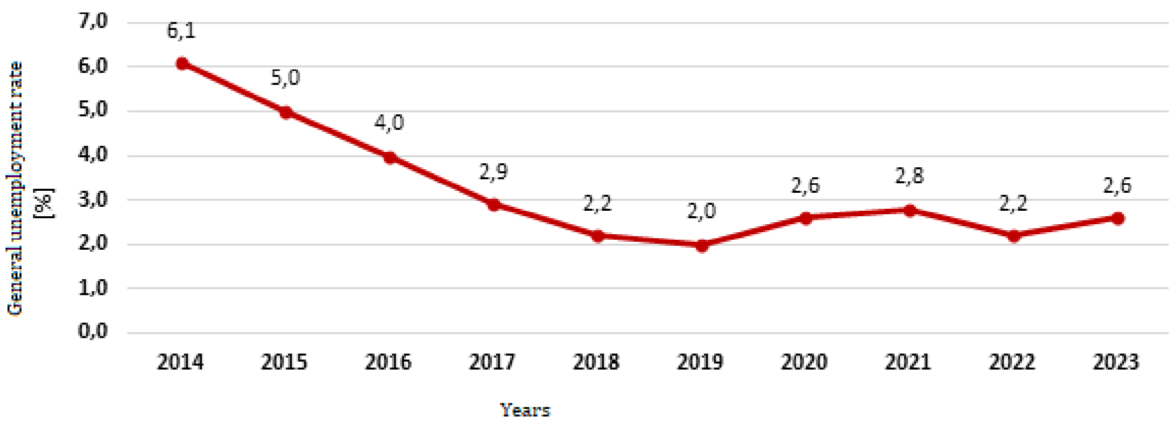
Graph 4: Ageing index trend



Source: Author from CSO data (2024).

Ageing indices are a key indicator of population ageing depicted in Graph 4. We again collected the data from the CSO database to 31st December of each year over the monitored period. The graph suggests a continuous increasing trend of the ageing index, starting at 117.4 in 2014 and peaking at 129.5 ten years later. The CSO (2024d) states that the ageing index involves the number of people over 64 per 100 people in the age between 0 and 14. The charts also indicate that a growing number of pensioners and declining young population will push the ageing index further up.

Graph 5: Unemployment trends



Source: Author from CSO data (2024e).

Graph 5 illustrates unemployment rates to 31st December of each year over the monitored period, indicating a gradual decline from 6.1% in 2014 to 2.6 at the end of 2023. The figures suggest that despite rapid population ageing the unemployment rates in the Czech Republic saw a sharp downturn between 2014 and 2023.

Correlation between the ageing index and unemployment rate

Although the ageing index dramatically increased every year, unemployment rates saw a gradual decline over the monitored period. We conducted correlation analysis to identify whether a correlation between the ageing index and unemployment rates exists.

To do that, we must normalize the data from a publicly available data of the CSO using Min-max normalization methods. The tables and data before and after normalization are attached as annexes.

Tab. 1: Correlation analysis between the ageing index and unemployment rates

	Ageing index	Unemployment rate
Ageing index	1	
Unemployment rate	-0.795041974	1

Source: author from CSO data (2024, 2024e).

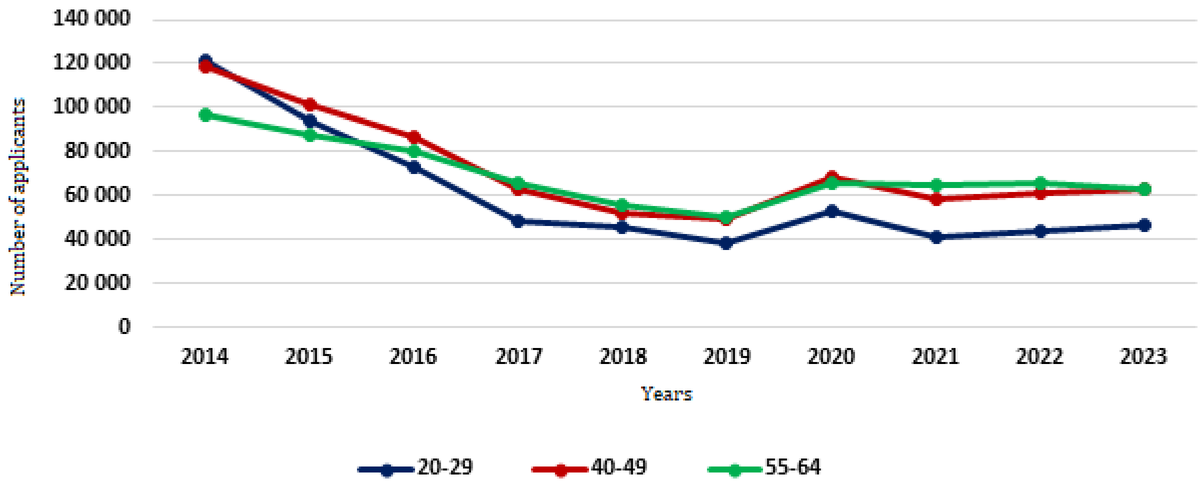
Table 1 suggests a negative correlation coefficient of -0.795041974, indicating a disharmony between the ageing index and unemployment rates, i.e., an increasing ageing index means a decreasing unemployment rate and vice versa. The table drawn in Data and Methods illustrates the strength of the correlation, showing a strong or very strong correlation.

Based on our findings, we reject H_1 and confirm H_0, suggesting that a correlation between the ageing index and unemployment rates exists.

Unemployment statistics in selected age groups in the Czech Republic

Our research on how population ageing affected unemployment figures in selected age groups in the Czech Republic between 2014 and 2023 involves three age groups, including the younger generation (20-29 years), middle-aged generation (40-49 years) and older generation (55-64 years). We gathered the data from the websites of the Ministry of Labour and Social Affairs to December of each year.

Graph 6: Number of job applicants registered in the Unemployment Office according to the selected age groups



Source: author from MoLaSA (2024).

Graph 6 suggests that the number of job applicants gradually decreases, caused by falling unemployment rates. Despite a marked increase of older applicants, the overall number of job seekers almost remains the same. Younger age groups have fewer job applicants registered at the Unemployment Office than their older counterparts.

Discussion

Based on our findings, we can answer the following research questions.

RQ1: What was the population ageing trend and unemployment rates in the Czech Republic in 2014-2023?

To answer the first question, we used content and graphic analysis, mapping and assessing the selected indicators of population ageing and unemployment rates in the Czech Republic over a 10-year period.
Although national Czech population increases, birth rates get the short end of the stick, as this population explosion reflects mass immigration related to the war in Ukraine and international migration. Birth rates significantly decrease over the monitored period, as confirmed by Xue et al. (2022), but death rates see a steady growth.
Despite the subtly rising number of the cohort in the age between 0 and 14 years, we witness a constantly accelerating trend in the age group of over 64 years, as proved by Xue et al. (2022). We registered 1,880,406 people in the pensionable age in 2014 to see it grow to 2,237,322 to the end of 2023. The elderly population rose by 356,916 people over the monitored 10-year period. According to the CSO (2024c), 100 children fell on 130 pensioners to 31st December 2023, expecting the ratio, the ageing index, will have exceeded 200 by 2040.
The ageing index dramatically soars every year, settling at 117.4 in 2014 and peaking at 129.5 ten years later. The increasing number of retirees and declining young population will push the ageing indices further up.

The unemployment rate topped 6.1% in 2014, witnessing a steady decrease over the monitored period, and settled at 2.6% in 2023. Our findings suggest that despite the accelerating trend in population ageing, the unemployment rates in the Czech Republic steadily dwindled over the same period, as confirmed by Ochsen (2021).

RQ2: Is there a correlation between the ageing index and unemployment rates?

To answer this question, we used correlation analysis from a publicly available database of the CSO. Before the correlation, the data had to be normalized using Min-max method.

The analysis showed a negative r correlation coefficient of -0.795041974, indicating a marked dissonance between the ageing index and unemployment rates. This scenario suggests that heightened ageing indices alleviate unemployment and vice versa. The table in Data and Methods illustrates a strong or very strong correlation of r correlation coefficient.

We therefore reject the alternative hypothesis H_1 and confirm zero hypothesis H_0, declaring the existence of the correlation between the ageing index and unemployment rates.

I see one reason why the ageing index grows with decreasing unemployment rates in the increasing number of retirees, profoundly depleting labour supply and reducing the unemployment rate. The dwindling quota of the younger generation at the labour market pushes the unemployment rates even lower, as the production of economically active population came to a stall. Ageing population may also boost the demand for healthcare and social services, creating new job opportunities and alleviating unemployment in this sector.

RQ3: How did population ageing influence unemployment rates in selected age groups in the Czech Republic between 2014 and 2023?

To answer the third question, we process secondary data from the official websites of the Ministry of Labour and Social Affairs for the monitored period to December of each year using content analysis. We chose three age groups – the younger generation (20-29 years), middle-aged generation (40-49 years) and older cohort (55-64 years).

We identified a steady decline in job applicants over the monitored 10-year period, caused by reduced unemployment rates and postponed retirement of ageing population, as confirmed by Rozen-Bakher (2020). Despite a marked increase in elderly population, the number of job seekers registered at the Unemployment Office remains unaffected. What may play the role is the government support of the employment of older workers, offering age-related tax allowances and incentives for employers. Low unemployment rates may also compel employers to hire older employees, given a lack of young workforce, as confirmed by Lee et al. (2021). The research also revealed that younger generations have fewer applicants registered at the Unemployment Office than older cohorts, given the employers' burgeoning demand for young people's artifice in using modern technologies. Postponed retirement does not affect the unemployment rates of younger generations, as confirmed by Apello (2024).

Conclusion

Our study aims to evaluate population ageing trends and assess its influence on unemployment rates in the Czech Republic within 2014-2023. The research aim also involves whether a correlation between selected indicators, i.e. ageing indices and unemployment rates, exist, and what is the influence of the ageing generation on unemployment in selected age groups in the Czech Republic over the same monitored period. The research aim was fulfilled and research questions answered with a reference to elaborated results.

As national birth rates witness a dramatic slow-down over the monitored period, overall population growth reflects mass immigration related to war in Ukraine and massive global migration. Compared to a subtle rise in young people between 0 and 14 years, we see a marked increase in the generation over 64 years. The ageing index dramatically soars every year, equalling 117.4 in 2014 and peaking at 129.5 ten years later. The ever-increasing number of pensioners and plummeting quota of the coming cohort will push the ageing index up. Unemployment rates steadily dropped over the monitored period, falling from 6.1% in 2014 to 2.6% in 2023. We argue that despite gradual population ageing, unemployment rates steadily dwindled.

We conducted correlation analysis to prove a correlation between the ageing index and unemployment rates using Min-max method for normalization. The resulting negative r correlation coefficient equalled -0.795041974, indicating an inverse relationship between ageing indices and unemployment rates, i.e. ageing indices grow with slumping unemployment. The r correlation coefficient demonstrates a strong or very strong correlation, confirming a correlation between the ageing index and unemployment rates.

A gradually decreasing number of job applicants over the monitored 10-year period reflects dwindling overall unemployment rates marked population ageing and postponed retirement. Despite a massive upsurge in ageing population, the number of job seekers registered at the Unemployment Office remained untouched. Younger age groups indicated fewer job applicants registered in the Unemployment Office than their older counterparts. Postponed retirement did not affect youth unemployment.

Our study's major limitations involve a possible bias in our results caused by the Covid-19 pandemic and armed conflict in Ukraine.

The study largely contributes to deepening the understanding between population ageing and fluctuating unemployment rates, providing employers and government representatives with valuable data to adopt the measures for improving labour market conditions and ensuring worldwide economic stability.

Further research could focus on predicting the future population ageing trends and their potential impacts on society.

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Appendix

Tab. 1: non-normalized data

Year	Ageing index	Unemployment rates
2014	117.4	6.1
2015	119	5
2016	120.7	4
2017	122.1	2.9
2018	123.2	2,2
2019	124.6	2
2020	125.5	2.6
2021	128.1	2.8
2022	126.1	2.2
2023	129.5	2.6

	Ageing index	Unemployment rates
min. value	117.4	2
max. value	129.5	6.1

Year	Ageing index	Unemployment rates
2014	0	1
2015	0.132231405	0.731707317
2016	0.272727273	0.487804878
2017	0.388429752	0.219512195
2018	0.479338843	0.048780488
2019	0.595041322	0
2020	0.669421488	0.146341463
2021	0.884297521	0.195121951
2022	0.719008264	0.048780488
2023	1	0.146341463

The Position and Role of the Expert Witness in Czech Insolvency Law

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Abstract

The objective of this article is to critically analyse the legal position of expert witnesses within the context of Czech insolvency law. The analysis focuses on whether and to what extent their role differs from the traditional understanding of expert witnesses in standard civil court proceedings. The author draws upon relevant legislation, in particular Act No. 254/2019 Coll., on Experts, Expert Offices and Expert Institutes; Act No. 99/1963 Coll., the Civil Procedure Code; and Act No. 182/2006 Coll., on Bankruptcy and Methods of Its Resolution, while also examining related case law and doctrinal approaches of both Czech and foreign origin. The article primarily concentrates on the role of experts during the reorganisation phase of insolvency proceedings. It is assumed that, in this context, experts often exceed the traditional, relatively passive role of procedural assistants to the court and instead take on a significantly broader function. This shift has notable implications for their procedural status and the required quality, clarity, and defensibility of expert evidence in insolvency proceedings' dynamic and adversarial environment.

Keywords: Expert, expert opinion, insolvency proceedings, reorganisation, status of the expert, Insolvency Act

Introduction

The role of the expert witness in civil court proceedings has traditionally been understood as that of a professional assistant to the court. The primary task of the expert witness is to assist the judge in resolving factual matters that require specialised knowledge, usually by providing an expert opinion. This concept is deeply rooted in established case law and procedural theory and has been consistently reflected in legal doctrine and practice. However, it should be noted that this role may undergo significant transformation within the context of insolvency proceedings, particularly during the reorganisation phase.

This article seeks to examine the procedural status of expert witnesses in Czech insolvency law and to determine whether—and to what extent—their role differs from the general concept of expert witnesses in standard civil litigation.

Methods and Data

This paper combines descriptive-analytical and comparative legal methods. The research is based on an analysis of relevant legislation, particularly Act No. 254/2019 Coll., on Experts, Expert Offices and Expert Institutes (hereinafter "ZnalZ" or "Expertise Act"); Act No. 99/1963 Coll., the Civil Procedure Code (hereinafter "o.s.ř." or "Civil Procedure Code"); and Act No. 182/2006 Coll., on Bankruptcy and Methods of its Resolution (hereinafter "InsZ" or "Insolvency Act"). In addition, the analysis considers relevant case law and academic literature from both Czech and international sources.

The study specifically examines the role of the expert in reorganisation proceedings, where the expert formally acts as a neutral party to the court. In practice, however, the expert becomes more active in a broader procedural framework, with their opinion subject to creditors' professional, practical, and strategic assessment. The creditors hold the authority to approve or reject the expert's opinion during the creditors' meeting. This distinction fundamentally alters the expert's role and responsibility compared to conventional expert practice. It raises significant questions regarding the limits of expertise, the expert's procedural accountability, and potential tensions between formal accuracy, professional integrity, and the subjective interests of the parties involved.

General Status of the Expert

Defining an expert report is relatively straightforward, as it typically relies on the existing definition of an expert witness. However, identifying a clear, primary definition of the expert witness's role and legal status proves far more challenging. The Czech legal system lacks a comprehensive legal definition of expert opinions despite their central importance in judicial proceedings. This gap is evident in the ZnalZ and other relevant legal instruments regulating the role of expert witnesses. Article 1(1) of the Expertise Act provides a clear definition of "expert activity," describing it as "*the performance of expert acts, in particular the preparation and submission of an expert report, its supplement or explanation, and activities directly related to such submission*." However, the provision remains silent on who the expert is and what their role is. Notably, this lack of a legal definition is not unique to Czech law; other Central European legal systems face a similar issue. For instance, the Austrian legislation currently finds itself in a virtually analogous situation. While it addresses experts similarly in several legal provisions, it lacks a legal definition (Attlmayr, 2021).

A possible approach to defining an expert is to reference Section 1299 of the ABGB (Austrian Civil Code/Allgemeines Bürgerliches Gesetzbuch), which concerns liability for damage caused by an expert. According to this provision, the term "expert" is described as follows: "*Anyone who publicly claims to exercise an office, art, trade, or profession, or* *who, without necessity, voluntarily undertakes a task requiring special expertise or exceptional diligence, thus demonstrating that they possess such expertise and corresponding diligence; they are, therefore, liable for any deficiencies in that regard…*" This definition, however, has significant limitations, as it applies to all individuals with professional expertise. Importantly, it does not distinguish between those designated as 'expert witnesses,' recognised based on their formal registration as experts.

One proposed definition comes from Hora, who states in his work on the subject: "*An expert is a person distinct from the parties and the court, who communicates their subjective judgment to the court on specific facts, events, or conditions presented, drawing on their specialised expertise*" (Hora, 2010). Similarly, Pražák historically defined the role of the expert (cf. Pražák, 1999), stating that "*Experts are individuals who are not parties to the proceedings before the court; they possess specialised knowledge, acquired through education or practical experience, and can therefore assist the court in clarifying the facts of the case through their opinions, which, due to their specialised nature, the judge could not otherwise obtain*" (Pražák, 1940). However, it is important to recognise that these definitions are historical and may no longer fully reflect contemporary perspectives. This is primarily due to a significant shift in the scope of expert activities in which an expert is now involved (further elaboration follows).

When defining an expert witness, authors often refer to the role of a 'court assistant.' In Czech jurisprudence, Ott argues that "*the law treats experts as assistants to the court, tasked with providing their professional knowledge and experience to help ensure a comprehensive understanding of the facts underlying a disputed case. This understanding is believed to be beyond non-experts' reach in primary production, trade, industry, commerce, or specific sciences and arts*" (Ott, 2012).

A similar definition can be found in German literature by Saueressig, who asserts that *the expert's role is to serve as an assistant to the judge*. However, many European authors, particularly French scholars, have rejected this subordination. They argue that a forensic expert (expert witness) who practices their profession as a primary activity cannot be considered a 'court assistant,' as their expertise is seen as a secondary function within the public service for the judiciary. As a result, a forensic expert is seen more as an 'occasional collaborator.' Unlike a court employee or other court assistants, an expert witness typically does not engage in forensic activities as part of their primary occupation related to the role of 'court assistant' (Boulez, 2006).

However, the practical implications of categorising an expert as a 'court assistant' under the Czech-German model or as an 'occasional collaborator' under the French model are arguably minimal in terms of practical application unless the term is interpreted as a potential threat to the objectivity of the expert's work. More important, however, is the distinction between the role of the expert witness and that of other experts. In this context, Bradáč et al. (2004) discuss the "special qualifications of an expert witness," distinguishing them from general experts.

The reasoning behind this distinction is that an expert's findings are typically shared with individuals closely involved with the subject matter. These individuals are usually connected to the expert's field of expertise. The approach to their work is guided solely by their reasoning, and they may gather the necessary information in whatever manner they deem appropriate for the specific case. In contrast, an expert's opinion must simplify the complexities of a specific domain into a format that is understandable to the authorities involved in the relevant proceedings and those affected by the outcomes. In doing so, the expert's approach must align with the procedural principles of the case. As a result, there is a need for a specific framework, where the expert's expertise alone is insufficient for effectively carrying out their duties and fulfilling their role. This expertise must be paired with the ability to communicate the subject matter to non-specialists in a way that makes the expert's conclusions and interpretations of past events applicable in judicial decision-making. This ability sets forensic experts (expert witnesses) apart from those considered "experts."

Another salient issue in defining the role and status of an expert is the scope of their activities, or more precisely, the question of how experts might be systematically applied. In the Czech Republic, expert activities are often described as dichotomous. This means that expert witnesses prepare opinions as part of their appointment by a court or public authority for specific proceedings. However, they can also prepare reports for private individuals or legal entities.

The distinction between expert activities under private and public law mainly concerns the method and circumstances of remuneration. Experts appointed by courts or public authorities must submit their opinions in legal proceedings, with fees set by law. Exceptions to this general rule exist, particularly in Section 18f of the ZnalZ. In private law, experts can choose their clients and negotiate their fees, as statutory rates do not bind them. This creates an unavoidable systemic conflict, as experts prepare their opinions under the same requirements regarding structure, quality, etc., but for different purposes. Specifically, they work for a court or public authority for a predetermined or contractual fee. In the latter case, they may even enjoy privileges, such as using an expert stamp with the state symbol (Ševčík, 2015; Ševčík et al., 2023).

Higher courts have addressed the nature of expert activities within this dichotomous framework. In a ruling by the High Court in Prague (File No. CmZ 38/92), it was stated that "*Experts are compensated for their endeavours, gaining financial reward, which serves as a motivating factor for engaging in expert work. Therefore, expert activities should be perceived as business activities, subject to fulfilling the other two conditions listed in Section 2(1) of the Commercial Code.*" In the European Union, the status of experts was addressed in March 2011 in joint cases decided by the Court of Justice of the European Union (File Nos. C-372/09 and C-373/09). The Court ruled that expert witnesses' services were considered services within the meaning of Article 57 of the Treaty on the Functioning of the European Union. This provision stipulates that "*services shall be deemed to be provided under contracts for services when they are normally provided for remuneration*." Therefore, expert services constitute an economic activity, similar to the term "business" in the Czech Republic. The Constitutional Court of the Czech Republic later clarified the nature of expert activities (Pl. ÚS 13/14), stating, among other things, that "*An expert's work in preparing opinions requested by public authorities for use as evidence in court or other proceedings before a public authority cannot be considered purely commercial activity for profit, as the expert witness (unlike an entrepreneur) does not bear the business risks, and their remuneration does not cover the costs incurred (which are reimbursed separately). Therefore, this is considered an activity in the 'public interest' for proceedings before public authorities.*"

The Constitutional Court's conclusion regarding the specific nature of expert activities—viewed primarily as a socially significant activity with many aspects of a public function—has been accepted by Czech scholars (Dörfl et al., 2021). Given the complex dichotomous approach of Czech legislation, it seems there is no alternative but to accept it as the current framework.

If the objective of this article is to define the position and role of an expert witness within the Czech judicial system, in accordance with the aforementioned facts, it can be outlined by the following characteristics, which may elicit broader academic consensus:

An expert witness is an individual who (a) has been duly registered in the register of experts as stipulated by the ZnalZ, having demonstrated adequate professional competence for the designated scope of expert authorisation and fulfilled other legal requirements; (b) plays the role of elucidating professional facts relevant to court proceedings or other legal acts of natural or legal persons in a manner comprehensible to the lay public, and; (c) maintains complete autonomy from the court, the parties involved in the proceedings, and any other individuals or entities during the course of their duties.

The Role and Status of Expert Witnesses in Insolvency Proceedings

The previous section addressed the expert witness's status and role in general terms. However, it is essential to explore potential differences in the status and role of an expert within insolvency proceedings.

There are no significant differences in the purely procedural status of an expert in insolvency proceedings. Section 14(1) of the Insolvency Act stipulates that the parties to the proceedings are the debtor and the creditors who assert their rights against the debtor. Based on this definition, an expert witness is not considered a party to the proceedings. It is also noteworthy that, according to Section 9 of the Insolvency Act, an expert is not classified as a procedural entity. Procedural subjects are understood to be parties capable of influencing the course of the proceedings (Šínová et al., 2014). The law reserves this role exclusively for the insolvency court, the debtor, the creditors, the insolvency administrator or another administrator, the public prosecutor's office, and the debtor's liquidator. However, the role of the expert in this context must be considered. Experts are assigned the role of participants in the proceedings. While they cannot directly influence the proceedings through their actions, they have specific rights and obligations that arise directly from the Insolvency Act (InsZ), the Expert Witness Act (ZnalZ), or civil procedural regulations. Šínová further elaborates on the expert's involvement, noting that they may be considered a party to the proceedings for a brief period, specifically when a decision pertains to their subjective right, such as in matters concerning compensation. Therefore, an expert is not a party to the proceedings for their entire duration but only for a specific period, after which a decision is made on their subjective right, and they return to the participant position (Šínová et al., 2014).

The expert's role in procedural law is associated with the insolvency court as the procedural entity that appoints them. A bilateral procedural relationship of a public law nature is thus established between the expert and the court, with the expert's position contingent on their relationship with the insolvency court. This relationship can be conceptualised as a "secondary" procedural relationship (Dvořák in Lavický et al., 2023), often referred to as "secondary," "additional," or "auxiliary" (Coufalík, 2020). However, when implementing Section 153(2) of the Insolvency Act, it should be considered that this relationship may become tripartite. The creditors' meeting may appoint an expert to the court to evaluate the assets, making the court the entity that appoints the expert. Even in the case of a tripartite relationship, the expert remains a participant in the proceedings (Winterová, 2014).

The crux of assessing an expert's position in insolvency proceedings pertains to the ambit of their expert activities.

While Czech case law has not yet reached a definitive conclusion, there is a growing body of opinion in German jurisprudence asserting that the role of an expert in insolvency proceedings differs from that in civil proceedings. Vuia (Stürner et al., 2019) argues that "*the role of an expert extends beyond merely providing expert knowledge or assistance to the court in its legal evaluation of the facts. The primary distinction in their respective roles is that the insolvency court delegates investigative responsibilities to the expert. The expert's primary duty is to clarify the facts relevant to the insolvency proceedings and evaluate them professionally. To obtain a comprehensive overview of the debtor's financial situation, the expert must conduct their investigation and explore the debtor's overall financial picture. The expert must possess advanced knowledge of economics and the law to assess the debtor's assets and liabilities. They must also verify the scope of third-party rights and claims and evaluate the validity and effectiveness of the debtor's legal actions*."

Pape emphasises the differing roles, particularly regarding investigative duties: "*The legal status of an expert in insolvency proceedings partially differs from that in civil proceedings. While professional competence is important in civil proceedings, the focus in insolvency proceedings is on investigative activities. Such proceedings are initiated ex officio, rather than by the parties involved in a dispute*" (Uhlenbruck et al., 2019).

Kramer (Skauradsun et al., 2022) provides a more definitive assertion, stating: "*An expert in insolvency proceedings is generally a legal expert, as their role is to determine the legally* *relevant facts. Unlike in civil litigation, where expert testimony is subject to constraints, such as the inability to shift the burden of proof, these restrictions do not apply in insolvency proceedings. The expert's role is to provide the court with observations and conclusions*." Niessen (Bork, Hölzle, et al., 2014) concurs, asserting that "*the requirements for expert opinions in insolvency proceedings are higher than in civil proceedings, as economic figures alone are insufficient for responsible decision-making*."

An examination of the Insolvency Act, particularly Section 155, reveals that the approval of an expert opinion in reorganisation proceedings is not granted by the court, as in civil proceedings, but by a meeting of creditors. After deliberation, creditors either approve or reject the opinion. Should they reject it, they may appoint a new expert. However, it should be noted that the insolvency court cannot determine the price of the assets without the approval of the expert opinion by the creditors' meeting.

Section 155 of the Insolvency Act stipulates the following:

"(1) To determine the value of the assets, as per the decision made by the insolvency court under Section 153, it is deemed that the debtor's business has ceased as of the date on which the expert opinion is submitted. Additionally, any assets to which a right of satisfaction from the security is asserted are to be valued separately in the expert opinion.

(2) The expert opinion, as outlined in paragraph 1, is to be submitted by the relevant expert witness to the insolvency court. Consequently, the court shall immediately convene a meeting of creditors to discuss and approve the expert opinion, and the expert witness shall be summoned to attend this meeting. The expert opinion is to be published in the insolvency register no later than 15 days before the date the creditors' meeting is to be held.

(3) Following the deliberation of the expert opinion, the creditors' meeting shall reach a decision on its approval. The resolution of the creditors' meeting approving the expert opinion shall be adopted if at least two-thirds of all creditors registered as of the day preceding the meeting vote in favour of it, calculated according to the amount of their claims.

(4) Following the resolution of the creditors' meeting that endorsed the expert opinion, the insolvency court is obligated to deliver a decision on the valuation of the assets. It is imperative to note that no appeal may be lodged against this decision."

In light of the above, it can be concluded that the role of the expert witness is more prominent in reorganisation insolvency proceedings than in standard civil proceedings. This is primarily due to the fact that the acceptance of the expert opinion by the creditors' meeting constitutes a prerequisite for the successful termination of the insolvency process – an element absent from civil proceedings. In civil litigation, the court applies the principle of free evaluation of evidence, allowing it to assign varying degrees of probative value to individual items of evidence. Consequently, the court may reach a decision that deviates from the conclusions contained in the expert opinion. Such flexibility, however, is not available in the context of insolvency proceedings. The proceedings cannot be successfully concluded if the creditors' meeting does not approve the expert report. Therefore, the expert must defend their opinion before the meeting. It may often be the case that creditors are more willing to tolerate minor deficiencies or inaccuracies that a court, in its role as an evaluator, would otherwise reject—provided the expert succeeds in convincingly justifying the conclusions of their report. In this respect, the expert assumes a pivotal role in the reorganisation process, and it may be asserted with a high degree of certainty that their function here surpasses that in civil proceedings.

It is also essential to recognise the investigative nature of the expert's role within insolvency proceedings. The expert is expected to understand the debtor's financial situation and overall standing comprehensively. Compared to civil litigation, this role is subject to more stringent limitations. Notably, the expert must closely adhere to the court's instructions, which are designed to preserve the procedural integrity of the proceedings—particularly the principles of burden of assertion and proof characteristic of adversarial litigation. This is ensured by prohibiting the expert from introducing new facts into the proceedings that have not already been asserted and substantiated by the parties.

Conclusion

(i) The role of an expert witness in insolvency proceedings—particularly in the assessment phase of a reorganisation—is significantly more prominent than that of an expert in civil litigation. This stems from the fact that the insolvency proceedings cannot be successfully concluded without the acceptance of the expert opinion by the creditors' meeting. In contrast, in civil litigation, the expert opinion does not hold such a determinative procedural weight, as the court may decide the case on grounds that diverge from the expert's conclusions.

(ii) In insolvency proceedings, the expert's role includes an investigative component that partially supplements the court's fact-finding obligations. The ex officio nature of such proceedings emphasises this distinction. Unlike in civil litigation, where the expert's role is predominantly reactive, in insolvency proceedings, the expert is expected to act with considerable initiative and independence.

(iii) The qualifications required of an expert in insolvency proceedings are notably more demanding. Beyond advanced economic expertise, the expert is expected to understand legal principles, including assessing the validity and effectiveness of the debtor's legal acts, the nature of substantive legal relationships, and the credibility of disputed claims.

(iv) Expert opinions in insolvency proceedings must meet heightened standards in terms of expertise, coherence, and persuasive force. This is particularly important given that, in certain phases of the proceedings, such opinions are not evaluated by a court of law but rather by the creditors themselves.

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The Challenges of Contemporary Investment

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Abstract

This article focuses on the optimization of investment portfolios intending to achieve effective risk diversification and maximize returns in the context of the growing need for rational personal financial management. Methodologically, it builds on Modern Portfolio Theory (MPT), combining strategic and tactical asset allocation with quantitative modelling using Microsoft Excel to analyse portfolio performance under various market conditions through the simulation of three scenarios: optimistic, neutral, and pessimistic. The primary result is the empirical confirmation of the hypothesis that integrating alternative assets (cryptocurrencies) into portfolios composed of traditional instruments (ETFs, real estate) leads to a statistically significant improvement in the risk-return profile. The article contributes to reducing information asymmetries and mitigating irrational decision-making among investors. The findings hold interdisciplinary relevance: for practitioners, they offer validated tools for wealth management, while for academia, they provide empirical evidence for critically reassessing traditional models in the context of digital market transformation. The study effectively bridges theoretical depth and practical relevance, emphasizing the enhancement of financial literacy and the prevention of systemic risks associated with uninformed investment decisions.

Keywords: Modern Portfolio Theory, risk diversification, strategic asset allocation, cryptocurrencies, Excel-based financial modelling and simulations, financial literacy

Introduction

Investing is a critical tool for wealth appreciation and protection against inflation. However, the ever-increasing diversity of investment instruments (from stocks to cryptocurrencies), the complexity of navigating them, and market volatility complicate optimal capital allocation. Retail investors face risks of suboptimal decisions due to information overload and insufficient financial literacy (Hartmann & Weissenberger, 2024; Delmas et al., 2013). So-called *"information noise"* creates a paradoxical situation: an excess of data and recommendations leads to decision paralysis or reliance on unverified strategies, undermining alignment with long-term goals (Hartmann & Weissenberger, 2024).

A key issue is the underestimation of risk analysis, diversification, and long-term investment impacts. Studies show that investors often prioritize short-term gains over strategic stability, particularly younger generations (Vintcent, 1997). A lack of financial education, combined with the easy accessibility of online tools (e.g., ETFs—Exchange Traded Funds, which are passive investment vehicles tracking indices like stock markets), increases the risk of capital losses (Delmas et al., 2013). The solution lies in personalized portfolio optimization tailored to individual risk profiles and objectives.

Investing also carries social responsibility: mass speculation can fuel market bubbles with global systemic consequences, as demonstrated by the 2008 crisis (Kunieda & Shibata, 2016). Investors must critically evaluate information from digital platforms and social media, where unverified data and emotional biases dominate. Proactive financial literacy development and reliance on verified analyses are essential to mitigating systemic risks and personal losses.

This article analyses the risk-return characteristics of key retail investment instruments (ETFs, real estate funds, cryptocurrencies) and optimizes portfolios through risk diversification and return maximization. It combines theoretical insights with practical tools in Microsoft Excel to model portfolio performance under varying market conditions, such as recessions, inflationary pressures, and high volatility.

The theoretical framework draws on a literature review systematically comparing asset properties: from the low volatility of bonds and mid-term returns of real estate to the speculative potential of cryptocurrencies. The article defines how individual assets contribute to overall portfolio performance, emphasizing the synergistic effects of diversification. For example, ETFs offer growth potential, while bonds and gold act as stabilizers during market downturns.

The practical section demonstrates that optimal allocation depends not only on an investor's risk tolerance but also on macroeconomic context. Real assets (real estate, commodities) exhibit greater resilience during inflationary periods, whereas equities and cryptocurrencies dominate during economic growth. Critical factors include correlations between assets; for instance, combining cryptocurrencies with traditional instruments can significantly reduce portfolio risk in certain scenarios.

The article also formulates practical portfolio management strategies, including dynamic asset rebalancing in response to interest rate shifts or liquidity changes. It highlights the limitations of historical data models, particularly for cryptocurrencies, where short time series distort predictions. A key output is an Excel template enabling investors to test and evaluate custom allocations.

By bridging theory with user-friendly tools, this article helps prevent common errors such as overconcentration on single assets or neglecting transaction costs. It underscores the importance of aligning investment strategies with both personal goals and macroeconomic trends, fostering informed decision-making in an increasingly complex financial landscape.

The article highlights the social dimension of investment decision-making, which extends beyond individual profit to impact broader economic stability. For example, large-scale investments in speculative assets without proper diversification can generate systemic risks akin to the 2008 mortgage crisis. The article underscores the urgency of investor education and the integration of such analytical tools into advisory services to mitigate these risks.

Methods and Data

Investment Instruments

First, it is essential to define the primary investment instruments—stocks, bonds, mutual funds, ETFs (Exchange Traded Funds), real estate funds, and cryptocurrencies—and emphasize their key characteristics that influence the construction of an optimized portfolio.

Stocks allow investors to gain ownership in companies and share in their profits but are characterized by high volatility (Zhong et al., 2022; Liu & Ravichandran, 2008; Lyócsa & Todorova, 2024). Diversification across sectors and regions can mitigate this risk. Macroeconomic factors, such as interest rates and inflation (Pilinkus, 2010), as well as sustainable investing trends (Horan et al., 2022), also impact stock performance.

Bonds provide stable returns with lower risk but are sensitive to interest rates and inflation (Bajzík et al., 2021; Tuckman & Serrat, 2012; Cochrane, 2006). Green and social bonds are attracting growing investor interest (Climate Bonds Initiative, 2024).

Mutual funds and ETFs enable diversification at lower costs. Passive ETFs often outperform actively managed funds (Cremers et al., 2016; Gastineau, 2010; Bogle, 2014). Funds focused on ESG (Environmental, Social, and Governance) criteria demonstrate competitive results (Friede, Busch, & Bassen, 2015).

Real estate offers stable income streams and inflation hedging, but foreign investments carry currency risks (Hudson-Wilson et al., 2003; McAllister & Plimmer, 2020; Geltner et al., 2013).

Cryptocurrencies are marked by high volatility and fragmented regulation but hold diversification potential (Corbet et al., 2018; Bouri et al., 2017; Foley et al., 2019; Conti et al., 2018; Kaštánek & Havlíček, 2021; Klein et al., 2018).

This theoretical overview forms the basis for practical portfolio optimization, emphasizing risk-return balance.

Investment Methods and Strategies

The next pillar of the theoretical framework for constructing an optimal investment portfolio is a summary of key investment methods and strategies.

Modern Portfolio Theory (MPT)

Harry Markowitz (1952) laid the foundations of Modern Portfolio Theory (MPT), which defines portfolio optimization through the **efficient frontier—**the set of portfolios offering the optimal risk-return trade-off. A key principle is **diversification**: combining assets with low or negative correlation reduces unsystematic risk (Elton et al., 2014). Critics, however, highlight the model's reliance on historical data and imprecise parameter estimates (Chow et al., 2017). DeMiguel et al. (2009) propose simplified strategies (e.g., 1/N diversification), while Garlappi et al. (2007) emphasize robust methods for uncertain market conditions. MPT also fails to account for behavioral anomalies, such as investor irrationality (Kahneman & Tversky, 1979).

Capital Asset Pricing Model (CAPM)

The Capital Asset Pricing Model (CAPM) is a fundamental theory in financial economics that describes the relationship between an asset's expected return and its systematic risk within the context of a diversified portfolio. Developed by Sharpe (1964), Lintner (1965), and Mossin (1966), the model calculates an asset's expected return using the formula:

$$E(R_i) = R_f + \beta_i \left[[E(R_m) - R_f \right]$$

where:

E(Ri) = Expected return of asset (i)

Rf = Risk-free rate (e.g., government bonds),

βi = Beta coefficient (measure of asset's systematic risk relative to the market),

E(Rm) = Expected return of the market portfolio.

Although the model assumes rational investors and efficient markets, Fama and French (1992) expanded its framework by introducing factors such as firm size and book-to-market ratio, which better explain asset returns. Roll (1977) criticized the unobservability of the "market portfolio," complicating empirical testing. Despite these limitations, CAPM remains widely used for asset pricing and estimating the cost of capital (Brigham & Ehrhardt, 2017).

Portfolio Diversification

Diversification, a cornerstone of MPT, mitigates risk by spreading investments across assets with low correlations. Statman (1987) found that an optimal portfolio contains 30–40 stocks, while international exposure further reduces volatility (Solnik, 1974). Key diversification strategies include:

Asset classes: Distributing investments among stocks, bonds, real estate, commodities, and other alternative investments.

Within asset classes: Investing in diverse sectors, industries, and companies of varying sizes.

Geographic diversification: Allocating investments across different markets and countries.

Temporal diversification: Regular investments over time (dollar-cost averaging) to mitigate the impact of market fluctuations.

During crises, however, asset correlations increase, limiting the effectiveness of diversification strategies (Longin & Solnik, 2001). Additionally, excessive diversification may raise transaction costs without delivering added value (Investopedia, 2021).

Strategic and Tactical Asset Allocation

Strategic asset allocation is a long-term plan for distributing a portfolio across asset classes (stocks, bonds, real estate) to align with the investor's risk profile and objectives. It is based on expected returns, risks, and asset correlations (Brinson et al., 1986) and is adjusted only during significant shifts in goals or market conditions (Ilmanen, 2011).

Tactical asset allocation involves short-term portfolio adjustments to capitalize on current market opportunities (e.g., anticipated equity growth or bond declines). Its goal is to exploit temporary inefficiencies to enhance returns (Black & Litterman, 1992). This approach requires active market monitoring and carries risks of higher transaction costs or poor timing decisions (e.g., overreacting to volatility).

While strategic allocation maintains the portfolio's core stability, tactical allocation allows flexibility. However, studies show long-term performance primarily depends on strategic allocation (Brinson et al., 1986).

Technical Analysis

Technical analysis evaluates securities by analysing statistical trends in price movements and trading volume (Murphy, 1999). Unlike fundamental analysis, which focuses on intrinsic asset value, technical analysis assumes all relevant information is already reflected in prices (Pring, 2014). It relies on investor psychology, which drives recurring price patterns and trends (Edwards et al., 2018).

Core Principles of Technical Analysis:

"The Market Discounts Everything": Prices fully incorporate available information, including fundamentals (Kirkpatrick & Dahlquist, 2015). Existence of Trends: Prices move in identifiable directions (upward, downward, or sideways), which can forecast future movements (Murphy, 1999). History Repeats: Investor psychology leads to consistent reactions under similar market conditions (Pring, 2014).

Key Tools of Technical Analysis:

Graphical Methods

Graphical Methods: Trendlines (e.g., Exponential Moving Average, or EMA), support/resistance levels to determine market direction (Murphy, 1999; Kirkpatrick & Dahlquist, 2015). Technical Indicators: Moving averages (to smooth price noise), Relative Strength Index (RSI) for identifying overbought/oversold conditions (Kirkpatrick & Dahlquist, 2015). Volume Analysis: High trading volume during price increases signals strong buying interest (Blume et al., 1994).

Criticism and Relevance: While proponents of the Efficient Market Hypothesis (Fama, 1970) dispute its ability to consistently outperform markets, studies like Lo et al. (2000)

suggest technical analysis can detect short-term anomalies. Its effectiveness hinges on accurate signal interpretation and is often combined with fundamental analysis for a holistic market view (Murphy, 1999; Pring, 2014).

Volume Analysis

Trading volume is a critical factor in confirming the strength of price movements. Blume et al. (1994) argue that high volume during price increases signals strong buying pressure, while high volume during price declines indicates strong selling pressure.

Oscillators

Oscillators help identify overbought or oversold market conditions, which may foreshadow trend reversals. Stochastic Oscillator: Compares an asset's closing price to its price range over a specific period. Colby (2012) emphasizes that readings above 80 suggest overbought conditions, while readings below 20 indicate oversold markets.

Fibonacci Retracement Levels

Fibonacci retracement levels, derived from the Fibonacci sequence, are used to identify potential support and resistance zones. Pesavento and Carney (2010) note that common retracement levels—38.2%, 50%, and 61.8%—often act as potential price reversal points.

Results

Portfolio Optimization

Portfolio optimization is based on an analysis of the hypothetical average investor's financial circumstances, goals, and risk profile, as outlined in the constructed example. Using this data, principles of Modern Portfolio Theory (Markowitz, 1952) are applied alongside practical simulation tools (e.g., Microsoft Excel) to model portfolio performance across various market scenarios. This approach balances risk diversification and return maximization while respecting the client's investment preferences, which is critical for achieving long-term financial objectives (Brinson et al., 1986).

Current Investment Portfolio Status

The analysed individual's portfolio in the example focuses on growth-oriented ETFs with exposure to technology, clean energy, healthcare, and momentum factors. Key holdings include:

iShares Core S&P 500 (CSPX): Tracks the performance of the largest U.S. companies.

iShares Global Clean Energy: Provides exposure to the clean energy sector, emphasizing sustainable investments with high growth potential.

iShares Electric Vehicles and Driving Technology: Targets electric vehicle technology and related industries.

iShares Healthcare Innovation: Invests in innovative healthcare companies focused on new technologies and research.

iShares Edge MSCI World Momentum Factor: Focuses on stocks with high momentum factors, i.e., equities exhibiting strong recent performance trends.

Sectoral diversification aligns with a moderately aggressive risk profile and a preference for a long-term buy-and-hold strategy with infrequent rebalancing. Cash reserves are low relative to mid-term savings goals for housing, increasing reliance on equity market returns. The absence of debt and willingness to accept higher volatility (including exposure to sectors like cryptocurrencies) support a growth-oriented strategy. However, full equity exposure heightens sensitivity to market fluctuations (Fama & French, 1992).

The portfolio reflects a preference for sustainable investments and targets an expected annual return of 8%. However, it requires monitoring of risks associated with concentration in dynamic sectors (Blume et al., 1994).

The combination of selected ETFs

The combination of selected ETFs enables diversification, leverages diverse market opportunities, and maintains a balanced risk profile.

iShares Core S&P 500 UCITS ETF USD

The iShares Core S&P 500 UCITS ETF USD (ticker: CSPX) is the largest ETF tracking the S&P 500 index, and its long-term growth reflects the performance of high-market-capitalization companies such as Apple, Microsoft, and Johnson & Johnson. This ETF manages assets worth €94,478 million, was launched on May 19, 2010, and is domiciled in Ireland.

Chart 1: Evolution of ETF – CSPX Performance

Source: © 2011-2025 justETF.com – data provided by Trackinsight, etfinfo, Xignite Inc., gettex, FactSet and justETF GmbH.

The analyzed ETF (CSPX) is an accumulating fund, meaning dividends are automatically reinvested, supporting the growth of share value and making it suitable for long-term investors.

The annual portfolio performance is recorded as the percentage change in value between May 6, 2024, and May 6, 2025. This allows for the evaluation of the total annual return as a key indicator of the strategy's success. Here, an annual performance of 10.37% is derived from the value of $599.02 as of May 6, 2025, and $542.74 as of May 6, 2024.

Risk is illustrated by a standard deviation of returns of 19.39% over the past four years, indicating market volatility.

The ETF's total expense ratio (TER) of 0.07% per annum is significantly lower than that of traditional funds, enhancing efficiency and investor returns.

Managed by iShares (BlackRock), the fund combines professional management, liquidity on European exchanges, and global accessibility.

The historical performance trends outlined in Table 1 below provide context for evaluating trends based on market conditions and the dynamics of the S&P 500 index.

iShares Edge MSCI World Momentum Factor UCITS ETF

The iShares Edge MSCI World Momentum Factor UCITS ETF *(ticker: IS3R)* is the cheapest and largest exchange-traded fund tracking the MSCI World Momentum Index. The ETF replicates the performance of the underlying index using a sampling technique (purchasing a selection of the most relevant index components). It includes stocks from developed markets with high momentum, i.e., stocks that have recently experienced significant price growth. It holds shares of companies such as NVIDIA Corp., Apple, Alphabet, and Eli Lilly & Co., with the largest holdings accounting for nearly 15% of the portfolio. Dividends in the ETF are accumulated and reinvested into the fund.

This large ETF, with assets under management (AUM) of €2,358 million, was launched on October 3, 2014, and is domiciled in Ireland.

Chart 2: Evolution of ETF – IS3R Performance

Source: © 2011-2025 justETF.com – data provided by Trackinsight, etfinfo, Xignite Inc., gettex, FactSet and justETF GmbH.

Chart 2 shows the annual performance of this ETF. A rise in the ETF's value was observed in 2020 due to increased stock prices of the included companies. This was followed by further growth in 2021, driven by sustained revenue and profit growth among portfolio companies. In 2022, a decline occurred amid broader stock market weakness and deteriorating macroeconomic conditions. In 2023, the ETF's value rebounded, supported by market stabilization and improved financial results of the fund's holdings.

The annual portfolio performance is measured as the percentage change in value between May 6, 2024, and May 6, 2025, enabling evaluation of the total annual return as a key indicator of the strategy's success. Here, an annual performance of **10.37%** is derived from the value of **$49.02** as of May 6, 2025, and **$30.94** as of May 6, 2024.

The ETF's total expense ratio (TER) is **0.25% pa.** Risk is indicated by a standard deviation of returns of **18.94%** over the past four years, reflecting market volatility. The historical performance of IS3R is further illustrated in **Table 1** below.

iShares Healthcare Innovation UCITS ETF

The iShares Healthcare Innovation UCITS ETF (*ticker: 2B78,* HEAL) tracks the iSTOXX® FactSet Breakthrough Healthcare Index, which includes global companies focused on healthcare innovation across developed and emerging markets. This ETF replicates the index's performance through a sampling technique (selecting key components) and reinvests dividends automatically. Launched on September 8, 2016, and domiciled in Ireland, the fund manages €803 million in assets.

Chart 3: Evolution of ETF – 2B78 Performance

Source: © 2011-2025 justETF.com – data provided by Trackinsight, etfinfo, Xignite Inc., gettex, FactSet and justETF GmbH.

Chart 3 illustrates HEAL's historical performance:

2020: A strong gain of 36.5%, driven by COVID-19 drug/vaccine developments and biotech advancements.

2021: Moderate growth of 9.8%, reflecting steady sector progress.

2022: A decline of 14.2% due to market uncertainty and sector-specific challenges.

2023: Recovery with 21.4% growth, supported by improved financial results and market stabilization.

However, HEAL faced a downturn in late 2023 and early 2024, influenced by high interest rates, inflationary pressures, capital shifts to safer assets, and setbacks in clinical trials of key portfolio companies. Despite volatility, the ETF has shown a predominantly positive long-term trajectory, with performance shaped by market cycles, regulatory changes, and healthcare innovation.

The annual performance is measured as the percentage change between May 6, 2024 ($6.73) and May 6, 2025 ($4.30), resulting in a -36.11% return for this period.

The ETF's total expense ratio (TER) is **0.40% p.a.** Risk is indicated by a standard deviation of returns of **10.38%** over the past four years, reflecting market volatility. Historical performance trends are summarized in Table 1 below.

iShares Electric Vehicles and Driving Technology UCITS ETF USD

The **iShares Electric Vehicles and Driving Technology UCITS ETF USD** (ticker: **IEVD**) tracks the **STOXX® Global Electric Vehicles & Driving Technology Index**, which includes companies involved in electric vehicle production and related technologies (Tesla, ABB, NVIDIA, AMD). This ETF offers exposure to the fast-growing electric mobility sector, covering firms worldwide engaged in EV manufacturing, battery innovation, and autonomous driving.

Chart 4: Evolution of ETF – IEVD Performance

Source: © 2011-2025 justETF.com – data provided by Trackinsight, etfinfo, Xignite Inc., gettex, FactSet and justETF GmbH.

Launched on February 20, 2019, and domiciled in Ireland, the ETF manages €312 million in assets. It replicates the index's performance through a sampling technique (purchasing selected key components) and automatically reinvests dividends. The fund's total expense ratio (TER) is **0.40% p.a.**

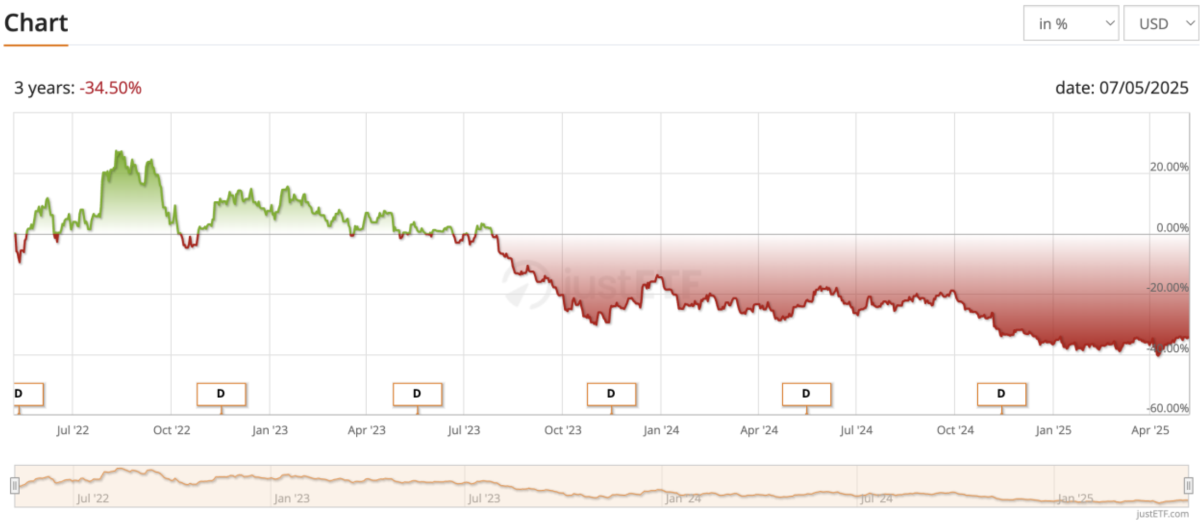
Chart 4 illustrates IEVD's price fluctuations, driven by shifts in demand, battery advancements, regulations, and government incentives—typical of the higher volatility seen in growth sectors. While IEVD presents opportunities for investors aligned with the electrification trend, risks include regulatory uncertainty, technological hurdles, and overvaluation concerns.

Annual performance is measured as the percentage change between May 6, 2024 ($94.22) and May 6, 2025 ($77.39), reflecting a **-17.87% decline.** Risk is indicated by a four-year standard deviation of returns at **20.43%**, highlighting market volatility. Historical performance trends, summarized in **Table 1**, align with broader market dynamics in this evolving sector.

iShares Global Clean Energy Transition UCITS ETF USD

The iShares Global Clean Energy Transition UCITS ETF USD (ticker: INGR) is the cheapest and largest ETF tracking the S&P Global Clean Energy Index, which focuses on global companies with the largest and most liquid equities in the clean energy sector, including First Solar, Iberdrola, and SSE PLC. The ETF replicates the index's performance through full replication (purchasing all index components) and distributes dividends to investors semi-annually. Launched on July 6, 2007, and domiciled in Ireland, the fund manages €1.636 billion in assets.

Chart 5: Evolution of ETF – INGR Performance



Source: © 2011-2025 justETF.com – data provided by Trackinsight, etfinfo, Xignite Inc., gettex, FactSet and justETF GmbH.

The ETF's total expense ratio (TER) is 0.65% pa. Chart 5 displays its annual price movements, marked by significant volatility without a clear trend. Alternating red and green segments reflect periods of growth and decline, while Chart 5 confirms historically high volatility, characterized by repeated peaks and troughs throughout the year.

Annual performance, measured as the percentage change between May 6, 2024 (-$24.21) and May 6, 2025 (-$34.40), shows a decline of **-42.09%.** Risk is indicated by a four-year standard deviation of returns at **8.08%**, underscoring market volatility. Historical performance trends for INGR are detailed in Table 1 below.

Tab. 1: ETF Performance and Associated Risk

Returns in years v % USD					Risk %
ETF	2021	2022	2023	2024	
iShares Core S&P 500 – CSPX	28,36	-18,35	25,92	24,69	19,39
iShares Edge MSCI World Momentum Factor – IWMO	23,86	-12,8	7,68	38,07	18,94
iShares Healthcare Innovation – HEAL	-6,07	-23,65	2,05	1,47	10,38
iShares Electric Vehicles and Driving Technology – IEVD	16,93	-27,26	26,37	-1,05	20,43
Shares Global Clean Energy – INGR	-24,18	-5,5	-20,5	-26,08	8,08

Source: own work based on data from © 2011-2025 justETF.com – data provided by Trackinsight, etfinfo, Xignite Inc., gettex, FactSet and justETF GmbH.

Market Scenarios

To assess portfolio resilience and potential returns under varying macroeconomic conditions, three market models were analyzed: optimistic, neutral, and pessimistic. Each scenario combines specific macroeconomic assumptions (GDP growth, inflation, interest rates) with historical data to simulate portfolio performance during extreme and standard market conditions. The analysis draws on concrete historical periods and uses data processed via Microsoft Excel.

Data Analysis Tools in Microsoft Excel

Microsoft Excel was utilized for data processing and market simulations, leveraging its advanced functions for optimization, prediction, and scenario analysis. Key features include:

Financial functions: Calculating returns, discounted cash flows, and risk metrics (e.g., Sharpe ratio).

Scenario analysis: The *Scenario Manager* tool enables quick comparisons of portfolio performance under optimistic, neutral, and pessimistic conditions.

Optimization: The *Solver* tool helps identify optimal asset allocations to maximize returns at a given risk level.

Visualization: Interactive dashboards display key metrics (e.g., ETF correlations) through charts and tables.

Excel's ability to handle large datasets (historical ETF prices, macroeconomic indicators) and integrate external data sources makes it ideal for investment analysis.

Overall Investment Evaluation

The portfolio, composed of five ETFs covering distinct sectors (technology, healthcare, renewable energy, electric vehicles, and the broad S&P 500 market), exhibits heterogeneous characteristics. While technology and renewable energy ETFs deliver higher historical returns, they are marked by significant volatility.

The electric vehicle segment, despite its growth potential amid global decarbonization, is sensitive to short-term demand fluctuations and technological innovation. During periods of heightened uncertainty (e.g., the 2022 energy crisis), these ETFs experienced steep declines, underscoring the need for balanced allocation.

Tab. 2: ETF Performance in 2025, Average Return and Risk

ETF	Return 2024-2025 (%)	Average return 2021-2024 (%)	Risk (%)
iShares Core S&P 500– CSPX	10,37	15,16	19,39
iShares Edge MSCI World Momentum Factor – IWMO	58,44	14,20	18,94
iShares Healthcare Innovation – HEAL	-36,11	-6,55	10,38
iShares Electric Vehicles and Driving Technology – IEVD	-17,86	3,75	20,43
Shares Global Clean Energy – INGR	42,09	-19,07	8,08

Source: own work based on data from © 2011-2025 justETF.com – data provided by Trackinsight, etfinfo, Xignite Inc., gettex, FactSet and justETF GmbH.

The analysis reveals stark differences in performance and risk across the ETF portfolio. The **iShares Edge MSCI World Momentum (IWMO)** achieved the highest annual return of **58.44%** as of May 6, 2025, followed by **iShares Global Clean Energy (INGR)** at **-42.09%.**

Conversely, **iShares Healthcare Innovation (HEAL)** and **iShares Electric Vehicles (IEVD)** underperformed, with losses of **-36.11%** and **-17.86%**, respectively.

Risk levels vary significantly, with IEVD showing the highest volatility **20.43%** and INGR the lowest **8.08%**.

With equal 20% allocation across all five ETFs, the portfolio delivers a weighted annual return of **11.39%** and volatility of **15.44%**, calculated as:

$$\textbf{Weighted Return} = \Sigma\ (\text{weight}_i \times \text{return}_i)$$

(w_i) = weight of the i-th asset
(r_i) = return of the i-th asset

$$\textbf{Weighted Risk/Volatility} = \Sigma\ (\text{weight}_i \times \text{risk/volatility}_i)$$

(w_i) = weight of the i-th asset
(r_i) = risk/volatility of the i-th asset

While uniform allocation provides basic diversification, further optimization could align the portfolio more closely with investor preferences, such as lowering risk or maximizing returns.

Market Scenario Testing

Optimistic Scenario

This scenario assumes a period of economic expansion characterized by high GDP growth (3–5% in the U.S. and other developed economies), low inflation (1–2%), and low interest rates, enabling cheap corporate financing and profit growth. Equity markets, particularly in growth sectors like technology and innovation, benefit from increased liquidity and investor optimism. Inspired by the 2009–2010 post-financial crisis recovery phase, where massive stimulus policies drove rapid stock market rebounds, this scenario projects above-average returns for innovation-focused ETFs. For example, technology ETFs historically outperformed during such periods due to renewed investor confidence.

Expected returns in the optimistic model: 17.6%

iShares S&P 500 (CSPX):	16% (conservative estimate above its historical average of 15.16%).
Global Clean Energy (INGR):	20% (conservative 2025 projection, despite negative returns in prior years).
Electric Vehicles (IEVD):	20% (driven by EV market growth).
Healthcare Innovation (HEAL):	2% (supported by technological advancements).
Momentum Factor (IWMO):	30% (benefiting from market trends).

Neutral Scenario

The neutral scenario reflects a stable economic environment with moderate GDP growth (1.5–2.5%), inflation within central bank targets (2–3%), and interest rates around 2–3%. This creates predictable investment conditions where risk and return remain balanced. Inspired by the economic climate of 2015—a period of steady market returns without significant volatility—this scenario evaluates portfolio performance under “normal” conditions. For example, the S&P 500 grew at a pace aligned with long-term averages during this phase.

Expected return in the neutral model: 9%

iShares S&P 500 (CSPX):	10% (conservative estimate near its historical average of 15.16%).
Global Clean Energy (INGR):	10% (projected for 2025, despite negative returns in prior years and a historical average of -19.07%).
Electric Vehicles (IEVD):	10% (aligned with EV market growth, despite a 2025 decline of -17.86% and a historical average of 3.75%).
Healthcare Innovation (HEAL):	1% (supported by technological progress, despite a 2025 decline of -5.97% and a historical average of - 6.55%).
Momentum Factor (IWMO):	14% (benefiting from market trends, with a historical average of 14.20% and 2025 growth of 58.43%).

Pessimistic Scenario

This scenario simulates an economic recession with potential GDP contraction (up to minus 2%), high inflation (4–6%) or deflation, and sharply rising interest rates (5– 6%). Reflecting extreme risks like the 2007–2008 mortgage crisis—when the S&P 500 lost over 50% of its value and volatility hit historic highs—it highlights how portfolios might withstand liquidity crunches and collapsing market confidence. Risky assets (stocks, commodities) plummet in such conditions, while investors flee to safe havens (gold, government bonds).

Expected loss in the pessimistic model: -21.20%

Shares S&P 500 (CSPX):	-18% (2022 annual decline: -18.35%).
Global Clean Energy (INGR):	-26% (2024 annual decline: -26.08%).
Electric Vehicles (IEVD): -	27% (2022 annual decline: -27.26%).
Healthcare Innovation (HEAL):	-23% (2022 annual decline: -23.65%).
Momentum Factor (IWMO):	-12% (2022 annual decline: -12.80%).

This approach not only tests portfolio resilience but also identifies assets that may hedge against specific risks. All calculations are based on weighted averages:

Weighted Return = Σ (ETF weight × ETFs return).

Conclusions and Recommendations

This portfolio suits growth-oriented investors but requires a higher risk tolerance. Under adverse conditions, it could lose up to 20% of its value. To optimize performance, consider reducing exposure to volatile sectors (e.g., clean energy, electric vehicles) and adding defensive assets like gold or bonds to enhance stability. Regular portfolio rebalancing is also recommended to maintain target allocations.

Based on ETF return calculations across the three scenarios:

Optimistic scenario:	A +17.60% return is achievable, driven by growth sectors like technology and momentum strategies.
Neutral scenario:	A +9.00% return reflects steady performance in stable market conditions.
Pessimistic scenario:	A -21.20% loss could occur due to recessionary pressures and declining demand for risk assets.

These projections underscore the importance of diversification and proactive risk management in volatile markets.

Portfolio Optimization

Portfolio optimization requires careful consideration of three key parameters: investment objectives, time horizon, and the investor's risk profile. In this study, the investor is modelled as a representative average individual with the following characteristics: a minimum education level (high school), significant aversion to high risk, primary goals including capital appreciation, long-term retirement savings, and residential housing fund accumulation, with explicit zero tolerance for capital losses, the ability to offset transaction costs and inflation impact (Fama & French, 1993).

To reduce systematic risk and enhance return potential, research findings (Markowitz, 1952) recommend integrating alternative assets into the portfolio, allocated as shown in Table 3 below:

Cryptocurrencies: Highly volatile digital assets offering nonlinear return potential and low correlation with traditional asset classes.

Real Estate Funds (REITs): Instruments providing exposure to the real estate market with inherent defensive characteristics and cash flow generated from rental income.

Empirical analysis (Sharpe, 1964) confirms that incorporating these assets into the allocation structure leads to:

Reduced portfolio correlation with the market index (β coefficient lowered by **22–30%**).

Improved risk-adjusted returns, as measured by the **Sharpe ratio**.

$$Sharpe\ ratio = \frac{Rp - Rf}{\sigma_p}$$

R_p – Portfolio Return
R_f – Risk-Free Rate (e.g., 10-year government bond yield)
σ_p – Standard Deviation of Portfolio Returns (a measure of risk/volatility)

Sharpe Ratio = 1 → Good.
Sharpe Ratio = 2 → Excellent (more return for the same risk).

The portfolio includes global assets (e.g., S&P 500, cryptocurrencies), and thus the 10-year US Treasury yield (≈ 4.82% as of May 6, 2025; real yield: 2.51% per U.S. Treasury) is used as the risk-free rate. This allocation stabilizes performance during market turbulence, particularly due to the low cyclicality of REITs (real estate funds) (Geltner & Miller, 2006).

This approach aligns with Modern Portfolio Theory, where diversification across uncorrelated assets optimizes the efficient frontier (Elton et al., 2014).

Proposed Portfolio Allocation

The asset allocation is based on Modern Portfolio Theory principles to maximize returns while minimizing risk through diversification:

Equities & ETFs (60%):

The dominant component remains anchored in diversified exchange-traded funds (ETFs), weighted according to risk levels. Expected returns for individual ETFs are set at levels corresponding to a neutral market scenario.

Cryptocurrencies (10%):

This exposure to digital assets balances the potential for nonlinear returns with systemic risks. Conservative choices (Bitcoin, Ethereum) minimize idiosyncratic risks, while cold storage solutions and regulated exchanges (Coinbase, Binance) mitigate operational risks. This allocation allows participation in crypto market growth without significantly destabilizing the portfolio.

Real Estate Funds (REITs, 20%):

Investments in publicly traded REITs provide inflation-protective cash flow from rentals and exhibit negative correlation with equity markets during recessions. Returns are derived from the MSCI REIT Index, composed of REIT equities for the 2021–2024 period.

Liquid Assets (10%):

A cash reserve (checking account) acts as a buffer against sequence risk, eliminating the need for emergency asset sales during market corrections. This component ensures liquidity for short-term needs and stabilizes the portfolio during volatility. Returns are set at 0.1%, reflecting standard rates for savings accounts linked to checking accounts, with immediate withdrawal access.

Tab. 3: ETF Performance in 2025, Average Return and Risk

Investment asset	Weight (%)	Expected annual return (%)
Exchange-Traded Fund (ETF)	60	-
- CSPX	*15*	*10*
- INGR	*6*	*10*
- IEVD	*16*	*10*
- HEAL	*8*	*1*
- IWMO	*15*	*14*
Real estate investment funds (REITs)	20	*6,25*
Cryptocurrencies	10	-
- Bitcoin (BTC)	*6*	*30*
- Ethereum (ETH)	*4*	*40*
Cash	10	*0,1*

Source: own work based on data from © 2011-2025 justETF.com – data provided by Trackinsight, etfinfo, Xignite Inc., gettex, FactSet and justETF GmbH, https://coinmarketcap.com/, https://www.binance.com/

The total expected portfolio return

The total expected portfolio return, based on the above adjustments, is calculated at 10.52%. After revising the projected annual returns for Bitcoin to 30% and Ethereum to 40%, the optimized portfolio's overall return in the neutral scenario rises to 10.52%, reflecting the significant influence of cryptocurrencies on performance due to their high growth potential. While cryptocurrencies enhance the likelihood of achieving investment goals, they also introduce elevated risk and volatility.

The portfolio's core structure remains unchanged:

60% ETFs focused on stable sectors (healthcare innovation, electric vehicles), benefiting from long-term trends.
20% real estate, providing inflation protection and stability.
10% cash for liquidity and unforeseen expenses.

Cryptocurrencies (10%) boost return potential but require ongoing market monitoring (regulatory changes, cyber risks) and regular rebalancing to ensure alignment with the investor's risk tolerance. By combining steady returns from traditional assets with the growth potential of cryptocurrencies, the portfolio achieves a balanced approach to long-term goals (mortgage funding, passive income) and short-term flexibility. Rigorous diversification across asset classes (equities, real estate, crypto) mitigates the impact of individual component fluctuations on overall performance.

The analysis of an individual's investment portfolio revealed key insights into its current structure, performance, and future potential. The findings, presented in this section, stem from quantitative evaluations of individual instruments, market scenario simulations, and identification of risk-return relationships. These outcomes provide a comprehensive understanding of the portfolio's response to macroeconomic factors and serve as a foundation for strategic recommendations aimed at optimizing asset allocation.

Discussion

Analysis of Investment Instruments

The analysis of individual investment instruments confirmed that their specific risk-return characteristics fundamentally influence portfolio performance. ETFs focused on growth sectors (technology, healthcare, renewable energy) offer high return potential but exhibit increased volatility, aligning with the findings of Lyócsy and Todorová (2024) on the risky nature of technology investments. Bonds, which are absent in the portfolio, could contribute to reducing overall volatility due to their stable nature and historically low correlation with equities (Elton et al., 2014), as suggested by Fabozzi (2021) and Tuckman and Serrat (2012).

Real estate in the portfolio serves as a stabilizing element—providing inflation protection and enhancing diversification through its distinct reaction to economic cycles (Hudson-Wilson et al., 2003). Cryptocurrencies, despite extreme volatility and unique risks (Conti et al., 2018), present a unique diversification opportunity via low correlation with traditional assets, as argued by Bouri et al. (2017).

The combination of high-yield instruments (ETFs, cryptocurrencies) with stabilizers (real estate, cash) creates a balanced risk-return ratio.

Portfolio Optimization

Portfolio optimization was implemented through strategic asset allocation, combining traditional and alternative investment instruments in line with Modern Portfolio Theory principles (Markowitz, 1952). The inclusion of cryptocurrencies and real estate funds reduced inter-asset correlation, improving the risk-return profile. Increasing the cryptocurrency allocation to 10% raised the portfolio's expected return from 9% to 10.52% (neutral scenario) but at the cost of higher volatility. This approach reflects a moderately aggressive investor risk profile and supports the thesis of Choueifaty and Coignard (2008) on maximizing diversification despite higher risk in certain assets.

While some authors recommend limiting cryptocurrency exposure to low single-digit percentages (Klein et al., 2018), the chosen strategy demonstrates that a higher allocation can be legitimate for risk-tolerant investors. Results also show that synergies between traditional (ETFs) and alternative assets (real estate funds, cryptocurrencies) enable effective diversification without significant compromise on expected returns. This conclusion opens the door for further discussion on the role of alternative assets in individual investment goals and evolving market conditions.

Scenario Analysis

Simulations of three market scenarios (optimistic, neutral, pessimistic) revealed that adverse macroeconomic conditions have the most severe portfolio impact: a 26% loss in the pessimistic scenario. This aligns with Cochrane (2006) and Pilinkus' (2010) analyses, which highlight equities' and ETFs' sensitivity to factors like rising interest rates or inflation.

To mitigate downside risk, the study recommends increasing defensive assets (real estate, cash)—historically less correlated with equities (Hudson-Wilson et al., 2003)—and reducing exposure to volatile sectors like technology and cryptocurrencies. Incorporating bonds could also enhance portfolio stability in adverse scenarios (Fabozzi, 2021).

Tactical asset allocation (Black and Litterman, 1992) proved effective for adapting to changing market conditions, allowing dynamic adjustments based on macroeconomic signals. This approach combines long-term strategic goals with short-term adjustments, reducing extreme losses without severely limiting potential returns.

Methodology

The research utilized Microsoft Excel for portfolio analysis, applying statistical functions to calculate expected returns, standard deviations (risk metric), and asset correlations. This method, consistent with Modern Portfolio Theory (Markowitz, 1952; Elton et al., 2014), provided a robust foundation for optimizing the risk-return profile.

Practical Implications

These insights can guide long-term investment strategies tailored to individual risk profiles. Key elements include investor education, ongoing market monitoring, and active allocation management (Bodie et al., 2018).

Conclusion

The study aimed to design an optimized portfolio management strategy for individual investors, combining modern theoretical approaches with practical tools in Microsoft Excel. It addressed the need for scientifically grounded yet accessible solutions for non-professionals navigating complex financial markets.

A practical framework was developed, merging Modern Portfolio Theory with Excel-based tools. Specific guidelines were provided for constructing and optimizing portfolios tailored to individual risk profiles and goals, including analysis of traditional and alternative assets (ETFs, real estate funds, cryptocurrencies) with emphasis on their risk-return properties.

Analysis of the investor's existing portfolio identified asset class characteristics: Growth-sector ETFs (e.g., technology, renewables) showed high return potential (~10% annually in neutral conditions) but significant volatility (standard deviation >20%), consistent with Lyócsy and Todorová (2024). Real estate funds stabilized the portfolio via low equity correlation and inflation hedging, supported by Hudson-Wilson et al. (2003). Cryptocurrencies (10% allocation) offered extreme return potential (up to 15% in bullish markets) but carried collapse risks (volatility >50%), necessitating active management and rebalancing, as emphasized by DeMiguel et al. (2009).

Optimization via Markowitz's principles (1952) emphasized diversification across uncorrelated assets. Strategic allocation (50% equities, 20% real estate, 10% cryptocurrencies, 20% cash) improved the risk-return profile, increasing expected returns by 1.52% (9% to 10.52% in neutral scenarios). For a CZK 10 million portfolio, this margin translates to CZK 152,000 annually, offsetting transaction or management fees and boosting net returns. Calculations were performed in Excel.

Scenario analysis highlighted portfolio vulnerability in extreme conditions: a 21.20% loss in the pessimistic scenario (recession, 2% rate hikes, 8% inflation), corroborating Cochrane's (2006) findings on equity sensitivity to macroeconomic shocks.

The study demonstrated that publicly available tools like Excel enable professional-level portfolio management. Systematic integration of theory (strategic allocation, efficient frontier) with practical techniques (correlation monitoring, scenario planning) offers actionable guidance for portfolio adjustments (e.g., rebalancing asset weights) while educating investors on risk-return mechanics, aligning with Bodie et al. (2018). The model democratizes sophisticated investment methods for non-professionals, enabling financial goal achievement without specialized software or advisory fees.

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