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AN ANALYSIS OF THE PERFORMANCE OF THE ESTONIAN II PILLAR FUNDS

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I hereby declare that I have compiled the thesis independently
and all works, important standpoints and data by other authors
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TABLE OF CONTENTS

ABSTRACT

This thesis is concentrated on the methods of the evaluation of the pension funds with traditional measures and proposes and alternative method of Data Envelopment Analysis. Pension funds are important players on the market and pension saving are the main income for the persons who is retired. Therefore, it is important to understand the actual performance of the chosen fund and be aware of the other possibilities.

This thesis provides an overview of the performance of the Estonian pension funds given with widely known methods and discussing the appropriateness of alternative method of DEA in evaluating the efficiency of financial bodies. The main question established throughout this work is how appropriate traditional measures for evaluation of pension funds are, are there alternatives and whether there are funds providing best trade-off between risk and return in Estonia. Traditional performance measures are undoubtedly useful and helpful giving mostly easy understandable and comparable results, but these methods do have some constrains. These deficiencies and lacks can be covered with DEA and thus more adequate and complete picture can be developed.

The results have revealed the high correlation between traditional performance measurement methods and DEA except for the situation where costs of the portfolio were included into the DEA model. The absence of addressing the costs in risk-adjusted measures is constantly mentioned by scholars. Analysis has revealed that there are efficient funds in Estonia whose risk-adjusted measures are also high. Risk-adjusted measures have to be treated together with some appropriate benchmark, while DEA creates an efficiency scores only among the chosen population and thus provides more thoughtful results.

Keywords: risk, return, pension fund, performance, DEA, risk-adjusted measures

INTRODUCTION

In a today's world people have vast majority of choices in all aspects of life and managing own finances is one of the most important areas, as money play essential part in fulfilling most of the desires. Given a freedom to choose what to do with your money, it is also a complicated decision for most of the people not close to the finance world. If a regular citizen can manage to decide on how to live everyday life, he or she seldomly thinks about the future and what is he or she going to do when will not be capable to work and earn money.

Aiming to protect people from poor elderly, governments have created the pension system offering an easy financial instrument for managing savings. As population around Europe becoming older and the proportion of pensioners increasing, the performance of pension funds is becoming more popular topic each year. Whereas having a choice of which funds to invest money in, decision might be difficult, as amount of information and advertisement may be overwhelming and misleading. Arguing how to choose an appropriate pension fund, the one can look on the funds' reports and prospects as a first point. However, usually the return of the investment is recorded as excess return which does not account for actual risks of investments. In case any risk-adjusted return measure is provided, it may be still hard to understand it and compare with other possibilities.

The performance of fund in Estonia is represented as a nominal return, meaning the total rate of return earned on an investment before adjusting for any costs and inflation. Following in this thesis I use term nominal return for return calculated as difference between original investment value and final value of investment and term real return for the return calculated with the same method and adjusted in any way.

It has been said many times among scholars that nominal return does not reflect the actual return (Carhart 1997). There are, however, several fund performance measures existing like Sharpe ratio, Jenson's alpha, Sortino ratio, etc., which measure performance adjusted with some risk factors. Modern portfolio theory also suggests using efficient frontier to evaluate the performance of the pension funds. The Data Envelopment Approach (DEA) is one way of the drawing of the efficient frontier.

The main difference between named performance measures and DEA consist in the fact that DEA does not require CAPM assumptions to be present and thus allows to analyse the performance of funds using any inputs and outputs according to user preferences. Moreover, DEA measures the efficiency among the certain population, what gives more precise results and future directions for the investor.

The objective of this thesis is to provide an overview of the performance of the Estonian II pillar pension funds' using several methods and discuss their appropriateness, given the nature of such investments. The evaluation is held using well-known performance measurement methods as well as data envelopment analysis (DEA) and following correlation analysis of the results is presented. During DEA analysis an output such as nominal return of the portfolio will be deployed with inputs reflecting the risk of the portfolio such as standard deviation of the returns, costs and downside deviation of the returns.

As result the answers to the following research questions will be discussed:

- What is the performance of the pension funds as measured with popular risk-adjusted measures?
- What is the performance of the pension funds as assessed using DEA?
- Is there a relationship between popular performance measurement methods and the outcome of DEA?
- Are there funds in Estonia, which have best trade-off between risk and return?

The rest of the thesis is organized as follows. In Chapter 1 a nature of the investment itself, return and risk will be explained, and the theoretical background will be presented. Following, the overview of the risk-adjusted performance measures such as Sharpe ratio, Jensen's alpha and Sortino ratio will be held. The theory is then followed by an overview of the empirical literature regarding the employing of risk-adjusted performance measures in funds' evaluation. In Chapter 2 the definition of DEA will be explained and the appropriateness of this method in funds' performance evaluation will be discussed. In this chapter the methodology will be explained in detail concentrating on the methods used in the empirical analysis. The overview of theoretical developments will be supplemented with review of empirical studies concluded on evaluation of performance of funds with DEA approach. In Chapter 3 the institutional background of Estonian pension funds, the description of data for the empirical evaluation and methods used will be presented. In the last chapter the results of the popular risk-adjusted performance measures and the DEA results will be reviewed and explained. The analysis of the appropriateness of the results and methods will be held, and conclusion drawn based on the empirical evidence received. Lastly, main conclusions and suggestions for the possible further development of the present work are given.

I would like to thank my supervisor Mr Karsten Staehr for providing a valuable advice, support, directions for improvements and guidance throughout the process of writing this thesis.

1. FUND PERFORMANCE MEASURES

1.1. Return and risk

Any investment has been made with some purpose, which is regularly to increase or save the value of money. In order to understand whether the investment is serving its goal, an investor should be able to measure the performance of the portfolio. While measuring the performance it is important to understand the difference between nominal and real returns. As mentioned in the introduction, term nominal and real return is employed in order to differentiate the metrics researched. In the academic literature, however, usually no special division created, but used such terms like excess or expected return and risk-adjusted return.

Regular investor of a II pension pillar has chosen some fund to invest his/her money in and has an opportunity to see the performance of chosen fund and consequently his/her personal investment by just reviewing the fund's reports or Estonian Funded Pension Registry website, where all information relating to Estonian pension funds is gathered. However, usually, the performance of Estonian pension funds is reflected as a nominal return, which is not adjusted on the risks of the investment and does not give a full picture of the performance. In order to understand the nature of return itself, it is first essential to get aware of the conception of risk and return.

Nominal return of investments is calculated as a growth of the investment value over a certain period, regularly since the first day of the investment. It does not consider possible deductions like fund managing costs, inflation, taxes or other fund fees. What is more important, nominal return does not account for the risks of the given portfolio. The risk of an investment is defined in terms of some uncertainty exposure related to the investment and that affects the expected returns. Whereas risk definition is broad, there are several types of risks in financial investment. Those are market risks, business risk, currency risk, volatility risk, etc., which can be compounded into two categories of risks – systematic and non-systematic (R. Turcan, C. Turcan, 2009, 696).

Regularly, portfolio bears both types of risks, whereas the systematic risk cannot be avoided, and non-systematic risk can be influenced through effective assets allocation. Systematic risk comes from such external factors like market interest rate, inflation rate, currency exchange rate, political and social factors and economics itself. This type of risk affects almost all investments and is not diversifiable. Non-systematic risk, in turn, depends on the nature of the investment and the issuer, like debt ratio or market share of the company, economic cycle of the specific industry and its developments. (R. Turcan, C. Turcan, 2009, 696) Non-systematic risk is regularly specific and is inherent to the investment.

As said by Farrell (1997), the objective of portfolio performance analysis is to assess how well an investment plan meeting its goals, as well as the degree to which investment managers are adding value in carrying out the investment plan. Measuring the performance of the portfolio gives the investor an understanding about how well an investment is meeting the goals of the investor. In that light, the existence of risk-adjusted performance measures is justified. Once performance of an investment is adjusted on a risk associated with this, it reflects the actual return and shows to the investor whether the portfolio is in align with person's risk preferences and required return.

Performance evaluations methods discussed further are built around measuring the market or systematic. Different types of market risks will be discussed further during the observation of performance measurement methods used. Before starting to analyse the methods of performance measurement it is appropriate to discuss a theory behind, giving an overview of the general asset pricing model, which explains the need for such methods.

1.2. Portfolio investment

Investment studies originate from the theory proposed by Harry Markowitz, which explains basic model of the portfolio selection. Later, based on his theory, all the rest methods were developed. According to modern portfolio theory introduced in 1952, the most important point in portfolio selection is to find an optimal balance between expected returns and accepted risks (Markowitz, 1952).

Any investment should be selected following mentioned principle, which helps to diversify risks while not reducing the expected returns. This view has become a cornerstone in other economic theories in finance and investment. With such a view it is then possible to construct an efficient frontier having the highest expected return for a given level of risk (Markowitz, 1952).

In the theory it is assumed that an average investor is risk-averse and wants to maximize the return of an investment given his/her risk preferences. In order to do so, an investor is aware of mean and variance of a portfolio's return. Following this rule, Markowitz's theory can be then called the "mean-variance model". (Markowitz, 1952) Thus, the risk and return are both important in measuring the performance of the portfolio and decision of whether invest in a security or not should consider abovementioned principles.

Based on the Markowitz's portfolio theory, the capital assets pricing model (CAPM) was later introduced by several scholars. It gained popularity among empirical researches and is still widely used. According to CAPM theory, the expected return of the assets is determined by market systematic risk, or portfolio's Beta. The assumptions used in CAPM are that markets are efficient, the average investor is rational and risk-averse, having similar to others time-horizon at the same time, there are no transactions costs and no restrictions on the investment. (Fama, French, 2004) Even though CAPM assumptions are unrealistic if considering all together, they are still useful in order to develop trackable model where risks and returns are combined as follows:

$$\text{Expected return} = R_f + \beta(R_m - R_f)$$

Where:

R_f = risk-free rate

β = Beta or market systematic risk

R_m = Return of the market portfolio

Following the CAPM model, many scholars presented more models later, taking into account other possible risks that might affect the returns, such as Sharpe ratio, Jensen's alpha and Sortino ratio. Named methods use such metrics like standard deviation, risk-free rate, market return and portfolio systematic risk to measure the return of an investment relative to the amount of risk represented in a portfolio.

It is important to notice that abovementioned performance measures do not separate portfolio's costs in performance evaluation, what might lead to not precise results, as some data reflecting return can be already without costs and some not. The absence of addressing the costs of portfolio is noted in most of the empirical researches as well as in theoretical explanations and gives a space for further developments of the methods which is also discussed in the thesis. Following, the major principles of three named methods are presented and their strengths and weaknesses discussed.

1.3. Sharpe ratio

Sharpe ratio measures the performance of the fund taking the excess return, relative to the risk-free rate, divided by the standard deviation of the portfolio excess return. The higher the ratio, the better is the investment. (Sharpe 1966)

According to William Sharpe (1966, 119), "the key element of the portfolio analyst's view of the world is his emphasis on both expected return and risk. The selection of preferred combination of risk and expected return depends of the preferences of the investor". Method proposed by Sharpe is universal attempting to combine risk and expected return into one metric, which shows greatest expected return for any given degree of risk. Sharpe has named the metric as a reward-variability ratio indicating a premium for the variability (risk) of each unit. (Sharpe 1996, 120) Following equation is used to calculate the Sharpe ratio:

$$S_p = \frac{R_p - R_f}{\sigma_p}$$

Where:

S_p = Sharpe ratio

R_p = return of the portfolio

R_f = risk-free rate

σ_p= standard deviation of the portfolio's excess return

Standard deviation measures the degree of fluctuations of the return in a given period from its average return and is widely used in other risk-adjusted measures. The risk-free rate has not been specified by the Sharpe, meaning that it should depend on the portfolio for which ratio is calculated. The risk-free rate means the nominal return of the portfolio not affected by market risks and which gives certain return in any situation. In empirical literature touching the Sharpe ratio usually the relevant government bonds return rate is used.

The advantage of this method is in its relative simplicity to calculate. Standard deviation covers both types of risks, which is suitable for any portfolio with different level of diversification and strategies. The deficiency consists on the relying on historical data, assuming that future is predictably similar to the past, what is not constant in dynamic market. Also, as standard deviation accounts for both positive and negative volatility, it does not reflect the difference between excess and negative returns. Additionally, the CAPM assumption of normal distribution of returns is hard to maintain in certain portfolios, where returns are asymmetric.

1.4. Jensen's alpha

According to Michael Jensen, the main difficulty consists in identifying the nature and measurement of risk, as more risky assets bring more return. Jensen's funds' performance measure refers to a fund manager's forecasting ability. He has suggested the measure, that "takes explicit account of the effects of "risk" on the returns of the portfolio". (Jensen 1968, 390)

Jensen's model, as well as Sharpe's one, is based on the assertion that all investors are risk-averse, have the same time-horizon and homogeneous expectations regarding investments opportunities, able to choose investments solely on the basis of expected returns and variance of returns as well as that all transaction costs and taxes are zero and all assets are infinitely divisible (Jensen 1968, 390). Jensen has suggested the model for measuring the performance of the portfolio in comparison with the benchmark portfolio, which uses risk-free rate as well as Sharpe ratio, but considers only systematic risk of the investment. Jensen added to his model the additional assumption that capital market is well balanced which led to the following equation:

$$\alpha = R_p - \left[R_f + \beta_p \left(R_m - R_f\right)\right]$$

Where:

α = Jensen's alpha α

R_p = return of investment

R_f = the one-period risk free interest rate

β_p = Beta of investment or portfolio systematic risk

R_m = market return or return of the chosen benchmark portfolio (Jensen 1968, 390)

The Beta or portfolio systematic risk is measured as the risk of an individual portfolio in comparison to the market. Beta is calculated by dividing the covariance of the portfolio's returns and the benchmark's returns by the variance of the benchmark's returns over a defined period:

$$\beta_p = \frac{COV(R_p, R_m)}{VAR\ (R_m)}$$

Jensen's alpha represents the average return of the portfolio showing whether portfolio earns return in accordance with risks accepted and measures excess returns comparing to a benchmark portfolio. A positive alpha indicates that an investment has better returns than a benchmark and thus earns excess returns and vice versa. In case having funds with similar Beta the investor should prefer the one with the higher Jensen's alpha as this indicates better return for the same risk taken. Main concern of this ratio consists in defining a right benchmark, which is not always possible and can lead to the faulty result.

1.5. Sortino ratio

The Sortino ratio is a modification of the Sharpe ratio where risk-free rate is replaced by the minimum acceptable return (MAR) and the standard deviation is substituted by the downside risk (Sortino 1994). Following equation has been developed by Sortino:

$$Sortino\ ratio\ = \frac{R_p - R_f}{\sigma_d}$$

Where:

R_p = return of investment

R_f = risk-free rate

σ_d = standard deviation of the downside risk

The downside risk means the standard deviation of negative portfolio returns. Sigma is calculated as the standard deviation of those returns which are below the MAR, whereas the number of observations is equal to the number of original return values. Thus, Sortino ratio measures the return of an investment relative to the bad risk only. It is worth to mention Markowitz's notice (1959), that downside deviation or semi-variance is more relevant to measure for performance of the investment as it measures the underperformance below the expected returns. The higher the return of the portfolio over the risk-free rate, the higher is the Sortino ratio and vice versa.

This ratio requires choosing some benchmark return or minimal acceptable return (MAR) for the comparison. However, unlike Sharpe ratio, Sortino ratio does not account for positive upside volatility, thus risk perspective might be incomplete. If we consider that the goal of the portfolio is to avoid negative returns, Sortino ratio is more appropriate than Sharpe ratio.

Being arguably ones of the most widely used, all three ratios consider only some certain risk of the portfolio, leaving management fees and other expenses out of scope. For this reason, those ratios cannot be considered as a best practice. What is more important, these ratios give us some absolute number, what can be interpreted differently depending on the individual's perception. These ratios show some risk exposure and portfolio performance considering this risk, but do not consider how much weight does investor put on the return and risk accordingly. This means that there is only a direct relation between these measures and the utility or welfare of the investor under very restrictive assumptions.

In order to determine more precise performance, there are also other ratios and methods developed, and one of them is DEA technique, which is used in this thesis. On the contrary named risk-adjusted measures, DEA allows us to choose which inputs and outputs are important in given circumstances and thus to create an efficient frontier of the certain population only, where investor's preferences are mapped accordingly. More precise DEA explanation is provided in Chapter 2.

1.6. Empirical literature overview

In order to justify the selection of methods chosen, the review of empirical literature is presented in this chapter. Below I discuss the methods used in several empirical researches on funds' performance from Europe and US and explain the results received. The specific results presented are useful for understanding of the Estonian pension funds' performance in a conclusion phase.

1.6.1. Empirical studies on funds' performance measurement

In its paper, OECD (2008) measures the performance of pension funds using popular risk-adjusted measures like Sharpe ratio and comparing observed pension funds' returns across countries with some artificially constructed benchmark portfolios using a Markowitz portfolio optimization approach with historical data.

OECD overall examines the performance of pension funds on a constant basis. In its latest research on a pension funds' performance for the 2019 and Q3 2020 OECD also mentioned, that "returns over the long term are more important than yearly returns" (OECD 2020, 28). Reviewing the OECD results it is also worth to mention the performance of Estonian pension funds in comparison to the other countries' pension funds. According to the research, pension plans earned a real investment rate of return (net of investment expenses) of 8.0% on average in the OECD, and 4.4% in other jurisdictions (OECD 2020, 27). At the same time, the performance of the Estonian funds was among the lowest: average nominal return was 3.0%, average real return was -0.1% (OECD 2020, 28). This, again, indicates, what nominal return does not reflect the actual performance.

In the book written for a World Bank, Hinz *et al.* (2010) notice, that pension funds, unlike mutual funds, have different time frame and attitude to risk as soon as those are created with the purpose to provide income at retirement. However, in evaluation of pension funds there are the same methods used as for other types of investments. Authors notice that in evaluating pension funds not only return is important, but also imposed regulations, investment costs, amount of contributions and behaviour of investors in choosing a retirement age. The book posits that traditional performance measures focus on short-term return and thus might be not the best option for evaluation of pension funds, where investments are regularly long term, ast short-term performance does not prove the same long-term performance. Beside concentrating on the strategic assets allocation and possible policy changes, paper discusses the acceptance of using Sharpe ratio in pension funds evaluation.

It is said that Sharpe ratio is suitable as it enables to evaluate the ability of manager to add value to the portfolio, however emphasized, that choosing the correct benchmark is essential as latter should reflect long-term nature of the investment. In this book the Estonian funds are also brought under the evaluation, where as a benchmark were used Estonia current account deposit rate as a short-term and Estonia long-term bond yield as a long-term. The book also posits that costs of the funds are one of the most important determinants of the long-term efficiency, as accumulated over long period, they may significantly affect the returns. (Hinz *et al.* 2010)

Overall conclusion of the book emphasizes, that Sharpe ratio is a good method to measure the performance, however, should be treated with caution, considering the quality and availability of data. The topic regarding choosing an appropriate benchmark resulted in the proposal of creating a set of specific benchmarks, what would reflect investors' preferences and time horizons, so the results of evaluation would be more meaningful and precise. Alternatively, studies propose to use some riskless portfolio with futures relevant to pension fund.

Bohl *et al.* (2011) in their paper researched the performance of two European counties pension funds - Poland and Hungary. They tried to explain the phenomena of Polish pension funds whose performance is higher than average. For their evaluation authors have measured the performance with Sharpe ratio, Treynor[1] ratio and Jensen's alpha. Finally they have compared the empirical results with selected developed markets pension funds performances and concluded that considering the mandatory nature of evaluated pension funds and their substantial portion of future pensions, the performance of pension funds prompt to be the key indicator for evaluating the success of pension reforms. (Bohl *et al.* 2011)

In the evaluation they also mention that the difference between Sharpe and Treynor ratio consists in the fact that Sharpe ratio considers the total risk of the portfolio, while the Treynor ratio accounts only for systematic risk. In case portfolio is perfectly diversified, the total risk equals to the systematic risk and both ratios should be similar. Thus, the comparison of Sharpe and Treynor ratio is useful to evaluate the diversification ability of funds' managers. For Jensen's alpha they use Jensen regression extended with time metrics - stepwise reduction of the interaction-dummy coefficients, to ensure that only the significant time effects influence the estimation. As both countries' funds have significant portion of bonds in their portfolios, authors created a capitalization-weighted market index as a combination of domestic government bond and equity indexes. As a result, they concluded that pension funds' portfolios are well diversified in Poland (meaning that the difference between Sharpe and Treynor rations are immaterial), whereas in Hungary most of ratios are negative and different. The last means that the covariance between

[1] Treynor ratio is one of the performance measures used widely. It measures the risks-adjusted return as a ratio of the difference of portfolio return and risk-free rate and beta of the portfolio returns. Thus, Treynor ratio considers only market systematic risk.

portfolio excess returns and benchmark is negative and indicates a countercyclical or inconsistent investment strategy. (Bohl *et al.* 2011)

Bauer and Frehen (2008) highlight that pension funds are major players on the market as they hold greater percentage of the equity investments than any other institution. In their study, the performance of US pension funds was evaluated with another performance measure, where return was defined as fund specific returns minus fund-specific benchmark return and minus costs of equity and called $NVA_{i,t}$. According to the paper, the fund specific metrics give more precise and accurate results than using some absolute benchmark metrics. Received return was adjusted by Fama and French three factors model, which are size-premium, value premium and momentum factor in order to capture the risks associated with size and book-to-market value and detect possible momentum strategies. Created model was estimated using ordinary least squares (OSL) method with respective assumptions. Authors concluded that adjusted performance of pension funds is close to zero, while mutual funds' performance is lower than style-matched benchmark. They argue that difference is caused by the hidden costs in the mutual fund industry, however it was also concluded that pension funds do not suffer from hidden costs. (Bauer, Frehen, 2008)

Kreander *et al.* (2005) have evaluated the performance of 60 European funds from four counties in order to examine the difference between ethical and non-ethical funds. For the evaluation, authors used Sharpe ratio, Treynor ratio, Jensen's alpha and size-adjusted Jensen's alpha. They also noticed that most of methods require to choose some market portfolio as a benchmark, which can be difficult to encounter. For Sharpe ratio authors used different risk-free rates based on the countries of origin of the funds. Treynor ratio is used as it deploys only systematic risk, which should be applicable for a large funds. For Jensen's measure they have added random error return into the calculation of the return. In modified Jensen's measure authors used two market indexes which are Small Capitalization index and Total Market index for the different national funds. This model thus takes into account the possible impact of small company investments, which called to dominate such funds. (Kreander *et al.* 2005)

During evaluating the results authors mentioned that the difference of size and age of the funds were not significant. The results of performance measures show that funds generally do not outperform the market, either international or domestic. According to Jensen’s alpha, the average fund performs similarly to the benchmark. Similar results were received for size adjusted alpha. (Kreander *et al.* 2005)

1.6.2 Conclusion on the empirical studies

To conclude on the studies presented above, it should be first said that those are only small part of the existing researches and evaluation of the performance of funds is popular and interesting area. The methods used across studies are different, but most of them deploy such measures like Sharpe, Treynor and Sortino ratios as well as Jensen's alpha. Benchmark used should be chosen carefully as well as results received must be treated with caution considering nature of the methods. It should be also considered, that due to regulations imposed on the pension funds, their performance might be different from mutual funds' one and reforms can impact the performance. Although, it has been said that pension funds do not suffer from hidden costs, this does not mean that those costs are considered in the evaluation.

Despite named deficiencies and the absence of certain framework for evaluating the performance of investments of pension funds, the studies presented give a meaningful input for the empirical evaluation. Taking into consideration abovementioned, I will use only three popular performance measurement methods in my research, which are based on CAPM assumptions. Chapter 3 of this thesis explains the methodology and data in details.

2. THE DATA ENVELOPMENT ANALYSIS

2.1. The introduction of DEA

Beside employing popular performance measures, I find it crucial to assess the performance of the pension funds using more flexible methodologies. One such key methodology is Data Envelopment Analysis (DEA), which allows to evaluate the performance of the funds putting them on an efficiency frontier. While commonly used performance measures give some absolute number of the performance, which does not consider the weights put by the investor on the risk and return, efficiency frontier concept introduced by DEA have no assumed perceptions and biases. It simply shows how each item in the population performs comparing to others and thus can be understood more easily. Moreover, it allows to choose inputs and outputs according to investor's preferences and thus gives more precise results. With traditional performance measures there might be extreme portfolios in the evaluation straining out of the median, which show, for example, very high returns and low risks, while in DEA, considered with other inputs, they can be actually non-efficient with comparison to the rest of the population.

Data Envelopment Analysis, also called frontier analysis, was first introduced by Charnes, Cooper and Rhodes in 1978 as a nonlinear programming model for measuring the efficiency of activities of entities participating in public programs. (Charnes *et al.* 1978, 429). Since then, the approach has been developed further and earned popularity among scholars in measuring funds' performance that indicates DEA's appropriateness and acceptability in evaluating the performance of financial institutions. Although it was first created for measuring of operational processes, later it was used widely across such sectors like non-profit, governmental, private and regulated in estimating the efficiency frontiers (Cooper *et al.* 2011, 7).

DEA is a "data-oriented" approach which is used to evaluate the performance of similar objects – Decision Making Units (DMU), which converts multiple inputs into multiple outputs. (Cooper *et al.* 2011, 1) The abbreviation DMU is used with the emphasize that original method was introduced for the measuring the performance of non-profit industry, avoiding such terms like "firm" and “industry”. Thus, the definition of DMU is flexible. DEA can be used to measure the performance of entities, such as hospitals, schools, cities, companies, etc. DEA method helps to study the relationships between multiple inputs and multiple outputs that were previously resistant to other approaches because of the complex or unknown nature. (Cooper *et al.* 2011, 2)

DEA has proposed a new way of obtaining empirical estimates of relations, what became widely accepted thanks to its ability to adjust to any area of evaluation and thus brings valuable contribution to previously accepted and used methods (Cooper *et al.* 2011). Thanks to its flexibility, DEA gives more thorough and accurate results of the investment performances as soon as it does not account for assumptions used in traditional performance measurement methods, which, as said previously, are not always honoured.

2.2. The theory behind DEA

Original DEA model called CCR was first introduced in Charnes *et al.* (1978) and it was widely used further in measuring the productivity in various organizations. CCR model was developed based on the Farrell’s concepts published twenty years earlier, in 1957. (Farrell, 1957) The need for this method came from the absence of flexible model, which is not restricted by a number of assumptions.

Farrell (1957) has proposed a method which suitable for any type of organization and has extended the concept of productivity towards efficiency. According to Farrell, the productivity itself is based on the ratio between the quantities of outputs and inputs used in the process. Efficiency thus creates a comparison between both productivity and DMUs. Farrell defined overall efficiency as a combination of technical and allocative efficiency. (Farrell, 1957) Technical efficiency means the ratio between the observed output and the maximum output, assuming that input is fixed and is defined as the capacity to maximize the outputs having certain amount of inputs and vice versa. Allocative efficiency or price efficiency means the best proportion of inputs and outputs in the light of predominant prices and technology. (Farrell, 1967, 255) Farrell’s efficiency thus can be shown in a Figure 1. having, for example, two input variables (x_1, x_2) and one output variable (y).

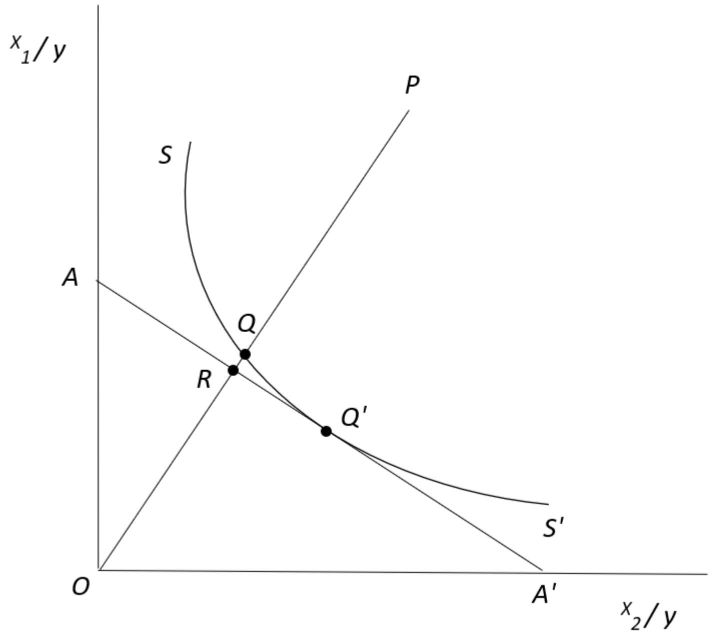


Figure 1. Technical and allocative efficiency frontiers (input-oriented model)
Source: Created by author

Technical efficiency is measured with SS' curve in Figure 1., which represents the isoquant relative to a total efficient firm under condition of constant returns to scale (CRS). Any point of SS' curve represents the optimal combination of inputs and outputs. As soon as curve SS' has a negative slope, an increase in the inputs per the same amount of outputs will decrease the technical efficiency. (Farrell, 1967, 254) CRS is appropriate when all DMUs operate at an optimal scale being in optimal competitive environment. Point Q in Figure 1. represents an efficient DMU as a relation of OQ/OP. Technical inefficiency is presented by the segment QP, what equals to the ratio QP/OP. The ratio will be between zero to one, where one relates to totally efficient unit in point Q and zero relates to total inefficiency. Technical efficiency is thus complimentary:

$$\text{Technical Efficiency (TE)} = \frac{OQ}{OP}$$

To measure the allocative efficiency, we need to consider the prices of resources and add to the figure the extend of which DMU uses the proportion of its inputs and outputs with the view on the prices. (Farrell, 1967, 254) The curve *AA'* in Figure 1. As a ratio of prices of inputs and outputs. The allocative efficiency is then found as follows:

$$\text{Allocative Efficiency (AE)} = \frac{OR}{OQ}$$

Adding this curve, the Q is no longer efficient, but Q' is efficient both technically and allocatively at the same time. Total efficiency is then found as follows:

$$\text{Total Efficiency (TE)} = \left(\frac{OQ}{OP}\right)\left(\frac{OR}{OQ}\right) = \frac{OR}{OP}$$

The measure of technical efficiency in equation is input oriented as it is based on the need to decrease inputs to produce the same amount of output in an efficient way. Hence, if we measure the increase of output given the same amount of inputs, it is then output-oriented model. Thus, DEA creates a linear efficient frontier determining whether DMU is efficient or not.

Beside CRS assumption, which is not always consistent, DEA allows to construct an efficient frontier under assumption of variable returns to scale (VRS) (Farrell, 1967, 256). VRS is appropriate when DMUs not operating in optimal environments, for example, there are certain regulations imposed or competition is imperfect. In case the DMU is not efficient (point *D* of the Figure 2. below), there are two ways of improving the situation and reach the efficient frontier: decreasing inputs to produce the same level of outputs (point *D'*), or increasing outputs leaving the amount of inputs at the same level (point *D"*). The comparison between CRS and VRS helps to reveal the sources of inefficiency. As soon as CRS computes both technical and allocative efficiency, it cannot be higher than efficiency scores with VSR assumption.

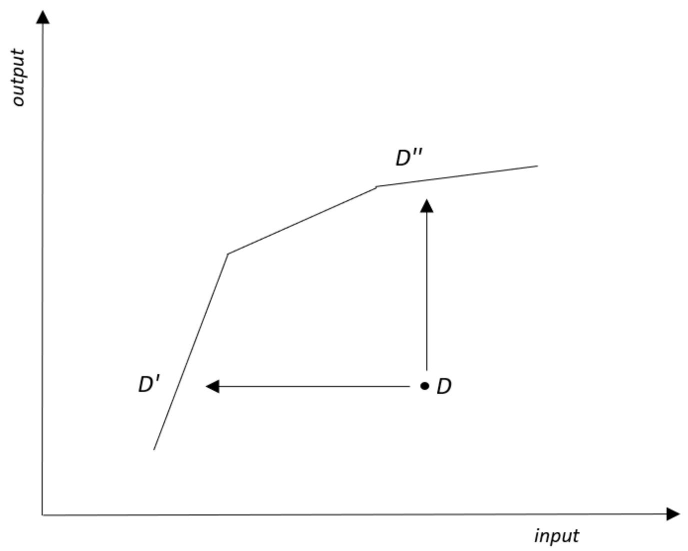


Figure 2. VRS efficient frontier
Source: Created by author

The efficient DMUs who require no modifications in amount of inputs or outputs are located on the efficiency frontier. As a result, input-oriented model will reduce (optimize) the amount of inputs leaving outputs at the same level and output-oriented model will on the contrary increase (also optimize) the amount of outputs while inputs will stay on the same level. With DEA it is easy to see which DMUs are efficient and which are not as well as the ways to improve the situation and which variations of inputs or outputs are possible. Based on named principles the DEA is considered as an unbiased benchmarking tool (Gregorjou *et al.* 2005).

2.2.1 DEA theory in the light of financial investment

Speaking about profit-oriented entities, Fama and Jensen in their research (1983) concluded that each type of organization was relatively most efficient in supplying its special brand of services. They assumed that performance of all firms occurs on efficiency frontiers. DEA studies, however, have shown that this approach has some serious deficiencies. While Fama and Jensen used only few summary ratios, DEA allows to study the relations of large amount of inputs and outputs for each DMU and estimate the inefficiencies. Complimentary, it allows to identify the peer group of efficient DMUs used in the evaluation and thus, develop a proper strategy to increase the efficiency of other DMUs. (Cooper *et al.* 2011)

If we concentrate on the measuring the performance of financial entities, we can look on the perspective of DEA explained by Cooper *et al.* (2011), who's paper designated on the evaluation of performance and activities of organizations such as business firms, government agencies, hospitals, educational institutions, etc. They measure the performance of a unit in a form of an efficiency ratio:

$$\frac{\text{Output}}{\text{Input}}$$

Easy examples can be: "output per worker hour" or "output per worker employed" are examples with sales, profit or other measures of output appearing in the numerator. Cooper *et al.* (2011, 35) noted, that combining all inputs and outputs into a single ratio helps to avoid attaching all inputs to some single output, which is usually some meaning of gain, as soon as not all inputs always attributable to one output. By doing so, DEA allows to to create an overall factor of efficiency.

As soon as named method causes difficulties in choosing appropriate outputs and inputs as well as weights to be used, the proposed approach does not require to account for weights to be attached to each input and output. As defined by Bowlin, (1998, 3), "DEA is a fractional programming model that can include multiple outputs and inputs without recourse to a priori weights and without requiring explicit specification of functional relations between inputs and outputs. It computes a scalar measure of efficiency and determines efficient levels of inputs and outputs for the organizations under evaluation".

Thus, the main benefit of applying a DEA model is that only a few specific assumptions have to be made with regards to the data set and these assumptions are more reliable and can be easily addressed comparing to CAPM assumptions. However, there is still a need for consideration about the choice of variables in order to construct a proper model. The variables should actually have some connection between them, otherwise, the results will not be sufficient. (Bowlin, 1998)

In order to use DEA, several assumptions should be accepted. First, the risk and return as input and output should be above zero. Otherwise, the ratio of a DMU will fall out of the scope. Due to different weights of DMUs, the deficiencies of DMUs are disguised by the unbounded weights (Tarim, Karan, 2001, 66). If we do not put any restrictions on the weights, there may appear to be extreme values in the evaluation, which will be classified as efficient DMUs, irrespective to their activities in other activities they are participating in (Levitt, Joyce, 1978). This called to be main deficiency of DEA, which, however, can overcome by putting bounds on the input and output values. This leads us to the second assumption, that all inputs and outputs are bounded to some maximum and minimum in order to exclude extreme variables. Moreover, zero weight DMUs can also give irrelevant results, and thus should be excluded from the observation. Third assumption is that all DMUs have similar access to inputs.

As the inputs define the result of the outputs, DEA helps to determine the optimal amount of inputs to be used to get a desirable output. The concept of frontier is especially important for the analysis of efficiency, because we measure efficiency as the relative distance to the frontier, while efficiency frontiers show clearly how far are the DMUs from the best combinations of inputs and outputs. The DMU is called efficient when the DEA score equals 1 and all slacks are 0. If only the first condition is satisfied, the DMU is called efficient in terms of "radial", "technical", and "weak" efficiency. If both conditions are satisfied, the DMU is called efficient in terms of Pareto optimality. (Ji Y., Lee C 2010, 270) Traditional performance measures, on the contrary, do not address this division and thus the interpretation of results received with Sharpe ratio, Jensen's alpha and Sortino ratio requires additional research in order to determine how to increase efficiency.

2.3 CCR input oriented model

The fist model developed by Charnes, Cooper and Rhodes (1978) is named as CCR by its authors and aims to produce the maximum ratio of weighted outputs to weighted inputs under condition that ratios for DMUs will be positive. Input oriented model means that it seeks to determine to which extent the inputs should be minimized to retain the same level of output.

In CCR model it is assumed that for each DMU there is virtual input and virtual output by weights (v_i) and (u_r) as follows:

$$Virtual\ input\ =\ v_1 x_{1o} + \ldots + v_m x_{mo}$$

$$Virtual\ outpit\ =\ u_1 y_{1o} + \ldots + u_s y_{so}$$

Then, using linear programming, the weights are determined with the following formula in order to maximize the ratio:

$$\frac{\text{virtual output}}{\text{virtual input}}$$

The weights are not assumed in advance, as was mentioned above. Instead, they are originated from data used and optimal weights vary from one DMU to another. For each DMU there is a best set of weights with values that may vary depending of DMU, meaning that with some variations DMUs are efficient. The actual metrics then show the direction of the improvement in order a DMU to become efficient. (Charnes *et al*. 1978)

Assuming having a number (n) of DMUs under evaluation (DMU_1, DMU_2, …, and $DMUn$), common features of inputs and outputs for each of j =1, 2, …, n DMUs should be considered:

- Positive numerical data for each DMU is available for every input and output used
- The choice regarding DMU, input and output should reflect an analyst's interest about DMU efficiency
- Usage of small input amounts and large output amounts is preferable
- The measurement of units of inputs and outputs should be corresponding (Charnes *et al.* 1978)

Supposing that each DMU uses a given amount of m input items to produce s output items, which follow the criteria named above, the input and output data for DMU_j will be (x_{1j}, x_{2j}, …, x_{mj}) and $(y_{1j}, y_{2j}, \ldots, y_{sj})$, respectively. This relation can be written in matrix form with (X) as input and (Y) as output, where X is an (mn) matrix and Y is (sn) matrix:

$$X = \begin{pmatrix} x_{11} & x_{12} & x_{1n} \\ x_{21} & x_{22} & x_{2n} \\ x_{m1} & x_{m2} & x_{mn} \end{pmatrix}$$

$$Y = \begin{pmatrix} y_{11} & y_{12} & y_{1n} \\ y_{21} & y_{22} & y_{2n} \\ y_{m1} & y_{m2} & y_{sn} \end{pmatrix}$$

Example of the matrixes for pension fund may be as follows:

$$X = \begin{pmatrix} 1 & 2 & 3 & 3 & 2 & 1 \\ 1.1 & 1.05 & 1.1 & 0.7 & 1.2 & 1.01 \end{pmatrix}$$

$$Y = \begin{pmatrix} 0.2 & 0.3 & 0.1 & 0.1 & 0.3 & 0.2 \\ 0.5 & 0.6 & 0.6 & 0.6 & 0.1 & 0.4 \end{pmatrix}$$

Here, $x1j$ = (inputs) fund costs and $x2j$ = standard deviation of returns, $y1j$ = (outputs) fund earned return and $y2j$ = net assets value for a share (NAV) for a DMU_j.

Given the data, the efficiency of each DMU_j can be measured with considering assumptions named previously as n optimizations needed. Originally, optimization formula is put into fractional programming model, which is solved through linear programming in DEA. In fractional programming model values of weights of inputs (vi) as (= 1, 2, …m) in denominator and values of weights of outputs ur as (r = 1, 2, … s) in numerator are obtained as variables in order maximize the ratio of DMU under evaluation. Variables assumed to have ratios between 0 to 1, so the maximum ratio between them is 1. (Charnes *et al.* 1978)

Linear program achieved by assuming that both v and x are positive and the denominator in fraction programming equals to 1. Moving it to constraint we maximize the numerator (output), resulting in the equation:

$$\max_{u,v} \theta \ = u_r y_{r0} + \ldots + u_S y_{S0}$$

Where, $max\ \theta$ is the optimal objective value or CCR ratio and u, v – optimal weights of inputs and outputs.

In this model, the DMU is efficient having a ratio of one. According to the model, only one optimal solution exists and the rest result showing the relative efficiency of the DMUs to the efficient DMU (Charnes *et al.* 1978). By comparing the performance of DMU relatively to the population of DMU we can also evaluate their relative efficiency to each other.

To recall the empiric implications conducted in Chapter 3 in this thesis, I assume that there are number DMUs to be evaluated and each DMU consumes some inputs, which represent risk measures, to produce one output – return, whereas both variables are positive. The model can be input or output oriented. In case we are interested in increasing the return, which is output, we can research the percentage till the full efficiency for a particular DMU with the following equation:

$$\theta \ = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}}$$

Where:

u_r, v_i = variables of DMUo

y_{r0}, x_{i0} = observed output and input values of DMUo without further additional constraints.

Assuming some u_r and v_i as optimal weights for certain DMUo (under evaluation), then value v_i shows optimal weights for input item i and its magnitude shows how higly the item the item is evaluated (x). Value u_r shows optimal weight for output r similarly. Following a simple example of DEA with one input and one output is presented.

2.3.1 CCR model example

Considering having a number of mutual funds. For each mutual fund there is a single output measure and a single input measure presented.

Table 1.1. Risk and return metrics for an example CCR model (%)

Fund	Annual nominal return	Standard deviation
A	2	3
B	5	4
C	10	9

Source: Created by author

To explain the data provided in Table 1.1., for example, the fund A in a given period had the nominal return of 2% relating to standard deviation of its' portfolio 3%. In order to compare given funds' performance, the outputs should be divided by inputs and certain ratio will be obtained. The ratios will then show us the efficiency of a given funds. From this simple calculation in Table 1.2. we see that B fund is most efficient having the highest ratio among the selection, while A is least efficient having the lowest ratio.

Table 1.2. Efficiency scores for an example CCR model

Fund	Efficiency
A	0.67
B	1.25
C	1.11

Source: Author's calculation

In order to measure the relative efficiency of these DMUs, each ratio should be divided by the best ratio of fund B following the equation:

$$0 \leq \frac{other\ DMUs\ ratio}{DMU\ B\ ratio} \leq 1$$

The results of the calculation are presented in Table 1.3. below.

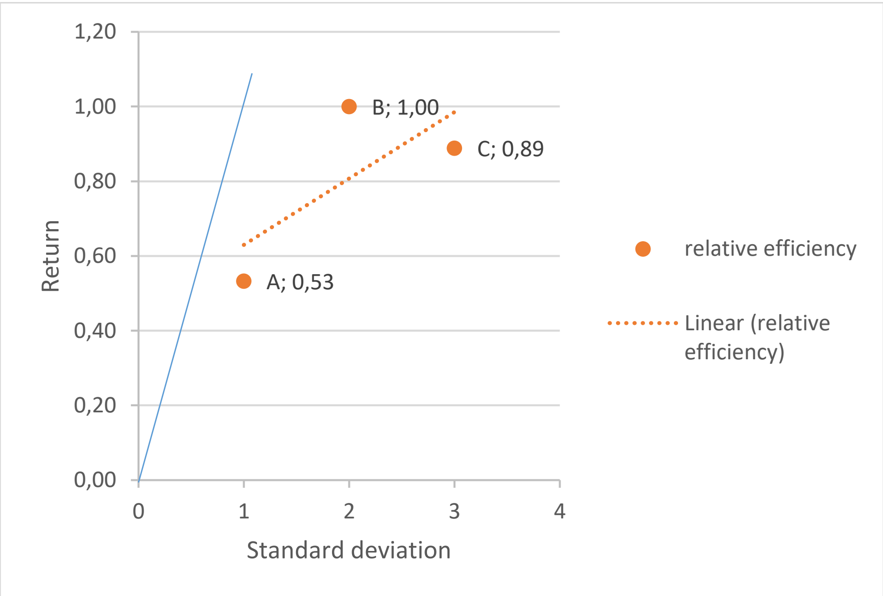
Table 1.3. Relative efficiency scores for example CCR model

Fund	Relative efficiency
A	0.53
B	1.00
C	0.89

Source: Author's calculation

Also, it is then possible to arrange other DMUs returns relative to B in the following order: 1= B > C > A = 0.53 (min result). Thus, the worst, A, attains 0.53×100% = 53% of B's efficiency. Through this comparison we can then take the decisions how to increase the efficiency of others closer to B's efficiency by choosing other investments, as an example. In a given model, as we have only one input, this can be done by reducing the risk, which is standard deviation, so that output, which is return, will not decrease at the same time.

Figure 3. Relative efficiency of DMUs for example CCR model



Source: Created by author

As the objective of DEA is to evaluate the DMUs relative to efficiency frontier, the ratios thus can be put into the axes, where the vertical axis is return, and the horizontal axis is the standard deviation of the funds' portfolios. Adding a trendline we can then measure the slopes of each DMU to the trendline and measure their relative efficiency to each other. Adding the efficiency frontier where risk and return both equal to 1, we can measure the DMUs efficiency to the optimal as shown in Figure 3. Logical conclusion can be done without calculating the slopes that in a given population B is the most efficient, whereas fund C is the closest to the optimal trade-off between risk and return.

To conclude, DEA is a useful tool for evaluating an efficiency with some certain input and output measures. As mentioned by Cooper et al. (2007, 14), the advantage of DEA is in its ability to identify sources and amounts of inefficiency in each input and each output for each entity and its ability to identify the benchmark members of the efficiency set used to effect these evaluations and identify these sources (and amounts) of inefficiency. Also, the possibility to freely chose desirable inputs and outputs to apply in the model. Named DEA advantages have resulted in its use in a number of studies involving efficient frontier estimation in governmental, non-profit, regulated and business sectors.

2.4 Empirical evidence using DEA for evaluation of funds' performance

Previously I have explained the simplest model with one output and one input. However, DEA can be extended to the use of multiple inputs and multiple outputs. Beside numerous of empirical researches using DEA approach there are some common DEA model variations of the original concept which are applied to the mutual funds' performances.

2.4.1 DEA modifications

First index applied in measuring the efficiency of mutual funds called DPEI and was developed by Murthi et al. (1997). The idea behind using DEA consists in criticizing traditional performance measures. The study mentions that such measures like Sharpe ratio and Jensen's alpha have deficiencies and thus might present inappropriate results. Main weakness of those methods is that the correct benchmark should be used, and the methods' assumptions originated from CAPM model are outdated. It is also mentioned that Sharpe ratio and Jensen's alpha do not consider the costs of the portfolio, what might significantly affect the results. Thus, authors have created their own model of DEA where transaction costs are included called DEA Portfolio Efficiency Index (DPEI). In this model, the inputs used are transaction costs value and standard deviation of the portfolio returns and output is portfolio average return. Authors also determined the weights associated to the inputs as positive. Through solving the DEA problem thus, the optimal weights of inputs and fund's efficiency level are found. (Murthi *et al.* 1997)

The transactions costs included into the analysis may be expense ratio, turnover index and other fees. Adding costs as an input gives more sufficient results as soon as investors seek to maximize return and minimize costs as at the same time. The results were compared with the Sharpe ratio and Jensen's alpha through the correlation analysis. Correlation analysis have shown positive results confirming that DPEI model is consistent with traditional performance measures. (Murthi *et al.* 1997)

The second variation of DEA developed by Basso and Funari, is based on the DPEI model described previously. Authors proposed model called $IDEA\_1$, that uses expected return as an output and subscriptions and redemption costs and risk measures (standard deviation of the returns and Beta) as inputs and thus generalize the DPEI model. (Basso, Funari, 2001, 481) $IDEA\_1$ includes only subscription and redemption costs, which considered to be direct costs for the investors, but not other costs, that prompt to be already extracted from the net return of the portfolio. By evaluating chosen mutual funds authors concluded, that DEA approach is appropriate and helpful in evaluating the performance of mutual funds. They have also analysed the correlation between DEA result and Sharpe, Treynor ratios and Jensen's alpha and found low correlation explained by the fact that transactions costs are not considered in traditional performance measures. (Basso, Funari, 2001)

The third model was developed by Morey and Morey (1998), where authors have mentioned, that average investor does not have enough information available to consider while choosing into which mutual fund to invest. The rankings of the mutual funds are mostly not adjusted at any risk and reflect the nominal return of the fund over different time horizons. Based on DEA methodology, authors have proposed two alternative approaches for ranking of the mutual funds, so that risk and return will be reflected in the ratings. Approaches address total risk and total return over different time-horizons, do not depend on weights and each mutual fund is evaluated to chosen endogenously created benchmark. First approach address increase of average return over the certain time-horizon, while the risk level remains consistent. The second approach with creating a benchmark fund aims to reduce risk during the certain period without affecting the average return. In their DEA model, authors have used variance return and correlation between funds' returns as inputs for certain periods. (Morey, Morey 1998)

The last is DEA model developed by Gregorjou, Sedzro and Zhu while evaluating the performance of hedge funds (Gregorjou *et al.* 2004). As soon as hedge funds do not have any benchmark to compare with, that makes traditional performance measures not applicable for the evaluating hedge funds. Hedge funds have asymmetric return, what means the absence of one of the significant assumptions used in traditional performance measures. Authors have used DEA BCC model with lower mean monthly semi-skewness (LSS), lower mean monthly semi-variance (LSV), and mean monthly lower return (MLR) as inputs and upper mean monthly semi-skewness, upper mean monthly semi-variance and mean monthly upper return as outputs. (Gregorjou *et al.* 2004, 558-559)

Results were compared with the modified Sharpe ratio and Jarque-Bera test was used to address not normal nature of returns. The results received show that most of hedge funds are inefficient. These funds, which were found to be efficient, have higher returns and positive skewness. The results identify that DEA can provide additional information to the investors, but it is not crucial tool in evaluating the hedge funds' performance. (Gregorjou *et al.* 2004)

2.4.2 Empirical studies using DEA

Basso and Funari (2001) posit that in evaluating the performance of the funds popular risk-adjusted performance measures like Sharpe, Treynor ratios or Jensen's alpha are usable for comparison of different portfolios, but they notice that those ratios have deficiency in relying of market historical data and investor's preferences. They also mention that these ratios do not account for portfolio managing costs and any other deductions, whereas, DEA, on the contrary, allows to choose inputs and inputs included into the model, meaning that costs can be also included.

Refereeing to DPEI model, Basso and Funari (2001) propose an easy model for evaluating the performance of an investment, where an output is a return measure and inputs are both some risk measures and the subscription or redemption costs. They notice that in case output is expected excess return, as in traditional methods, the negative value may appear. In case output is determined just expected return, negative values are eliminated. As inputs were used such risk measures as standard deviation, half-variance risk and beta of the portfolio. They have seen that developed DEA index generalizes the traditional Sharpe, Treynor and reward-to-half-variance indexes. The developed index considers subscription and redemption costs only, what found to be appropriate as those are main costs burdening an investor. (Basso, Funari 2001)

In addition to previously described disadvantages of standard performance measures, authors argue that traditional indexes are sensitive to chosen time horizon. Thus, the Sharpe ratio, Jensen's alpha and Treynor ratio will vary depending on the time frequency used. Also, this might be different from the investor's investment horizon. Study mentions that Beta coefficient is not affected by changes in the investment period as soon as Beta is calculated as the ratio between a covariance and variance which are both proportional to the length of the investment period. Authors argue that effect of change of the investment horizon of time frequency used is reflected through change in the expected rate of return as change of the measurement units used. (Basso, Funari 2001)

In the result study notes that using two output indicators instead of one increases the number of efficient funds. Meaning, that adding one more output brings one more indicator with respect to which some funds might be considered as efficient. By adding as input more costs, the efficient funds do not change. The correlation analysis between DEA results and other performance measures reveals the correlation between 0.449 to 0.919. However, in case excess returns are negative in standard measures, the correlation results are meaningless. In conclusion authors say that DEA methodology complements the traditional indexes and permits to perform additional analysis through using desirable input or output parameters. (Basso, Funari 2001)

In evaluating the performance of Turkish Capital Market Tarim and Karan (2001, 65) defined the performance as the ratio of expected returns to risks assumed and other factors like management fees and turnover costs. Reminding that traditional performance measurement methods do not consider transactions costs, authors use DEA, as it makes it possible to account both for risks taken and the costs occurred, and thus makes DEA appropriate approach to measure the efficiency.

Authors also argue, that traditional performance measures are based on CAPM and assumptions used for these measures are not realistic, mainly because CAPM requires the identification of efficient market portfolio. This assumption is very difficult to maintain in current market, especially due to the fact that in benchmark portfolio all assets should be included – marketable and non-marketable. Authors use DPEI model mentioned previously what is considered as a generalization of Sharpe index as soon as it considers costs as well. In analysis authors extended DPEI model by introducing restrictions on weights of the factors to overcome zero weight problem. Authors have concluded that DPEI model is consistent with traditional performance measures and can be used as an alternative method. They also mention that correlation between result is high due to all methods include risk as one of the inputs, which is named to be most significant factor in DEA analysis. (Tarim, Karan 2001)

Chen and Lin have found DEA a useful technique in evaluating the performance of mutual funds due to its ability to combine various types of risks measures associated with the fund performance. Authors have developed previously described $IDEA\_1$ index adding such metrics like VAR (value-at-risk) and CVAR (conditional value-at-risk) into it. By measuring the Chinese funds' performance, authors mention that in order to use DEA the inputs should be chosen carefully and have to appropriate given a certain population. (Chen, Lin, 2006)

The last but not least research presented here was made by Barros and Garcia (2006) evaluating the performance of Portuguese pension funds with four DEA models: CCR, BCC, cross-efficiency DEA model and super-efficiency DEA model, discussing the possibility to apply alternative models beside basic CCR model on performance evaluation. It is said that in competitive markets DEA output-oriented model is widely used assuming then DMUs have control over inputs and seek to increase the output values. The use of two latter DEA models is motivated by the fact that both CCR and BCC models tend to rate many DMUs as efficient.

In the analysis authors used number of funds, value of funds and pensions paid to subscribers as outputs and number of full-time employees, value of fixed assets and value of received contributions from investors as inputs. For analysis they used output-oriented technical efficiency DEA index explaining that funds aim to maximize the profits with VSR methodology assuming strong disposability of inputs and outputs. With comparing efficiency scores received with CCR and BCC model they compare overall efficiency with CCR model to technical and scale efficiency calculated with BCC model and thus calculated the overall scale efficiency. As a result, authors concluded that scale has high importance to pension funds and that CCR model should not be used alone in the evaluation of such funds' performance. The correlation between scale or value of assets and CCR results is positive, supporting conclusion that large pension funds have higher efficiency among the population and in order to overcome the inefficiency the scale of activities should be analysed first. (Barros, Garcia 2006)

2.5 Conclusion on DEA empirics

The numerous empirical researches demonstrate that DEA is an appropriate technique to evaluate the performance of the funds and is more flexible and universal in comparison with traditional risk-adjusted measures. Most of empirical studies criticize traditional performance measures and try to find alternative ways of evaluating the performance not using restrictive assumptions. Scholars have come up with the solution of using DEA, where they include costs of portfolio as well, which is also one sufficient deficiency of traditional performance measures. We can argue, that costs of the portfolio can be subtracted from the return used in traditional performance measures, but there is no opportunity to include them as a separate input. Despite this, the DEA results found to be correlated to the traditional measures.

The main advantage of DEA thus in the possibility to choose on inputs and outputs used and develop a measure of performance (or “efficiency”) of the portfolio which has a relatively straightforward interpretation without requiring restrictive assumptions. It is important to keep in mind that any inputs and outputs can be used in DEA, if they actually have some weight to the author. Correlation analysis can show how appropriate is DEA to the other performance measurement methods, which should give a space for future researches. However, results should be interpreted solely based on the individual’s perspective. Only in this case they can give some meaningful input.

3. METHODOLOGY OF RISK-ADJUSTED PERFORMANCE MEASUREMENT AND DEA

In this chapter the overview of pension funds institutional background is presented first. Following, the description of data and methodology used in empirical evaluation with chosen traditional performance measures and DEA is described. Lastly, the results are presented and discussed.

3.1 Pension funds' background and overview

Pension funds are acting similarly to the any other investment fund. Security Exchange Commission has identified investment fund as "a financial company that pools capital from many subjects and invests it in stocks, bonds or other assets". (Security Exchange Commission, 2005) European Central Bank had defined the investment fund as "a collective investment undertaking that invests capital raised from the public in financial and nonfinancial assets." (EU Regulation 1073/2013 art 1, p 1)

The concept of the pension fund is the same – funds invest money trusted to them into different assets and securities having thus a certain portfolio consisting of different bonds, stocks and other instruments. Estonian Investment Funds Act determines the investments funds as a "legal entity or pool of assets which involves the capital of a number of investors with the view of investing it in accordance with a defined investment policy for the benefit of the investors in question and in their common interests". (IFS § 2) As soon as Estonian pension funds created with the aim to provide people with their saved money once retired, the objective is at least to save the given amount of money.

The Estonian pension system has three pillars: state pension, mandatory funded pension and supplementary funded pension. The contributions to the I pillar is calculated from the salaries, where 33% social tax paid is divided as 13% to the health insurance and 20% to the pensions of current pensioners. This system cannot be influenced by an individual. The II pillar is also mandatory pension for the people born after 1983[2]. Contributions to this pillar come from individual's salary payment usually as 2% pension tax and then 4% is added by the state from 33% social tax calculated from the same salary. The III pillar is voluntarily, and no restrictions are set on the amounts of contributions. The deductions from II and III pillar are taxable. (Estonian Funded Pension Registry, 2021)

All collected pension payments for II and III pillars are then managed by individual pension funds. In this thesis I concentrate on the II pillar pension funds' performance as this pillar is mandatory, has a greater number of funds and is subject to various reforms and changes, which makes it most interesting to research. An individual can access the data regarding his/her savings from different sources, but all of them will report several important metrics, i.e. chosen fund, NAV values (historical and current) and amount, nominal return of an investment, the current value of assets. NAV records the net assets value and number of NAVs defines investor's part in the portfolio. NAV is calculated as the fund's total assets minus its total liabilities and then divided by the number of shares.

It is important to mention that fund's NAV grow or return, and individual investor NAV return are usually different. The reason is that pension fund most probably uses other period of calculation than investor. For example, for investor joining a fund 5 years ago, the NAV grow, or return earned, should be measured as the difference between original NAV value and last NAV value over last 5 year, while fund measures NAV value grow for a total existing period. Regularly, the assets invested are withheld from a person's income and paid out to the person proportionally after last reaches a certain age. When money withheld, a person cannot decide on the way this money will be invested; this is the decision of the fund manager. A regular person has only the opportunity to decide on the fund where his/her money will be invested in based on his/her risk-preferences and time-horizon.

Following this logic, the pension funds in Estonia are divided into several categories in accordance to the risks taken: low, medium and high risk level. The table 2. below presents the II pillar pension funds, its' total assets value, number of investors and assigned risk levels existing in Estonia as at 31 December 2020.

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[2] In 2021 the reform of II pillar was held and pillar contributions became voluntarily. The main changes regarding the reform can be found at Estonian Funded Pension Registry official website.

Table 2. Layout of Estonian II pillar pension funds as of 31.12.2020: NAV, total assets value, number of investors, assigned risk level in descending order by total assets value.

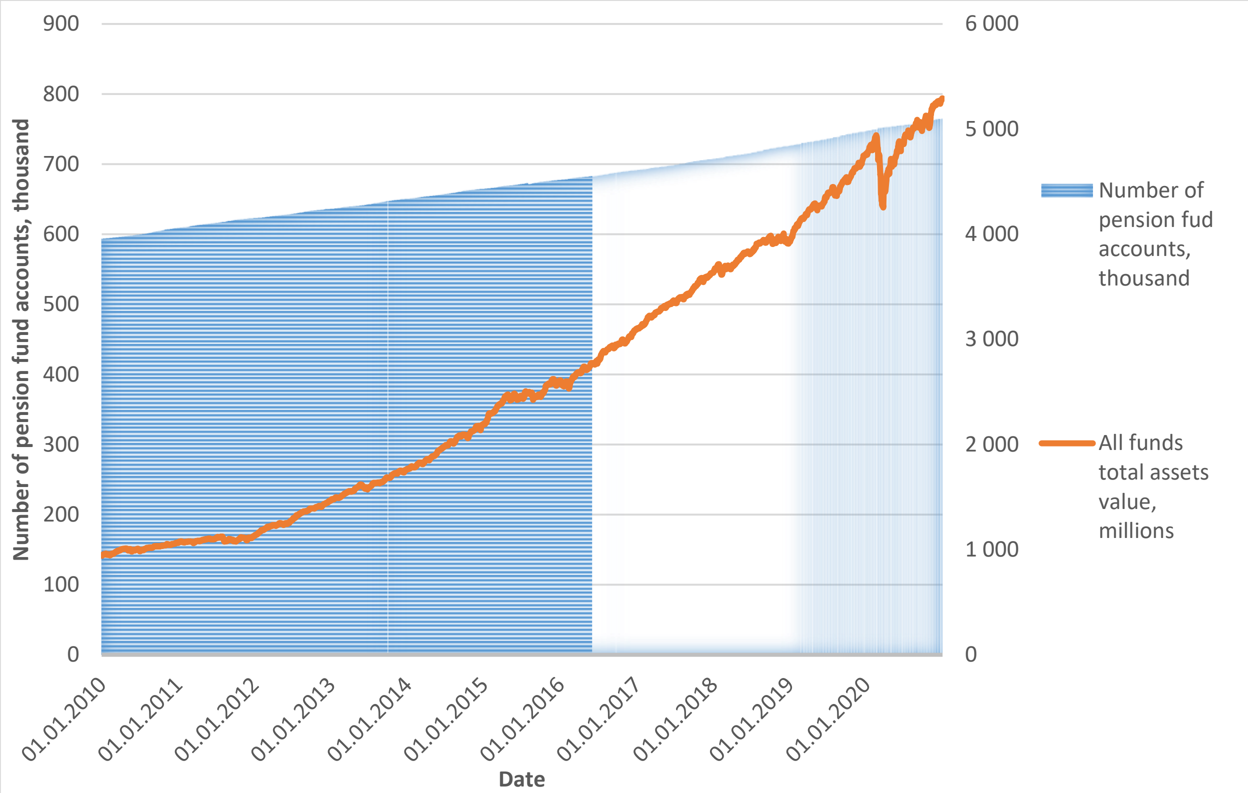
Number	Fund	NAV	Total assets value	Number of investors	Risk level
1	Swedbank K60	1.38	1 188 770 272	133 610	medium
2	LHV L	1.81	1 003 438 971	101 459	medium
3	SEB Progressiivne	1.18	672 447 256	85 168	medium
4	Swedbank K100	1.13	485 543 039	107 037	high
5	Swedbank K30	1.05	378 947 190	42 736	medium
6	Luminor A	1.31	315 788 690	25 221	medium
7	LHV XL	1.63	231 724 320	39 524	high
8	Tuleva Maailma Aktsiate	0.80	184 944 337	22 076	high
9	SEB Energiline	1.06	167 386 483	34 953	medium
10	LHV M	1.35	145 346 370	13 761	medium
11	Luminor A Pluss	1.15	83 305 194	8 376	high
12	Swedbank K10	0.86	77 312 502	10 860	low
13	SEB Konservatiivne	0.93	69 175 577	11 509	low
14	LHV S	1.30	53 420 265	8 417	low
15	SEB Optimaalne	0.93	40 991 611	6 014	low
16	LHV Indeks	0.84	38 529 416	6 275	high
17	Luminor B	1.11	32 872 896	2 340	medium
18	SEB Indeks 100	0.87	32 863 429	9 871	high
19	LHV XS	1.21	24 620 352	4 659	low
20	Luminor C	0.97	23 070 511	4 501	medium
21	Swedbank K1990-1999 indeks	0.88	22 764 822	20 798	high
22	Tuleva Maailma Võlakirjade	0.69	10 898 820	2 377	low
23	LHV Roheline	1.25	4 696 708	3 891	high
24	SEB 100	0.69	4 017 459	924	high
	Total		5 292 876 460	706 357	

Source: Estonian Pension Funded Registry (2021), created by author.

As it can be seen from the Table 2. above, as at 31 December 2020 there were 24 II pillar pension funds in Estonia. The most popular fund with the greatest assets value and the number of investors was Swedbank 60K with medium risk level assigned. During the empirical evaluation of the funds' performance I will review whether the assigned risk levels in Estonian Pension Funded Registry are in align with the risk metrics received in empirical evaluation.

Number of pension accounts and assets growth during last ten years highlight the importance and popularity of the topic. Figure 4. below represents the number of opened pension funds' accounts and total amounts of all funds' assets during years between 2010-2020.

Figure 4. The number of pension accounts and total amounts of all funds' assets during 2010-2020.



Source: Estonian Pension Funded Registry (2021), created by author.

From Figure 4. we can see that the number of accounts is slowly growing while the value of assets is affected by the economic situation. The decline in the value in early 2020 was related to the COVID-19 pandemic, where people had an option to stop pension contributions for some period.

The advantage of pension funds is the same as in investing in any other mutual fund, i.e. diversification, access to global market, liquidity and professional management. Whereas funds can be active or passive. Actively managed funds seek to find undervalued assets and thus to achieve higher return, while passively managed funds follow some chosen benchmark.

Like any other entity, funds also have costs. Those can be transaction costs, ongoing operating costs, any other fees. Such expenses may not be shown separately by the fund, but they have potentially a great impact on the return of the investment.

3.2 Description of data and methodology used

Currently, there are 24 pension funds in Estonia as presented in Estonian Funded Pension Registry (2021). For each fund the following data is available: 15, 10, 5, 3 years and current NAV values, the percentage of fund's fees, the actual number of active investors and total value of assets.

In the first observation the *daily* NAV data for the period from 01.01.2010 to 31.12.2020 is used. Following the collection of the data there are in total 17 pension funds whose data is presented for the whole period of 10 years. This sample is defined as "long sample" further in this thesis. The remaining 7 funds' data is presented starting from 8.11.2016 (LHV Indeks), 07.12.2016 (Swedbank K1990-1999 indeks), 9.12.2016 (SEB Indeks 100), 28.03.2017 (Tuleva Maailma Aktsiate and Tuleva Maailma Võlakirjade), 20.09.2019 (SEB 100) and the latest from 16.03.2020 (LHV Roheline). Second observation was made for a shorter period in order to include index funds. The reason for this is that index funds historically have shown better risk-adjusted returns, and it would therefore be usefully to compare them as well. Second observation includes 22 funds for the period of 01.01.2018 to 31.12.2020 and referred as a "short sample" following n this thesis. In the first observation the coverage percentage of chosen funds amounted to 94.36% and 99.84% in the second observation from all funds' total assets value as at 31.12.2020. As soon as NAV of the funds is presented in daily periods, the average returns are annualized accordingly assuming 252 trading days in a year. To determine the risk factors, such as standard deviation and downside deviation, the historical data is annualized as well.

It is important to notice, that NAV data recorded has different calculation logics across the funds, as some funds calculate the NAV as net of assets and some of the funds also extract the fees and current costs from the calculation. As for my investigation, the funds of Swedbank and Luminor do extract portfolio costs from the NAV calculation, while SEB, LVH and Tuleva funds do not. In this thesis the costs data was not separated from the daily NAV values and these differences should be considered while interpreting the results received with empirical research. This is also one of the reasons, why I use DEA approach as an alternative method of evaluation, where funds' costs percentage are taken as one of the inputs and output (annualized return) is then calculated as net of costs.

Mentioning the importance of choosing a right benchmark, I find it suitable to use German 10-years government bond as a market portfolio. The risk-free rate is then constructed as an average

German 10-years bond yield for the observational period. Dynamic approach used in order to capture previous periods accordingly. German 10-years government bond is chosen as Germany is the biggest countries in European Union and has the most stable economic. Also, as I research the performance of pension funds with long time-horizon, the 10-years yield is more appropriate than, for example, local OMX stock index (which is not risk free actually) or Estonian current account deposit rate. In 2020 Estonia issued government bonds, however these bonds are not traded and also do not exist for the full 10-year period as at 31 December 2020, and thus cannot be used as a benchmark.

No Estonian country risk premium has been added to the risk-free rate as pension funds' portfolios consist mostly of foreign equities and instruments. Speaking about preferences of the investor I am concerned it is less possible that the one would prefer to allocate assets into Estonian securities rather than into some other European countries. German risk-premium amounts to zero as at 8.01.2021. (Damodaran, 2021) The topic on appropriate risk-free rate for Estonia has been discussed also by European Central Bank in 2010 in its Convergence Report (ECB, 2010, 37). It was concluded that there is no suitable county metric and using other EU counties bonds is acceptable. Once European Union issues their own funds in mid-2021, they could become a suitable benchmark.

As mentioned previously, in DEA analysis I use volatility of the returns and costs of portfolios as inputs and annualized nominal return as an output. That should be noticed that other inputs can be also used in the analysis, that might be an area of future development.

4. THE RESULTS OF RISK-ADJUSTED PERFORMANCE MEASURES AND DEA

4.1 Results of risk-adjusted performance measures

This chapter presents the results and short discussion on empirical evaluation of Estonian II pillar pension funds with Sharpe ratio, Jensen's alpha and Sortino ratio in two observational periods. Following the period of 01.01.2010 – 31.12.2020 for 17 funds is defined as "long sample" and the period of 01.01.2018 – 31.12.2020 for 22 funds is defined as "short sample". All three ratios used with the assumptions that pension funds in population have similar time-horizon, that there are no other sources of wealth (solely pension contributions) and that consumption goods prices correlate with pension funds return (as assets are similar). The benchmark used is average 10-year German government bond yield for Sharpe ratio and Jensen's alpha for a respective period. For Sortino ratio MAR is defined as 0% return. While describing the results it should be reminded, that NAV values used have slightly different calculations' logic and thus should be treated accordingly.

4.1.1. Sharpe ratio

Sharpe ratio was first computed for a long sample and the results are presented in the Appendix 1. From the results it is seen that LHV pension funds XS, M and S have the highest risk-adjusted performance. The higher the Sharpe ratio, the better is the performance. In case ratio is below 1, the portfolio does not outperform the benchmark. Results show that nominal return, despite being relatively high (for example for Luminor A Pluss and Swedbank K100), does not reflect the risks of the portfolio. Average Sharpe ratio for all funds is 0.67, what indicates overall funds' performance as below the benchmark.

The results of computing Sharpe ratio for a short sample are presented in Appendix 2. Results are different from first observation, that is obvious as soon as different period has been used. In the last three years LHV M had the highest risk-adjusted return. It is interesting to observe that on the top 3 there are Swedbank K10, whose 10-year ratio was among the lowest, and Tuleva Maailma Võlakirjade fund. The latter partly supports previously mentioned statement regarding index funds' higher performance. The average Sharpe ratio for all funds is 0.75. This is higher, than for a long sample, and indicates that during last three years Estonian pension funds have performed relatively better.

4.1.2. Jensen's alpha

Calculated Jensen's alpha results for a long sample are presented in Appendix 3. Reminding the theory, the higher the Jensen's alpha, the more systematic risk portfolio brings. First observation results reveal that most systematic risk exists in Luminor A Pluss and Swedbank K100 funds' portfolios. Such finding is obvious as both portfolios consist of 100% shares. At the same time these funds underperform the benchmark according to Sharpe ratio. LHV pension funds, which have the greatest Sharpe ratios, in turn have relatively low exposure to the market systematic risk.

The highest the Beta coefficient the more portfolio is in align with the benchmark. The negative Beta in all of the funds can be treated differently, but inverse relation mostly means that pension funds' portfolios do not follow the direction of benchmark. LHV L fund has the closest to 1 Beta coefficient. As its strategy is to invest in up to 50% into bonds, such ratio seems to be reasonable. The highest Beta has SEB Energiline, while it allocates only 75% of the fund's assets into the shares. Such finding seems illogical and indicates inconsistency in fund's strategy. Average Jensen's alpha for all funds is 2.39%, however this ratio should be treated only in relation to some other.

Short sample results are presented in Appendix 4. Results show higher exposure to market systematic risk among index funds and the lowest for LHV funds, which had highest Sharpe ratio previously. In this observation, the average Beta is still negative, however, there are funds with positive Beta. Luminor B fund has closest to 1 Beta, meaning that this fund managed to follow the benchmark. It is interesting to compare results of Tuleva Maailma Võlakirjade – it has extremely strong Beta coefficient, below average Jensen's alpha and one of the highest Sharpe ratio. So far, it seems to be a good option.

4.1.3. Sortino ratio

For the Sortino ratio I used MAR as 0% return. Thus, in calculation of Sortino ratio I have used annualized portfolio returns, which are above the MAR, what represents the difference between portfolio return and the benchmark return in the Sortino equation. It must be said here that MAR should reflect investors' preferences and results should be interpreted taking this fact into account.

In setting the MAR we, again, face with the main problem of such ratios – they show some statistical number, so we can come up with any MAR based on our preferences. If we, for instance, would accept MAR as some country risk-premium or some average return, results will be different. The fact, that government bonds and other instruments included into pension funds' portfolios may have negative return indicates that future expected returns may also be negative. However, as an investor, I would prefer do not have such instruments in the portfolio, thus the MAR is set as 0%.

Results for the long sample are presented in Appendix 5. Here, again, the highest performance attained to LHV pension funds. Such results are logical as those funds have higher Sharpe ratios and low exposure to market systematic risk. The lowest performance have, again, Swedbank K100 pension fund and SEB Energiline fund. Swedbank K10 have relatively low nominal return as well as Jensen's alpha, but at the same time its' Sortino ratio is among the highest. This fund could be an option for the investor concerned about negative returns and systematic risk. Average Sortino measure for all funds is 1.17, that reveals overall positive performance during the last ten years.

Calculated Sortino ratios for the short sample are presented in the Appendix 6. In this observation there are the same funds on the top, which were with Sharpe measure. At the same time, the index funds' ratios are located across the funds. This shows that not all index funds perform similarly and some of them have better portfolios than other. Average Sortino measure for all funds is 0.77, meaning that last three years returns were on average lower than for ten years.

Concluding on all three ratios several points can be said. Higher nominal return regularly means higher volatility and higher systematic risk of the portfolio, Estonian pension funds' portfolios do not move together with the benchmark and lower downside deviation generally attains to lower nominal returns with some deviations among the peers. Lastly, index funds do have relatively high performance among the peers. All three ratios give some useful information, but as they do not separate costs and do not considers the weights put by the investor on the risk and return, it is not enough to fully understand the actual performance and efficiency of these fund. These results only indicate some relative number of the performance, but it is hard to judge them separately, what supports the need for some alternative valuation method.

4.1.4. Comparison of results with assigned risk categories

As was mentioned previously, the information reflected by the pension funds to the investors might be one-sided. In order to see the difference between information reported by Estonian Pension

Fund Register and empirical results obtained, the comparative overall tables is presented in Table 3. and 4. for two observational periods. The funds with higher assigned risk level marked with orange, the funds with medium risk level marked with light orange and funds with low risk level left blank accordingly.

To compare assigned risk level the standard deviation results should be reviewed. From the comparison below it is seen that actually not all assigned levels of risks are in accordance with the actual risks taken. For example, there are funds, whose risk levels in the way of standard deviation is different from those reported by Estonian funded Pension Registry in both periods (SEB Optimaalne and LHV XL).

Table 3. Risk-adjusted scores of 17 funds for the period 01.01.2010 to 31.12.2020 in descending order by annualized standard deviation.

Pension fund	Annualized nominal return	Annualized standard deviation	Sharpe ratio	β^a	Jensen's alpha	Annualized downside deviation	Sortino ratio	Assigned risk level
LHV XS	2.38%	1.04%	1.36	-0.185	1.42%	0.90%	2.65	low
LHV S	2.20%	1.09%	1.13	-0.373	1.23%	0.95%	2.31	low
Swedbank K10	1.52%	1.19%	0.47	-0.451	0.55%	0.99%	1.53	low
SEB Konservatiivne	1.16%	1.75%	0.11	-0.229	0.20%	1.79%	0.65	low
LHV M	3.32%	1.78%	1.33	-0.198	2.36%	1.64%	2.02	medium
Luminor C	2.44%	2.41%	0.62	-0.630	1.48%	2.25%	1.08	medium
Swedbank K30	2.71%	2.49%	0.70	-0.256	1.75%	2.17%	1.25	medium
SEB Optimaalne	1.86%	3.11%	0.29	-0.637	0.90%	2.72%	0.68	low
LHV L	4.19%	3.38%	0.95	-0.181	3.23%	3.08%	1.36	medium
Luminor B	3.31%	3.72%	0.63	-0.790	2.35%	3.41%	0.97	medium
LHV XL	4.64%	4.39%	0.84	-0.187	3.68%	4.03%	1.15	high
SEB Progressiivne	2.92%	5.03%	0.39	-0.744	1.96%	4.48%	0.65	medium
Swedbank K60	4.26%	5.65%	0.58	-0.320	3.30%	5.00%	0.85	medium
Luminor A	4.60%	6.32%	0.58	-0.908	3.64%	5.67%	0.81	medium
SEB Energiline	4.31%	8.05%	0.42	-1.201	3.35%	7.07%	0.61	medium
Luminor A Pluss	5.59%	9.37%	0.49	-0.919	4.63%	8.27%	0.68	high
Swedbank K100	5.55%	10.08%	0.46	-0.435	4.59%	9.05%	0.61	high
Average	3.35%	4.17%	0.67	-0.509	2.39%	3.73%	1.17	-

Source: Author's calculation

[a] Beta is scaled by factor 10000

Table 4. Risk-adjusted scores of 22 funds for the period of 01.01.2018 to 31.12.2020 in descending order by annualized standard deviation.

Fund	Annualized nominal return	Annualized standard deviation	Sharpe ratio	β[a]	Jensen's alpha	Annualized downside deviation	Sortino ratio	risk
LHV S	0.49%	0.60%	0.91	0.082	0.55%	0.53%	0.93	low
LHV XS	0.71%	0.66%	1.17	0.333	0.77%	0.57%	1.25	low
Swedbank K10	0.93%	0.75%	1.32	0.469	0.99%	0.71%	1.31	low
LHV M	1.77%	1.12%	1.64	0.144	1.83%	1.05%	1.68	medium
SEB Konservatiivne	0.52%	2.49%	0.23	1.784	0.58%	2.90%	0.18	low
Tuleva Maailma Võlakirjade	2.98%	2.52%	1.21	2.260	3.04%	1.94%	1.53	low
Swedbank K30	2.13%	3.18%	0.69	0.607	2.19%	3.02%	0.70	medium
LHV L	3.53%	3.19%	1.13	0.290	3.59%	3.05%	1.16	medium
SEB Optimaalne	1.73%	3.41%	0.52	0.436	1.79%	3.52%	0.49	low
Luminor C	2.94%	3.51%	0.86	3.084	3.00%	3.60%	0.82	medium
Luminor B	3.37%	4.73%	0.72	0.912	3.42%	4.77%	0.71	medium
LHV XL	4.35%	5.16%	0.85	0.039	4.41%	5.01%	0.87	high
SEB Progressiivne	2.41%	6.46%	0.38	0.880	2.47%	6.28%	0.38	medium
Swedbank K60	3.50%	7.41%	0.48	0.247	3.55%	7.21%	0.48	medium
Luminor A	4.84%	7.70%	0.64	-1.888	4.90%	7.76%	0.62	medium
SEB Energiline	5.62%	10.53%	0.54	-1.199	5.68%	9.99%	0.56	medium
Tuleva Maailma Aktsiate	8.12%	11.52%	0.71	-2.001	8.18%	11.27%	0.72	high
Luminor A Pluss	5.44%	11.69%	0.47	-4.324	5.50%	11.45%	0.48	high
Swedbank K100	5.44%	13.64%	0.40	-0.913	5.50%	13.59%	0.40	high
Swedbank K1990-1999 indeks	10.11%	16.60%	0.61	-3.233	10.17%	15.72%	0.64	high
SEB Indeks 100	9.75%	17.05%	0.58	-3.363	9.81%	16.12%	0.60	high
LHV Indeks	7.12%	17.64%	0.41	-2.503	7.18%	16.64%	0.43	high
Average	3.99%	6.89%	0.75	-0.357	4.05%	6.67%	0.77	-

Source: Author's calculation

[a] Beta is scaled by factor 10000

Overall, funds with low risk level generally have higher Sharpe and Sortino ratios, lower standard and downside deviation and lower Jensen's alpha. The comparison can give insights in choosing the pension fund based on investor's risk and time preferences considering previously mentioned limitations of the ratios.

4.2. Results of DEA analysis

4.2.1. DEA method applied and data used

The DEA model is created with Excel DEA solver addition, what was developed by Joe Zhu. Named DEA assumption mentioned in Chapter 2 addressed as follows:

1. Input and output values should be positive: NAV values, volatility metrics and costs percentages are positive for all funds.
2. Weights of the inputs and outputs should be positive: assuming having only positive values of outputs and inputs I do not except negative values nor any extreme result. During computing conventional performance measures, it has been seen, that both risk and return measures are positive and amounted up to 10. Important concern here is that DMUs with zero weight can also give some result, and this will influence overall DEA metrics. To exclude the assumption of having zero weight DMUs in the population the review of amounts of the funds' assets as at 31.12.2020 was held in previous section – there are no DMUs with zero weights.
3. All DMUs have similar access to inputs: in pension funds this works - data is available for all funds, access to assets and markets as well.
4. All entities (DMUs) use the same input(s) to produce the same output.

Three DEA models has been designed for the analysis. DEA model 1 is constructed with annualized nominal return as an output and volatility as an input assuming those are the main metrics what interest a regular investor not close to the investing and they are understandable. DEA model 2 includes also costs percentage as an input and nominal return is calculated as net of costs for all funds. Second input in DEA model 2 is standard deviation and it should be considered that costs were not excluded from the calculation of this input due to complexity and limited availability of data. DEA model 3 is computed with nominal return as an output and annualized downside deviation as an input in order to see the efficiency scores of funds from the perspective of only negative returns. Beta metrics were not used in the analysis due to mostly negative ratios received.

All three DEA CCR input oriented models are solved for each pension fund in two observational periods mentioned previously as long and short sample using a constant return-to-scale (CRS) assumption and thus the efficiency scores of the pension funds are determined. The reason for doing so is in fact that CRS condition we receive a measure of overall efficiency, while VSR index shows only technological efficiency and indicates whether there is any connection between the size of the fund and the efficiency score. The correlation analysis between the CCR CRS scores and total assets of funds indicated the average correlation of -0.060 for period of ten years and -0.098 for the period of three years, meaning that there is no strong connection between scale and the efficiency. Thus, in this thesis I have used only CRS scores.

In each DEA model presented, the DMU, which is assigned a score of 1 is considered as an efficient. In all models slacks are zero. All other DMUs, those scores are below 1, considered to be less efficient. According to scale efficiency, which is reported as constant, decreasing or increasing return-to-scale (RTS), the efficient fund has a constant RTS, while others have either decreasing or increasing RTS. Decreasing RTS indicates that scale should be decreased in order to achieve efficiency or inputs should be decreased and vice versa. Funds with increasing RTS are too small in size meaning that they need to increase inputs to became efficient. The optimal lambdas with benchmark or weight associated represent the relative importance of a DMU to the efficient DMU.

4.2.2. Results of the DEA

The results of first DEA model for a long sample are presented in Table 5 and explained further. From the observation we can see that the best trade-off between risk and return has LVH XS. Similar results have been received with traditional performance measure previously. The least efficient or inefficient funds are SEB Energiline and Swedbank K100, which the traditional measurement ratios discussed in Section 3.2 were also among the weakest. The mean efficiency is 0.457, what indicates the average of all 17 funds together are inefficient. This result reveals that there is a space for improving input as 1 – 0.457 = 0.543.

First DEA model results for a short sample are presented in Appendix 7. Due to restrictions of the applicant used, the number of DMUs should be no more than 20. From originally 22 fuds I have excluded those, who were least efficient during the first observation – SEB Energiline and Swedbank K100. However, the size of these funds are not the lowest, we have seen previously that those two funds have also relatively low risk-adjusted performances. So, I consider extracting those funds from the population appropriate and this will not have a significant impact on the results.

On the contrary to the first observation, in last three years the most efficient fund was LHV M and the least efficient ones were SEB Konservatiivne and SEB Prograssiivne. Those funds have to modify their inputs by 71% and -36% accordingly to become efficient. The mean efficiency is 0.473, what is similar to the first observation. The ranking of efficiency scores is generally similar to those with risk-adjusted measures.

Table 5: DEA model 1. results for long sample

DMU No	DMU Name	Input-Oriented CCR Efficiency	Sum of lambdas	RTS	Optimal Lambdas with Benchmarks	Benchmark
1	LHV XS	1.000	1.000	Constant	1.000	LHV XS
2	LHV S	0.881	0.922	Increasing	0.922	LHV XS
3	Swedbank K10	0.557	0.636	Increasing	0.636	LHV XS
4	SEB Konservatiivne	0.290	0.488	Increasing	0.488	LHV XS
5	LHV M	0.817	1.395	Decreasing	1.395	LHV XS
6	Luminor C	0.445	1.025	Decreasing	1.025	LHV XS
7	Swedbank K30	0.477	1.138	Decreasing	1.138	LHV XS
8	SEB Optimaalne	0.262	0.780	Increasing	0.780	LHV XS
9	LHV L	0.543	1.758	Decreasing	1.758	LHV XS
10	Luminor B	0.389	1.389	Decreasing	1.389	LHV XS
11	LHV XL	0.464	1.950	Decreasing	1.950	LHV XS
12	SEB Progressiivne	0.255	1.227	Decreasing	1.227	LHV XS
13	Swedbank K60	0.331	1.790	Decreasing	1.790	LHV XS
14	Luminor A	0.319	1.930	Decreasing	1.930	LHV XS
15	SEB Energiline	0.235	1.811	Decreasing	1.811	LHV XS
16	Luminor A Pluss	0.261	2.346	Decreasing	2.346	LHV XS
17	Swedbank K100	0.241	2.330	Decreasing	2.330	LHV XS
	Average	0.457	1.407	-	1.407	-

Source: Author's calculation

Second DEA model is solved following the same logic using annualized standard deviation and costs percentage as inputs and annualized nominal return as net of costs as an output for LHV, SEB and Tuleva funds. Swedbank and Luminor outputs are already calculated as net of costs. Including costs into the analysis is similar to previously described DPEI and *IDEA*_1 models, where costs were included as separate inputs.

Long sample results for a second DEA model are presented in Table 6. In the first observation we have several funds ranked as efficient, i.e. LHV XS, Swedbank K60 and Swedbank K100. The results are similar to the ones described by Basso and Funari (2001) who also find that using more than one parameters increase the number of efficient funds. In this model, Swedbank K60 and Swedbank K100 are efficient in respect to the both standard deviation and the costs. However, the benchmark fund for all the rest funds is still LHV XS. The least efficient funds here are SEB Konservatiivne and SEB Optimaalne, who need to increase both inputs by 66% on average to reach to efficient frontier. With DEA it is also possible to see separately to which extend each input should be modified. The mean efficiency is 0.699.

Table 6: DEA model 2. results for long sample

DMU No	DMU Name	Input-Oriented CCR Efficiency	Sum of lambdas	RTS	Optimal Lambdas with Benchmarks	Benchmark
1	LHV XS	1.000	1.000	Constant	1.000	LHV XS
2	LHV S	0.813	0.851	Increasing	0.851	LHV XS
3	Swedbank K10	0.762	0.514	Increasing	0.433	LHV XS
4	SEB Konservatiivne	0.315	0.285	Increasing	0.229	LHV XS
5	LHV M	0.808	1.308	Decreasing	1.292	LHV XS
6	Luminor C	0.661	1.232	Decreasing	1.166	LHV XS
7	Swedbank K30	0.952	1.127	Decreasing	0.867	LHV XS
8	SEB Optimaalne	0.218	0.393	Increasing	0.335	LHV XS
9	LHV L	0.677	1.417	Decreasing	1.241	LHV XS
10	Luminor B	0.623	1.603	Decreasing	1.462	LHV XS
11	LHV XL	0.712	1.438	Decreasing	1.085	LHV XS
12	SEB Progressiivne	0.393	0.680	Increasing	0.404	LHV XS
13	Swedbank K60	1.000	1.000	Constant	1.000	Swedbank K60
14	Luminor A	0.708	1.726	Decreasing	1.144	LHV XS
15	SEB Energiline	0.540	0.816	Increasing	0.056	LHV XS
16	Luminor A Pluss	0.695	1.668	Decreasing	0.630	LHV XS
17	Swedbank K100	1.000	1.000	Constant	1.000	Swedbank K100
	Average	0.699	1.062	-	0.835	-

Source: Author’s calculation

Short sample results for a second DEA model are presented in Appendix 8. During the calculation of annualized nominal return as net of costs LHV S had negative return as it’s annualized nominal return is 0.49% and costs are 0.62%. Mentioning that all metrics should be positive, I excluded this fund from the population. Additionally, SEB Optimaalne was left out as least efficient during the first observation. Such a simple calculation already indicates LHV S has a negative return, which were not seen in other measures. In this model the efficient are Swedbank K10 and index funds of Tuleva and Swedbank, serving as a benchmark for all the rest funds. These results are different from the rest. The conclusion can be drawn that adding costs to the efficiency ratios, we actually have better result. The least efficient funds here are SEB XS and SEB Konservatiivne funds, whose inputs require a sufficient modification of 90% on average. Mean efficiency here is 0.638, which is close to the first observation.

Third DEA model is solved using annualized downside standard deviation as an input and annualized nominal return as an output. The results for long and short samples are presented in Table 7 and Appendix 9 accordingly.

Table 7: DEA model 3. results for long sample

DMU No	DMU Name	Input-Oriented CCR Efficiency	Sum of lambdas	RTS	Optimal Lambdas with Benchmarks	Benchmark
1	LHV XS	1.000	1,000	Constant	1.000	LHV XS
2	LHV S	0.871	0,922	Increasing	0.922	LHV XS
3	Swedbank K10	0.576	0,636	Increasing	0.636	LHV XS
4	LHV M	0.762	1,395	Decreasing	1.395	LHV XS
5	SEB Konservatiivne	0.244	0,488	Increasing	0.488	LHV XS
6	Swedbank K30	0.471	1,138	Decreasing	1.138	LHV XS
7	Luminor C	0.408	1,025	Decreasing	1.025	LHV XS
8	SEB Optimaalne	0.257	0,780	Increasing	0.780	LHV XS
9	LHV L	0.513	1,758	Decreasing	1.758	LHV XS
10	Luminor B	0.366	1,389	Decreasing	1.389	LHV XS
11	LHV XL	0.434	1,950	Decreasing	1.950	LHV XS
12	SEB Progressiivne	0.246	1,227	Decreasing	1.227	LHV XS
13	Swedbank K60	0.321	1,790	Decreasing	1.790	LHV XS
14	Luminor A	0.306	1,930	Decreasing	1.930	LHV XS
15	SEB Energiline	0.230	1,811	Decreasing	1.811	LHV XS
16	Luminor A Pluss	0.255	2,346	Decreasing	2.346	LHV XS
17	Swedbank K100	0.231	2,330	Decreasing	2.330	LHV XS
	Average	0.441	1.407	-	1.407	-

Source: Author's calculation

During a ten-year period, the efficient was, again, LHV XS. The least efficient or inefficient funds are SEB Energiline and Swedbank K100. The mean efficiency is 0.441, showing that Estonian funds are less efficient from the perspective of negative returns having a space for improvement of 66%. During second observation, least efficient funds from first observation were excluded, i.e. SEB Energiline and Swedbank K100 following the same logic as in first DEA model. Similarly, in last three years the efficient fund was LHV M and least efficient were SEB Konservatiivne and SEB Prograssiivne. Those funds have to modify their inputs by 89% and -72% accordingly to become efficient. The mean efficiency is 0.474, what is similar to the first observation. The ranking of efficiency scores is similar to those with risk-adjusted measures.

4.2.3. Conclusion on DEA

From efficiency scores provided with DEA we can see that there are one or sometimes several efficient funds among the populations. Efficiency scores show how far a certain fund is from being fully efficient and indicate the directions for improving the situation. Scores are not tightened to some weights and user can decide on used inputs and outputs to measure the efficiency. We can have specifications of the preferences of the investor and address them in the analysis. While in traditional performance measures there are predetermined inputs and their weights and ratios are relative to some hypothetic benchmark, DEA analysis getting around this point and makes it possible to assess certain the performance independently of preferences. It gives a measure of the performance what say us how much we can squeeze inputs to get the same amount of outputs and thus reach the efficient frontier. DEA makes multiple factor assessments and relative efficiency measurements possible. The results are sensitive to the time horizon used, as was mentioned by Basso and Funari (2001).

Results reveal that there might be actually efficient funds, whose risk-adjusted performances do not reveal this fact. This supports Morey and Morey conclusion (1998) that average investor does not have enough information while choosing an investment. Most of Estonian funds are not efficient in the sense that they could offer higher returns, lower risks or lower costs if they performed as well as the best performing funds (those at the efficient frontier). In deploying Sharpe ratio, Sortino ratio and Jensen’s alpha, we, in turn, have observed high results.

4.3. Correlation analysis and conclusion

4.3.1. Results of correlation analysis

In order to evaluate the efficiency scores solved with DEA methodology it may be useful to investigate the relationship between these results and the results obtained with popular performance measure methods like Sharpe ratio, Jensen’s alpha and Sortino ratio. In this connection the correlation results between the performance scores of different measures are presented in Table 8. and explained further.

Table 8. Correlation coefficient of risk-adjusted measures and DEA efficiency scores in two observed periods

1st observation	Sharpe ratio	Jensen's alpha	Sortino ratio
DEA (model 1)	90.08%	-34.79%	99.70%
DEA (model 2)	58.19%	35.62%	48.78%
DEA (model 3)	88.85%	-34.94%	100.00%
2nd observation	Sharpe ratio	Jensen's alpha	Sortino ratio
DEA (model 1)	93.95%	-34.03%	92.41%
DEA (model 2)	31.13%	57.56%	34.63%
DEA (model 3)	94.18%	-34.15%	94.97%

Source: Author's calculation

Correlation analysis reveals high positive relation between DEA models 1 and 3 with Sharpe and Sortino ratios and is consistent with academic studies presented in Chapter 2. High correlation with Sharpe and Sortino ratio achieved since both measures employ standard deviation as a risk measured into the calculations. The relation between DEA model 1 and 3 with Jensen's alpha results is negative, which is obvious as soon as DEA analysis did not consider the market systematic risk. On the contrary, DEA model 2 in both observations has relatively low correlation to traditional performance measures. Such deviations are caused by the costs included into DEA models. These findings are in line with the conclusion made by Murthi *et al.* (1997) and Basso in Funari (2001) in Chapter 2.

4.3.2. Conclusion on results

Results with DEA are different, as those are based only on the given population. This helps us to reveal the sources of inefficiency among the funds and adjust the strategy accordingly. Reviewing those with risk-adjusted measures give in total the understanding of the funds' performance in Estonia as we then see their efficiency scores and some absolute ratio of performance, which altogether help to create a full picture. Adding costs to the evaluation reveals the inefficient funds, those risk-adjusted measures in turn, show relatively good performance. In some cases even comparing the nominal return and the amount of costs indicates actually negative performance.

Below, the summary of most efficient funds among DEA and risk-measures is presented as a concluding remark in Table 9. and 10., where best results are marked with colour. Funds are brought by highest Sharpe and Sortino ratios, Beta closest to 1, lowest Jensen's alpha and DEA efficiency scores equal to one. Table below supports high correlation between results, but at the same time we do see some efficient funds, whose risk-adjusted performances are not the best ones.

Identified funds are not the exclusive options for the investor, but they have shown the best results among the analyses. The investor should still be aware of his/her preferences; however, these results give some meaningful input to the decision.

Table 9. Best scores for long sample

Fund	Sharpe ratio	β[a]	Jensen's alpha	Sortino ratio	risk	DEA 1	DEA 2	DEA 3
LHV XS	1.36	-0.185	1.42%	2.65	low	1.000	1.000	1.000
LHV L	0.95	-0.181	3.23%	1.36	medium	0.543	0.677	0.513
Swedbank K60	0.58	-0.320	3.30%	0.85	medium	0.331	1.000	0.321
Swedbank K100	0.46	-0.435	4.59%	0.61	high	0.241	1.000	0.231
SEB Konservatiivne	0.11	-0.229	0.20%	0.65	low	0.290	0.315	0.244

Source: Author's calculation
[a] Beta is scaled by factor 10000

Table 10. Best scores for short sample

Fund	Sharpe ratio	β[a]	Jensen's alpha	Sortino ratio	risk	DEA 1	DEA 2	DEA 3
LHV M	1.64	0.144	1.83%	1.68	medium	1.000	0.657	1.000
LHV XL	0.85	0.039	4.41%	0.87	high	0.531	0.596	0.515
Swedbank K1990-1999 indeks	0.61	-3.233	10.17%	0.64	high	0.384	1.000	0.382
Tuleva Maailma Võlakirjade	1.21	2.260	3.04%	1.53	low	0.745	1.000	0.910
Tuleva Maailma Aktsiate	0.71	-2.001	8.18%	0.72	high	0.444	1.000	0.428
Swedbank K10	1.32	0.469	0.99%	1.31	low	0.782	1.000	0.778
LHV S	0.91	0.082	0.55%	0.93	low	0.514	-	0.553

Source: Author's calculation
[a] Beta is scaled by factor 10000

CONCLUSION

The aim of this thesis was to evaluate the performance of the Estonian II pillar funds in the recent years. The evaluation was held using widely known risk-adjusted performance measurement methods like Sharpe ratio, Jensen's alpha and Sortino ratio and alternatively the technique of Data Envelopment Analysis was used. The main objective of this thesis was to discuss the appropriateness of DEA method and traditional performance measures in evaluating the pension funds. During the analysis the of pension funds thesis seeks to find out whether there are funds, which provide best trade-off between risk and return with both conventional and alternative methods.

This thesis brings out the issue that performance of pension funds in Estonia is shown to investors in very limited or proxy numbers, whereas real return depends on many factors as different risks and costs of the investment. It assesses risk-adjusted performance with traditional measurement methods and uses several DEA models to address other neglected areas such as costs and discusses the appropriateness of methods used. Thesis does not focus on legislation and policy established nor on assets allocation of the funds. Thus, I do not discuss the difference of pension and other funds or investments in detail, which definitely are, and this is the area for future researches. Thesis proposes methods for evaluating Estonian pension funds and concludes on the evaluations of latter.

The correlation between most of the DEA scores and other performance measures is high, indicating that DEA is appropriate technique to measure the efficiency of financial bodies. Weak relation between the DEA scores and risk-adjusted measures is noted when costs of the portfolio were included into analysis. The last reveals that there are some funds, which are inefficient while their risk-adjusted measures were relatively high.

DEA is more open-minded and allows broader variance of inputs than traditional performance measures, and, thus, can address more clearly the question of funds' efficiency. In comparison to the popular performance measures, DEA enables users to choose on data used in evaluation and thus it is more flexible to the constantly changing environment. DEA has proved itself as a powerful tool in analysing efficiency across wide range of areas also due to its ability to construct an efficiency frontier inside the chosen population and not being connected thus to some absolute benchmark. Main difference in DEA approach from popular risk-adjusted performance measures it that it does not require establishing the CAPM assumptions and weights of the parameters are not assumed in advance.

Thesis imputes into discussion of the appropriateness of traditional performance measures for pension funds and proposes some alternative. It reveals the need for some further thoughtful analyses in this area, taking into consideration the nature of pension investments. Thesis addresses very limited consideration that might be taken. The Word Bank paper discusses the nature of pension funds widely with all possible directions to consider, which can be used for further development as well. And perhaps, at some point, some will develop perfect method at least for Estonian funds.

KOKKUVÕTE

EESTI II SAMBA FONDIDE TULEMUSLIKKUSE ANALÜÜS

Margarita Vladimirskaja

Magistritöö eesmärk oli hinnata Eesti II samba fondide tulemuslikkust viimaste aastate jooksul. Analüüsis kasutati tuntumaid riskiga korrigeeritud tootluse hindamise meetodeid nagu Sharpe suhtarv, Jenseni alfa ja Sortino suhtarv ning alternatiivina kasutati andmete analüüsimise meetodi nimega Data Envelopment Analysis (DEA). Peamine tööeesmärk oli arutada kuivõrd on asjakohased DEA ning riskiga korrigeeritud tootluse arvutamise meetodid pensionifondide tulemuslikkuse hindamisel. Töö peamine uurimisküsimus oli uurida kas on Eestis fondid, kes pakuvad parimat suhe riski ning tootluse vahel mõlema meetodiga.

Magistritöö pöörab tähelepanu asjaolule, et Eesti pensionifondide tulemuslikkus on näidatud investorile väga piiratud numbriga, kus tootlus ei peegelda tegelikku olukorda. Eesmärgiga katta rohkem aspekte tootlikkusest kasutatakse DEA meetodi, kus erinevate mudelite abil uuritakse pensionifondide kasutegur. Antud töö ei kirjelda fondide varade jaotamist ega ka pensionifondidele kohaldatavaid seadusi ning piiranguid. Seega, ei arutata vahe pensionifondide ning avatud investeerimisfondide vahel, mis võib olla üks ala edaspidiseks uurimiseks. Magistritöö pakub alternatiivmeetodi pensionifondide hindamiseks ning arutab antud meetodiga saadud tulemused.

Korrelatsioonianalüüs riskiga korrigeeritud tootluste ja DEA tulemuste vahel on positiivne, mis toetab pakutud meetodi asjakohasust. Nõrk korrelatsioon DEA mudeliga on märgatud vaid juhul, kui investeeringutega kaasnevaid kulusid on lisatud analüüsi. Antud tulemus näitab, et tegelikult on Eestis fondid, mis ei ole piisavalt efektiivsed, vaatamata kõrgetele tootlustele.

DEA meetod pakub laiemaid võimalusi tootlikkuse hindamiseks, kuna see võimaldab kaasata analüüsi spetsiifilisi näitajaid, millest investor on huvitatud ning näitab kuidas saaks nõrgad kohad

parandada. Võrdlemaks DEA traditsiooniliste meetoditega, on see paindlikum ning seega rohkem adapteeritav turumuutustele. Tänu võimalusele luua efektiivsus kõvera antud populatsiooni raames ning mitte olla seotud kindla standardiga, on see meetod laiali kasutusel nii finantsvaldkonnas, kui ka mujal. Peamine erinevus tuntumatest riskiga korrigeeritud tootluse hindamise meetoditest seisneb sellest, et DEA ei põhine kapitalivarade hinnakujundusmudeli (CAPM) eeldustele ning ei määra ette tegurite osakaalu.

Magistritöö täiendab arutelu riskiga korrigeeritud tootluste hindamise meetodite asjakohasusest pensionifondide jaoks ning pakub üks alternatiividest. Antud ala vajab kindlasti rohkem uuringuid, võttes arvesse pensioniinvesteeringute eripärad ning töö on toonud esile vaid mõned kaalutlused. Maailma Pank on arutanud pensionifondide hindamise probleeme laiali, mis võib olla ka järgnevate magistriuuringute teema.

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APPENDICES

Appendix 1. Sharpe ratio results for a long sample in a descending order.

Pension fund	Annualized nominal return	Annualized standard deviation	Sharpe ratio
LHV XS	2.38%	1.04%	1.36
LHV M	3.32%	1.78%	1.33
LHV S	2.20%	1.09%	1.13
LHV L	4.19%	3.38%	0.95
LHV XL	4.64%	4.39%	0.84
Swedbank K30	2.71%	2.49%	0.70
Luminor B	3.31%	3.72%	0.63
Luminor C	2.44%	2.41%	0.62
Swedbank K60	4.26%	5.65%	0.58
Luminor A	4.60%	6.32%	0.58
Luminor A Pluss	5.59%	9.37%	0.49
Swedbank K10	1.52%	1.19%	0.47
Swedbank K100	5.55%	10.08%	0.46
SEB Energiline	4.31%	8.05%	0.42
SEB Progressiivne	2.92%	5.03%	0.39
SEB Optimaalne	1.86%	3.11%	0.29
SEB Konservatiivne	1.16%	1.75%	0.11
Average	3.35%	4.17%	0.67

Source: Author's calculation

Appendix 2. Sharpe ratio results for a short sample in a descending order

Fund*	Annualized nominal return	Annualized standard deviation	Sharpe ratio
LHV M	1.77%	1.12%	1.64
Swedbank K10	0.93%	0.75%	1.32
Tuleva Maailma Võlakirjade	2.98%	2.52%	1.21
LHV XS	0.71%	0.66%	1.17
LHV L	3.53%	3.19%	1.13
LHV S	0.49%	0.60%	0.91
Luminor C	2.94%	3.51%	0.86
LHV XL	4.35%	5.16%	0.85
Luminor B	3.37%	4.73%	0.72
Tuleva Maailma Aktsiate	8.12%	11.52%	0.71
Swedbank K30	2.13%	3.18%	0.69
Luminor A	4.84%	7.70%	0.64
Swedbank K1990-1999 indeks	10.11%	16.60%	0.61
SEB Indeks 100	9.75%	17.05%	0.58
SEB Energiline	5.62%	10.53%	0.54
SEB Optimaalne	1.73%	3.41%	0.52
Swedbank K60	3.50%	7.41%	0.48
Luminor A Pluss	5.44%	11.69%	0.47
LHV Indeks	7.12%	17.64%	0.41
Swedbank K100	5.44%	13.64%	0.40
SEB Progressiivne	2.41%	6.46%	0.38
SEB Konservatiivne	0.52%	2.49%	0.23
Average	3.99%	6.89%	0.75

Source: Author’s calculation

Appendix 3: Jensen's alpha results for a long sample in a descending order

Pension fund	Annualized nominal return	β^a	Jensen's alpha
Luminor A Pluss	5.59%	-0.919	4.63%
Swedbank K100	5.55%	-0.435	4.59%
LHV XL	4.64%	-0.187	3.68%
Luminor A	4.60%	-0.908	3.64%
SEB Energiline	4.31%	-1.201	3.35%
Swedbank K60	4.26%	-0.320	3.30%
LHV L	4.19%	-0.181	3.23%
LHV M	3.32%	-0.198	2.36%
Luminor B	3.31%	-0.790	2.35%
SEB Progressiivne	2.92%	-0.744	1.96%
Swedbank K30	2.71%	-0.256	1.75%
Luminor C	2.44%	-0.630	1.48%
LHV XS	2.38%	-0.185	1.42%
LHV S	2.20%	-0.373	1.23%
SEB Optimaalne	1.86%	-0.637	0.90%
Swedbank K10	1.52%	-0.451	0.55%
SEB Konservatiivne	1.16%	-0.229	0.20%
Average	3.35%	-0.509	2.39%

Source: Author's calculation

[a] Beta is scaled by factor 10000

Appendix 4: Jensen’s alpha results for a short sample in a descending order

Fund	Annualized nominal return	β[a]	Jensen's alpha
Swedbank K1990-1999 indeks	10.11%	-3.233	10.17%
SEB Indeks 100	9.75%	-3.363	9.81%
Tuleva Maailma Aktsiate	8.12%	-2.001	8.18%
LHV Indeks	7.12%	-2.503	7.18%
SEB Energiline	5.62%	-1.199	5.68%
Luminor A Pluss	5.44%	-4.324	5.50%
Swedbank K100	5.44%	-0.913	5.50%
Luminor A	4.84%	-1.888	4.90%
LHV XL	4.35%	0.039	4.41%
LHV L	3.53%	0.290	3.59%
Swedbank K60	3.50%	0.247	3.55%
Luminor B	3.37%	0.912	3.42%
Tuleva Maailma Võlakirjade	2.98%	2.260	3.04%
Luminor C	2.94%	3.084	3.00%
SEB Progressiivne	2.41%	0.880	2.47%
Swedbank K30	2.13%	0.607	2.19%
LHV M	1.77%	0.144	1.83%
SEB Optimaalne	1.73%	0.436	1.79%
Swedbank K10	0.93%	0.469	0.99%
LHV XS	0.71%	0.333	0.77%
SEB Konservatiivne	0.52%	1.784	0.58%
LHV S	0.49%	0.082	0.55%
Average	3.99%	-0.357	4.05%

Source: Author’s calculation
[a] Beta is scaled by factor 10000

Appendix 5: Sortino ratio results for a long sample in a descending order.

Pension fund	Annualized nominal return	Annualized downside deviation	Sortino ratio
LHV XS	2.38%	0.90%	2.65
LHV S	2.20%	0.95%	2.31
LHV M	3.32%	1.64%	2.02
Swedbank K10	1.52%	0.99%	1.53
LHV L	4.19%	3.08%	1.36
Swedbank K30	2.71%	2.17%	1.25
LHV XL	4.64%	4.03%	1.15
Luminor C	2.44%	2.25%	1.08
Luminor B	3.31%	3.41%	0.97
Swedbank K60	4.26%	5.00%	0.85
Luminor A	4.60%	5.67%	0.81
SEB Optimaalne	1.86%	2.72%	0.68
Luminor A Pluss	5.59%	8.27%	0.68
SEB Progressiivne	2.92%	4.48%	0.65
SEB Konservatiivne	1.16%	1.79%	0.65
Swedbank K100	5.55%	9.05%	0.61
SEB Energiline	4.31%	7.07%	0.61
Average	3.35%	3.73%	1.17

Source: Author’s calculation

Appendix 6: Sortino ratio results for a short sample in a descending order.

Fund	Annualized nominal return	Annualized downside deviation	Sortino ratio
LHV M	1.77%	1.05%	1.68
Tuleva Maailma Võlakirjade	2.98%	1.94%	1.53
Swedbank K10	0.93%	0.71%	1.31
LHV XS	0.71%	0.57%	1.25
LHV L	3.53%	3.05%	1.16
LHV S	0.49%	0.53%	0.93
LHV XL	4.35%	5.01%	0.87
Luminor C	2.94%	3.60%	0.82
Tuleva Maailma Aktsiate	8.12%	11.27%	0.72
Luminor B	3.37%	4.77%	0.71
Swedbank K30	2.13%	3.02%	0.70
Swedbank K1990-1999 indeks	10.11%	15.72%	0.64
Luminor A	4.84%	7.76%	0.62
SEB Indeks 100	9.75%	16.12%	0.60
SEB Energiline	5.62%	9.99%	0.56
SEB Optimaalne	1.73%	3.52%	0.49
Swedbank K60	3.50%	7.21%	0.48
Luminor A Pluss	5.44%	11.45%	0.48
LHV Indeks	7.12%	16.64%	0.43
Swedbank K100	5.44%	13.59%	0.40
SEB Progressiivne	2.41%	6.28%	0.38
SEB Konservatiivne	0.52%	2.90%	0.18
Average	3.99%	6.67%	0.77

Source: Author’s calculation

Appendix 7: DEA model 1. results for short sample

DMU No	DMU Name	Input-Oriented CCR Efficiency	Sum of lambdas	RTS	Optimal Lambdas with Benchmarks	Benchmark
1	LHV S	0.514	0.277	Increasing	0.277	LHV M
2	LHV XS	0.683	0.402	Increasing	0.402	LHV M
3	Swedbank K10	0.782	0.528	Increasing	0.528	LHV M
4	LHV M	1.000	1.000	Constant	1.000	LHV M
5	SEB Konservatiivne	0.130	0.291	Increasing	0.291	LHV M
6	Tuleva Maailma Võlakirjade	0.745	1.681	Decreasing	1.681	LHV M
7	Swedbank K30	0.422	1.203	Decreasing	1.203	LHV M
8	LHV L	0.697	1.994	Decreasing	1.994	LHV M
9	SEB Optimaalne	0.319	0.975	Increasing	0.975	LHV M
10	Luminor C	0.528	1.662	Decreasing	1.662	LHV M
11	Luminor B	0.449	1.901	Decreasing	1.901	LHV M
12	LHV XL	0.531	2.455	Decreasing	2.455	LHV M
13	SEB Progressiivne	0.235	1.361	Decreasing	1.361	LHV M
14	Swedbank K60	0.297	1.975	Decreasing	1.975	LHV M
15	Luminor A	0.396	2.735	Decreasing	2.735	LHV M
16	Tuleva Maailma Aktsiate	0.444	4.586	Decreasing	4.586	LHV M
17	Luminor A Pluss	0.293	3.075	Decreasing	3.075	LHV M
18	Swedbank K1990-1999 indeks	0.384	5.712	Decreasing	5.712	LHV M
19	SEB Indeks 100	0.360	5.508	Decreasing	5.508	LHV M
20	LHV Indeks	0.254	4.021	Decreasing	4.021	LHV M
	Average	0.473	2.167	-	2.167	-

Source: Author’s calculation

Appendix 8: DEA model 2. results for short sample

DMU No.	DMU Name	Input-Oriented CCR Efficiency	Sum of lambdas	RTS	Optimal Lambdas with Benchmarks	Benchmark
1	LHV Indeks	0.616	0.701	Increasing	0.551	Swedbank K1990-1999 indeks
2	LHV L	0.654	1.960	Decreasing	1.614	Swedbank K10
3	LHV M	0.657	0.974	Increasing	0.974	Swedbank K10
4	LHV XL	0.596	1.653	Decreasing	0.615	Swedbank K10
5	LHV XS	0.223	0.194	Increasing	0.194	Swedbank K10
6	Luminor A	0.617	2.022	Decreasing	0.191	Swedbank K10
7	Luminor A Pluss	0.520	1.771	Decreasing	0.180	Tuleva Maailma Aktsiate
8	Luminor B	0.647	2.311	Decreasing	1.563	Swedbank K10
9	Luminor C	0.767	1.961	Decreasing	1.273	Swedbank K10
10	SEB Energiline	0.541	1.248	Decreasing	0.284	Tuleva Maailma Aktsiate
11	SEB Konservatiivne	0.006	0.007	Increasing	0.002	Swedbank K10
12	SEB Indeks 100	0.896	0.956	Increasing	0.839	Swedbank K1990-1999 indeks
13	SEB Progressiivne	0.225	0.524	Increasing	0.015	Tuleva Maailma Aktsiate
14	Swedbank K10	1.000	1.000	Constant	1.000	Swedbank K10
15	Swedbank K100	0.564	0.922	Increasing	0.597	Tuleva Maailma Aktsiate
16	Swedbank K1990-1999 indeks	1.000	1.000	Constant	1.000	Swedbank K1990-1999 indeks
17	Swedbank K30	0.646	1.036	Decreasing	0.315	Swedbank K10
18	Swedbank K60	0.586	0.907	Increasing	0.229	Tuleva Maailma Aktsiate
19	Tuleva Maailma Aktsiate	1.000	1.000	Constant	1.000	Tuleva Maailma Aktsiate
20	Tuleva Maailma Võlakirjade	1.000	1.000	Constant	1.000	Tuleva Maailma Võlakirjade
	Average	0.638	1.157	-	0.672	-

Source: Author’s calculation

Appendix 9: DEA model 3. results for short sample

DMU No	DMU Name	Input-Oriented CCR Efficiency	Sum of lambdas	RTS	Optimal Lambdas with Benchmarks	Benchmark
1	LHV S	0.553	0.277	Increasing	0.277	LHV M
2	LHV XS	0.740	0.402	Increasing	0.402	LHV M
3	Swedbank K10	0.778	0.528	Increasing	0.528	LHV M
4	LHV M	1.000	1.000	Constant	1.000	LHV M
5	Tuleva Maailma Võlakirjade	0.910	1.681	Decreasing	1.681	LHV M
6	SEB Konservatiivne	0.106	0.291	Increasing	0.291	LHV M
7	Swedbank K30	0.418	1.203	Decreasing	1.203	LHV M
8	LHV L	0.686	1.994	Decreasing	1.994	LHV M
9	SEB Optimaalne	0.291	0.975	Increasing	0.975	LHV M
10	Luminor C	0.485	1.662	Decreasing	1.662	LHV M
11	Luminor B	0.419	1.901	Decreasing	1.901	LHV M
12	LHV XL	0.515	2.455	Decreasing	2.455	LHV M
13	SEB Progressiivne	0.228	1.361	Decreasing	1.361	LHV M
14	Swedbank K60	0.288	1.975	Decreasing	1.975	LHV M
15	Luminor A	0.371	2.735	Decreasing	2.735	LHV M
16	Tuleva Maailma Aktsiate	0.428	4.586	Decreasing	4.586	LHV M
17	Luminor A Pluss	0.282	3.075	Decreasing	3.075	LHV M
18	Swedbank K1990-1999 indeks	0.382	5.712	Decreasing	5.712	LHV M
19	SEB Indeks 100	0.359	5.508	Decreasing	5.508	LHV M
20	LHV Indeks	0.254	4.021	Decreasing	4.021	LHV M
	Average	0.475	2.167	-	2.167	-

Source: Author’s calculation

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