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Explaining loan activities of Israeli banks with real options

Wyjaśnienie działalności kredytowej banków izraelskich przy pomocy opcji rzeczywistych

Doctoral thesis

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Content

Introduction

In the last decades the banking literature have shown a growing attention to different elements of the bank lending process. On one side researchers concentrate on the effects of credit scoring (Hand and Henley, 1997), and the presence of intangibles in lending decision-making (Cañibano et al, 2000). On the other side they investigate the loan officers' behavior and the meaning of the risk management in bank lending process (Ruggeri et al, 2018), including the real-options approach (Choi and Smith, 2002).

The loan granting process consists of two interrelated components: loan granting policy (the procedure) and decision making. The loan granting policy (the procedure) represents loan granting methodology to assess credit risk by establishing a wide range of requirements and standards for loan granting. These requirements and standards are similar in most banks and include standards on market segment, quality and liquidity of loan applicant's assets, its value, collaterals, loan limits, creditworthiness and credit reputation (Purinsh et al, 2012). Decision-making represents a series of actions that should be executed by loan officers in order to conform to all standards and requirements established in the loan granting procedures. The major point of the decision-making in loan granting is to approve or deny the loan at the end of the process. Today, loan officers use hard and soft types of information in loan assessment to evaluate the risks of loan defaults (Berger and Udell, 2006). Despite the wide range of this information loan officers may make mistakes during loan granting process (Trönnberg and Hemlin, 2012). Therefore, it is so important that they assess the risk associated to a loan carefully.

The major risk factors in loan granting are an interest rate changes and a default of a borrower (a situation in which a company cannot repay a loan because of loss of income, bankruptcy, etc.) (Choi and Smith, 2002). In the case of the interest rate banks can reduce risks by requiring payment of high interest rate for each risky loan, as a compensation for higher risk. The case of a loan delay in loan repayment is more complicated. If a single delay in loan repayment is a failure to make payments when they are due, extended delay in loan repayment can result in a loan default, i.e. the failure to repay a loan. Loan default can cause an increase of the most important risk of a bank, which is a credit risk. The growth of credit

risk hinders the growth of a bank performance (Zheng et al, 2018).

Despite multiple methods and tools, it is still difficult to predict risk of a loan default. Banking industry has critical importance to national and global economy (Lobo, 2017). Therefore, banks must be careful in granting loans.

A loan officer (and therefore a bank) has an exclusive right to approve or to reject requests from a loan applicant. In simple words, **from a bank's perspective granting a loan is a possibility, where a bank has to decide if to grant it or not, and under which conditions**. Among all bank activities, the loan granting procedure related to the request of financial loans entails effort to assess accurately all risks related to loan seeker.

Without a doubt, a decision made by a loan officer can be based on one or more of the most common traditional methods, such as DCF, NPV, IRR, ROI and payback. But in fact, these methods are not dynamic or flexible enough to capture risks that may take place during the period of a loan repayment (Myers 1984; Hodder and Riggs, 1985; Ingersoll and Ross, 1992). Therefore, it is necessary to use a method that takes into account the uncertainty. Real options can be such method and this due to its flexibility.

The author of this PhD thesis suggests considering loan granting through the prism of real options. The original definition of a real option was proposed in 1977 by Stewart C. Myers. The term "real option" originates from the fact that the option's underlying asset is a tangible asset. The tangible asset is the asset that has a physical form. Tangible assets include both fixed assets and current assets. A fixed asset is a long-term asset that a firm owns and uses for income production. For example, it may be land, building, other real estate, or any equipment like computers or furniture. Current assets are the short-term assets, that represent the value of all assets that can be converted into cash within one year. For example, it can be cash and cash equivalents, inventory, marketable securities, and other liquid assets.

A real option is defined as the right, but not the obligation, to take an action (e.g. deferring, expanding, contracting, or abandoning) at a predetermined cost called the exercise price, for a predetermined period of time, which is the life of an option (Copeland and Antikarov, 2003). A fundamental premise of real options theory is that a value of investment will increase if real options are embraced in decision process, because of the ability to change course of investment decision, when uncertainty exists (Ragozzino, Reuer, and Trigeorgis, 2016). If information about the value of an investment at the decision time is inaccurate, it will lead to a wrong decision (Posen, Leiblein, and Chen, 2017). To be closer with research topic, lack or

inaccurate information about a loan applicant may lead to a wrong decision about a loan granting (Trönnberg and Hemlin, 2012), and further to a loan default and losses for a bank. Therefore, it is important, interesting and worth to investigate the role of real options in explaining loan granting.

Taking into account the above, there are three **main goals** of this thesis: one theoretical and two empirical ones. Theoretically the thesis aims **to explain conceptually the relationship between loan activities in banks and real options**. Empirically it aims to **propose and test a model describing bank loan activity in terms of** bank characteristics, macroeconomic situation and **ambiguity on loan activity (which replaces uncertainty and can be a measure of a real option)** as well as to **examine the effect of ambiguity on loan activity of banks according to their size**. Such a combination is designed to test the ability to predict and influence of the ambiguity as an indicator for real option on a bank's lending process. The empirical study is set in Israeli banking system, which is in the biggest interest and recognition by the Author.

There are **four hypotheses** derived from these goals:

- H1 – *Inclusion of Ambiguity in loan granting process*: Apart from the 3 bank characteristics: capital, capacity and character and profit from loan the banking loan activity can be explained in terms of ambiguity in loan granting process.
- H2 – *Ambiguity Explanatory Ability*: The proposed method of ambiguity estimation in loan decision-making process has better explanatory ability than uncertainty measuring method, presented in Choi and Smith (2002) study.
- H3 – *Bank Size Importance for Ambiguity*: Large banks are less cautious in decision-making process of loan activities than medium and small banks.
- H4 – *Proposed Model Significance*: All the components of the model are statistically significant.

The thesis consists of five chapters. Chapter One provides the theoretical background for credit risk assessment, including different types of existing models. Chapter Two contains of general characteristics of real options in which at the end the author comes to differences in understanding of risk, uncertainty and ambiguity on loan activity which is the equivalent of real options. Chapter Three examines possible applications of real options in different

financial and non-financial industries. Chapter Four describes the banking system in Israel, where the empirical research setting is situated. Chapter Five provides full description and theoretical background of the proposed real option-based model, including tests and comparison of its results with a model of Choi and Smith (2002) which was used as a basis for the development of proposed model.

There are several points of this PhD thesis which are the **contribution to the literature**. The author proposes a model that explains a bank's loan activity as a function of bank's characteristics, borrower's characteristics and macroeconomic condition. The model is based on "dry data" from financial annual Israeli banks statements and statistical macroeconomic data for Israel. Such a method may help to build a single model that will fit all banks. For the author best knowledge, such model has not been proposed before. Additionally, the author of this PhD thesis uses ambiguity instead of uncertainty. In the author's opinion, ambiguity is more suitable for the process of granting loans because during the process (1) future outcomes are known; (2) actions that can be used are known; (3) payoffs action and its outcome is known; (4) absolute probabilities of such outcomes is also known.

The author looks at the problem complexly, however he is aware of the **limitations of his PhD study**. The most important limit he finds is the research sample, narrowed to the banks in Israel. The author works in Israeli banking system and understands its needs the most. However, he knows the research sample might be extended, not only for the purposes of testing the proposed model, but also for the comparisons among banking systems in different countries or regions. He hopes the possibilities for comparisons would be a motivation and a topic to deepen explaining loan granting with real options in future research.

Chapter 1.

Theoretical background for credit risk assessment

This chapter discusses credit risk that is the essential element of bank operations which can be an underlying asset of real options. As the starting point the author presents the definition of credit risk and shows that it differs between researchers, but the major idea is joint. It is very important to understand the concept of credit risk, or more generally the connection between risk and return. It will help to evaluate needed compensation to cover extra risk taken by a bank and to comprehend the effect of risk aversion on loan granting.

After explaining the essence of a credit risk, the author presents a number of different credit risk models and its development since the first model until the present. Presentation of existing models consists of the advantages along with disadvantages of each model. In addition, the author reviews the academic literature in the field and concerns the possibilities to cope (i.e., reduce, prevent) with the credit risk and the damages caused by this risk.

1.1. Definition, types and determinants of credit risk

Among all financial activities, loan granting remains the oldest and traditional operation of bank institutions. Formally, a loan can be seen as a contract, in which a person or legal entity gives an amount of money to another person or entity for a limited period of time, under pre-determined conditions. The party of contract that gives the money is called a "lender", while the party that receives the money is called a "borrower". The amount of money given in a loan is called a "fund". The purpose of the loan is to enable the borrower to carry out economic activity when loan applicant is in a state of lack of sufficient economic resources. Without obtaining a loan, loan seeker must collect enough money in advance, to achieve required economic activity.

The loan granting process, according to existing literature, consists of two interrelated components: loan granting policy (the procedure) and decision-making process. The loan granting policy (the procedure) represents loan granting methodology to assess credit risk by establishing a wide range of requirements and standards for loan granting. Decision-making represents a series of actions that should be executed by loan officers in order to conform to all standards and requirements established in the loan granting procedures. The major point

of the decision-making in loan granting is to approve or deny the loan at the end of the process. Loan granting procedures in commercial banks include a wide range of requirements and standards aimed to help assess risks in lending. These requirements and standards are similar in most banks and include standards on market segment, quality and liquidity of loan applicant's assets, its value, collaterals, loan limits, creditworthiness and credit reputation (Purinsh, Reizinsh, Braslinsh and Svitlika, 2012).

Despite the large number of instruments, loan granting process isn't deprived of risk. The major risk factors are:

- interest rate changes,
- a default of a borrower (Choi and Smith, 2002).

In the case of the interest rate banks can reduce risks by requiring payment of high interest rate for each risky loan, as a compensation for higher risk. The case of a loan delay in loan repayment is more complicated. If a single delay in loan repayment is a failure to make payments when they are due, extended delay in loan repayment can result in a loan default, the failure to repay a loan. Loan default can cause an increase of the most important risk of a bank, which is a credit risk. Credit risk hinders the growth of a bank performance (Zheng, Sarker and Nahar,2018). Additionally, credit risk is one of the fundamental factors that determine banks profit from granting loans.

Credit risk refers to the possibility of default by one of the sides in a financial contract (a loan). Default can be triggered by a missed or delayed interest payment or bankruptcy (Bessis, 2015). The probability of default affects the future cash flows and, as result, causing profit or loss. According to Anderson (2013, p. 292) credit risk is "the probability that a legally enforceable contract may become worthless (or at least substantially reduced in value) because the counterparty defaults and goes out of business." Saunders and Cornett (2011, p.186) define credit risk as "risk that the promised cash flows from loans and securities held by financial institutions may not be paid in full." Hull (2012) adds that credit risk arises due to default by debt issuers and counterparties in derivatives transactions. In terms of uncertainty, credit risk arises from uncertainty in a given counterparty's ability to meet its obligations.

Basel Committee on Banking Supervision defines credit risk as the potential that a bank borrower or counterparty will fail to meet its obligations in accordance with agreed terms. Rose (2002) calls this potential a probability that some of a bank's assets, especially its loans, will fall down in value and even will become worthless.

Credit risk is associated with banks traditional lending activity. Therefore, credit risk can be defined as partially or full non-repayment of a loan. Sources of credit risk exist throughout the activities of a bank, included in the banking book and in the trading book, and both on and off the balance sheet. Another exposure to credit risk can arises from holding bonds or other securities (Casu, Girardone, and Molyneux, 2006).

For banks credit risk is the risk that a borrower may not repay a loan and that the lender (i.e., a bank) may lose the principal of the loan or the interest associated with it. Additionally, it may lead to disruption in future cash flows, and increase in collection costs. Credit risk arises because borrowers tend to use future cash flows to pay current debts. Interest payments from the borrower are a lender's (i.e., a bank) compensation for assuming credit risk.

Credit risk can be divided into three types:

- **credit default risk**: this type of risk is associated with a situation where a debtor having difficulties to pay its loan obligations in full or the debtor is more than 90 days past due on any material credit obligation. default risk may impact all credit-sensitive transactions, including loans, securities and derivatives;
- **concentration risk:** this type of risk arises from any single exposure or group of exposures, with the potential to inflict large losses, that can be threat for bank's core operations. it may appear in the form of single company concentration or industry concentration;
- **country risk:** the risk of loss appears when a sovereign state freeze foreign currency payment (transfer/conversion risk) or when it defaults on its obligations (sovereign risk).

According to Bielecki and Rutkowski (2004) and Anson, Fabozzi, and Choudhry (2000) credit risk consist of three components: default risk, spread risk and downgrade risk.

- **default risk** refers to the possibility that the issuer or counterparty will fail to fulfill the obligation which were determined in financial contract; this may happen in standard loans as well as in online loans (Zhu et al. 2023);
- **credit spread risk** refers to loss or low performance of an issue or issues because of an increase in the credit spread. Credit spread reflects the reaction of financial markets on deterioration in credit quality when issue occurs;
- **downgrade risk** is the risk of lowering of credit ratings. for example, rating agency (e.g. Moody’s, Fitch, S&P) can give for an issuer a new rank, that is lower than previous

rank.

There is a fairly close relationship between these three types of credit risk. According to Bessis (2015) credit risk in banks consists of a settlement risk and a pre-settlement risk. Settlement risk is the risk that one side of a contract will fail to reach the terms of a contract with another side at the time of settlement. settlement risk can also be the risk associated with default, along with any timing differences in settlement between the two sides of a contract. default risk can also be associated with principal risk. settlement risk is often called delivery risk. Pre-settlement risk is a possibility that one side in a contract will fail to meet its obligations under that contract, resulting in default before the settlement date. This default would prematurely end the contract. This type of risk can lead to the replacement cost risk because the injured party needs to enter into a new contract instead of the old one. The market conditions and terms may be less favorable for the new contract.

Lenders can reduce credit risk using several methods:

- **risk-based pricing:** lenders can require a higher interest rate from borrowers who are more likely to default, as the compensation for higher risk. Such practice is called risk-based pricing. Thus, lenders take into account different factors relating to a loan such as loan purpose, credit rating, loan-to-value ratio and estimates the effect on yield (credit spread);
- **covenants:** lenders may add conditions on the borrower, called covenants, into loan agreements such as:
  - submission periodical statements on its financial condition;
  - avoiding from paying dividends, repurchasing shares, borrowing further, or other specific, voluntary actions that can have negative affect on the company's financial position;
  - full repayment of a loan, at the lender's request, in specific events such as changes in the borrower's debt-to-equity ratio or interest coverage ratio;
- **hedging credit risk by using credit insurance and credit derivatives:** lenders and bond holders may hedge their credit risk by purchasing credit insurance or credit derivatives. These contracts transfer the risk from the lender to the seller (insurer) in exchange for payment. the most common credit derivative is the credit default swap;
- **loan restriction:** lenders can reduce credit risk by reducing the amount of credit extended, either in total or to certain borrowers;

- **loan diversification:** lending to a small number of borrowers (or kinds of borrower) s connected a high degree of unsystematic credit risk, called concentration risk. Lenders reduce this risk by diversifying the borrower pool;
- **deposit insurance:** many governments establish deposit insurance to guarantee safety of deposits in case of banks bankruptcy. Such protection intends to prevent massive withdraw of money by customers, when a bank is becoming insolvent. Another goal is to avoid a bank run, and to convince consumers to keep holding their savings in the banking system.

Credit risk controlling is the crucial fundamental condition for stability of the banking sector. And this is due to the critical importance of the banking industry to national and global economy (Lobo, 2017). Banks face six major risks: credit risk, liquidity risk, market risk, interest rate risk, solvency risk and earning risk (Rose, 2002). Bessis (2015) claims that those risks can be grouped as credit risk, market risk and operational risk, and Lewis and Davis (1987) and Hughes, MacDonald (2002) and Pozo (2023), add that currency risk, country risk and cross-border risk as well as foreign shocks, appear in case of international lending. Recently Chen et. al. (2023) add to this list a digital transformation. So, credit risk matters a lot.

Loans is the largest bank's asset. Generally, loans represent from half to almost three-quarters of the total value of all bank assets (Rose, 2002). Therefore, credit risk is the major risk in the banking sector. Additionally, banks can be exposed to credit risk from the domestic sovereign fund (Gennaioli et. al. 2014a, Gennaioli et al., 2014b, Abinzano et. al. 2021 and Gómez-Puig et. al. 2023 found it for European banks; Acharya and Steffen (2015) and Chernov et. al. 2022 for banks outside Europe, including the ones operating in emerging markets).

Apart from lending also other bank activities like accounting, money transfer, cash management and services can have direct or indirect effect on credit risk. Lending is the most profitable banks activity, but, from the other side the largest source of credit risk for most banks, large and small. It is almost never possible to be sure that borrowers will have enough funds to repay their debts. That is, there are risk that customers will not be able to fulfill their loan obligations. Such risk can change performing loans to the „bad" loans, also called **non-performing loans** (NPL). A non-performing loan (NPL) is a sum of loans upon which the borrower has not made the predetermined payments for a specific period. The status of a non-performing loan vary, depending on the specific loan's terms: "no payment" usually

refers to zero payments of either principal or interest. The specific period also varies, depending on the industry and the loan type. Generally, the period is 90 days or 180 days.

The case of non-performing loans was widely studied in different ways to find its effects on the credit risk. A loss from a bad loan indirectly transfers to a capital deficit. Thus, increase in capital deficit due to non-performing loans and additional losses (e.g., monitoring costs) increases credit risk. Some researchers (Duican and Pop, 2015; Mileris, 2012; Mileris, 2014; Betz et al., 2020, Nwafor and Nwafor 2023) show relations between the macroeconomic conditions and non- performing loans in the banking system. The sum of past non-performing loans interacts with the macroeconomic changes and indicate that banks with more non-performing loans are more affected by the macro shocks. Thus, the findings suggest that non-performing loans increase across banks as macroeconomic risks rise. There is highly a correlation between interaction terms and the macroeconomic conditions, so it is difficult to distinguish the independent effects of each macroeconomic variable. Banks with a higher exposure to macroeconomic risk are expected to face with larger non-performing loans. Additional conclusion is that macroeconomic variables such as GDP, interest rate, exchange rate, public debt, sovereign debt, unemployment, the volume of imports, the volume of exports, have a significant influence on the dynamics of non-performing loans in emerging economies[1], but do not have a notable influence in the case of developed economies (Castro, 2013; Istrate, Ionescu and Haralambie, 2016).

When a bank can establish a relationship between macroeconomic conditions and **systematic credit risk factors**, this may help in assessing and managing credit risk through the time. Also, it may be useful in an environment with varying economic conditions which can cause different situations of default. In case of economic growth rise up, investors tend to have more optimistic expectations about the future and lending standards rolls down and credit grows fast. Opposite, if the economic growth slows down, this causes a shock in crediting (Koju, L., Koju, R. and Wang, S., 2020).

[1] Some examples are worth mentioning. Marki, Tsagkanos and Bellas (2014) find that the macroeconomic variables have a significant influence on non-performing loans in the Euro area. Based on analysis conducted in Greece, Makri (2015) concludes that the probability of non-performed loans influenced by unemployment, public debt, GDP, inflation, outstanding loan, capital adequacy, liquidity and profitability. Makri and Papadatos (2016) argue that the macroeconomic environment (e.g. public debt, unemployment, inflation) affect the repayment of loans in arrears. Skala (2014) analyzes factors that have effects on the credit policy of 356 commercial banks in Poland from 2006 to 2012. She finds that the macroeconomic indicators have a strong impact on the non-performing loans. Recently, Wang et al. (2023) find the impact of Fintech on risk reduction of NPL in the Chinese commercial banks.

Another factor that has an effect on credit risk is **moral hazard**. Moral hazard is the risk that one party of a contract has not entered into a contract in good faith or has provided misleading information about its assets, liabilities, or credit capacity (McGowan and Nguyen 2023). In addition, moral hazard also may mean that a party has an incentive to take higher risks in an attempt to earn a profit before the contract is arranged. Moral hazards can appear at any time, when two parties come into agreement. Each party of a contract may have the equal opportunity to gain profit from acting contrary to the principles established by the agreement (Li, Yang and Zongfang, 2014).

A moral hazard occurs when one party of a contract has the opportunity to take additional risks which have negative effects on the other party. Such decision is based not on what is considered right, but what provides the highest level of profit. For that reason, this risk called moral hazard (Mohsin, Mudeer and Nafis, 2023). This risk can apply to activities within the financial industry, such as the contract between a borrower and a lender, as well as in the insurance industry (Lin and Xiaoyong, 2023). For example, when an individual takes a loan from the bank, the loan agreement is based on the idea that the loan applicant will provide reliable and up-to-date information in order to enable an appropriate risk assessment and repayment ability, and will maintain regular payments, will avoid delay and other situations that may cause losses to the bank.

Credit losses may seriously deplete banks current reserves or necessitate large provisions relative to earnings. Therefore, loan granting process must be well defined and well understood. Prudent credit risk management may not only avoid losses. It can also maximize a bank’s risk-adjusted rate of return using maintaining credit risk exposure within acceptable parameters. Banks need to characterize each risk as: decreasing, stable, or increasing for next monitoring process (Liu, Huoqing and Chengsi, 2023). Moreover, banks should be able to respond to changes in asset quality and/or market conditions.

The effective management of credit risk is a critical component of a comprehensive approach to risk management and necessary to the long-term success of any financial institution (BIS, 1999). The credit policy should be consistent with the bank's overall strategic direction. Additionally, credit analysis and covenant monitoring should be performed regularly and adequately. Banks need to manage the credit risk of loan portfolio as well as the risk of individual loan.

Credit risk can be monitored by following up the changes in medium-quality loans on total

assets ratio. Thus, the bank can reduce its credit risk by lowering this ratio (Rose, 2002). But, the problem is that necessary data is not always available. If the data on medium-quality loans is unavailable, traditional credit risk ratios can be applied (Casu, Girardone, and Molyneux, 2006; Rose, 2002):

- ratio of total loans to total assets,
- ratio of non-performing loans (NPL) to total loans,
- ratio of loan losses to total loans,
- ratio of loan loss reserves to total loans,
- ratio of total loans to total deposits,
- ratio of non-performing assets to total loans and leases,
- ratio of net charge-off loans to total loans and leases,
- ratio of annual provision for loan losses to total loans and leases,
- ratio of annual provision for loan losses to equity capital,
- ratio of non-performing loans to non-performing loans and equity capital,
- ratio of foreign currency loans to total loans,
- ratio of allowance for loan losses to total loans and leases,
- ratio of allowance for loan losses to equity capital.

Credit risk ratios listed above can create a wrong picture that credit risk monitoring in banks is very easy. But it is far-far away to be true. The reality is that credit risk in banking is a very complex issue. There is a lot of criticism on all credit risk indicators listed above. These indicators lag in time behind the returns gained by taking higher risks. Instead, Hempel and Simonson, 1999 propose that indicators as: loan concentration in geographic areas or sectors; rapid loan growth; high lending rates; and the ratio of loan loss reserves to non-performing loans (NPLs) should be taken into credit risk analysis. Even more appropriate approach is using not indicators, but models of credit risk assessment. More details about them will be presented below.

1.2. Methods of credit risk assessment

Since the second half of the last century and until today credit risk has attracted much attention both in academic and business world (Altman, Brady, Resti, Sironi, 2005). During this period, a large number of credit risk models theories and concepts have been developed.

According to Altman and Sanders (1997), the forces that motivated development of the field of credit risk are:

- a worldwide increase in the number of bankruptcies,
- a trend to withdraw money from bank accounts by the highest quality and largest borrowers,
- more competition between loan suppliers,
- a decreasing in value of real assets (i.e., collateral) in different markets,
- significant growth of off-balance-sheet instruments with exposure to default.

The efforts of academics and practitioners has resulted in (Altman and Sanders, 1997):

- developing new more sophisticated credit-scoring/early predicting models,
- developing new models with ability to price credit risk,
- developing models with better measuring of credit risk of off-balance-sheet instruments,
- developing credit concentration measuring (e.g., portfolio risk), not only individual loan risk analysis.

Thanks to all this laborious work, the credit risk became clearer. Also, credit risk became a major component in risk management process in financial institutions (Altman and Sanders, 1997).

1.2.1. Default prediction models

In this chapter, the author provides an overview of different models for predicting bankruptcy of companies. The first model is an Altman model that was used as a basis for developing additional models for predicting bankruptcy. A comparison between models will be made at the end of the chapter.

Corporate bankruptcy as well as bank bankruptcy is a very important and widely studied topic in the finance literature (Atiya, 2001). Banks need to be able to predict the possibility of loan seeker default before granting a loan. Such decision has an influence on banks profitability and, even on banks survivability.

Beaver (1966, 1968) and Altman (1968) conducted a study of corporate bankruptcy prediction models. These models use account-based measures as variables. Modern accounting-based models use composed measures that statistically integrate several

accounting variables, such as Altman (1968) Z-Score and Ohlson (1980) O-Score.

Altman's Z-Score

Altman's Z-score is the first modern-day quantitative model of credit risk, based on multivariate discriminant analysis of five accounting ratios (Benzschawel 2012). The Altman's Z-score indicates the probability of a company to get into bankruptcy within the next two years. In general, the high score refers the lower probability of firm's bankruptcy. A score above 3.0 indicates bankruptcy is unlikely, a score below 1.8 means high probability of bankruptcy.

Altman's Z-Score for commercial loans is calculated as follows:

$$Z = 1.2\,X_1 + 1.4\,X_2 + 3.3\,X_3 + 0.6\,X_4 + 1.0\,X_5 \qquad (1.1)$$

where:

X_1 – working capital / total assets

X_2 – retained earnings / total assets

X_3– earnings before interest and tax (EBIT) / total assets

X_4– market value of equity / total liabilities

X_5– sales / total assets

There are some limitations in using credit scoring models. Altman's model is linear whereas the way to bankruptcy is non-linear. The historical data that used in credit scoring models do not always contain enough necessary information required to evaluate future performance. The historical data do not reflect current credit environment. Additionally, fixed value of company's assets and debts could affect the accuracy of measuring the threshold of default.

Hillegeist, Keating, Cram and Lundstedt (2004) highlights several problems when default probability modelling is based on accounting data. The first one comes from financial reports. Financial statements are designed to measure past performance of a company, where estimation (prediction) of default probability is the future event. As a result, accounting data may not be able to point out the future situation of the company. The second is the principle of conservatism. Fixed assets as well as intangible assets are sometimes valued below their market prices. An underestimate of asset prices will cause accounting-based leverage measures to be overstated. The third is limitation by design a financial statement. Design of a financial statement is based on the going concern concept that assumes the firm will not default. Such a design restricts the predictive ability of these models.

Additionally, accounting-based default prediction models do not take into account an asset volatility. In asset pricing models' volatility is a critical factor. Therefore, during estimation of the default probability, it is highly important to be accurate in the asset price valuation. Despite it, both the Altman (1968) and Ohlson (1980) corporate default prediction models ignored asset volatility. Because companies demonstrate significant cross-sectional variation in volatility, ignoring volatility measurement in the accounting-based models may lead to a considerable decrease in their prediction accuracy (Campbell, Lettau, Malkiel and Xu, 2001). Without taking into account volatility, such models will fail to capture the likelihood of company's situation, where its assets value is below its debts. High volatility will increase the probability of default. Default prediction accounting-based models are easy to calculate but have lower prediction accuracy compared to other models. By introducing volatility of assets and debts into these models, the assessment accuracy may be substantially improved.

Springate Model (S-Score)

Springate model, also known as Canadian model, was developed in 1979 by Gorgon L.V. Springate. Similar to Altman, in his study Springate (1978) uses stepwise multiple discriminate analysis of 19 popular financial ratios in order to differentiate between a healthy firm and a bankrupt firm. Finally, he chose 4 ratios and the Springate's model formula is as follows (Springate, 1978):

$$S = 1.03X_1 + 3.07X_3 + 0.66X_6 + 0.4X_5 \quad (1.2)$$

where:

X_1 - working capital / total assets

X_3 - net profit before interest and tax / total assets

X_6 - net profit before tax / current liability

X_5 - sales / total assets

According to Springate (1978), if the company has S-score less than 1.062 – the company is bankrupt. The company with S-Score more than 1.062 is a healthy company.

Grover Model

Grover investigated 35 bankruptcy and 35 non-bankruptcy companies. He also used the Altman's model to create a new own model. Grover added 13 new variables to Altman's model. By analyzing the data of 70 companies (35 bankruptcy and 35 non-bankruptcy), he

came to a conclusion that only 3 new variables needed to be added to the model. As result, Grover developed a new model described as follows:

$$G - Score = 1.650X_1 + 3.404X_3 - 0.016ROA + 0.057 \quad (1.3)$$

where:

X_1- Working capital/Total assets

X_3 - EBIT/Total assets

ROA = net income/total assets

According to SIiamni, Majid and Siregar (2018), that analyzed several bankruptcy prediction models, the bankruptcy prediction accuracy of Grover model is low - only 42%. Hantono (2019) in his research reached a similar conclusion. From the over hand, research in Iran shows that Grover model is the best model for bankruptcy prediction for Iranian companies. Grover model showed coefficient of determination 0.98 (Pakdaman, 2018).

In research of Gunawan et al. (2017) that analyzed 110 Indonesian companies in 2014, Grover model presents the highest accuracy. The same conclusion was at study of Husein and Pambekti (2014) and Putri (2018). From the other side, Yoewono (2018) and Pakdaman (2018) in their studies found that Grover model has low accuracy in bankruptcy prediction.

Fulmer Model

Another bankruptcy prediction model is Fulmer H Score, also known as Fulmer H factor. This model was developed in 1984 and presented in article "A Bankruptcy Classification Model for Small Firms". Fulmer uses multiple discriminate analysis to evaluate the success or failure of companies. Based on analysis of 40 financial ratios for 60 companies (30 bankrupt and 30 non-bankrupt) Fulmer defines a regression equation for diagnosing bankruptcy risk. According to Fulmer (1984), the model has a 98% accuracy rate to detect problematic companies one year prior to bankruptcy and an 81% accuracy rate more than one year prior to bankruptcy. The disadvantage of the model is that this is a probabilistic model, that is the results will not always be accurate.

The model described as follow:

$$H - Score = 5.528V_1 + 0.212V_2 + 0.073V_3 + 1.270V_4 - 0.120V_5 + 2.335V_6 + 0.575V_7 + 1.083V_8 + 0.894V_9 - 6.075 \quad (1.4)$$

where:

$H < 0$ - bankrupt

V_1- Retained Earning/Total Assets

V_2 - Sales/Total Assets

V_3 - EBT/Equity

V_4 - Operating Cash Flow/Total Debt

V_5 - Debt/Total Assets

V_6 - Current Liabilities/Total Assets

V_7 - Log Tangible Total Assets

V_8 - Working Capital/Total Debt

V_9 - Log EBIT/Interest

Taffler Model

This model was developed by professor Tafler in 1983. Taffler (1983) studies 80 carefully selected ratios from the accounts of selected bankruptcy companies between 1968 and 1976 and 46 randomly selected non-bankruptcy companies. Taffler (1983) uses a stepwise linear discriminant analysis to derive the best set of ratios for bankruptcy prediction**.** Taffler suggests that failure models should include crucial variables of corporate solvency and performance such as profitability, working capital adequacy, financial risk, and liquidity. Taffler developed a new model described as follows:

$$Z - Tafler = 3.20 + 12.18X_1 + 2.50X_2 - -10.68X_3 + 0.0289X_4 \quad (1.5)$$

were:

$Z - Taffler < 0$ - bankrupt

X_1 - EBT/Current Liabilities

X_2 - Current Assets/Total Liabilities

X_3 - Current Liabilities/Total Assets

X_4 - (quick assets – current liabilities)/((sales – PBT – depreciation)/365)

Zmijewski Model (X-Score)

Zmijewski (1984) proposed first logic regression model for bankruptcy prediction (Prabowo, 2019). He studied the research in bankruptcy prediction field that have been carried out in the last twenty years. In his model, Zmijewski uses different ratios, such as ROA, DEBT Ratio and Current Ratio, that is measuring company leverage, company performance

and company liquidity (Zmijewski, 1984). Based on probit model, the Zmijewski X-Score calculated as following:

$$X = -4.3 - 4.5X_7 + 5.7X_8 - 0.004X_9 \quad (1.6)$$

where:

X_7- Net Income/Total Assets (NI/TA) or ROA

X_8 - Total Liabilities to Total Assets (TL/TA) or Debt Ratio

X_9 - Working Capital to Total Assets (WC/TA) or Current Ratio

According to Zmijewski Model (1984), the company with positive X-Score is a bankruptcy company, negative X-Score refers than the company is healthy.

Ohlson Model (O-Score)

The next bankruptcy prediction model was presented by James A. Ohlson in 1980. Like the Altman, Olson uses Multiple Discriminant Analysis (MDA). In his study he tested the data with normality requirements. Olson added the size variable, unlike previous models and studies in the field, because he believed that large companies is more stable and have a less tendency to bankruptcy and this because such companies function and conduct themselves better and more efficiently (Ohlson, 1980). Ohlson O-Score model is calculated as follows:

$$O = -1.32 - 0.407X_1 + 6.03X_2 - 1.43X_3 + 0.0757X_4 - 2.37X_5 + \quad (1.7)$$
$$-1.83X_6 + 0.285X_7 - 1.72X_8 - 0.521X_9$$

where:

X_1 - log (Total assets to GNP price – level index) (Size)

X_2 - Total liabilities to total assets (TL/TA)

X_3 - Working capital to total assets (WC/TA)

X_4 - Current liabilities/Current assets (CL/CA)

X_5 - dummy variable: 1 if total liabilities > total assets (TL>TA), otherwise = 0

X_6 - Net income to total assets (NI/TA)

X_7 - EBITDA to total liabilities (EBITDA/TL)

X_8 - dummy variable: 1 if net income (NI) is negative for the last two years, otherwise = 0

X_9 - (Net Income (NIT) – Net Income (NIT)-1) / (| Net Income (NIT) | + Net Income (NIT)-1)

According to Ohlson (1980) the company with O-Score more than 0.38 has tendency to bankruptcy. On the other hand, company with O-Score smaller than 0.38 is healthy company that has less tendency to be bankrupted.

J-UK Model (J-Score)

Jeehan Almamy, Jhon Aston and Leonard N. Ngwa (2015) examined the resilience to bankruptcy of companies in United Kingdom, before, during and after financial crisis. As a baseline they take Altman's Z-score model. The result of the study was development of J-Score model in 2015. The contribution of their study was the addition of a variable (sixth) to Altman's Z-score model. Compared to the Altman Z-Score model, J-Score model classified 64.1% of companies, were Z-score model classified 51,5%. During the crisis, the new model showed even better results: 67.4% companies were classified by Altman Z-Score, while the J-Score classified 79.2%. After the financial crisis the new model (J-Score) continues to show better results than Altman Z-score: 71.5% of UK companies were classified by Z-score, when J-score classified 81.2% of companies (Almamy, Aston and Ngwa, 2015). According to results, Almamy, Aston and Ngwa (2015) concluded that their model (J-Score) is more accurate in bankruptcy prediction in all situations (before, during and after financial crisis). The J-score Model is described as follows (Almamy, Aston and Ngwa, 2015):

$$J = 1.484X_1 + 0.043X_2 + 0.39X_3 + 0.004X_4 + -0.424X_5 + 0.75X_6 \quad (1.8)$$

where**:**

X_1- working capital/total assets

X_2 - retained earnings/total assets

X_3 - earnings before interest and taxes/total assets

X_4 - market value equity/total liabilities

X_5 - sales/total assets

X_6 - cash flow from operations/total liabilities

Table 1. Comparison between Bankruptcy Prediction Models

Name of the model	# of variables	Method
Altman’s Z-Score	5	Bankruptcy prediction
Springate Model (S-Score)	4	Bankruptcy prediction
Tafler	4	Bankruptcy prediction
Grover	3	Bankruptcy prediction
Fulmer	9	Bankruptcy prediction
Ohlson S-Score	9	Logistic Regression
Zmijewski Model (X-Score)	3	Logistic Regression
J-UK Model (J-Score)	6	Bankruptcy prediction

Source: Authors own work.

Neural Networks (NN)

Another default prediction method is **Neural Networks (NN)** approach. Neural networks are computer-based systems (simulates of human brain action) which use data in econometric models to make decisions models, often based on trial-and-error method. Such system usually tries to find correlations among variables used in discrete choice models (e.g., logit model).

Odom and Sharda (1990) were first who use the Neural Network (NN) to the bankruptcy prediction problem in their studies. They used Altman's financial ratios as inputs to the NN. The study includes 128 companies in United States, where the data consist of bankrupt companies and active, healthy companies. Odom and Sharda (1990) in their method applied the multivariate discriminant analysis technique (MDA) to compare bankrupt and healthy companies. The dataset that used for the bankrupt companies was taken from the last financial statement before bankruptcy declaration. The results of this method show that bankruptcy prediction accuracy improved approximately five percent on average.

Atiya (2001) developed the Neural Network bankruptcy prediction model based on traditional credit rick model, developed by Merton (1974). Atiya (2001) proposed novel inputs extracted from the equity markets. From dataset of 120 potential indicators (e.g., data from financial statement, ratios, stock price data, transformations of these), by an initial prescreening procedure based on individual indicator prediction accuracy and correlation matrix, and then a subsequent cross-validation procedure to narrow down the choice, Atiya select five or six indicators, which is best for bankruptcy prediction.

For the financial ratio system, the next indicators were chosen:

1. book value/total assets (BV/TA);
2. cashflow/total assets (CF/TA);
3. rate of change of cashflow per share (ROC(CF));
4. gross operating income/total assets (GOI/TA);
5. return on assets (ROA).

For the financial ratio and equity-based system the indicators are:

1. book value/total assets (BV/TA);
2. cashflow/total assets (CF/TA);
3. price/cashflows ratio (P/CF);
4. rate of change of stock price (ROC(P));

5. rate of change of cashflow per share (ROC(CF));
6. stock price volatility (Vol).

Neural Network is designed to predict default for three years ahead. Thus, it provides a fairly long-horizon forecast (Atiya, 2001). The model results present that the use of these indicators in addition to traditional financial ratio indicators improves significantly prediction accuracy (outside the sample) from 81.46% to 85.5% for a three year ahead forecast (Atiya, 2001).

Atiya (2001) explained the results by the tendency of the equity markets to be highly predictive, not only by company's situation, but also by economic conditions, which in turn affects the creditworthiness of a company.

Forward intensity approach

Duan, Sun and Wang (2012) developed a new model for corporate default prediction. They propose a **forward intensity approach** to calculate bankruptcy prediction. Similar to the Duffie, Saita and Wang (2007) model, Duan, Sun and Wang model takes into account both defaults/bankruptcies and other types of firm exits such as mergers and acquisitions. They analyze large sample of the US industrial and financial firms from the period 1991–2011 on a monthly basis. Duan et al. (2012) derives the forward intensity rate at time τ. The model's advantage is very accurate prediction for shorter horizons, where disadvantage is that model's accuracy deteriorates somewhat when the horizon is increased to two or three years. Despite such deteriorate, model's prediction remains still reasonable.

1.2.2. Structural models

First generation of structural models is represented by Merton's (1974) **Distance to Default** (DTD) model. The Merton model is similar to Black and Scholes (1973) option pricing model. The assumption is that the default can take place if the value of the company's assets A will fall below a critical value of the total liabilities *L*, which is calculated based on a company's long-term and short-term liabilities. The model refers to companies as a call option, and total value of asset TA is financed from the market with value of equity E and a zero-coupon bond with notional value F and maturity at time T_1, where there are no payments and no dividends until the maturity time T. Only at end of time T it will be possible to assess if a company will default or not. In the other words, default can occur at maturity

time T only. Thus, a company bankruptcy will happen when the value of assets A is below the value of its liabilities L at the maturity.

The important assumption of structural-form models is that an independent log-normal distribution of stock price with annual volatility σ is as follows:

$$\ln A_t \sim N\left(\ln A_t + \left(\mu - \frac{\sigma^2}{2}\right)(T-t), \sigma^2\,(T-t)\right) \tag{1.9}$$

Thus, when asset value A falling below the liability value L , the value of equity E will be zero. Hence, payoff to equity holders is described as follow:

$$E_t = \ max\ (0, A_T - L) \tag{1.10}$$

Using the Black-Scholes formula for European call option the equity value E can be calculated:

$$E_t = \ A_t N(d_1)\ -\ Le^{-r(T-t)}N(d_2) \tag{1.11}$$

where E is the equity value, t is the duration, A_t is the assets value as a function of equity value and time duration, L is liability value, r is the risk-free rate for the duration T, N is the cumulative normal distribution, and d_1 and d_2 are defined as:

$$d_1 = \frac{\ln\left(\frac{A_t}{L}\right) + \left(r + \frac{\sigma^2}{2}\right)(T-t)}{\sigma\sqrt{T-t}}, \qquad \text{and} \quad d_2 = d_1 - \sqrt{T-t} \tag{1.12}$$

The probability of default can be valuated after calculation of values of A_t, L, σ^2 and μ by formula:

$$Default\ prediction = N\left(\frac{\ln\frac{L}{A_t} - \left(\mu - \frac{\sigma^2}{2}\right)(T-t)}{\sigma\sqrt{T-t}}\right) \tag{1.13}$$

The next parameters will be estimated: A_t (market value of assets at time t), μ (expected annual asset returns), and σ (annual asset volatility).

Merton Distance to Default (DTD) is the deviation of assets value from default point L. The Distance to Default can be calculated as following:

$$DTD = \frac{\ln A_t + \left(\mu - \frac{\sigma^2}{2}\right)(T-t) - \ln L}{\sigma\sqrt{T-t}} \quad (1.14)$$

The probability of default (PD) is defined as the probability of the asset value falling down below the liability threshold at the end of the maturity time T:

$$PD = 1 - N(DTD) \quad (1.15)$$

There are several reviews on Merton's DTD model. The first is that Merton's model considers a company as European call option. That is, Merton's DTD model complies the same assumptions that Black and Scholes (1973) option pricing model. In fact, most of Black and Scholes option pricing assumptions do not exist in real life. Black and Cox (1976), Geske (1977), and Vasicek (1984), by omitting some of not realistic assumptions, develop the original Merton model. The first unrealistic assumption in the original Merton model is that default will occur only at the end of the maturity. In his model, Merton paid no attention to the possibility of company's reorganization before default will occur. Conversely, Black and Cox (1976) add sections in agreement which allows debt holders to force the companies to reorganize when the value of a company falls below a limit and to receive a discounted value of the debt's amount into the contract.

The second is that Merton's original model ignores the interest rate payment. Some researchers assume that interest rate payment must be included into the original Merton's model. According to Black and Cox (1976), interest rate payments are continuous and not a closed form solution for discrete payments. Geske (1977) suggests valuing the bonds with an arbitrary number of discrete payments. Geske (1977) model considers the structure of corporate debt as a coupon bond. Geske (1966) considers interest rate payment as a compound option. Hence, his models allow bonds to have interest rate discrete payment.

The third non-realistic assumption is that the Merton's original model assumes only a single type of a company debt. That is, this model does not allow tranche structure. According to tranche structure, senior bond has higher priority compared to another type of bonds in the event of company liquidation. That is, if a company goes bankrupt and is liquidated, holders of a senior bond must be paid before holders of a junior debt. Seniority structure of a company's debt are very important and complex. Seniority rule states that senior debt must

be repaid before subordinated or junior debt is repaid. Empirical evidence shows that violation of this seniority rule is very common in practice. Tranche structure must be allowed in company's debt. Therefore, Black and Cox (1976) added it into their model.

The last assumption is that Merton's model ignores the structure debt as the term. The structure of debt has a significant effect on default probability. The short-term debt and long-term debt must be treated differently, when estimating the probability of default. When tranche structure and debt structure are both taken into account, it can mislead the results. Vasicek (1984) analyses short-term and long-term liabilities in different cases and find that company's mark-to-market asset value, as well as a company's maturing debts and high-priority debt, would affect the expected losses for the company.

Merton's model and Merton's based models still have some limitations. The first-generation structural models have a small amount of inputs. Therefore, such models could not capture enough information on the company. These models do not take into account expected returns of assets, risk aversion, accounting ratios and macroeconomic variables. Additionally, such models assume that interest rates are flat and constant. No stochastic process exists in these models. The structure of interest rate has a significant influence on the value of company's debts. Applying stochastic process in the interest rates structure will allow correlations between asset values and, as result, would improve the Merton models' performance (Fons, 1994; Longstaff and Schwarts, 1995).

1.2.3. Reduced-form models

Another group of credit default models are reduced-form models. They assume an exogenous Poisson random variable that leads to the situations of default. A company will not fulfill its obligations (meet the default) when the external random variable enters in its level at any time interval. According to Poisson process, default is unpredictable situation. Thus, default cannot be predicted based on a company's assets value. The Poisson process is one of the most important stochastic processes. It is a randomly jumping process where the variable jumps instantaneously from one value to other. In reduced-form models, the situation in a Poisson process mentioned before is "the default". The stochastic intensity parameter $\lambda(s)$ is called "the default intensity". It describes the likelihood that the numbers of situations $N(t)$ occurs in the time interval $[0, t]$. λ relates to the rate at which situation happen. Before the maturity time, where $N(t)$ is not equal to zero, default situation is occur.

The distribution of probability is described as:

$$P(N_t = k) = \exp(-\lambda t)\frac{\lambda t^k}{k!}, \qquad k = 0,1,2,\ldots \tag{1.16}$$

where: λ is constant.

Based on a simple single-period model of bank lending and credit risk transfer, Parlour and Winton (2013) developed a **credit default swap model** (CDS). This is a financial derivative or a contract, that allows an investor to "swap" or offset his credit risk with a risk of another investor. In case of loan, if a lender is worried that a borrower will go to default on a loan, the lender can use a CDS to offset or to swap that risk. In other words, to swap the risk of default, the lender buys a CDS from another investor who agrees to compensate on lender losses in the case of borrower's default. Figure 1 summarizes the mechanism of CDS.

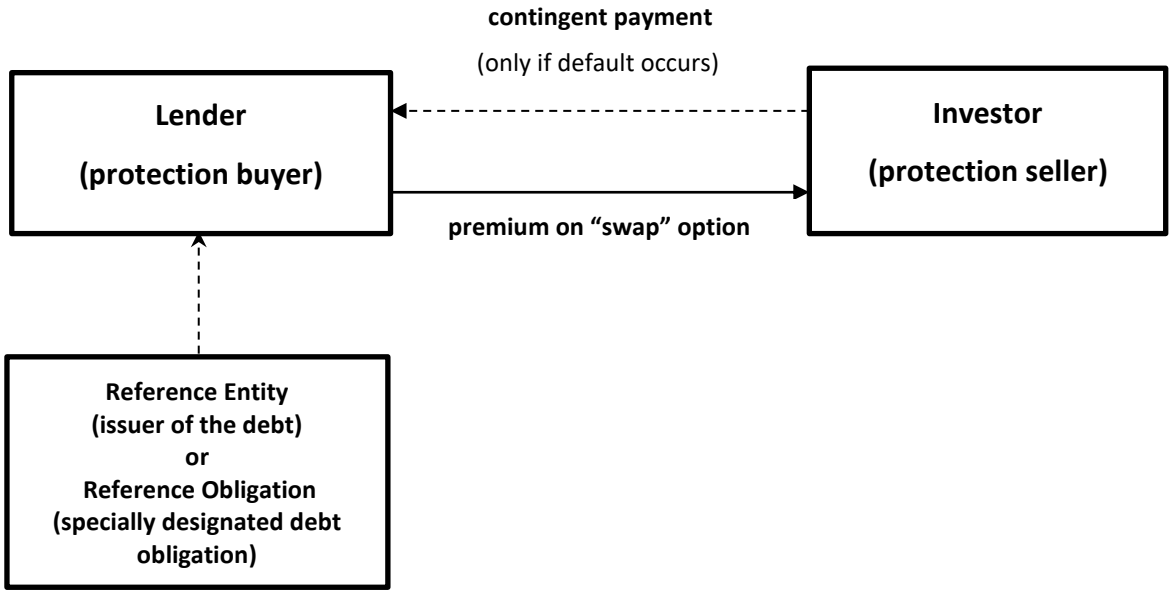

Figure 1.Credit Default Swap

Source: Anson et al. (2000).

Most CDS require a premium payment for contract maintenance. That is, CDS is like an insurance policy (Anson et al. 2000).

A bank granting loans, learns if monitoring is needed, and then decides whether to lay off credit risk. The model assumes that each company has a positive net present value (NPV) risky project. In order to start such a project, company looks for funds from a bank. As a part of loan granting process, the bank assesses the success probability of this risky project. Because

a bank is exposed to capital shocks, it will not be profitable to hold the loan due to credit risk (Bartram, Conrad, Lee and Subrahmanyam, 2022). A bank has two ways to deal with such credit risk: to sell the loan to third party, or through CDS (Shanuka and Copp, 2015). By using the first option, this bank, as a loan seller, transfers control rights on loan to a loan buyer (Anson et al. 2000). Credit risk transferring causes to superfluous monitoring of risky credits and insufficient monitoring of safe credits. By using second option, the bank continues to hold the control rights on loan by itself. Typically loan agreement has a number of covenants whose breach gives the bank control through the threat of default. It is crucial to understand the difference between two options: the control right importance stems from ability of loan monitoring at cost, to ensure control rights existence (Amiram, Beaver, Landsman, and Zhao, 2017). Thus, if company's success probability is lower than expected, loan monitoring can prevent losses. For example, it can prevent moral hazard by company's owners or management and raises company's success probability.

Banks capital requirements, both from the market and from regulators, bind them to hold expensive equity capital against their credit exposures. Thus, banks have a motivation to sell these credit exposures.

According to a five-period model, a business entity obtains funds from a bank to carry out a risky project. After a loan is granted, a bank has two ways to lay off the credit risk: through credit default swap (CDS) market or a loan sales market. The loan owner can make expensive efforts and, in some cases, reduce the likelihood of default (Anson et al. 2000):

- period $t = 0$: a take-it-or-leave-it offer. A business entity obtains fixed sum of money from a bank for the project funding.
- period $t = 1$: a bank recieves a private signal about the management of the project and the loan quality. There is a probability of $(1 - \theta)$ that the bank will fall as victim of moral hazard. Parlour and Winton (2013) allows two types of banks, p and $p\Delta$, depends on the project selected by a business entity.
- at period $t = 2$: the bank can lay off the credit risk from its balance sheet. A bank can do this by two options: by trading on the CDS market, and, by selling the loan. If a bank enters the first option, it buys insurance (credit default swap, CDS) against default. When a bank buys such protection, it will pay a nominal value of the loan in case of company's default.
- at period t=3, the loan owner can exert expensive effort (i.e., loan monitoring).

- and period t=4. this is final period: all claims' payoffs.

Figure 2 illustrates the events.

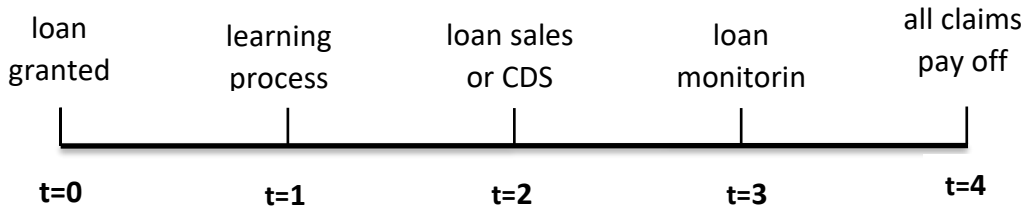

Figure 2.Sequence of events in the Credit Default Swap model

Source: Parlour and Winton (2013).

The first reduced-form model for credit risk modelling was proposed by Jarrow and Turnbull (1995). The company's assets value does not define the probability of default in reduced-form models. The reduced-form models are based on assumptions that both recovery rate and probability of default are dynamic. Recovery rate is independent and exogenous from default probability. In the case of default event, the recovery will be paid only at the maturity time. Jarrow and Turnbull (1995) take into account the credit ratings of issued debts that will provide the information about the financial status of the company without considering the company's assets value.

The disadvantage of Jarrow and Turnbull (1995) model is that the model describes only two possible situations: survival and default. Rating agencies periodically publish its credit ratings with different probabilities.

Jarrow, Lando, and Turnbull (1997) study the term structure of credit spread in a Jarrow and Turnbull (1995) model with the default process following a Markov chain in credit rating. Jarrow, Lando, and Turnbull (1997) include credit ratings into the valuation process of a contingent claim model. One of the model assumptions is that both recovery rate and stochastic processes of risk-free rate are dependent. Another assumption is that recovery rate is exogenous, and the recovery payoff can be obtained only at maturity time, even the default occurs before maturity. In fact, this assumption is unrealistic. Jarrow, Lando, and Turnbull (1997) define recovery rate as exogenously specified percentage of risk-free bonds. Therefore, recovery payment may be bigger than real recovery payment at the event of default. The real recovery payment that depends on company's liquidation value is fluctuating

through the time.

Duffie and Singleton (1999) proposed a new method for modelling valuation of contingent default claim. To be in line with previous reduced form models, they relate to default as an unpredictable situation that is dominated by a hazard-rate process. They propose that company's default probability distribution follows a transmitted single-factor square root diffusion process. Also, Duffie and Singleton (1999) parametrized the losses at default in terms of fractional reduction of market value as result of default event and fix some contingent claim as: in the case without default, pays X at time T. According to authors, in the no-default situation, this claim can be priced by replacing the regular used short-term interested rate process r by default-adjusted short-rate process R as described following:

$$R = r + hL \tag{1.17}$$

where: r is regular used short-term interested rate,

h is hazard-rate for default,

L is expected fractional loss in market value.

Thus, initial market value of the defaultable claim to X is:

$$V_0 = E_0^Q \left[exp\left(-\int_0^T R_t \, dt \right) X \right] \tag{1.18}$$

where: R_t defined as default-adjusted short-rate process as presented in equation 1.9,

E_0^Q refers risk-neutal conditional expected value at date zero.

In simple words: the value of a default claim is a present value of the expected payoff discounted by the adjusted short rate R. Duffie and Singleton (1999) model allows to make the recovery payment at any time. Also, the model holds the recovery rate as a fixed fractional of the non-default bond price in the situation of default. Therefore, the recovery payment will fluctuate that depending on the company's liquidation value at the event of default.

Jarrow and Yu (2001), motivated by financial crises in East Asia and the United States where the downfall of a small number of companies widely affected all economy, develop **counterparty risk approach**. Counterparty risk is defined as a risk that the default of a company's counterparty might affect its own default probability. The work of Jarrow and Yu (2001) is complementary to the existing literature on default risk modeling by introducing a concept of counterparty risk. Jarrow and Yu (2001) model assumes that each company has its unique (company-specific) counterparty structure that arises from its relationship with other

companies in the economic environment.

Reduced-form models developed by Lando (1998) assumes dependency between credit and market risk through the use of a doubly stochastic Poisson process, also known as "Cox process". Jarrow and Yu (2001) model generalizes Lando (1998) models by including counterparty default risk.

Counterparty risk approach has two advantages. Firstly, the more the public is aware of the counterparty's relationship, the prices of the marketed securities will reflect the market's assessment of the risk of a counterparty. Based on the idea of market efficiency, this model makes it possible to derive this information, which has potential importance for the pricing of the defaultable bonds and credit derivatives. Secondly, the additional default correlation obtained by a counterparty relationship allows determining the approximation of the observed clusters. For example, a group of companies can be so interdependent that the default of only one can be a trigger for the cascade of defaults. Because the likelihood of default is higher for all companies during the recession, this cascading effect is much more likely to be observed then. This has important implications for management credit risk portfolio, where the default correlation needed to be simulated.

The concept of counterparty risk is not limited only to the portfolio perspective. With adapting to the just-in-time manufacturing processes, companies are more and more rely on the smooth operation of other companies, and this broken expectation may have an impact on a company's likelihood of bankruptcy. The counterparty risk modelling is achieved through an extension of the existing reduced-form models. In this model, default intensity is influenced both by a set of wide range of economic variables, and by a collection of counterparty-specific jump terms capturing intercompany linkages. This form allows to maintain the simplicity of a reduced-form model while incorporating company-specific information provided by the market. In case where companies hold well-diversified credit risk portfolios, the counterparty risk become a part of their default intensities and will disappear. Thus, counterparty risk model is reduced to a standard model.

1.2.4. Multi-period credit risk model

Orth (2013) presents a multi-period credit risk model. His model is based on study of Campbell, Hilscher and Szilagyi (2008) and presents high predicted accuracy outside the sample. Orth (2013) observes obligor i, $i = 1, \dots, N$ for T_i period and recording his default

history and a vector of time-varying covariates x_{it}. For each period t, $t = 1, \dots, T_i$ Orth (2013) denotes Y_{it} to be lifetime (i.e., time until event of default) of obligor i starting in period t. Therefore, the model observes lifetimes for each obligor because there is no information about the lifetime starting in last period. The model defines an additional variable: the corresponding censoring indicator C_{it} which is equal to zero in case of censoring, i.e., the lifetime ends with an event of default and one for censored lifetimes. Orth (2013) applied in the model the terms of the continuous-time hazard rate, defined as:

$$\lambda(y) = \lim_{\Delta y \to 0} \frac{P(y \leq Y < y + \Delta y \,|Y \geq y)}{\Delta y} \tag{1.19}$$

The hazard rate measures the instant risk of default.

Orth (2013) assumes that at a point in time t they want to predict the probabilities of default for the next H periods using the existing information. A simple solution is to detail the hazard rate in period $\mathrm{t} + \mathrm{s}$, $\lambda(\mathrm{t} + \mathrm{s})$, as a function of the covariates in period t, $\mathrm{x_{it}}$, and the forecast time s. For example, within the proportional hazard (PH) framework a possible specification can be described as:

$$P(Y_{it} \leq H) = 1 - \exp\left(\int_0^H \lambda(t + s, x_{it}) ds\right) \tag{1.20}$$

where: $\lambda_0(s)$ is the baseline hazard rate that the variation of the hazard rate over the forecast time, which can be seen as a kind of duration dependence. The forecast time s is the analogon to the lag length Campbell, Hilscher and Szilagyi (2008). The hazard rate can be freely fluctuating for different s due to the repeated estimation of the model. Orth (2013) applies a structure on the evolution of the hazard rate over the forecast time by integrating s as an argument into the functional form of the model. The probabilities of default are calculated in closed form:

$$\lambda(t + s, x_{it}) = \lambda_0(s) \exp(\beta' x_{it}) \tag{1.21}$$

The disadvantage of Orth model (2013) is that the model focuses on credit risk of single obligor and cannot be used in portfolio credit risk analysis (Zamore et. Al. (2018).

1.2.5. Recovery rate

Most of the literature on credit risk models and instruments relates to the recovery rate (RR) variable as a function of historic average default recovery rates (stipulated on seniority and collateral factors) but in almost all cases as independent of expected or actual default

rates (Altman, Brady, Resti and Sironi, 2005).

The first recovery rates model was introduced by Frye in 2000. Frye (2000a) model is based on Finger (1999) and Gordy (2000) assumptions. Such assumptions allow only one systematic factor – the economic conditions. The model's assumption is that economic conditions causing default to grow up, and recovery rates to decrease. The common dependence on the systematic factor causes correlation between default and recovery rate. Frye (2000a) claims that when a borrower cannot repay a loan (e.g., goes to default), a bank's way to recovery depend on the value of the loan's collateral. The value of this loan's collateral, as the value of other assets, depends on economic conditions. For instance, in the case of recession, recovery rates may decrease just as default rates tend to increase. That is, there is negative correlation between default rates and recovery rates.

Altman et al. (2005) were first who both theoretically and empirically provided the examination of the role of supply and demand of defaulted bonds in determining aggregate recovery rates. Compared to other models that focused on relationship between Probability of Default (PD) and recovery rates (RR) Altman et al. (2005) analyzed more specific determinants of recovery rates using self-developed univariate and multivariate models. To examine recovery rates on corporate bond defaults, Altman et al. (2005) used several variables under assumption that these variables could be correlated with aggregate recovery rates. The sample consisted from data during period 1982-2002. The variables are presented in table 2.

Table 2.Variables and its definitions in recovery rate model

Variable	Description
BDR	The weighted average default rate on bonds in the high yield bond market and its logarithm.
BDRC	One-year change in BDR.
BOA	The total amount of high yield bonds outstanding for a particular year (measured at midyear). This variable represents the potential supply of defaulted securities.
BDA	Sum of defaulted bond - an alternative for BOA.
GDP	The annual GDP growth rate.
GDPC	The change in the annual GDP growth rate from the previous year.
GDPI	If GDP growth was less than 1.5% the value is 1 and if GDP growth was greater than 1.5% the value is 0.
SR	The annual return on the S&P 500 stock index.
SRC	The change in the annual return on the S&P 500 stock index from the previous year.

Source: Altman et al. (2005).

Their result had very important implications for portfolio credit risk models, for markets depends on recovery rates as a key variable (e.g., securitizations, credit derivatives. etc.) and on Bank for International Settlements (BIS) recommendations for capital requirements on bank assets.

RAROC model

Risk Adjusted Return On Capital (RAROC) approach was developed during the late 1970's by Bankers Trust. To be more specific, Dan Borge was the principal designer. RAROC developed as an answer to the demand by stockholders to improve performance, especially the maximization of shareholder value. RAROC is also used as a profitability-measurement framework, based on risk, that allows analysts to examine a company's financial performance and establish a stable view of profitability across business sectors and industries. Since 1980's this concept grew in popularity and was used as a major instrument for the banking industry. In the early 1990's, many banks have widely declared that they used RAROC in their risk assessment (Jameson, 2001; Power, 2005).

A RAROC formula is shown below:

$$RAROC = \frac{Adjusted\ incime}{Capital\ at\ risk} \tag{1.22}$$

where:

adjusted income = revenues – expenses – expected loses + return on economic capital +/– transfer values/prices.

capital at risk = capital reserved to cover worst-case loss (less expected loss) to required confidence threshold (e.g., 95%) for credit, market and other risk.

The RAROC numerator reflects the adjusted expected income from a one-year loan. Adjusted income is defined as the sum of spread and fees, minus expected losses and operational costs. The spread reflects the direct income on the loan, or, in simple words, the difference between the loan rate and cost of the bank funds. The fees must be attributed to the loan over the next year. Based on large number of RAROC models, from the spread and fees to calculate the adjusted income two conclusions can be derived. The first conclusion is that expected losses is a part of normal banking activity and deducts these from direct income. The second conclusion concerns a loan's operating costs, such as a loan officer's time and resources spent on the loan monitoring (Saunders, 2007).

The RAROC of a loan can be compared with some hurdle rate (i.e., minimum rate of return) that reflects the bank's cost of funds or the opportunity cost of stockholders in holding equity in the bank. Such hurdle rate can be the stockholders' returns on equity (ROE) or the weighted average cost of capital (WACC). In general, WACC is less than ROE, especially if debt costs are after taxes. In case of RAROC is higher than the hurdle rate, the loan is pointed as value adding, the bank capital must be allocated to the activity. If RAROC is higher than the hurdle rate, it means that available bank's capital exceeds its limits. Therefore, the bank needs additional time to generate new equity to fund all valuable activities (Saunders, 2007).

Today, RAROC is one of the most widely used instrument for financial valuation around the world. Banks and other financial institutions use RAROC as utility in decision making on portfolio allocation and product pricing (Milne and Onorato, 2009). In addition, RAROC is used to calculate the potential value that will be received if additional resources are allocated in a new business. In the case of banks such resources are new loans that would be granted (Mark and Bishop, 2007). RAROC also can be seen as a Sharpe ratio for business entity.

Even though the RAROC approach has become a major instrument in banks and, perhaps, one of the best approaches in risk assessing, it has still some limitations. The most important aspects of limitation are described as follows (Jameson 2001; Artzner, Delbaen, Eber and Heath, 1999; Merton and Perold, 1993; Turnbull, 2000): rule of thumb of risk could be suitable to a certain portfolio, but they are not connected with the individual portfolio, or any fundamental model of risk. Thus, they often tend to underestimate or overestimate risk. Asset management using RAROC approach seems favorable, because it assumes only one risk factor - operational risk. Because a brokerage earns fees derived from the assets value in its customers' accounts, these profits influenced from the market risk position in the underlying funds in which their customers are invested. A short-sighted focus on the profit in risk modeling ignores possible changes in asset value. Thus, net income simulations for asset management consider risk of default only in credit risk models. Risk tends to be measured in each field of activity in a way that concerns requirements of risk control of its own activity. Poor accounting of risk diversification: it is difficult to to keep account without considering interaction of different risks, such as market risk and operational risk, when trying to calculate enterprise wide RAROC numbers. The RAROC Value-at-Risk denominator fails to provide sub-sensitivity. Thus, when combining portfolios, it is possible, that the overall VaR of the new portfolio could be higher than the sum of the individual VaRs.

And finally, RAROC is sensitive to the level of standard deviation of the risky asset. Also, RAROC is sensitive to the correlation of the return on the underlying asset and the market portfolio.

1.3. Literature review on credit risk assessment

Credit risk is the oldest type of financial risk, dating back to the ancient Egyptian times, approximately 1800 BCE (Caouette, Altman, and Narayanan 2008). It became to the hot topic in academic, business and regulators worlds especially in the last five decades, especially the last one, after the financial crisis of 2008-2009. The literature on this topic is enormous and it is difficult to present it all. In the following section the author presents the critique and development of models of the credit risk assessment that are important in the field and from the point of view of this thesis.

Altman and Narayanan (1997) examine the predictability of various models, including the Altman model on companies in 21 countries outside the US. Results was compared with the US and non-US developed and developing countries. They show correlation between the results of the model in the US and other countries even after a long time since models was developed. In addition, they check a few companies that have gone bankrupt and find that some accounting ratios are more efficient in default prediction in the Zeta model than in Z-score model.

After academic criticism that his models are irrelevant in the modern financial world and must be included within them data other than financial ratios, In 2000 Altman reviews again the two models: Zeta and Z-score. He finds that the models provide a qualitative prediction of the situation the company's financial well after a long time from the publication of the model (Bell, Brooks and Prokopczuk, 2013). Altman also builds a model to predict the default of bond series based on the Z-score model and the Zeta model called “Z” (Bell, Brooks, Prokopczuk, 2013).

Altman and Hotchkiss (2006) improve the credit ratings of his models by setting thresholds separately for each rating group, where the threshold value defined as an average score for companies in each group.

Since the 1970’s, many structural models have been developed to predict and price credit risk. Merton (1974) first develops a structural model that presented a systematic theoretical approach to the process leading to the company's bankruptcy. The model uses both capital

and market data, in addition to accounting data.

Structural models are also called Merton models. Structural models provide a starting point to extract the probability of default based on information from market prices (Cheung,1991; Dhaliwal, Trezavant and Wang, 1992). There is two basic advantages of structural models based on market data. One is that accounting data can be more susceptible to manipulations, whether it is legitimate accounting planning or manipulations prohibited by law, as opposed to market data that are less susceptible to these manipulations. The second advantage is that the use of market data enables to recruit the latest information about large number of companies operating in the capital market.

Black and Scholes (1973) and Merton (1974) presented the basic approach to stock and bond pricing as derivative assets. Under this approach, these assets can be priced using the principle that in equilibrium, arbitrage cannot be generated by creating a risk-free portfolio. They noted that this approach makes it possible to relate to the company's share capital as options on the company's assets, so that the shareholders receive the balance of the value of the company after payment of the company's liabilities. As result, if the value of the company's assets is higher than the company's liabilities, the value of the share capital should be the difference between the value of the company's assets and the debt and if the value of the company's assets is lower than the company's debt, the value of the company's shares is equal to zero and the holders of the company's debt will receive the company's assets.

Merton (1974) focused and expanded the issue of debt pricing and the company's share capital and examined bonds with a coupon. The Merton model created a large-scale research branch as well as commercial uses in the area of credit risk.

Black and Cox (1976) presented the possibility that when the value of a company's assets falls below a certain threshold, even before debt maturity, the company becomes a default. This possibility was presented by the existence of restrictions in the form of financial criteria (Safety Covenants) of the company's debtors. Geske (1977) develops the model for a more complex debt structure and added the option that the company would initiate the issuance of shares to generate additional equity to meet debt payments. Longstaff and Schwartz (1995) present a model that included the application of a stochastic interest rate. Additionally, they are discussing about the case where there is no clear priority among the debtors in case of default. Collin-Dufresne and Goldstein (2001) expand Longstaff and Schwartz (1995) model by adding a certain level of leverage that the company converges with

as time progress. Hsu Requejo and Santa-Clara (2010) add to this model a stochastic default limit determined by the company's value after theoretical bankruptcy.

Leland (1994) suggests that when there are no restrictions on financial covenants that protect debtors, shareholders can choose the threshold of default to maximize their capital value - endogenous bankruptcy. Leland and Toft (1996) develop the idea for a model with the variables such as cost of bankruptcy, taxes, etc. They assumed that the company mobilized in each period a new debt with a fixed maturity horizon. Acharya and Carpenter (2002) combined the endogenous bankruptcy model with stochastic interest rate and the company's stochastic value.

Since presentation, the original Merton's model has been improved in many ways, but still have some disadvantages. Such disadvantages are that Merton's model not always has realistic assumptions. One of that unrealistic assumption is that default occurs only at the time of maturity. In the real financial world, a company will fall to default at any time between issuance time and maturity when it fails to pay interests or coupons. Another unrealistic assumption is that a risk-free rate is constant. Kim, Ramaswamy and Sundaresan (1993) develop Merton's original model with assumption that default event may occur anytime in the entire life cycle of the bond and introducing a stochastic process for the evolution of the short-term rates. They argue that net cash flow is one of the key factors when measuring a company's default risk. One assumption of their model is that the bondholders and shareholders receive net cash flow from the company and the company's assets cannot be sold. As a result, when a company fail to have enough net cash to make a coupon payment - the default event take place, even though the company's assets value may be higher than the value of the company's liability. In addition, since most corporate bonds are callable, the study of yield spread between callable corporate bonds and treasury bonds is important. Kim, Ramaswamy and Sundaresan (1993) find that the call policy is more sensitive to interest rates than to the company's value. And because the interaction between the call provision and the default risk, the stochastic interest rates have a significant effect of the yield difference between a callable treasury bond and a callable corporate bond.

Another original Merton's model assumption is flat term-structure of interest rates. Thus, incorporating stochastic processes in interest rate will affect capital structure of a company and the uncertainty of interest rate may have a significant effect of credit spread. But Kim et al. (1993) show that such effect is limited.

On the practical level, several studies examined the Merton model's predictability of bond prices and spreads yield. Jones, Mason and Rosenfeld (1984) find that the Merton model presents a missing evaluation of yield spreads systematically. Ogden (1987) supported the criticism on Merton's model by finding that the model predicts a missing estimate of yields of 104 basis points on average. Eom, Helwege and Huang (2004) find partial support for these conclusions but show that in cases of high standard deviation or high leverage ratios, most of structural models actually shows overestimating of margins yield.

The Merton model is recognized not only in the academic world but also in the business world. One of the best-known companies in the field of default predicting is Moody's KVM[2]. The company uses a model developed by Vasicek and Kealhofer, based on the Merton's model. This model contains insights and developments from various researches in the field. The model is confidential for commercial use. From beginning of 1990's, a few articles exposed some of the methods used by the company. Crosbie and Bohn (2003) argue that KMV model allows for a more complicated debt structure and different types of stocks. But the company's main advantage is its use of a broad historical database to calibrate the results of the model instead of usual practice of using the normal distribution of the probabilities of default.

Duffie, Saita and Wang (2007) estimate the Merton model and show that the Merton model does have predictive power. More other, combination of the model with macro-economic data improves the model's predictability. Campbell, Hilscher and Szilagyi (2007) combine the probability of the Merton model with the hazard model along with other parameters relevant to default and find that the Merton model contributes relatively little to predictability relative to other parameters.

Hillegeist et al. (2004) compares the Merton model to the Altman (1968) Z-score and Ohlson (1980) O-score models. They find that the Merton's model better then two other model. Du and Suo (2007), on the other hand, find that a reduced-form model could be better than the Merton model in prediction of default.

An accepted alternative to structural models is the reduced-form models. In this approach, it is assumed that the date of default is inaccessible and that it is based on the "dormant" variables, which are very difficult to predict in the future. Therefore, the probability of default

[2] The KVM model is called by the first letters of the last name of people who developed it: Kealhofer, Vasicek and McQuown.

is estimated on the basis of variables external to the company's activity, such as debt rating, CDS prices, etc. The main argument of those who support the use of reduced-form models is that structural models fit the environment of complete information, for example, information that possess company management, whereas for an external body that has the access to the market, it is better to use reduced-form models. In contrast, Arora, Bohn and Zhu (2005) argue that the major disadvantage of these models in relation to structural models lies in the absence of a clear method of the process of default prediction and that the assumption of complete information in the framework of structural models is only an approximation that makes it easier to examine the company's operation. They argue that the proper evaluation of the various models should be by examining their appropriateness for application in the "real world".

Despite the fact that most credit risk researches in last two decades focus on reduced-form models, structural models are still popular. For example, Camara, Popova and Simkins (2012) present a comparative study of default probability by using structural models for global financial corporations, which options are trading in the United States. The capital structure of financial companies are very complicated. For this reason, most of recent researches focus on valuating the default risk of non-financial companies. The obvious advantage of their model is that the model can be easily applied in other markets or other financial areas.

According to Das, Freed, Geng and Kapadia (2006) both default probabilities and default correlations are changing through the different economic conditions. Accurate measurement of correlated default risk is crucial for financial system credit risk management because financial institutions are more exposed and sensitive to credit risk. There is a few researches that observed time-series variation in default probabilities. Such time-series presented high volatility during changing from one economic condition to another. For example, in case of high default risk, default probabilities are more than double, compared to situation than default risk is low. Dembo, Deuschel and Duffie (2004) propose that macroeconomic variables are very important in the default probabilities explanation. Other studies points on common risk factors such as GDP growth rate, market volatility, and interest rates that have a direct influence on joint default risk. Duffie, Saita and Wang (2007) propose that macroeconomic variables are not the only reason of correlated default risk. Both "contagion factor" and "latent frailty" factors have a significant role in joint default risk explanation. The "contagion effect" is the situation which one company default will affect default risk of other company.

Default risk could expand quickly especially in financial companies through credit derivatives like CDS and CDOs. Jorion and Zhang (2007) and later Stulz (2010) and Castellano et. al. (2022) argue that the counterparty risk is transferred through financial protection products (e.g., CDS). Thus, the seller will expose to higher default risk caused by the buyer's protection. The "frailty" factors are the remaining sources of the joint default risk. Macroeconomic and contagion factors cannot explain the "frailty" factors.

The correlated default risk models are well developed and include intensity based models, barrier-based company's value models, and copula-based models. Traditional reduced-form model of portfolio appears as a bottom-up model or a top-down model. The bottom-up model assumes portfolio intensity is an aggregate of individual intensities, where the top-down model assumes portfolio intensity is calculated without including individual intensities. The disadvantage of intensity-based models is the complex of calculations that can take a lot of time (Schönbucher, 2003). For the barrier-based models the disadvantage refers to the difficulty of calibration and implementation of the model.

The copula-based models show some natural superiority based on the mathematical properties of correlated default modelling. The copula-based models allow higher flexibility in choosing a marginal distribution for each sector. Random variables with different marginal distributions can be easily connected with the copula function. Li (2000) was first who introduce Gaussian copula to default risk for simulation of dependence structure of the times until the default event.

***

This chapter brings a reader to the theoretical background of credit risk and its assessment. The author explains the essence of a credits risk, defines it and presents a number of various credit risk models with their advantages and disadvantages in practical utilization by financial institutions. In the next chapter the author presents the characteristics of real options, that in this PhD thesis are in the core interest as they may play an important role in explaining loan granting in a bank.

Chapter 2.

General characteristics of real options

A *real option* is an option related to an physical (tangible) asset. The word *option* comes from the medieval French and is derived from the Latin *optio, optare*, that means to choose, to wish or to desire. A word *real* comes from the Late Latin word *realis* and refers to fixed, permanent, or immovable things, as opposed to unreal things. This chapter introduces a reader with the general characteristics of real options. This characteristic involves their definition and classifications as well as its comparison to the financial options and methods of its valuation. All this allows us to understand what real options are and leads us to finding out what can be their application in the financial institutions, including banks.

2.1. Definition and classification of real options

The original definition of a real option was first stated by Myers in 1977. According to Myers (1977) a real option is a right, rather than an obligation, whose value is contingent on the uncertain price(s) of some underlying asset(s). In other words, a real option is a flexibility to alter the course of action in a real asset decision, depending on future developments. According to Myers (1977) and later by Lambrecht and Myers (2012, 20217) real options necessarily assumes the existence of three conditions:

- **creation of real option** - the real option must be "harvested" from the beginning of investment or the project,
- **irreversible costs** - it must be associated with irreversible (at least partially) costs,
- **uncertainty** - the future is unpredictable situation, but the real option must to allow better decision making in any way.

Dixit and Pindyck (1994) define real options as opportunities to acquire real assets. Real option investments are characterized by sequential, irreversible investments made under conditions of uncertainty. Dixit and Pindyck (1995) further explain that real options are based on an important analogy with financial options. A company with an opportunity to invest holds something much like a financial call option: it has the right but not the obligation to buy an asset at a future time. The use of real options in the capital markets is widely recognized

in the literature, e.g., by Henderson and Hobson (2002), Hugonnier and Morellec (2007), Thijssen (2010), Perotti and Rossetto (2007), Busaba (2006), and recently by Ewald and Taub (2022) among others.

Copeland and Antikarov (2003) define real options as the right, but not the obligation, to take an action (e.g., deferring, expanding, contracting, or abandoning) at a predetermined cost called the exercise price, for a predetermined period of time, which is the life of the option.

According to Triantis (2000) real options are opportunities to delay and adjust investment and operating decisions over time in response to the resolution of uncertainty. Another research performed by Borison and Triantis (2001) gives us the valuable insight that practitioners have different interpretations of the term "real options". Borison and Triantis (2001) come up with the three categories of interpretations:

(1) real options as a way of thinking,

(2) real options as an analytical tool,

(3) real options as an organizational process.

In each category, however, corporate decision-making is improved by a better understanding of the role of uncertainty on investments.

Panayi and Trigeorgis (1998) explain that real options involve discretionary decisions or rights, with no obligation to acquire or exchange the value of one asset for a specified value or price. Trigeorgis (1993) explicitly states that managerial flexibility is a set of real options. As he suggests, the use of option-based techniques to value the managerial flexibility implicits in investment opportunities.

And finally, Luehrman (1998) claims that real options capture the value of managerial flexibility to adapt strategic decisions in response to unexpected market developments. Companies create shareholder value by identifying, managing and exercising real options associated with their investment portfolio. The real options method applies theory of financial options to quantify the value of management flexibility and leverage uncertainty in a changing world. The literature on utilizing real option logic in management is summarized by Ipsmiller et. al. (2018).

There are different ways that the real options may be classified. The most important and clear **classification of real options** is presented by Panayi and Trigeorgis (1988). They divide real options into two categories (see Figure 3): those without strategic value, which are cash-

generating and are (usually) structured and so-called simple options as well as those with strategic value, which are not cash-generating and are (usually) structured and so-called compound options. This classification uses similarities between real options and financial options.

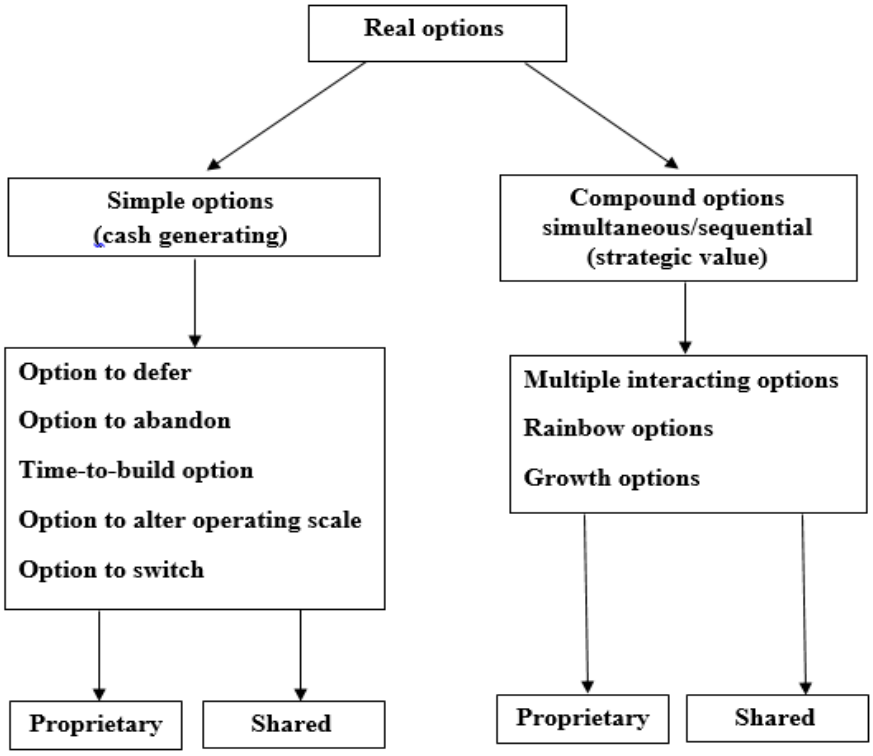

Figure 3. Categories of the real options

Source: Panayi and Trigeorgis (1998)

A **single option** is the one used throughout the life of a project or an investment. A **compound option** can be described as an option on an option. It can be two or more simple options. There are two types of compound options

- **simultaneous compound option** – during the life of the second option, both options are alive simultaneously;
- **sequential compound option** – the second option is created only when the first option is exercised.

Proprietary real options are opportunities that are held by one company only. In contrary to proprietary real options **shared real options** are the opportunities that are jointly held by a number of competing companies or even an entire industry and can be exercised by anyone of the collective owners. Examples of classification of the real options are listed in Table 3.

Table 3. Examples of different types of real options

Simple proprietary real option	a government concession to develop natural resources or a potential expansion of capacity to produce a unique product protected by patents.
Simple shared real option	number of potential expansion decisions in competitive industries.
Compound proprietary real option	exploration investments protected by government licenses.
Compound shared real option	a pilot project proving the market and creating customer acceptance.

Source: Damodaran (2005).

Trigeorgis (1999) groups simple real options into the following classes:

- **option to defer (learning option)** – this includes options where the time point of an investment is not determined but flexible allowing this time point to be optimized. Those options can also arise from changes in the term structure of interest rates over time, even if the future cash flow is deterministic,
- **option to abandon (put option, insurance)** – this is an option to sell a project. The value that can be regained by selling the project (salvage value) is included in the pricing of the project and can substantially alter the project's NPV calculation,
- **time-to-build option** – this is an option that allows to stop a step-by-step investment within a project, if market conditions turn unfavorable. Such an option is particularly valuable in R&D,
- **option to alter the operating scale** – this is an option to react upon a changing market and to expand operations (favorable market conditions) or to scale down operations (unfavorable market conditions). Such an option can be implemented when a firm wants to introduce a new product or would like to enter a new market, for example in the consumer goods industry,
- **option to switch** – this option comprises the possibility to react upon changed market conditions by changing the input and output factors via input shifts and/or output shifts. This is a classical real option,
- **growth option** – growth options are strategic options. Such options are particularly relevant for projects which are not advantageous in themselves but may generate lucrative opportunities in the future. This type of an option can especially be found in R&D. In the pharmaceutical industry, e.g., it takes more than ten years for a product to

develop from the original idea to the final product with a success probability of only a few percent. However, during the course of a project the original investment may generate various other applications which are profitable and generate a positive NPV for the whole investment.

According to Trigeorgis (1999) compound real options can be:

- **multiple interacting options** – they are combinations of real options of the types described above. In practice they are the most frequent ones,
- **rainbow options:** those are options driven by multiple sources of uncertainty, where the option value is dependent on two or more underlying variables, e.g. price of a unit of output and the quantity that might be sold (Copeland and Antikarov, 2003). All types of real options listed above can be grouped into call like options and put like options.
- **call-like option** is an opportunity to increase part of the investment. This type of real options has the same characteristic as a usual financial call option, as shown in the Figure 4.

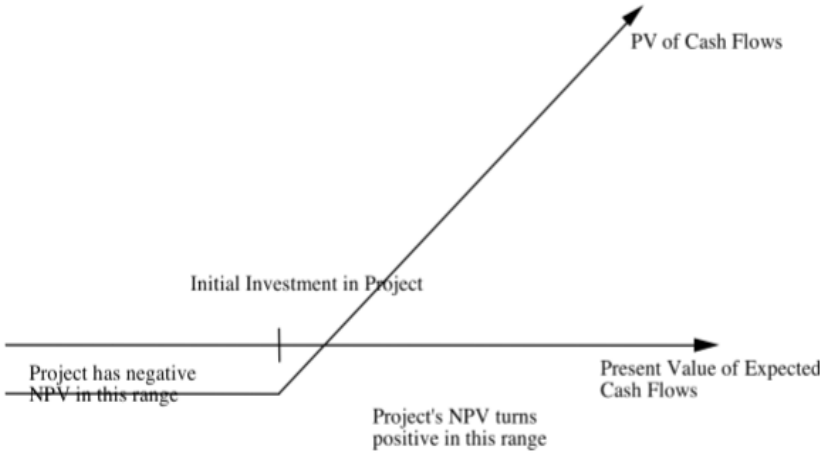

Figure 4. Call-like real option

Source: Damodaran, A (2005).

A **put-like option** is an opportunity to reduce or to abandon/to defer the investment. This type of a real option has the same characteristic as a usual financial put option, as shown in Figure 5.

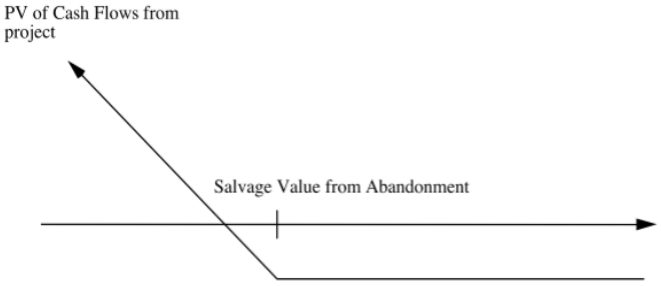

Figure 5.Put-like real option

Source: Damodaran, A (2005).

Additionally, like a financial options, real options are classified into a number of styles, the most common of which are: **American option:** this option can be exercised at any time during its lifetime period and **European option:** this option can be exercised only on their maturity date.

Table 4. Real options in terms of financial options

Name of real option	Type of option	Classification of option
Option to defer (learning option)	call	American call
Option to abandon	put	American put
Time-to-build option	put	European put
Option to alter the operating scale	call (favorable market conditions) put (unfavorable market conditions)	American call
Option to switch	call	American call
Growth option	call	European call

Source: author's own work

2.2. Comparison of real options and financial options

The most well-known option is an option used in finance (Roodhof, 2012). Real options have started to receive corporate attention only in the past three decades (Mun, 2006). Financial options are daily used and traded on financial market. Therefore, they are very recognizable. Real options are harder to recognize.

There are similarities and differences between real options and financial options. They both give the right to buy or sell an asset at certain price. Like in financial options the value of real options depends on five basic variables (although others may come into the picture), plus an important sixth one (Copeland and Antikarov, 2003). The five basic variables are:

1. **value of the underlying risky asset** – in the case of real options this may be a project, investment or acquisition. If the value of the underlying asset goes up, the value of a call option goes up too. One of the important differences between financial and real options is that the owner of financial option cannot affect any change on the value of the underlying asset (e.g., a share of any company stock). In case of real options, the management that operates a real asset can raise its value and thereby raise the value of all real options that depend on it,
2. **exercise price** – this is the sum of money invested to exercise the option if any person "buys" the asset (using a call option), or the sum of money received if a person "sells" it (using a put option). If the exercise price of an option increases, the value of the call option decreases and the value of the put increases,
3. **time to expiration of the option** – as the time to expiration increases, the value of the option increase too,
4. **standard deviation of the value of the underlying risky asset –** the value of an option increases with the riskiness of the underlying asset because the payoffs of a (call) option depend on the value of the underlying asset exceeding its exercise price and the probability of this increases with the volatility of the price of the underlying asset,
5. **risk-free rate of interest over the life of the option** – as the risk-free rate goes up, the value of the option also goes up.

The sixth and the last variable is a **dividend** that may be paid out by the underlying asset. It may be the cash outflows or inflows during the underlying asset lifetime.

There are important differences between both types of options. Brach (2003) compares parameters that determine the value of both options. Table 5 shows the differences in parameters describing real options and financial options.

For financial options *S* means the spot price (price of the share). With real options this can be compared to the discounted value of the total future cash flows of the project. It can be calculated with the traditional discounted cash flow method. In fact, this is the value of the asset at time 0.

Table 5. Parameters of financial options and real options

Financial Options	Varible	Real Options
Spot price	*S*	Discounted future cash flow of the asset
Strike price	*K*	Cost to buy the asset (investment) Cost to sell the asset (abandon option only)
Time to expiration	*T*	Option term
Volatility	*Σ*	Changes (fluctuation) of cash flow from the project during the it's life cycle
Risk free rate	r_f	Risk free interest rate (time value of money)

Source: Brach (2003).

K is the strike price of financial options and is predetermined in most of the time. In the case of real options *K* can be seen as the investment that has to be made to exercise the option. In contrast to financial options the amount of the investment is often insecure with real options. So, in practice, it is the investment that has to be made to get the option.

The time of the option, *t*, is for both financial options and real options the time, in which it must be exercised. From that point of view real options seem more like American options because the point of time when the option must or can be exercised is not predetermined.

Volatility, *σ*, is seen as the future degree of uncertainty. Both for financial and real options, a higher volatility leads to a higher premium of an option. The possibility that the price of a stock will increase is greater, because the downside risk is covered up to the maximum loss of the premium.

The *r* is the risk-free interest rate, and for both options this has the same meaning and content. An increase of the risk-free interest rate will have a positive effect on a financial call option and a negative effect on a financial put option. For a real option is it important to understand what kind of effect the change of the risk-free interest rate has on its operational activities[3] (Engels, 2002).

In addition, it is possible to distinguish real options from financial options according to the criteria shown in table 6.

[3] Operating activities refers to company's core business activities, such as manufacturing, distributing, marketing and selling a product or service. Those activities should provide the majority of a company's cash flow and largely determine whether a company is profitable.

Table 6. Comparison of real options and financial options

	Real options	Financial options
Potential and strike price	Complex	Easy
Trading	Not traded	Daily
Timeline	Fixed and known	Flexible
Liquidity	Does not exist [4]	High
Underlying asset price	Not always available	Always available and clear
Viewpoint	Management tool	Contract
Exercising	No market changes	Changes will be in supply and demand

Source: Roodhof (2012).

As far as the potential and strike prices are concerned a big difference between financial options and real options is the character of the underlying asset. The underlying asset with financial options is financial (not physical), the underlying asset with real options is physical. With financial options it is more about the difference between the potential and the strike price. In the case of real options, the environment is more complex than in financial options. For example, technological and market developments, management competences and others, will have a greater influence on the value of the real option then financial option.

Financial options are traded on daily basis, so the information on valuing options and decision making (to hold or to exercise) is available at any time. This is not the case with real options (Copeland and Tufano, 2004). Real options are not traded on daily basis, therefore, valuating a decision making is more difficult. In fact, real options are created when an investment or a project is created. When the investment or the project is sold, it being sold together with real options.

The concept of timeline is another difference. In the case of financial options expiration day is preset and known. With real options timeline is not so clear. The moment of the exercise will result in another option or exclude other options, so options have and will influence on each other reciprocally. Long time can pass between exercise point of option and financial effects of this action. During the project realization new information can emerge that could have change the market.

[4] Unlike financial options, real options are not traded alone. A real options is an integral part of a project/investment therefore an investor gets ("purchases") a real option together with a project/investment.

There is a difference in liquidity between real options and financial options. Financial options are easy to trade on financial markets. Real options in themselves are not traded, unlike financial options, but when the asset is sold, it is sold with all existing real options. In fact, real options is an integral part of investment or project. It is very similar to the reputation of a business - reputation alone cannot be bought (although it can be calculated), but when the business is sold - it is sold together with reputation. Therefore, their liquidity is limited.

Shares, like other financial assets (options, derivates, currencies, commodities, etc.,) are traded every day, therefore the price of underlying asset is always available and clear. In the case of real options, the value of underlying asset is not always clear. The underlying asset usually are not traded on daily basis. The underlying asset of a real option is often a future product, which makes it difficult to accurately estimate its price in the market. For example: oil or gas that is sought in a certain place. We know exactly what the price of a barrel of oil is today but can only estimate the future price that will affect the price of a real option. In reality, a real option by itself is not traded: it can be produced or bought together with its underlying asset.

Financial option is a contract between two separate parties: an option holder and an option writer. Real option can be seen as management/risk management tool for project controlling and monitoring. For a holder of an option a real option creates flexibility. That flexibility can be used for continuing new insights or changes that can occur in the market and may influence the future cash flows. Real options can be described as opportunities that the management in the future holds on to. With financial options this opportunity is the right to sell or buy a common stock for a predetermined price. With real options, for example, the opportunity is the possibility to delay an investment or the possibility to launch a new product.

In terms of supply and demand, when financial option is exercised, the market does not change. The reason for it is that when a financial option is exercised there will be no larger numbers of shares on the market. When a real option is exercised changes would be seen in terms of supply and demand.

Financial options is a zero sum game: holder's loses are writer's profit. When a financial option is exercised, there is no added value. When a real option is exercised there is a possibility of an investment. This creates added value (Witvoet et al, 2007).

2.3. Real options valuation

2.3.1. Mathematical background

Since in 1971 the famous and widely used option valuation model was proposed by Fisher Black and Myron Scholes and extended by Robert Merton (1973), option evaluation became a hot topic in many scientific research until today. For decades, many economists and mathematicians around the world have carried out a large number of researches, and their results have contributed to the Black-Scholes-Merton formula, until the final result was presented in 1973. The major assumption of the formula is that stock prices are a continuous stochastic process and its derivation is built on four processes which were introduced by mathematicians to try to capture the behavior of stock prices. Those four processes are described below.

Markov Process: Stochastic process named after the Russian mathematician Andrey Markov. It provides the *Markov property*, usually characterized as "memory lessness". It assumes that historical data of a variable is not important when predicting future underlying asset prices. Future prediction of the price is uncertain and is expressed in the terms of probability distributions where the time intervals are independent.

Weiner Process: Wiener process is a continuous-time stochastic process named in honor of Norbert Wiener. It is often called standard Brownian motion, after Robert Brown. It is one of the best known Lévy processes (càdlàg, right-continuous with left limits) stochastic processes with stationary independent increments), that are frequently used in mathematics, economics, quantitative finance, and physics. In fact, the Wiener process is a particular case of *Markov process* which assumes a normal distribution with the mean of zero and variance of one $N(1,0)$. If any variable, z, is considered to follow a Wiener process it must supply two important properties (Hull, 2011):

(1) changes in z over some small-time interval, Δt is: $\Delta z = \epsilon\sqrt{\Delta t}$

where: $\boldsymbol{\epsilon}$ has a standardized normal distribution with mean 0 and variance 1.

(2) two different changes of z over two non-overlapping time intervals are independent.

The changes in the mean of a stochastic process are often referred to as the mean rate and variance rate, mostly known as volatility in option valuation. In fact, stock prices do not have a 0-mean rate and do not have a volatility of 1. To adjust to these characteristics a

generalized Wiener process is more suitable to value changes in stock prices, and it is defined as:

$$dS = \alpha(S,t)dt + \sigma(S,t)dz \qquad 2.1$$

where: $\boldsymbol{dt}$ is an infinitesimal change in time, $\boldsymbol{dz}$ is a standard Wiener process and $\boldsymbol{\alpha(S,t)}$ is the drift rate and $\boldsymbol{\sigma(S,t)}$ is the variance rate, they are functions of the underlying variable $\boldsymbol{S}$ at time $\boldsymbol{t}$ (Trigeorgis, 1999). The process described by equation (2.1) is called an *Itô process*.

Geometric Brownian motion (GBM): Also known as ***exponential Brownian motion***, is a continuous-time stochastic process in which the logarithm of the randomly varying quantity follows a Brownian motion, also known as Wiener process, with drift. It is an important example of stochastic processes satisfying a stochastic differential equation (SDE). It applies in mathematical finance to model stock prices in the Black–Scholes model. Geometric Brownian motion is a special case of a Wiener process, and it defines changes in stock price as:

$$dS = \mu S dt + \sigma S dz \qquad 2.2$$

where: $\boldsymbol{\mu}$ is the expected rate of return of the underlying asset $\boldsymbol{S}$. The volatility is denoted by $\boldsymbol{\sigma}$ and $\boldsymbol{dz}$ is the Wiener process.

Option value is a function of the underlying asset and the time to expiration of the option. It is possible to evaluate the underlying asset price option from the previous processes, but it can be too complex. The Japanese mathematician Kiyoshi Itô introduced a method which is known today as ***Itō´s lemma*** (Itō, 1944) that captures the behavior of stochastic variables. The lemma is widely applied in mathematical finance, and its best-known application is in the derivation of the Black–Scholes-Merton equation for option values.

2.3.2. Valuation

Three types of numerical techniques have been developed for option valuation (Hull, 2009):

(1*) approximation of the underlying stochastic process directly by Monte Carlo simulation* (Boyle, 1977);

(2*) use of various tree approaches, such as binomial option pricing method* (Cox, Ross and Rubinstein, 1979; Boyle, 1988);

(3) *discretization of a partial differential equation by finite difference methods*, as in Black

and Scholes (1973).

Monte Carlo method was first introduced to finance in 1964 by David B. Hertz. Phelim Boyle (1977) was the first who applied the Monte Carlo simulation in valuation of derivatives. The method is used to simulate the various sources of uncertainty that may affect (e.g., worst scenario and best scenario) the value of an asset, portfolio, or investment decision, and to then calculate a representative value, that gives these possible values of the underlying assets. In terms of financial theory, this is an application of risk neutral valuation (risk neutrality). This is usually done by using the stochastic asset models. The advantage of the Monte Carlo method over other techniques increases as the dimensions (sources of uncertainty) of the problem increase. Additionally, the Monte Carlo simulation can be applied in option pricing and default risk analysis.

In Real Options Analysis (ROA), Monte Carlo methods are used to construct "stochastic" or probabilistic financial models as opposed to the traditional static and deterministic models. In this case, in order to analyze the characteristics of a project's net present value (NPV), the cash flow components that are very impacted by uncertainty are modeled, incorporating any correlation between them, mathematically reflecting their "random characteristics". Then, these results are combined in the NPV histogram (i.e. the project's probability distribution), and the average NPV of the potential investment, as well as its volatility and other sensitivities, is observed. This distribution allows, for example, for an estimate of the probability that the project has a net present value greater than zero (Gamba, 2002).

Black and Scholes model is complex by the fact that it uses many parameters. The application of the model may be difficult to obtain a reliable baseline data necessary to calculate (e.g., dispersion). Therefore, such an assessment model is suitable mainly for simple assessment of real options that are the only source of uncertainty and a single date solutions. The value of a call option in the Black-Scholes model can be written as following:

For a call option:

$$C = S_0 N(d_1) - K e^{-rt} N(d_2). \qquad 2.3$$

For a put option:

$$P = K^{-rt} N(-d_2) - S_0(-d_1), \qquad 2.4$$

were: $d_1 = \frac{\ln\left(\frac{S}{K}\right)+\left(r+\frac{\sigma^2}{2}\right)t}{\sigma\sqrt{t}}$,

$d_2 = d_1 - \sigma\sqrt{t}$.

S_0 is a current value of the underlying asset, K is a strike price of the option, t is life to expiration of the option, r is riskless interest rate corresponding to the life of the option, σ is standard deviation, $N(d_1), N(d_2)$ is cumulative function of normal distribution.

Restriction of the model are:

- an estimated asset must be liquid (availability of the market is necessary for the estimated asset),
- price variability of an asset remains identical (i.e., there are no sharp jumps in prices),
  - an option cannot be exercised before its expiration (European option),
- there is no possibility of arbitration.

After Black and Scholes model that was presented in 1973, Cox, Ross and Rubinstein (1979) developed an alternative method to calculate the price of options, known as ***binomial option pricing model*** **(BOPM)**. In fact, the Cox-Ross-Rubenstein binomial option pricing model is a variation of the original Black-Scholes option pricing model. The model is popular and most frequently used because it considers the underlying asset over a period of time, instead of just one point of time, by using a lattice-based model, so it considers American option where early exercise (and value) of an option is possible, not like in Black and Scholes model, where the exercise (and the value) of the option is possible only at expiration. Like in a Black and Scholes model, this method is built on an assumption that there are no opportunities for an arbitrage profit. This model uses a binomial tree to represent possible paths for the stock price. According to the model, stock price process might be followed, in any time period, by two possible prices: ***up*** or ***down***. The formulation of a two-step stock price process that follows the binomial is shown in the figure below.

In this figure, S_0 is a current stock price that can move up to S_u with a risk-neutral probability p and down to S_d with a probability $1-p$ in the first step. In the second step a stock price can move up from S_d to S_{dd} with the same risk-neutral probability, p, but it also can move down to S_{ud} with a probability $1-p$. By the same way, a stock price can move down from S_d to S_{dd} with a probability $1-p$, but it can also move to S_{ud} from S_d with a

probability p.

Technique of construction of this model is more difficult than the previous one, but still allows to take into account any additional factors, and investment or project scenarios, and obtain more accurate results in the case where there are several sources of uncertainty or a large number of decision-making dates. As the number of decision-making dates are bigger throughout the year, real options evaluation using the binomial model may be close to the value obtained using the Black and Scholes model.

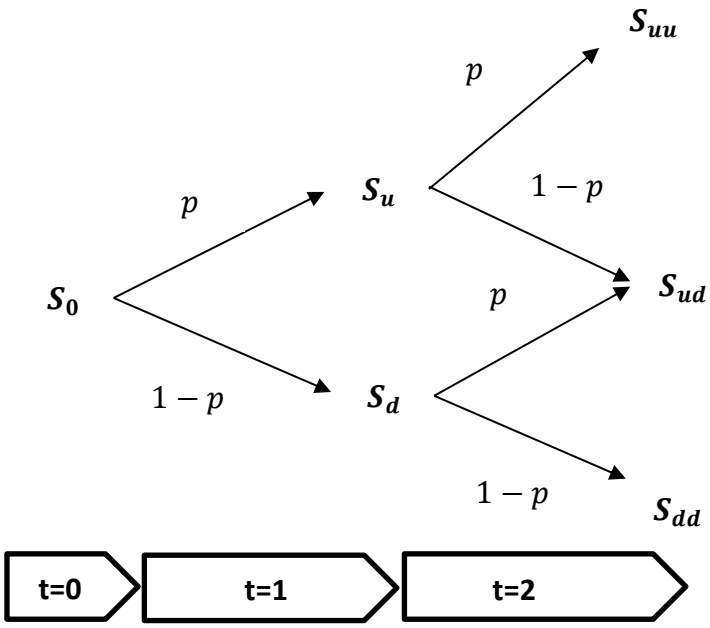

Figure 6. Formulation of two-step binominal option pricing model

Source: Authors own work

When the number of state variable is large enough, all three methods (i.e., Monte Carlo simulation, binominal option pricing method and finite difference method) become inefficient. This is because the memory space and calculation time grow exponentially as the values of variables increase. Usually, when there are more than three state variables and the options are path dependent, both binominal option pricing and Black-Scholes-Merton methods cannot value options efficiently. In this case, only the simulation approach can provide the best choice for a complex option valuation problem.

2.3.3. Flexibility of real options

The most common traditional investment methods used in decision making in projects and investment are DCF, NPV, IRR, ROI and payback. The calculations for those methods are static, not dynamic or flexible enough to capture uncertainties that may take place in the future. Therefore, it became necessary to develop an instrument that takes into account the uncertainty of the future. To illustrate this argument, author of this thesis want to use the following example.

Let's suppose a company is going to invest in the operation of the production line of new products. The project is calculated for two years. Initial investments of $150K is necessary to complete the project preparation phase lasting one year. $100K more is needed to be invested the following year at the beginning of a production process. It is expected that cash flows arising from sales of new products will enter the company's disposal until the end of the second year since the start of the project. However, now it is difficult to determine whether a new product will be in demand on the market. Inheritance positive probability of events (expected income will be a $400K) makes 65%, and negative (expected income - $40K) - 35%. Rate of return, r is 10%.

Let's calculate the NPV, using the standard approach:

$$NPV = (-150) + \frac{(-100)}{(1+0.1)} + \frac{400 * 0.65 + 40 * 0.35}{(1+0.1)^2} \qquad 2.8$$
$$= -\$14{,}46\ thousand < 0$$

Net present value of this investment is less than 0. In other words, this investment is not profitable. Thus, according to NPV criteria decision, it would be logical to abandon this investment.

Now let's suppose that in a year it will become clear whether the new product finds demand in the market. Thus, it will be able to decide whether to continue to invest. In the event of adverse changes, it will be advantageous to stop the investment. Let's calculate the NPV now:

$$NPV = (-150) + \frac{(-100) * 0.65}{(1+0.1)} + \frac{400 * 0.65 + 40 * 0}{(1+0.1)^2} \qquad 2.9$$
$$= \$5{,}785\ thousand\ > 0.$$

Now net present value is positive, therefore, this investment is profitable. According to NPV decision criteria, this investment can be recommended for execution. In practice, if a company wants to accept the project with a negative NPV, such a decision is called "strategic".

However, it is necessary to differentiate the real option and the choice. If the company has no opportunity to perform the investment or the project step by step or in case of failure to leave the investment or the project before its completion, having minimized losses, then in that case the company faces the choice. The choice is to invest now or not. This is not a real option.

The most important part of the real option method investment analysis is the **flexibility**. By using different types of real options such as the option to expand, defer, abandon or contract, company´s management can achieve more control over the investment and its outcomes. In the changing market conditions, by taking flexibility into account, companies might be better to deal with the uncertainty and various risks that are facing. It is very important to understand the differences between the risk and uncertainty. The differences between the uncertainty and risk are explained below:

Uncertainty is a situation where are multiple alternatives results in a specific return on investment, but the probability of the return is not certain, and this is because of lack or poor information (Knight, 1921). Taking into account the uncertainty is one of the main advantages of real options. Real options model includes a learning process that helps managers to make better decision when uncertainty has resolved due to events, actions and certain points in time (Leggio, Bodde, Taylor, 2006). Such approach considers numerous ways that are a result of high uncertainty combined with the possibility of choosing best responses when the new information is obtainable (Leggio, Bodde, Taylor, 2006).

It is important to clarify the classification of the types of uncertainty, because different types of uncertainty require different approaches to modeling the real options (Courtney, Kirkland, Viguerie, 1997). Four levels of uncertainty are described below:

- **level one:** enough clear future (forecast only).
- **level two:** various options (multiple scenarios).
- **level three:** the range of different variants (range of multiple scenarios).
- **level four:** absolute uncertainty (nothing can be predicted).

Risk is the situation of uncertainty where some possible returns on an investment have an

unexpected, undesired effect or significant loss (Knight, 1921).

Ambiguity: in simple words it refers to a situation where there can be two or more possible solutions (options). The reason for multiple solutions (options) can be:

- lack of information.
- quality of information (incorrect information).
- conflicting information.

All the factors mentioned before may make the decision-making process difficult and complicated. As a result, a decision maker may receive a number of possible outcomes, when he has difficulty calculating and choosing the best option for the given case. Major of existing scientific literature defines ambiguity as probabilistic ambiguity, where decision making person is not sure which probability of distribution to use for calculating outcome (Aggarwal and Monhanty, 2021).

Ambiguity is different from uncertainty not only by its definition. The way for reducing uncertainty is linear, where reducing of ambiguity is iterative (Oppi, Campanale and Cinquini, 2022). Thus, decision making person ask a question and receive the answer. This answer reduces ambiguity, but temporarily, only for question that was asked. Next question will arise ambiguity while it's answer will reduce it. It can take a lot of time when decision making person will be able to get the right solution (Wright and Davidson, 2000).

To be close to this doctoral research, uncertainty is defined as a situation where a loan officer is not sure about the probability of paying back a loan.

How can ambiguity affect a bank? The answer is that it means ambiguity about bank's business activity. Thus, for example, a central bank can issue a regulation or a government can enact a law that may affect banking activity. A bank does not know for sure whether and how a law will affect its business activity, for better or for worse? Changes in the macroeconomic situation may also leave the bank in the dark. **In these situations the bank has a number of scenarios that will happen but the bank does not know for sure which scenario is a real scenario** (Wright and Davidson, 2000).

The comparison of risk versus uncertainty and ambiguity is presented in Table 7.

Table 7. Risk versus uncertainty versus ambiguity

	Risk	Uncertainty	Ambiguity
Probability	assigned	not assigned	not assigned
Measurement	can be measured	can't be measured	can't be measured
Control	controllable	uncontrollable	uncontrollable
Reducing	cyclical	linear	iteratively
Returns on investment	known or may be calculated	unknown and can't be calculated	can have more than one outcome

Source: author's own work.

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Using real options may be effective when there is uncertainty level two or higher. There is no need to use real options for dealing with a level one uncertainty. As uncertainty rises, so does the feasibility of the use of real options. Again, different types of real options can be used as a tool for risk management. A reader will find out more about it in the next chapter, where the author of this PhD thesis presents the examples of utilizing real options in financial and non-financial industries.

Chapter 3.

Possible application of real options in different industries

This chapter discusses the possible application of real options in various sectors of non-financial and financial industries. Industries are presented by frequency of using real options: from the most to the least common use. In addition, discussion presents examples of application of real options in a real life. By doing so the author wants a reader to understand the concept of real options in non-financial and financial industries better and to see the biggest differences in the use of real options in those industries.

3.1. Non-financial industries

Using real options as an instrument for valuation investment decision is relatively new in the corporate world. It has been evolving since about 1980´s (Myers, 1987). It is based on the idea of using financial options to value investment opportunities. Real options allow much more flexibility than net present value approach (NPV), as shown in the example in previous chapter.

Today, real options can be applied to many industries, from small companies to large world corporations. According to Brach (2003) real options are used in oil drilling and mining companies, for research and development projects as well as in telecommunication and airline sector. Table 8 shows different industries in which real options of the growth or flexible type are in use.

Table 8. Application of real options in various industries

Industry	Growth option	Flexibility option
Oil & gas	Lease blocks	Delay production
Power	Global expansion	Peak generating plants
Real estate	Undeveloped land	Redevelop with adjusted mix
Airline	Aircraft delivery options	Contingency rights
Pharmaceuticals	Research and development	Outsource production or sales
Telecommunications	Mergers and acquisitions	Re-deploy
Internet	Marketing investments	Outsource services
Computer hardware	New model under brand name	Assembly configuration
Financial services	IT infrastructure	Abandon service or divest

Source: Rogier (2013).

3.1.1. Natural resources industry

The reasons for investing in natural resources have always been strong. Whether it's oil or gas, lumber, coal or gold, natural resources are at the core of production. The pool of investable natural resources is growing as the world population requires more and more of these resources. Natural resources industry is an industry where the prevalence of the use of real options is the highest. In a natural resource investment, the underlying asset is the natural resource, and the value of the asset is based upon two variables - (1) the estimated quantity, and (2) the price of the resource. The comprehensive review the operations literature on real options in natural resources producing energy can be found in Nadarajah and Secomandi (2023).

The author chose to start the presentation from oil and gas industry, a sector of natural resource industry, as an example of possible applications of real options in natural resources industry. Real options listed below are useable successfully in gold mining, silver mining, coal mining and diamonds, as well as in oil and gas industry.

Many uncertainties exist in the oil and gas industry: in oil and gas prices, in oil and gas reserves in the ground or sea, in geological and reservoir structures and more. Companies that operate in the oil and gas industry are required to invest large sums for their activities, for example, for the purchase of an oil platform, a pumpjack, or some other expansive equipment. This is the reason a use of real options in oil and gas industry is greater than in the other industries.

As was discussed before, the oil and gas industry is a very high-risk industry: it requires a large initial investment, while gains are full of uncertainty. Five major risks in oil and gas industry: dry-hole, drilling, production, price and political risks, are described below (Haushalter, 2000):

- **dry-hole risk:** company investing in drilling must invest a large amount of capital, but the result has no guarantee for the revenue from oil or gas because none can be found in the penetrated geologic formation;
- **drilling risk:** high drilling costs can often destroy the investments profitability. Even if companies do their best to estimate them accurately, unexpected geological or mechanical difficulties can be reasons for significant variability in actual costs. The failures of drilling operation in e.g., oil and gas fields may cause big economic losses owing to several technical consequences such as safety incidents, machinery damages,

environmental impacts etc. (Hatefi and Balilehvand 2022);

- **production risk:** even when oil or gas reservoirs are discovered after drilling, there is a high probability that point estimates of the size and recoverability of the oil and gas reserves other time are wrong;
- **price risk:** along with the cyclical nature of oil and gas industry, product prices can also vary unexpectedly during influential political events, such as a war in middle east, overproduction, cheating by the OPEC cartel, interruption in supply such as large refinery fires, labor strikes or political uprising in large producing nations (e.g., Venezuela in 2012), and changes in world demand;
- **political risk:** significant amount of the world's oil and gas reserves are controlled by nations with unstable governments. Companies that invest in oil and gas exploration in these countries take significant risks that the governments and leaders with whom they have signed contracts will no longer be in power when earned revenue streams should be shared contractually. In many well-documented cases, corporate investments in property, plants, and equipment (PPE) are simply nationalized by local governments, leaving companies without revenue or the equipment and facilities that they built to earn that revenue. That is the reason why the impacts of economic policy uncertainty, geopolitical instability, and natural resources rents on economic complexity differ between advanced and emerging economies (Hoang et. al. 2023).

The average lifetime of the project in the oil and gas industry is in the range of 40 - 50 years. Therefore, uncertainty and complexity are very prevalence in oil and gas industry. Consequently, quantitative tools are long used for decision making (Smith and McCardle, 1999).

Two fundamental parameters are important - the price of oil and an inventory quantity. Oil inventory valuation depends on many factors of uncertainty. Some of them can be overcome, for example, the quality of geological research will manage to be estimated. But some over factors of uncertainty, for example, regional political risks often represent "bad" to the uncertainty. This scenario was occurred for Royal Dutch/Shell with its oil field in Nigeria. In oil and gas industry, investment decisions are usually based on NPV returns calculated for expected oil price which varies from company to company. This method is inaccurate because it assumes a single line of scenario for all lifetime of project and incorporates the probability of failure into the overall expected value for the project. That probability of failure is carried

as a discount rate, which in itself can be difficult to assign a value since the discount rate typically is adjusted for the level of risk associated with the project. Hence, the traditional methods for making investment decisions are not effective in the oil and gas industry where large number of uncertainties exist (Abisoye, 2007, Trigeorgis, 1993).

Real Options Analysis (ROA) is a useful instrument for investment decision making, e.g. expansion planning (Nur et. al. 2023), because it takes into account uncertainty and builds flexibility in the system (Lin and Wang, 2012). ROA often deals with investments that do not have a lot of historical statistics, for example, a new oil or gas field development (Abisoye, 2007, Trigeorgis, 1993). By means of a method of real options the Texaco company estimated the oil fields which are in initial stage of development, and the British Petroleum company carried out assessment and developed strategy of development of oil fields in the North Sea.

A company has a license to start drilling on undeveloped land with potential oil reserves. Starting this project may require additional costs, for example equipment or construction of infrastructure. Oil extraction can start only after equipment and constructions are completed. For the company, to start receiving cash flows from investment in oil or gas field, three steps must be completed: exploration, development, and extraction. This is the reason that ***compound sequential options*** (options on options) are very prevalence here. Using compound real options may help the company to cope with uncertainty and risks that exist, may appear, or grow in future. Compound sequential options may be compound from simple options (all or some of options, it very depends on the project) as shown in figure 3 below (Trigeorgis, 1993; Brach, 2003).

Figure 7 shows the general view of compound sequential options. In each decision point a company puts a particular scenario, for example, success or failure. Each scenario has its own probability. The probability varies over the life of the investment/project. In each decision point the company has one type of real option, which allows the company flexibility in decision making to help the company make decisions such as which action better to take in the future. When one type of real option has exercised, the company will proceed to the other type of real option. Real options which can be applied in the oil and gas industry are listed and described below.

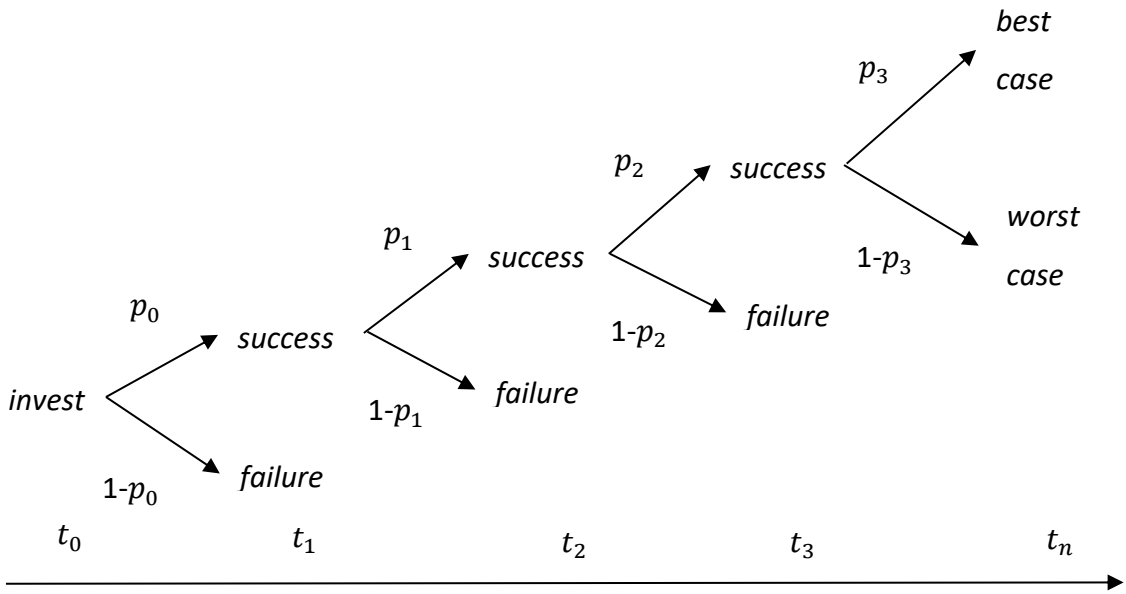


Figure 7.General view of compound sequential options

Source: Trigeorgis (1993); Brach (2003).

Note: the order of real options, which are listed below is random. In reality, real options can appear in a different order.

Option to defer investment: an option to defer is similar to an American call option on the gross present value of expected operating cash flows generated from completed investment $\boldsymbol{V}$, with an exercise price being equal to the required outlay, $\boldsymbol{I_1}$. Investment without delaying assumes abandon of the option to wait. This option value loss may be seen as an additional investment opportunity cost, approving investment only if the value of cash benefits, $\boldsymbol{V}$, actually exceeds the initial outlay by a substantial premium. An option to defer is especially valuable in resource extraction industries due to high uncertainties and long investment horizons. Let's imagine a company that has a license for oil field development, in reality it has a right, but not an obligation for the oil exploration. Oil is a high liquidity exchange traded asset which can be sold relatively easily (at a profit or loss in relation to the investment, depend on market price) and thus cover all increases/expenses or minimize losses. Thus, company would invest $\boldsymbol{I_1}$ in exploration of the field *only if* oil prices exceed their expectations. In other words, company would exercise its option to extract oil. By the same way, company would not commit to the investment, *if* oil prices are below expectations, the company will be able to scale back planned investments and limit their downside exposure. Before

expiration of the license, value will be $\boldsymbol{max(V - I_1, 0)}$. Figure 8 below shows example of an option to defer investment of such a company.

As shown in Figure 8, a company estimates, with probability p_1 (e.g., good market conditions) to extract its license, and with a probability $1 - p_1$ (e.g., bad market conditions) to defer investment until new information appears. Such new information may change future decisions. For example, after deferring investment, company can change decision to invest, if market conditions will change to better, or to stop the project (abandon), if market conditions remain bad.

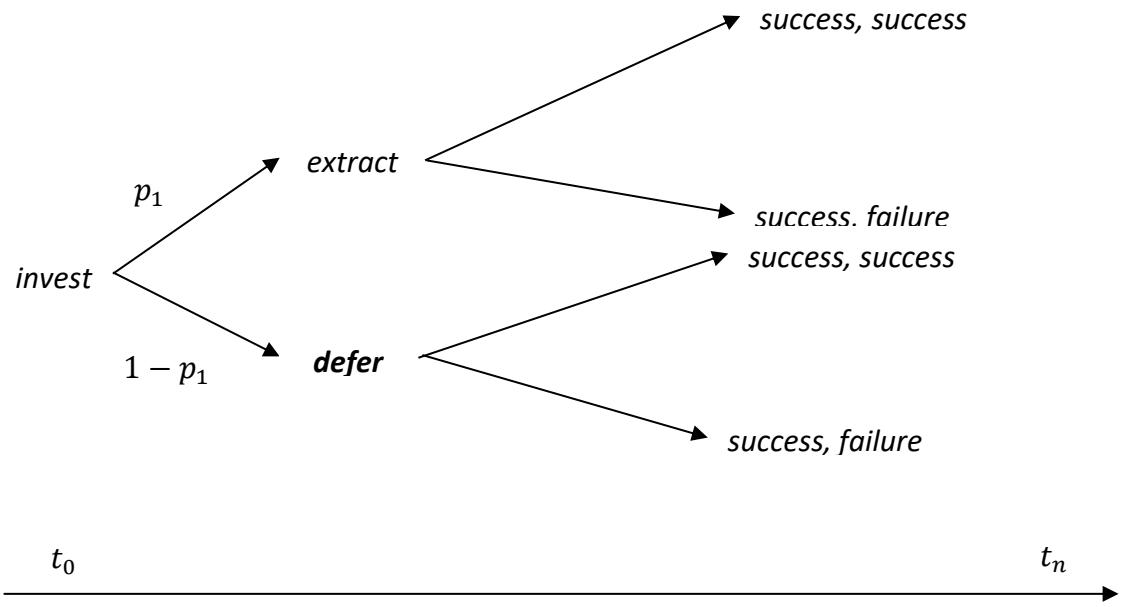


Figure 8. Option to defer investment

Source: Author example.

Time-to-built option: in most real-life projects, the required initial investment is not enough to complete the project. In fact, large number of projects, especially in natural resource industry, is a series of investments performed in stages, one after the other (Trigeorgis, 1993). Such staging of an investment as a series of outlays over time creates valuable ***options to default*** at any given stage, for example, if after exploration stage, the oil reserves discovered as very low, or oil prices, or world demand fell very strongly. Therefore, each stage (for example, building necessary infrastructure stage), can be seen as an option on the value of subsequent stages by investing the additional amount, required to proceed to the next stage of the project (e.g., stage 2). Thus, ***time-to-build option*** can be valued similar to ***compound options***.

Figure 9 below presents example of time-to-build option. As shown in Figure 9, the company estimates, with a probability p_1, that market conditions are good enough to continue investment in the project, therefore, the company will decide to invest an additional amount into next stage of the project. From the over hand, company estimates, with a probability $1 - p_1$, that market conditions do not justify investment in the next stage of the project, therefore, a company may decide to delay investment in the next stage. Such new information may change future decisions. As a next stage, if market conditions remain favorable, a company can decide about the continuation of investment. But if market conditions are worsened, the decision may be to delay the investment or abandon the project.

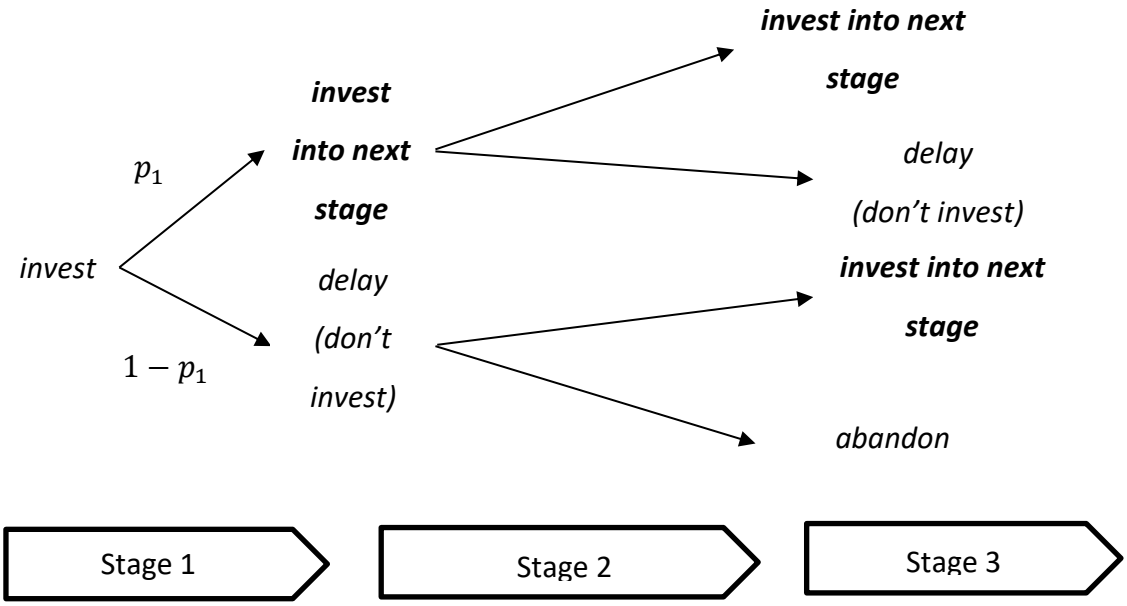


Figure 9. Time-to-built option (staging option)

Source: Author example.

Option to expand: if oil or gas prices and/or other market conditions exceed their expectations, a company can increase its profitability by accelerating the rate or expand the scale of production by x%. This action will result in additional costs (explicit costs ($\boldsymbol{I_E}$)) to the company. This type of a real option is similar to a call option to purchase an additional part of the underlying asset, (x%), paying $\boldsymbol{I_E}$ as exercise price. Such an investment opportunity with the option to expand can be viewed as a compound option: initial investment plus a call option on future investment, i.e., $\boldsymbol{V + max\,(xV - I_E, 0)}$. When a company plans an investment,

it can choose to invest in more expensive technology for the built-in flexibility to expand production when and/or if it becomes acceptable. The option to expand may also be of strategic importance, especially if this option enables the company to take advantage on future growth opportunities. For example, when the company purchase unoccupied undeveloped land, or when it builds a small facility in a new geographic location (domestic or overseas) to position itself to take advantage of a developing large market, it essentially builds an expansion/growth option. Only if future market conditions turn out favorable, this option will be exercised. Moreover, this option can make a seemingly unprofitable investment (based on static NPV) to a profitable one, as shown in examples from the previous chapter.

Figure 10 below presents an example of an option to expand. As shown there, with favorable market conditions (probability p_1), a company will decide to invest additional amount for project expansion. Conversely, a company will decide to stay in current position, if market conditions are not favorable (probability $1 - p_1$).

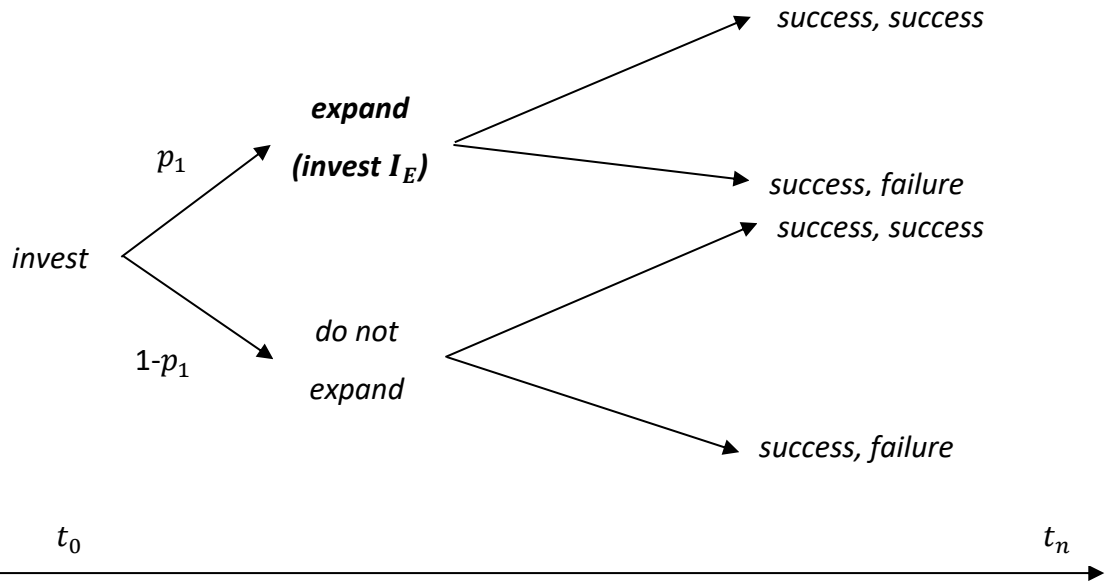


Figure 10. Option to expand

Source: Author example.

Option to contract: if oil or gas prices or market conditions are below its expectations, company can operate below capacity or even reduce the scale of productions by c%. by this way company saves part of the planned investment outlay $\boldsymbol{I_C}$. This flexibility to reduce losses is similar to a put option on part of the underlying asset, c%, with exercise price equal to the

potential cost savings ($\boldsymbol{I_C}$), giving $\boldsymbol{max(I_C - cV, 0)}$. The option to contract, like as the option to expand, may be especially valuable in the case of new product performances in uncertain markets. In addition, the option to contract may be important, for example, in choosing among technologies or facilities with a different construction to maintenance cost mix. If market conditions will turn out unfavorable, it may be preferable for a company to build a facility with lower initial construction costs and higher maintenance outflows in order to obtain the flexibility to contract operations by decreasing down on maintenance costs.

Figure 11 presents example of option to contract. As presented, in contrast to an option to expand, if market or other conditions are not favorable (probability $1 - p_1$), company will choose to contract its productivity. Such action helps a company to save outlays and prevent or reduce losses. Another possible choice is staying in current position.

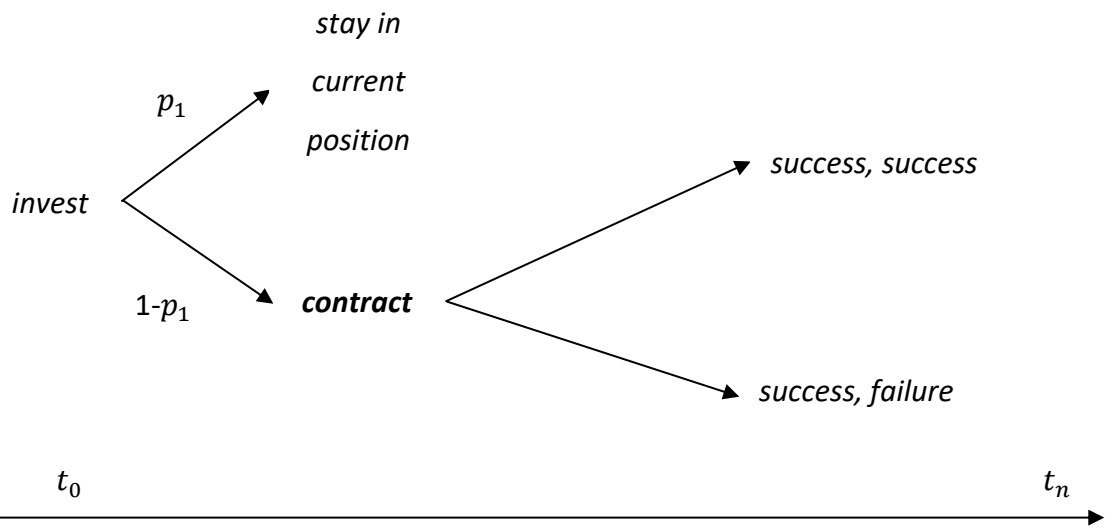


Figure 11. Option to contract

Source: Author example.

Option to shut down (and restart) operations: as discussed before, in a real world, the oil and gas prices can increase or decrease. This may affect the world or domestic demand on oil and gas products. For example, oil prices may reach a level so low that the company would not be economically viable to extract oil or to operate a refinery, because the cash revenues fail to cover the variable operating costs (e.g., maintenance). In such a case, a company should temporarily stop the process. Especially if the costs of switching between the operating and time out are relatively small. If oil prices rise sufficiently, a company can start operations

again. Therefore, an operation in each year can be seen as a call option to acquire that year's cash revenues ($\boldsymbol{C}$) by paying the variable costs of operating $\boldsymbol{I_V}$ as exercise price, i.e., $\boldsymbol{max}$ ($\boldsymbol{C - I_V, 0}$). Options to alter the operating scale (expand, contract, or shut down) are in general found in natural resource industries, such as mine operations and facilities planning and construction (Trigeorgis, 1993).

Figure 12 presents example of option to shut down (and restart) operation. As can be seen in this figure, if market or over conditions are worst (probability $1 - p_1$), the company will choose temporary shutdown operation. If in the next period market or other conditions will improve (probability p_2), a company will decide to restart its operation. If such conditions will be worse (probability $1 - p_2$), a decision to stop producing will be prolonged or even the exit from the project will be planned.

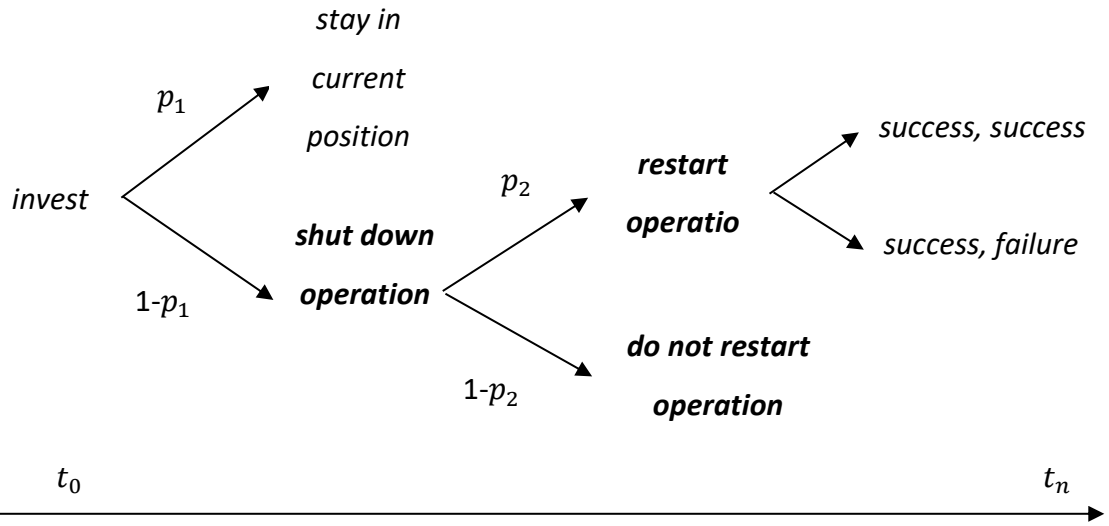


Figure 12. Option to shut down (and restart) operation

Source: Author example.

Option to abandon: if oil or gas prices suffer sustainable decline or the operation does not work fine for some other reason, a company does not have to continue to increase losses by collecting the fixed costs. Thus, company may have a valuable option to abandon the project permanently in exchange for its salvage value. By this way company would resale value of its capital equipment and other assets in secondhand markets. The proceeds obtained from the sale will cover the company's expenses made up to abandon point, all or at least some of them. Option on abandon is similar to an American put option on current investment value (**V**) with exercise price the salvage or best alternative use value (**A**), allowing company to

receive $\boldsymbol{V + max(A - V, 0)}$ or $\boldsymbol{max(V, A)}$. More easy-to-sale assets indicate a higher salvage and option abandonment value than difficult-to-sale assets. For example, vehicle fleets are easier to sell than one oil platform. Valuable abandonment options are generally found in capital intensive industries, such as oil and gas and more others.

As appears in Figure 13, if project will fail (probability $1 - p_1$), a company must decide to abandon it. Successful abandon of a project means selling a project for its real value. Thus, company will be returned its investment in the project. Another possibility is that a company will receive a partial cost for the project, for example by selling only a part of the equipment. By this way company will receive only a part of the investment carried out.

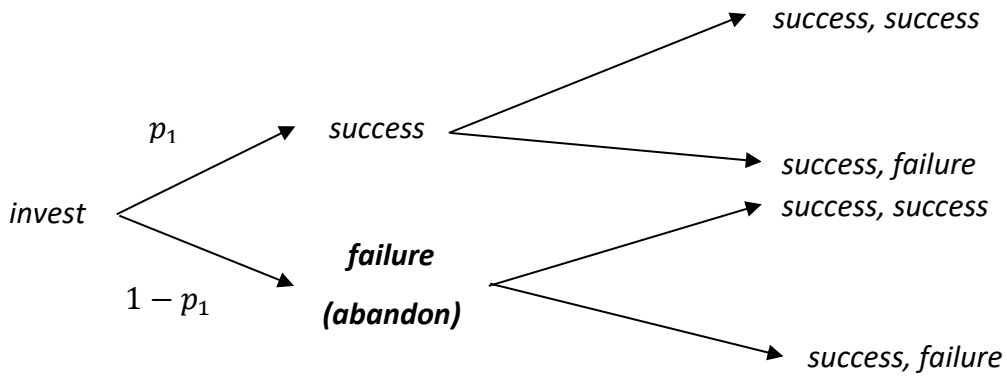


Figure 13. Option to abandon investment

Source: Author example.

Option to switch: suppose that a company considers a construction of a crude oil processing facility. That company has two options: one is to build a facility to produce only one product, for example, fuel. A second option is to build a facility with a production capacity of several products in parallel, for example, fuel and lubricants. Obviously the second option is more complicated and expensive because it requires purchasing expensive equipment. The first option is cheaper and easier to perform, but does it give any response on an changes in a market demand? In response to the changes of a market demand it may be necessary to establish more expensive flexible capacity to receive a capability to change a product assortment or a production scale. Therefore, the second option is more feasible. This way would provide valuable built-in flexibility to switch from the current assignment (e.g., crude oil) to the cheapest future input, or from the current output to the most profitable future product mix, as the relative prices of the inputs or outputs change over time (Trigeorgis,

1993). As mentioned before, the real option must be harvested when a company plans an investment. Therefore, because it gives alternatives, company will choose to invest in such flexible technology. The sum that company will pay for future flexibility will be seen as a premium. If this way a company can develop additional uses for its assets over its competitors, it may place it at a significant advantage. Product process flexibility can be achieved not only by technology (e.g., by building a flexible facility that can switch among alternative inputs), but also by maintaining relationships with a variety of suppliers, changing the mix as their relative prices change (Trigeorgis, 1993). Such contracts allow a company further flexibility to contract the scale of future operations at a low cost in case of unfavorable market conditions. A multinational oil company may easily place a new production facilities in different countries in order to acquire the flexibility to shift production to the lowest-cost producing facilities, other local market conditions, or exchange rates change over time. According to Mun (2006), in the oil and gas companies spend millions of dollars to refurbish their refineries and add new technology to create an option to switch their mix of outputs to capture the demand and price cyclicality in the market.

Figure 14 presents an example of option to contract. As presented in this figure, if there are no alternatives for inputs or outputs, or they are not profitable, a company will keep the option to switch open. But, if profitable alternatives appear, a company will exercise the option and to change inputs or outputs.

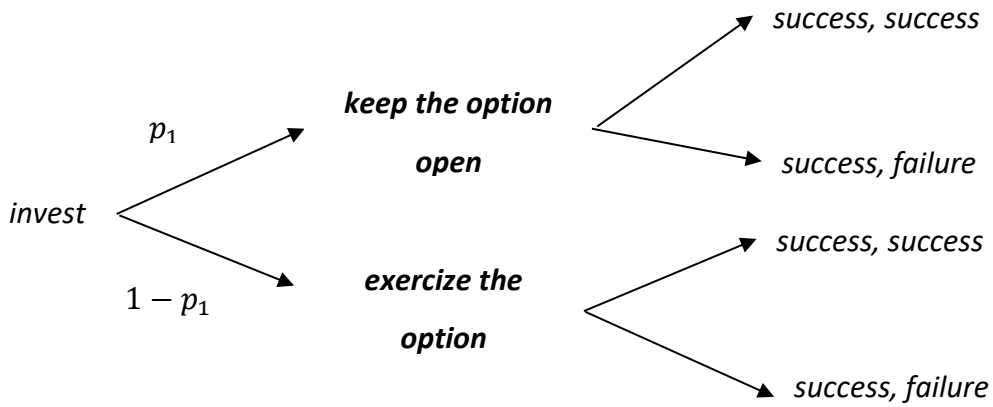


Figure 14. Option to switch

Source: Author example.

Growth options: another version of the earlier option to expand of a great strategic importance are corporate growth options that pave the route of future opportunities (Trigeorgis, 1993). Let's suppose that a company is considering a possibility to build a new

refinery based on a new superior technology for oil refinement, developed and tested internally on a pilot plant basis. From the one side, this facility may appear unattractive, because nobody knows if new technology will be in demand on the market. But, from the other side, it could be only the first step in the series of similar facilities if the process is successfully developed and commercialized and may lead to entirely new oil products. For example, many early investments (e.g., a lease contract on undeveloped land or a contract with potential oil reserves, a strategic acquisition, research and development or new technology), can be seen as early conditions or links in a chain of interrelated investments. The value of these investments derives not so much from their expected cash flows, but rather from unlocking future growth opportunities (e.g., a new generation of products or processes, oil reserves, access to a new or expanding market, strengthening of the firm's core capabilities or strategic positioning). By calculating the profitability of this investment, a negative NPV may appear. But the experience, infrastructure, and potential products generated during the development of the first-generation product may serve as springboards for developing the next low-cost and/or high-quality generations of the product in future, or even for generating new uses of the product into other areas. Without that initial investment, subsequent product generations or other uses cannot be feasible. The experience and infrastructure gained can be a company's proprietary and can make a company more competitive (competitive advantage), which may help to reinforce itself. Growth options are found in all infrastructure-based or strategic industries, such as natural resource industry.

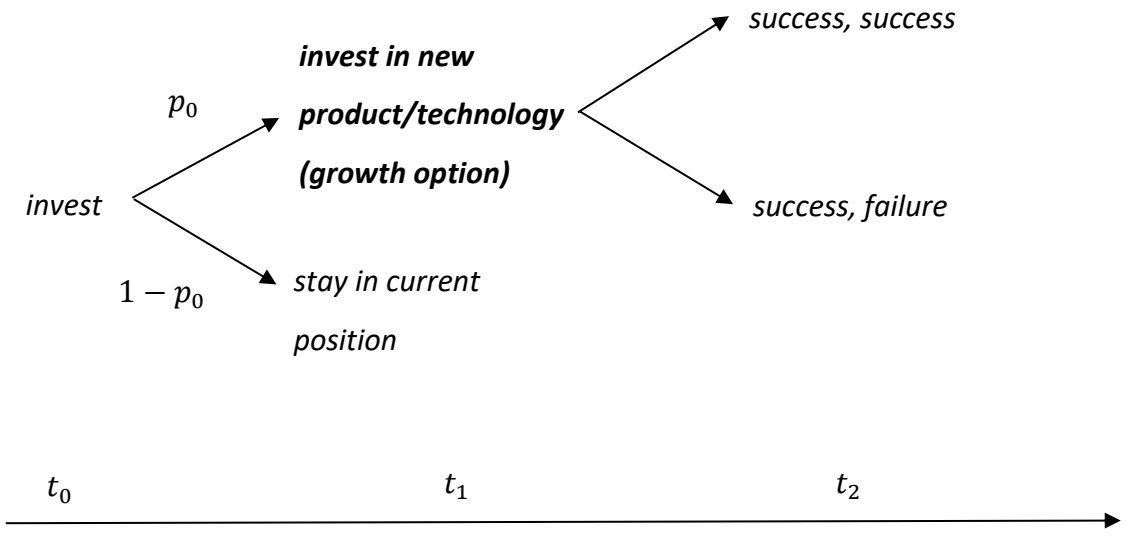


Figure 15. Growth option

Source: Author example.

3.1.2. Real estate industry

Real estate is a property comprised of land and the buildings on it as well as the natural resources of the land including uncultivated flora and fauna, farmed crops and livestock, water and minerals. Real estate can be grouped into three broad categories based on its use: residential (e.g., undeveloped land, houses, condominiums and townhomes), commercial (e.g., office buildings, warehouses and retail store buildings) and industrial (e.g. factories, mines and farms). In real estate industry, a real option is an option where an underlying asset is land or buildings. For example, undeveloped or agricultural land is a real asset with an attached perpetual American option to convert to urban uses (Capozza and Sick, 1994).

Real estate industry is the second sector with a high-frequency usage of real options, after natural resource industry. There are at least two reasons for that. First, similar to natural resources industry, in real estate industry investors need to invest very large amounts at the beginning of the project, while the expected cash flows can be received only when the project is finished. Secondly, like the natural resources industry, real estate industry is characterized by many risks and high level of uncertainty. Six major risks connected to real estate industry are described below (Houe, 2016):

- **development risk:** is the risk that the project does not generate sufficient income to cover the desired return. The reason may be a lack of sale, or the necessity to sell at a lower price than expected. The development risk is often harder to forecast when a project is more unique than the usual, as misreading the market then is more likely;
- **time risk:** construction time has the great influence in real estate development. As long as the project is under construction it does not generate any cash flow but, on the contrary, expenses in the form of cost of capital. This will reduce the return on the project when it is delayed;
- **cost risk:** despite the cost of real estate development can be valued by comparing to similar projects, it is far from a fixed factor. Both internal factors such as construction time and external factors such as financial risks can have devastating consequences for entrepreneurs. Fixed contract with a low-profit margin will result in insolvency, due to wrong cost estimates;
- **financing risk:** a project developer often depends on external financing due to high costs at beginning of a project and a long period without cash flow. This means that they are affected by interest rates and their source of financial structure;

- **building site risk:** if building site needs to be modified in order to be useable, it creates to risks for project developer. This is especially a case when a project is undertaken on a difficult landscape, or exists possibility of polluted soil, or when there is uncertainty about how much support a ground can offer, and therefore what type of construction can be built on it;
- **approval risks:** a real estate development needs to be approved by municipalities or other entity prescribed by law, and in line with the official planning rules. This could cause to a risk of delaying the project or may alter the desired construction.

The value of real estate is closely connected to a geographical area. In contrast to many other assets, inability to move it makes the location to one of the most important attributes of the price. The following factors: vacancy rate, rent level, construction and absorption are very important and can have a great impact on the economic outcome of the project. The vacancy rate refers to the percentage of non-occupied building space. The construction is the quantity of new construction, which is an important factor, as more construction will, all else being equal, lower the demand. Absorption is the amount of additional space that is occupied within a year. High sunk costs and fixed location, but also due to other factors, such as the unknown future demand and general economic situation of the target group also can have a great impact on the economic outcome of the project.

Real estate market is highly influenced by several socio-economic conditions, such as loan opportunities, interest rates and the general income level of the target group. Due to the high risks and complexity of the real estate industry, investors often use compound real options, which consist of number of simple real options (see Figure 7). Types of simple real options that are in use in real estate industry are listed and discussed below.

Option to defer: as it was mentioned before, similar to companies operating in the natural resources industry, in real estate industry companies are required to make substantial investments while a level of uncertainty is very high. Option to defer gives an ability to an option-holder to delay an investment, until more information about the project is known. This option is an American option, that gives a holder an ability to delay exercising an option to a desired date. In the case of real estate development, an investor might delay the project until price or demand uncertainty has been resolved. This option is common in real estate development and has been described in relation to real estate in several academic papers as

Titman (1985) and Quigg (1993), where the optimal timing of development and defer value have been of interest. The option to defer should be checked against the loss-value from undeveloping the project and the costs of holding the option. For example, leaving land undeveloped creates an option to develop at the later date and at a more profitable level. In theory, investor can wait for an infinite amount of time, and real options provide the solution for the optimal timing and price trigger value (Mun, 2006).

Switching option: if real estate developer has the switching option, it gives him the flexibility to switch input or output. It creates option value that allows the investor to better respond to changes in market conditions. The value of a switch option is the costs saved, or the extra cash flow generated, by switching the process or product. For example, if a real estate developer doing a project understands, that it is more profitable to switch from a car parking to a commercial property (e. g., office building or hotel), the flexibility to switch will indeed provide a value.

Option to alter the operating scale* (*option to expand/option to contract): the option to expand gives to the option holder the ability to increase the investment in the project, if the market conditions are more favorable than expected. In contrast, if the market conditions turn out to be less favorable, a decreasing scale might be applied. The option to expand can be valued as an American call option, where a contraction is an American put option (Brach, 2003).

In the case of real estate industry, investing in real estate development embeds an option to expand or contract the project, for example, by expanding or reducing the total premises (amount of square meter) if there are changes in market conditions. Altering real estate development, however, can lead to certain difficulties when the project is started, because not always it is possible to make the desired changes. That is the reason the option might not be as common in real-life situations.

Growth option: a growth option often requires high initial investment costs than the expected revenue, so it gives a negative NPV, where the value derives from creating future growth opportunities (Brach, 2003). The option to grow is an American call option. An example of growth options in real estate industry is investing in land with the possibility of

developing it at a later date.

Option to abandon: as mentioned before, the real estate projects are usually characterized by high initial investment and high risks. In addition, due to its complexity, the construction process may take a long time. During that time, market conditions may make the project unprofitable. Option to abandon may help the investor to minimize losses.

The option to abandon is an American put option giving the option holder the right to abandon the project in exchange for its salvage value, for example, in the event of declining market conditions or poor operation. This type of real option is especially important in projects with a high capital requirement and a long time to completion, which is the case for many larger real estate developments.

Staging option: larger projects often unfold over several stages. The staging of capital investment as a series gives the investor the ability to invest amounts only needed to perform a certain stage, and not spend the amount needed to complete the project. This allows the investor to wait to uncertainties are more resolved, and therefore, create valuable options whether to abandon or continue at the given stage.

A stage option is a compound option, meaning it is an option on an option, which is often seen in R&D projects and large-scale constructions (Trigeorgis, 1995).

3.1.3. Airline industry

The airline industry is a part of the service sector that plays a very important role in the tourism and transportation industry. There are two major players in airline industry. On one hand there are aircraft manufacturing companies, most big and well-known companies as Boeing and Airbus. On the other hand, airlines like Polish LOT, German Lufthansa, EL-AL appear.

The airline industry has large specific risks. High capital intensity in terms of expensive production goods (e. g. airplanes), strong fluctuations in demand and homogeneity of product make investments in this sector risky and changeable. Moreover, changes in fuel prices complicates the planning process and lead to additional uncertainty (Joppien, 2006). Application of real option provides companies operating in this sector better way to cope with risks and uncertainty. Ss discussed earlier, real options allow flexibility in decision-making

process. Such flexibility has significant importance in case of possible responses for future changes.

There are two categories of real options that are in use in this sector. One category of real options is product of aircraft manufacturers (e.g., Boeing and Airbus), and it is in their own use only. This category is called ***proprietary real options***. Another category of real options is also a product of aircraft manufacturers but, their use is done not only by its option-creator, but it is also in use by all companies in the industry. Such options are called ***shared real options,*** as shown in Figure 16 below.

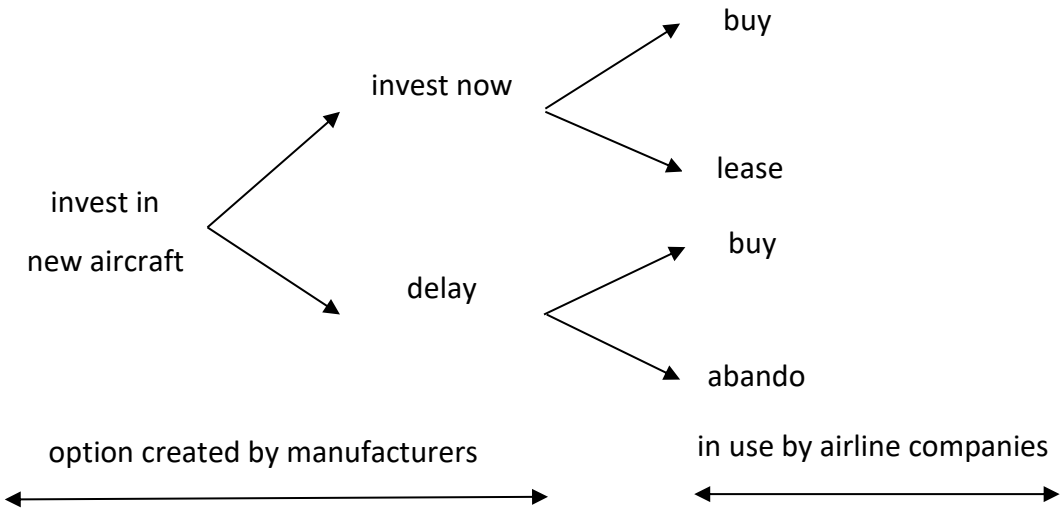


Figure 16. Shared real options in airline industry

Source: Author example.

Types of real options that are in use in this industry are listed and discussed below.

Option to defer: supply of aircraft, particularly for larger models, were expected to take place in 3 to 5 years. Prices range for aircrafts starts from 80 million dollars up to 400 million for the large models. Therefore, for both reasons above, aircraft manufacturers, for example Airbus or Boeing, allows to airline companies, which bought an aircraft, to make a future purchase of additional aircraft, at an agreed price and date (Luftman, 2003). In fact, that is shared real option and it can be seen as a call option on additional new aircraft.

This option allows the airline company to delay the purchase of additional aircraft until market conditions become more clearer and the purchase can be justified, for example, if expected passenger traffic would significantly increase. It also reserves the airline company a place in a manufacturing queue, for a guaranteed delivery slot. Depending on economic

conditions, manufacturers often sell aircraft purchasing options below the real value of the aircraft (Holloway, 2003).

If market conditions justify purchasing, the airline can obtain the aircraft at that date, rather than placing an order and waiting in queue for delivery, which might take years. If the future conditions do not justify purchasing, the airline has no obligation to purchase the aircraft. Rolling options differs from ordinary aircraft purchasing options, in that the delivery slot is assigned at a later date, when the option is exercised or expires.

Another application of deferring options in airline industry is aircraft leasing. Companies often tend to use operating leases for flexibility when they need to adopt a new type of aircraft. For example, British Airways, has financed 10 of its 15 Airbus A320 family fleet under 10-year extendable operating leases. By the same way, Singapore Airlines has financed 747–400 fleet. The aircrafts are financed under leases running from 4–10 years, with 2-year extension options and full sub-leasing rights (Gibson and Morrell, 2004).

Option to switch: as noted previously, aircraft manufacturing process can take several years. Therefore, to reserve an aircraft on a particular date, airline companies uses options to defer (purchase options), to decide later whether they need an additional aircraft. If market conditions change (e.g., passenger traffic decrease) and now a company still has needs in additional aircraft, but a smaller one, switching option allows a company to switch to a smaller aircraft, to give better response to its needs. For example, Airbus offers a purchase option that includes the right to switch from delivery of an A320 to an A319, a smaller aircraft (Brealey, Myers and Allen, 2008). Similarly, Airbus allows to switch to a larger aircraft, between members of same aircraft family (Gibson and Morrell, 2004). Similar to Airbus, Boeing also allows switching options. For example, Philippine Airlines switched from Boeing 747-400 to Boeing 777-300ER.

Option to abandon: in the airline industry, aircraft manufacturers spends billions of dollars and several years to decide which aircraft model should even be built. If the wrong model will be built, competitors may gain a competitive advantage relatively quickly.

There are many uncertainties, that are involved in decision-making process about aircraft model: technical, engineering, market, and financial. To deal with such uncertainties, need to create an option to choose through parallel development of multiple plane designs

simultaneously. By this strategy, aircraft manufacturers will be able to decide which model to abandon or continue when these uncertainties and risks become known over time. This way increasing development cost that can be seen as a premium on the option. One of the companies which successfully apply this method is Boeing. By this way, the company can hedge itself against making the wrong initial decision, and benefit from the knowledge gained through parallel development initiatives (Mun, 2006). Also, the method was applied in case of a value assessment of such companies as Airbus (Coppeland and Antikarov, 2001).

Growth option: research and development by aircraft manufacturing companies may lead to a new technology or a new product, and thus it can discover new markets for companies and competitive advantages. Therefore, it can be seen as a ***growth option***.

For example, in 2007, Boeing worked on construction of small experimental unmanned aerial vehicle (UAV), or pilotless drone aircraft. Such UAV has a number of possible applications: the monitoring of electrical transmission and pipeline safety, forest health, and border security and others (Mathews, Datar, and Johnson, 2007). Today, these kinds of work are done by trained pilots flying small planes over remote stretches of back country. This is a monotonous, hazardous, and expensive work. Today, these types of work are done by trained pilots flying small planes over remote stretches of back country. This is a monotonous, hazardous, and expensive work. Mathews, Datar, and Johnson, (2007) suppose that, depends on progress in the current technologies in aviation control systems, remote sensing, and global positioning, new market for a UAV promises reduced cost and higher effectiveness.

3.1.4. Pharmaceuticals and Research and Development industry

Research and development process can be found in various industries. For example, oil and gas companies are spending a lot of money in research to develop the types of new fuel or oil. Research and development requires a large capital investment, may take a long time and there is the high level of uncertainty. *Pharmaceuticals* and *Research and Development* industries require greater capital investment and with many risks, after *National Resources* and *Real Estate*. Similar to natural resource industry, in research and develop industry ***compound options*** are very common (see Figure 17). More precisely, the companies that operate in the field of R&D apply the compound rainbow options, because the uncertainty is

uncorrelated (Smit and Trigeorgis, 2006). Companies put large effort and sums in research and development in order to gather information that will help in the future to develop a new technology or a new product. New technologies and products must be protected by patents, in order to maximize the company's profit. Patent can be viewed as a call option, where the product itself is the underlying asset (Schwartz, 2002).

Pharmaceutical companies operate in the sector where risk in research and development process is very common. When a company wants to introduce to the market a new drug, it spends a large amount on research and development. When a company develops a new drug, it does not know anything about potential market demand and if cash flows will cover the development costs. However, if a company successfully launches and patents a drug, this can significantly increase its profits. When the patent expires, generic companies begin to manufacture and market this drug, thus reducing the income of a company that developed the drug. That is the reason for the fierce competition in the pharmaceutical industry, which is the trigger why companies are constantly working to develop new drugs against various diseases and release them to the market (Hartmann and Hassan, 2005). For example, the largest international pharmaceutical company Merck many years has applied option methods to assessment of billion investments into development of new medicines.

There are two major risks in assessment of investment opportunities in pharmaceutical industry: **market risk** and **technology risk** (Willigers and Hansen, 2008). Market risk is an important factor in development of new drugs, and the company must be able to evaluate risk of the drugs which has no demand in the market Kellogg and Charnes (2000). Both risks are independent, and it is impossible to estimate the project without taking them into account, what makes the project evaluation more complicated. Traditional investment analysis tools, such as NPV, are inaccurate to estimate this type of an investment opportunity. Real options are useful here, because flexibility awarded by the option can take into account all complicated elements. The real options that can be useful here are described below.

Time to build options (staging invest): Research and development process is more complex pharmaceutical industry than in other industries. Because large requirements, long project life and high uncertainty, research and development in this industry carried out by stages, or, by using time to build options (***staging investment***). In the *first stage*, the research phase, researchers spend a lot of time in laboratories in order to find a cure for a particular

disease. If studies gave positive results, a company can move to the next stage: clinical test stage. Companies operating in the United States must be approved by the U.S Food and Drug Administration (FDA). Companies operating in other countries in the world requires approval of domestic government regulator. Clinical test stage usually consists of three phases. At the end of each phase the company must to make the decision if they continue development of drug to the following phase or leave it, if results of a phase are unsuccessful. Only when all clinical tests are finished, and FDA gave their approval, then drug marketing stage can be started. At each stage, company has an ***option to defer (option to wait***) and see what happens as well as the ***option to abandon*** or the ***option to expand*** into the next stages.

Growth options: as noted earlier, fierce competition in the industry is pushing companies to invest in research and development. Such early investment is a prerequisite to new generation product (e.g., new drugs). In simple words, early investment in research and deploy opening up a future growth opportunity for the company. The possibility to defer cost and continue only if situations are permissible created value for the investment (Mun, 2006).

As shown in Figure 17, a company can choose which option to use in each stage, according to probability. By this way company will decide to move into next stage, to delay, or to stop investing.

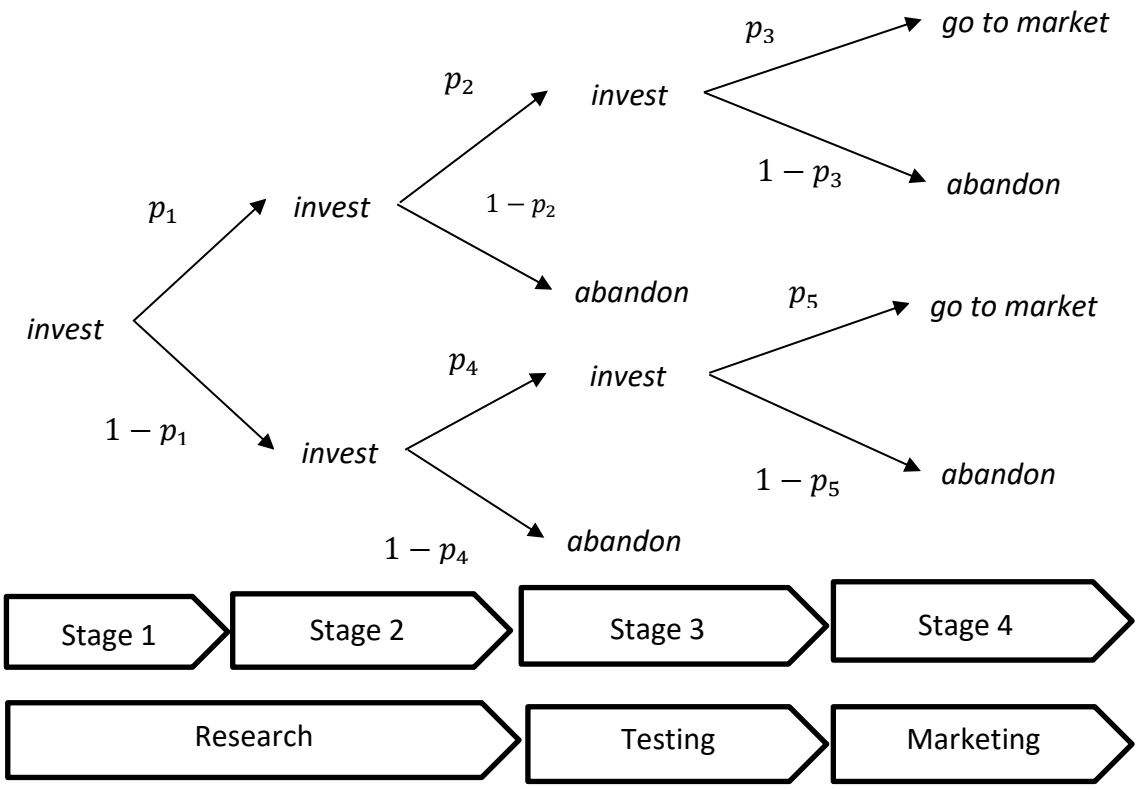


Figure 17. Compound real options in pharmaceutical industry

Source: Copeland and Antikarov (2003).

3.1.5. Telecommunication industry

Telecommunication industry is one of the most innovative, high-growth, capital-intensive sector of the economy (Harmantzis, Trigeorgis and Tanguturi, 2006). Investments in the telecommunications industry include high uncertainty, large costs and irreversibility. Real options methodologies are thus most suitable to study investment decisions in this industry (Harmantzis, Trigeorgis and Tanguturi, 2006).

The telecommunications sector is characterized by high-cost technological investments and increased volatility. For example, a project that requires a significant irreversible investment for developing networking equipment or a telecom service can be a very risky decision due to inherent uncertainty (Harmantzis, Trigeorgis and Tanguturi, 2006). The source of uncertainty is in the technology or product, because future demand on technology or product is unknown, while the large amount is already invested (e.g., irreversible costs). Therefore, technology selection can be seen as a compound option (Trigeorgis, 1996; Trigeorgis, 1993) Because of high irreversible costs, companies use ***compound real options***

(options on options) which consist of numbers of simple real options. Types of ***simple real options*** that are in use in telecommunication industry are listed and discussed below.

Learning options: in technological environment that changes frequently, companies should carefully learn the market needs. Based on the results in the learning phase, the companies would be able to choose if should going commercial (Harmantzis, Trigeorgis and Tanguturi, 2006). By using this type of an option, companies may be able to recognize if the technology or the product can find market demand and profitability.

Option to defer: as presented before, traditional Net Present Value (NPV) analysis is limited in handling uncertainty or changing course of action when new information arrives (see equations 8.1 and 8.2). Real options framework is more suitable for such valuations, because models are adjusted to real market conditions. In the case of irreversible investment and high uncertainty around the success of deployment of new technology, companies can choose a wait-and-see-strategy or defer the investment until new information is available (Amram & Kulatilaka, 1999; Pindyck, 1988). The option to defer allows delaying the investment decision for a certain period of time. Such action will prevent investment in non-profitable project and to save money for profitable one.

Growth option: in telecommunication industry creating growth option refers to invest in building of infrastructure (e.g., cable network for Internet or Base-Station for mobile-phones network). This creates needs to spend billions of dollars on infrastructure that will not be used for years to come. For example, in the past, companies like Sprint and AT&T installed more fiber-optic cable and other telecommunications infrastructure that any other company. Such process was done to create a growth option in future by providing a secure and extensive network, and to create a high barrier to entry providing a fist-to-market advantage (Mun, 2006).

Option on abandon: if market conditions are not suitable, company will choose to abandon the project. Companies should use this type of option when no other options are viable. Using this option will help the company to minimize losses and avoid wasting resources. For example, the company will choose using option on abandon if alternative technologies are more usable and attractive.

3.1.6. Other non-financial industries

Automobile and manufacturing industry

Application of real options can also be useful in automobile and manufacturing industry. The most common real option type of option in this industry is a ***switching option***. As it was discussed earlier, by using a switching option a company can switch from the current assignment to the cheapest future input, or from the current output to the most profitable future product. In other words, switching option allows companies to use the cheaper resource, when the price of other resources increases.

For example, General Motors (GM) uses real options to create switching options in producing a new series of vehicles (Mun, 2006). This option allows GM to hold excess raw materials and to deal with multiple global suppliers for similar materials with excess contractual obligations above what is necessary for projects. The excess contractual cost is outweighed by the significant savings of switching suppliers when certain raw material becomes very expensive in a particular region of the world. By spending the additional amount in contracting with suppliers as meeting their minimum purchase requirements, company essentially pays the premium on purchasing a switching option. This is important especially when the price of raw materials is significantly unstable in different regions around the world. By holding this option, a holder is protected against pricing risks (Mun, 2006).

Utilities industry

The utilities industry is a sector that provides utilities such as gas and power. The sector consists from companies such as electric, gas and water firms, and integrated providers. Utility providing requires significant infrastructure, these companies often carry large amounts of debt with a high debt load. Utility companies became sensitive to changes in the prices of gas, oil, other fuel and interest rate (Schwartz and Trigeorgis (2004)).

In the utilities industry, the real option that are in use is ***option to switch***. For example, an energy company can build a power plant that can generate electricity from two types of fuel: coal and gas. This allows flexibility in the transition from one type of fuel to other. If the price of one type of fuel becomes more expensive, company will change power generation from the cheaper type of fuel (Brach, 2003). Construction of such a power plant is more expensive than a power plant operating on one fuel type only. This difference can be seen as a premium

for the option.

Mergers and Acquisitions

In estimating a firm value for acquisition, not only the revenues and cash generated from the company operations must be considered but also the strategic option that come with the company (Smit and Moraitis, 2010). In fact, in mergers and acquisition, there are a several types of real options, as discussed below.

Option to expand: if a company is highly successful, it can be evolved into other industries or new products and services that can be developed through the exercising of an *option to expand*.

Option to abandon: if the acquired company does not exceed buyers expectations can be executed where it can be sold for its tangible assets and intellectual property (e.g., patents). a company acquires other company for increasing its existing portfolio of products or geographic location or to obtain new technology (option to expand), or to divide the acquisition into many smaller companies and sell them as in the case of a corporate raider.

Option to contract: if a company merges to form a larger organization due to certain synergies and immediately lays off many of its employees.

An example of the application of real options in mergers and acquisitions is described in a figure below. Problems may occur when a seller does not estimate its real options, it like to leave money on negotiation table or when the buyer does not estimate these strategic options, it is underestimating a potentially highly profitable acquisition target (Mun, 2006).

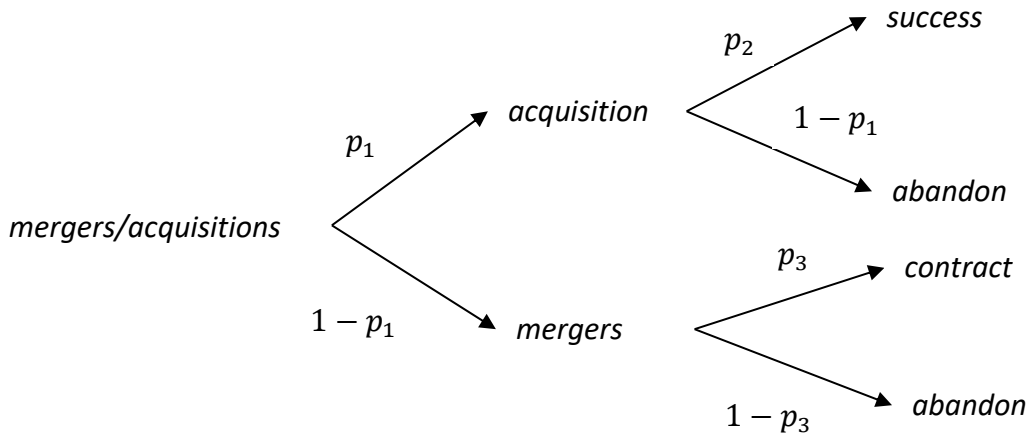


Figure 18. Real options in mergers and acquisitions

Source: Smit and Moraitis (2010).

3.2. Financial industries

Since 1977 and until today, financial sector, and especially banking sector, has not paid enough attention to real options. Because financial sector has unique characteristics, real options may not be adopted to all types of activities of banking. Their application to IT Banking is the most common at the moment but it seems not to be enough. Below the author describes the potential usage of real options in financial institutions, i.e., banks, insurance companies, brokerage houses and venture capital funds.

3.2.1. Banking industry

A bank is a financial institution, licensed by a central bank or a government, to receive deposits and make loans. Banks also provide financial services, such as wealth management, currency exchange, safe deposit boxes and stock exchange transactions. There are two types of banks: commercial/retail banks and investment banks. In most countries, banks are regulated and monitored by a national government or a central bank.

The real option in banking is a derivative tool which isn't traded in the public market but is directly connected by the cost with an asset which, on the contrary, is traded or can be traded in a public market. The ability to use the control mechanism for options gives possibility to manage risks and opportunities of a bank. Many processes in commercial banks can be determined also through a lens of real options. Below the author describes especially IT banking, loans and other examples of areas of banking where real options may be utilized.

IT banking

Investment or development of Information Technology (IT) can be seen as a call option, discovering to a bank new opportunities. Information Technology includes all hardware and software that a firm needs to use in order to achieve its business objectives. It can be explained in business context as set of interrelated components that collect or retrieve, store, and distribute information to support decision making and control in an organization (Laudon and Laudon, 2010). Information Technology (IT) has been defined by Ige (1995) as the modern handling of information by electronic means, which involves its access, storage, processing, transportation or transfer and delivery. Langdon and Langdon, (2006) also define IT as a set of interrelated components that collect or remove, process, store and distribute information

to support decision making, coordination and control. Technology banking is defined as the automated delivery of new and traditional banking products and services directly to customers through electronic, interactive communication channels (Sathye, 1999). Technology banking also includes all the systems that enable financial institution and customers to access accounts, transact business, obtain information on financial products and services by technological means. Laudon and Laudon (1991) argued that managers cannot ignore Information Systems because they play a critical role in contemporary company. Well-known examples of Information Technology in banking that are frequently used in daily life are: Automatic Teller Machines (ATMs), Internet Banking, Branch Network, Telephone Banking (TeleBank) and Mobile Banking Applications. Such technology allows viewing account balances and transaction histories, paying bills, transferring money between accounts, requesting credit card advances, requesting, or repaying loans, and ordering checks for more faster services that can be provide by domestic and foreign bank. Thanks to technology, a range of traditional banking services are available for customers twenty-four hours, seven days a week, and eliminated the need to get to the branch. Technology has lowered the cost of processing financial transactions, making it profitable for financial institutions to create new financial products and service for the public. It has made it easier for investors to acquire information, thereby making it easier for firms to issue securities and have resulted in many new financial products and services in Europe and other countries (Mishkin and Eakins, 2009).

The popularity of the application of real options in IT banking is caused by the technological development. Using a real option in this area is like using real options in research and development (R&D). For example, when a bank wants to upgrade ATMs it can replace all ATMs simultaneously. However, such a project may fall. Another way is using real options. Bank can divide the project into stages (**time-to-build option**). In a first stage a bank installs a new ATM's in a certain area for a certain period of time. By this way, it is possible to learn about the risks of the project. When this phase is successful, the upgrade can be extended to other areas gradually, until the end of the project. No doubt that this bank must be ready for changes in market conditions (**option to switch**). For example, if a payment by smart phones gains some attention and thus reduces the need for ATM's, a bank will have to adjust to its clients (create the custom software development, etc.). At every stage of the project a bank must keep his option to leave the project, in case if it fails (**option to abandon**).

Another version of the earlier option to expand of a great strategic importance are

corporate **growth options** that pave the route of future opportunities (Trigeorgis, 1993). Growth options are found in all infrastructure-based or strategic industries, such natural resource industry (Trigeorgis, 1999). Most growth opportunities share a common feature: uncertainty. In today's economy, strategic investment must be made without a pinpoint forecast of the future (Amram and Kulatilaka 2000).

Let's suppose that a bank is considering the possibility to develop a new digital application, based on a new superior technology, developed, and tested internally on a pilot users. From the one side, this application may appear unattractive, because nobody knows if new technology will be in demand on the market. But, from the other side, it could be only the first step in the series of applications and it's upgrades if the process is successfully developed and commercialized, and may lead to entirely new useful application. For example, many early investments (e.g., a strategic acquisition, market research and new products development or new technology), can be seen as early conditions or links in a chain of interrelated investments. The value of these investments derives not so much from their expected cash flows, but rather from unlocking future growth opportunities (e.g., a new generation of products, access to a new or expanding market, strengthening of the firm's core capabilities or strategic positioning). By calculating the profitability of this investment, a negative NPV may appear. But the experience, infrastructure, and potential products generated during the development of the first-generation product may serve as springboards for developing the next generations of the product in future, or even for generating new uses of the product into other areas. Without that initial investment, subsequent product generations or other uses cannot be feasible. The experience and infrastructure that is gained can be company's proprietary and can make the company more competitive (competitive advantage), which may help to reinforce itself. Growth options can provide to bank additional opportunities, such as new market. New opportunities will provide future growth of the bank.

Loans

Banks may also use real options for **loans**. For example, a company wants to take a large loan from the bank for a new project. The company may have a brilliant idea, but the bank has always a risk that a borrower will not return the loan. In order, not to endanger the loan, bank can wait for more information about that project, and only then decide whether to give the loan or not (**option-to-defer/learning option**). By this way bank can learn about the risks

of the project and that company. Also, bank can divide the loan to small parts, when receiving another part of the loan is to carry out the terms of the previous part of the project successfully (**staging option**). Moreover, a bank can sell the loan after giving it. In what conditions the bank would be prepared to sell the loan? This condition is written in the equation below:

$$P = NPV + Pr \tag{3.1}$$

Where: *P* is price of loan, *NPV* is a cash flow of the loan, and *Pr* is a premium.

The gain of the bank in this case is that it reduces risk and releases funds for other activities. In payment of *premium* bank could see a compensation for waiving future income from selling the loan. Also, premium can be explained by reducing the risk. For example, the bank will not sell a loan immediately after giving it to a borrower. At the start point there is a risk that a borrower will not return the loan. As time passes and a customer repays her loan, the risk that she will not return the full amount of a loan is being reduced. In addition, the loss in case a borrower fails to repay the loan goes down too. What do the buyers of a loan (investors) earn? The loan buyers (investors) will get the loan returns that were paid to the bank. Additional royalties also can apply. The idea behind the *premium* is similar to a financial option, to allow the loan buyer, within a predetermined period of time, to decide to buy a loan or not.

Other examples

Other examples of possible applications of real options in banking are described below.

Option on abandonment is usually popular in financial sectors. Even small decrease in requirement can lead to liquidation of the investment idea. For example, minor change of a credit risk or interest rates can lead to the fact that the bank will want to sell a part of the credit portfolio. By using this type of option, bank can get rid of bad and not profitable projects or products and thus release and redirect resources to good, profitable projects or products. This move will have a positive impact on the sustainable growth of the bank.

Option to switch is the option on change of a product line. The option on switching can belong or to switching of the entering or outgoing business processes. If market demand for product increased, the bank will perform additional investments to expand the opportunities (Copeland and Antikarov, 2003**)**.

A growing and dynamic banking sector is essential for economic growth of each country in

the world. It can provide an easy access to credit, which would encourage a greater level of private sector investment and consumption, which in turn, would boost economic activity and lead to a greater level of employment creation. Without a strong, progressive, and dynamic banking sector, availability and accessibility to credit would not be possible due to which consumers and companies would not be able to finance their needs. This would lead to an undesirable effect, resulting in outlays levels decreasing, a reduction in economic, and an increase in unemployment levels (Trigeorgis (1993), Trigeorgis, 1999). For example, along with a mortgage or a loan for a new car, bank can offer suitable insurance policy. Such process will strengthen as competitive advantage of a product, and minimize risks which bank takes, in case of crediting. For provision of cross-products it isn't necessary to perform additional expenses at all. On the other hand, there is a number of the problems connected to a back office and servicing of this sort of transactions that increase an account part. Additionally, the option on switching can be realized in case of closing of crediting limits on this or that product or the client.

Another example, a condition of the return redemption of agreement obligations which for bank is non-core in its activities, can be seen as the sold put the option and one purchased **call option for liabilities**. The possibility of a credit bonus for the client can also be the option. For example, purchase of a car on a credit card can be considered as the option issued by bank to the client. In fact, it may be seen as put option with a strike price - the car price. If the debt exceeds the franchise on a car, the bank closes the option.

The current assets can be also considered as an option. The liability from the client to pay one million dollars within seven days in case of risk of a default of equal zero percent doesn't contain the option. The same liability, but with risk of a default, even in the presence of providing already has an option component. If net assets value is lower than an amount of liabilities, in this case it is possible to provide a loan. This can be seen as a long-term put with strike price in the amount of net debt.

The deposit or share on securities depending on security quotations can be also seen as the **option with delay of execution** which cost changes depending on volatility of the market and the demand for a product.

In strategic decisions and product line have similarity to real options or contain similar lines. As discussed before, real options are not traded, these created with investment. Real options which owns and are used by bank, create essential value for shareholders. On the

other hand, real options, in which the bank is a subscriber, is a source of risks and instability, by analogy with the financial option.

Built-in options can be found in **banking products**. Retail banks usually more use the liabilities for funding of credit products of physical persons. However, for large banks it makes a sense to use external borrowings for crediting of physical persons. In this case bank assets and liabilities can have lines, similar to real options. If the bank sells or pledges shares, here it is already possible to estimate the option since it is derivative the financial instrument. For example, if the bank buys the bond which is subject to the return redemption, then on it is possible to look how on a debt and the built-in call option with an interest return rate which belongs to bank and on the contrary the sold bond is the call option sold by the company.

Private and small investors, possessing smaller tools on trade in financial options and futures, usually, give the right to banks. It is just visible on the example of those products when the bank offers a deposit product with a binding of an interest rate to the price of this or that share.

At the expense of it the bank removes from itself risks of an overpayment of percent if the stock market will begin to decrease. It can be seen that the bank has the call option in the stock market. In case of market growth, the bank pays expenses due to the choice of similar strategy. Similar strategy is very effective since the bank has always enough space for maneuver at the rate and risk of an overpayment of real percent, in case of change of an environment in the market is absent. On the other hand, the client also has the right to obtaining additional profit if the market grows.

The similar situation arises also with **credit products**. In that case if the interest rates goes down, the borrower always has an opportunity to refinance the credit that will allow to save on percent. In general, it means that the holder of a mortgage always has the call and a put option. The call option allows to obtain the new credit or to refinance it. The put option allows to repay the credit at the expense of refinanced. In this case, it is necessary to expect strikes of options, i.e., prepayment penalties.

Another interesting and simple, daily life example of the usage of real options is a car **leasing**. At the end of the specified car lease period, the lessee has the three options: the first is to leaseback, the second is to walk away, and the third is to buy the car for a fixed price predefined at the beginning of the lease contract, as shown in figure 19. In this case the right (not obligation) to buy the car is the real options – **option to defer** (**option to wait**), and the

amount that paid at the lease period is the **premium**. The option not to buy the car may be seen as **option to abandon**. This is a ***rainbow real options***, because there are more than two potential results (see Figure 19).

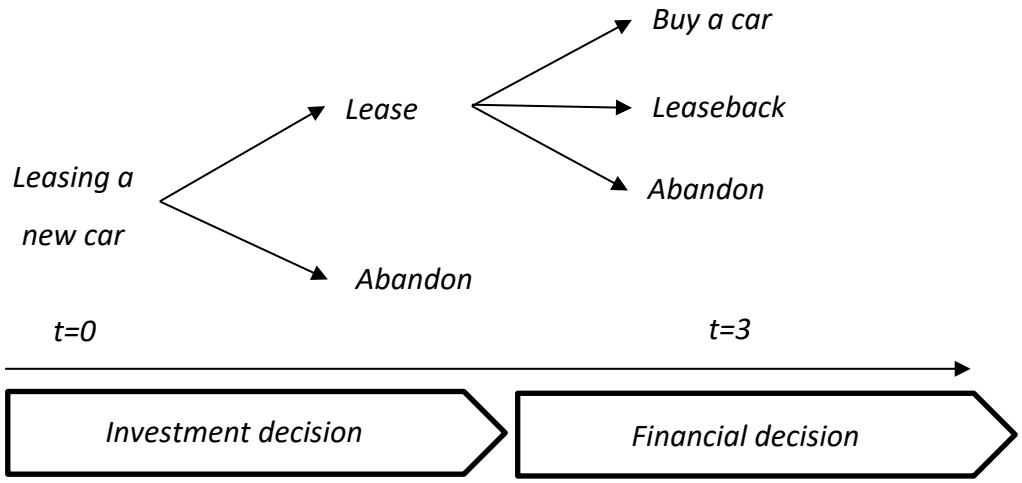


Figure 19. Real options in car leasing

Source: Autors example.

3.2.2. Insurance industry

Insurance is a contract, represented by an insurance policy, in which an individual or a company receives financial protection or against losses from an insurance company. Insurance policy is used to hedge against the risk of financial losses, both big and small, that may result from damage to the insured or her property, or from responsibility for damage or injury caused to a third party. An insurance company pools clients risks to make payments more affordable for the insured (Adams, 2004). An insurance company provides coverage, (i.e. compensation), resulting from loss, damages, injury, treatment or distress in exchange for premium payments. The company determines the payment for the loss to determine the premium amount by calculating the risk of occurrence (Coppola, D'Amato, Levantesi, 2018).

Real options can be compared to insurance policies (Horn, Kjærland, Molnár and Steen, 2015). Incorporating options into capital investments produces payoffs or cash flows with returns that are over and above returns from insurance policies. While insurance policy holders pay premium that restore their assets to their original forms in the event of loss or theft or any other unfavorable circumstances, option holders not only pay premium to preserve the value of the assets, but the option prices also give the right to payoffs far above their asset prices in favorable circumstances.

Three types of real options can be applied by insurance companies (Sinha and Macmillan, 2004):

- ***learning options**:* by using this type of option, company may learn about market needs and then to offer custom insurance policies;
- ***option to delay**:* unlike regular contracts, insurance contract made in the opposite manner. While in regular contract company offers its services to the customer and the customer can accept or refuse the offer, in insurance policies a customer (individual or company) offers to buy a company service (i.e. insurance policy), and an insurance company is the one that may decide whether to insure the client or refuse. Hence, the company has an incentive to postpone the decision until new information will appear. That may influence the decision significantly: demand for of a higher premium payment, or refusal to insure;
- ***option on abandon**:* insurance contracts are made for a limited time. If there are types of insurance that are not in line with the market demands, regulator demands or non-profitable, a company cannot renew it (abandonment).
- ***option to expand:*** an insurance company can increase its activity or market share by entering new markets, such as opening operations in other countries. When an insurance company opens its operations in another country, it can take advantage of the knowledge it acquired in the country of origin for the purpose of managing similar risks and risks in another country. Another way to increase activity is a merger with another insurance company or by purchasing another insurance company. This way the company gets access to new markets and customers without the need to re-establish its activity, which reduces the company's costs.

3.2.3. Investment fund industry

There are various types of investment funds described and studied in the literature and practice. Here the author concentrates on two of them: the traditional mutual funds and the alternative venture capital funds. In both cases real options can be recognized and possible to be utilized.

A **mutual fund** is an investment tool made up of a pool of funds collected from many investors for the purpose of investing in securities such as bonds, stocks, money market instruments and similar assets. Mutual funds are operated by money managers, who invest

the fund's capital and attempt to produce capital gains and income for the fund's investors. A mutual fund's portfolio is structured and maintained to achieve the investment objectives specified in its prospectus. As mentioned before, real option is the right, but not the obligation, to make a capital investment decision (Myers 2004). The real option that is usable in mutual funds, like in some other investment tools is ***option to delay***. This type of option allows to investor to use wait-and-see strategy. Such strategy decreases uncertainty and helps to investors in decision making process. When market conditions become the worst, investors may decide to stop the investment (***option on abandon***).

Venture capital funds are investment funds that manage the money of investors who seek private equity stakes in startup and small or medium-sized enterprises with strong potential growth. These investments are characterized in general as high-risk and high-return opportunities. The real options approach of venture capital investments depends on the special competence of venture capital investors. Real options can be viewed as a decision-making method and valuation technique, a logic for strategic planning (Driouchi and Bennett, 2012). The reason why real options can be applied in venture capital investments is that the investors provide managerial assistance. As they provide equity type financing, the investors become owners of the invested companies, thus they can influence the operation of the invested companies (Nagy, 2002; Becsky-Nagy, 2014).

Venture capitalists use special methods and instruments that allow them to create and take advantage of the options of investments (Becsky-Nagy and Fazekas, 2014). The practice of multi-staged financing (***time-to-build option***) is generally used by venture capitalists, so staging option (***time-to-build option)*** occurs in these investments. Staging plays a very important role in the risk management of venture capital. The first financing round can be viewed as a pilot period, where the investors can collect more information about the invested companies without committing the full amount of capital that is needed to the investment ***(learning options)***. Staging can reduce losses in case of unprofitable companies while keeping alive the potentially successful ones. Monitoring and participation in the company's operation is also very important in the real options approach. The information provided by the operation is crucial in the management of the companies (Fenyves et al., 2014), because the uncertainty directly connected to the invested companies and is endogenous to the enterprises and generated by the investment process itself (Rózsa, 2007). Monitoring is necessary in order to be able to collect this information and react to the opportunity of the

companies (e.g., *option to defer, option to expand/option to contract*.).

Option to defer allows to postpone decisions on an occasion of the main investments until some moment in the future, thus reducing risk of the project. At a delay the company must to possess rather unique assets to be sure that other companies cannot occupy its niche, having made investments into earlier terms.

Option to expand/option to contract is the possibility to change the scale of the project. The ***option to expand*** is that at a favorable situation (growth of clients, demand for production and so forth) additional resources can be invested in the project. At deterioration in a situation the project can be reduced (***option to contract***) until reduction of limit expenses positively influences on has arrived.

Option on abandon allows the company to refuse implementation of the project at sharp deterioration in market condition. The company can then sell under the counter assets, having paid a part of the damages, or to use them in other investments.

Learning options: As stated before, the knowledge acquired during the investment is of great importance. Thus, investors can harness this knowledge in their future investments and they can increase their efficiency. That is the reason why ***learning options*** also have importance: the knowledge collected by the investment process has value (Yeo and Qiu, 2003).

3.3. Literature review on real options usage in different industries

Real options theory, first introduced by Myers (1977), has been applied with success in solving problems faced in different industries.

There is a large number of research in natural resources industries. Brennan and Sehwaaz (1985) studied the problem regarding to estimation of the value of a copper mining project when a cash-flow characteristic by high risk. In their research, they put together short-term assets of futures contracts, and long-term assets of mineral resources in compound financial portfolio. As result, they achieve a partial differential equation of copper values. Trigeorgis (1990) analyzed the evaluation of natural resource project, where NPV of the project is negative. Project managers applied real options using binary option pricing methodology: delay options, abandonment options and options of conversion scale during the whole

lifetime of the project. As result, the NPV of the project was positive.

In the Real Estate research field, Titman (1985) used options by adjustment of the option pricing methods, which was first presented by Fisher Black, Myron Scholes and Robert Merton, for estimation of the value of the undeveloped land when uncertainty of the future price of building units exists. Titman (1985) suggests seeing the unoccupied land as a Call Option, the building costs as the strike price, and defines the unoccupied land's price through a combination of building cost and government bonds. Quigg (1993) empirically analyzed the price of undeveloped land in Seattle using real estate transaction data between 1976 and 1979. Quigg (1993) discovered that the price 6% higher than the average price of developed land. According to Quigg (1993) to hold the undeveloped land is similar to holding American Call option. In addition, she developed the option-based model for land evaluation. Capozza and Sick (1994), similar to Quigg (1993) proposed that agricultural land changed to urban land can be seen as an American call option. Capozza and Sick (1994) in their research presented positive correlation between the price of the land waiting for changing and the rent price of urban land. The higher rent prices of urban land - higher value of option for development agricultural land.

In the field of Corporate Strategy, Keser (1984) concluded that in decision making in investment projects with long-term strategic value, negative NPV does not mean that investment cannot be worthwhile in future. According to Keser (1984), in such projects, the real options approach must be applied. Additionally, In the case that competitors have the same options, the company must use options as soon as possible. Thus, company my prevent losses. Kulatilaka and Marks (1988) constructed two companies to make comparative research of strategic value of flexibility options under assumption that one company can use only a one strategy, while another company can use several different strategies. By this way the second company getting strategic value due to flexibility of option.

Morris, Teisberg and Kolbe (1991) studied Research and Development (R&D) projects, which characterized by high risk and uncertainty. They conclude that in projects with active managements the risks regarding investment in such project reduced gradually. According to Morris, Teisberg and Kolbe (1991), the flexibility of management allows to choose more risky projects. According to Nichols (1994), in the pharmaceutical R&D projects such as science and technology companies (i.e., Merck Company), the value of investment frequently underestimated. The volatility cannot be evaluated properly by DCF method.

Chung and Charoenwong (1991) studied company valuation using real option approach. They conclude that the company that do not recognize the option of future investment as the value of growth opportunities miss out good investment opportunities. They argue that companies value must include not only all existing assets, but the value of future growth opportunity too. Schwart and Moon (2000) used real option in capital budgeting to evaluate the value of internet companies. They constructed and proposed a real options model that based on the continuous time, estimate model parameters, perform sensitivity analysis. This model applicable not only for Internet companies, these for valuation of technology companies too. Kellogg and Charles (2000) use the decision-tree method and binomial-lattice method for evaluation of the high-tech company's share price. They discovered that although the products is in early stages of development, high-tech biotechnology companies have a high stock price, while still do not receive any revenue from the product. Kellogg and Charles (2000) conclude that by using real options methods, the early value of the high-tech company can be estimated more accurately.

Mendez-Suarez and Crespo-Tajero (2021) underline that specifically real options are used to solve marketing problems. Jones and Yeoman (2009) applied the real options rationale to optimally price tickets for events. Gong, Van der Stede and Young (2011) modeled the growth and abandonment options of the U.S. motion picture industry; when films meet or exceed the desired revenue target, studios invest more marketing dollars to promote the film, but if the film's revenues fall below expectations, executives may abandon the film by cutting marketing efforts.

Moon and Kwon (2011) proposed a real options model for pricing internet advertising. Suzuki, Goto and Ohno (2015) modeled consumers' decisions to purchase or postpone purchasing underprice uncertainty, stating that customers make their decision by considering the option value of postponing a purchase.

Trigeorgis and Baldi (2016) used real options to value brand equity and proposed a model for leveraging brand value via a portfolio of growth options. Specifically, in customer lifetime value (CLV) valuation, Haenlein et al. (2006) laid the foundation to apply real options theory in a CLV context, valuing the option to abandon unprofitable customers. Koosha and Albadvi (2015) analyzed the different contexts in which real options may be applied to CLV applications.

As far as financial sector is concerned Levett et al. (1999) analyzed the real options that

buyers and sellers have in business relations, stating that the simple NPV model could be an over-simplification. Adams (2004) applied real options theory to insurance companies, valuing the option to wait until signing a contract and concluding that this value should be added to customer NPV (i.e., CLV) to account for total customer value.

Chapter 4.

General characteristics of Israeli banking system

Banking system in Israel is the research setting of this PhD thesis. This chapter presents its characteristics, especially its structure and the most important players in the system. As a part of an introduction to the banking system in Israel, this chapter surveys the history of Israeli banks selected for research, since their foundation until today. Among all history of Israel banking sector, four periods can be identified, each with distinct influence on banks and banking industry: British mandate (1920–1948), state building (1948–1977), market model (1977–1994), and globalization (1994–present). In each of the periods, Israeli banks had to adapt to the new reality, which included, among other issues, new regulation and market conditions.

In order to provide a broader picture of Israeli banking industry, this chapter describes a number of shocks in the economic and legal environment of Israel and the effect of these changes on the banking institutions. In addition, it presents various data from financial statements of Israeli banks, when some of the data are presented in comparison with European and American banks. To be in line with the topic of this PhD thesis, this comparison is focused on loan granting and credit risk. However, what must be indicated, the data compared comes from different time horizons, sometimes reaching 2018, sometimes newer data of 2022. The data presentation and comments depended on its public availability.

4.1. Structure of Israeli banking system

The Israeli banking system, like those in other countries, has been undergoing a revolution in recent years, which is rapidly and dynamically changing banking activity and the competitive environment (Israel's Banking System, Annual Survey, 2022). As end of 2022, in Israel there were 10 banks, 4 licensed foreign banks, and 4 credit card companies. All of them are under a supervision of the Bank of Israel's Division for Banking Supervision.

The banking system in Israel is characterized by a high degree of concentration. This concentration consisted of 6 domestic banking groups: Bank Hapoalim, Bank Leumi, Israel Discount Bank, Bank Mizrahi-Tefahot, First International Bank of Israel (FIBI) and Bank of

Jerusalem, that hold 100% of the assets of the all-banking system in Israel, shown in Figure 20. The foreign banks operating in Israel are presented by: Citibank N.A, HSBC Bank plc, Barclays Bank plc., BNP Paribas Israel SA and State Bank of India.

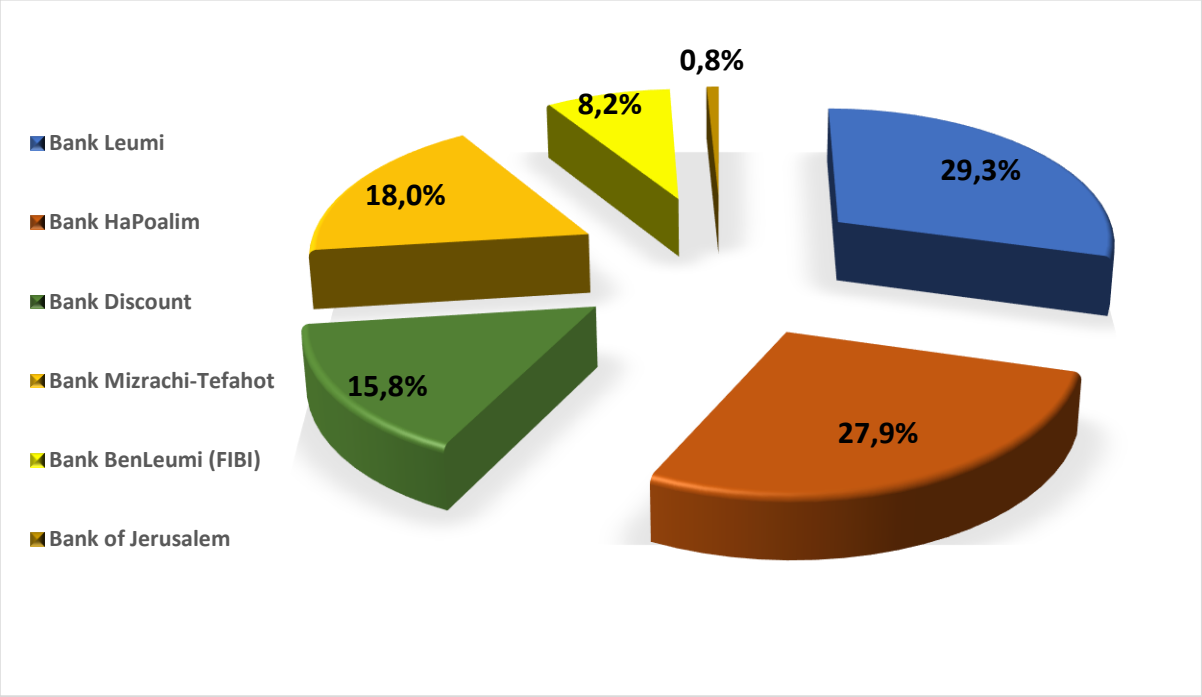


Figure 20. Distribution of assets of the banking system, 6 banks, 2018-2022 1st Q (in percent)

Source: Israel's Banking System, Survey, June 2022, https://www.boi.org.il/media/shmdron3/20000.pdf.

Table 4.1 – Israeli banks total assets, 2022

Bank	**Total Assets** (in million NIS)
Bank Hapoalim	666 665 000
Bank Leumi	682 477 000
Bank Mizrahi Tefahot	434 110 000
Bank Discount	387 472 000
Bank Ha-Benleumi (First International Bank in Israel)	204 312 000
Bank of Jerusalem	20 151 500

Source: data from banks financial statement, first quarter of 2023.

This structure is the result of many factors and measures policy influenced for decades on the number of players and its size, including:

- a small size of Israel market did not allow many banking institutions to reach the volume

of activity necessary to ensure the completion of economies of scale and heterogeneous, operational efficiency, and appropriate diversification of risks. This constraint has led to the early decades since establishment of Israel having a large number of bankruptcies after which many credit unions and small banks merged with large and medium banks. This created a multi-branch system, and medium and large banks expanded their business activity to the communities of the periphery, places that previously received services from Cooperative Societies.

- government policies pushed to increase the concentration - the lessons from the past that led to construction of the Israeli government and the Bank of Israel (a central bank), and the fact that during most of the 60s' and 70s' of XX century, they had a policy to encourage the concentration in the banking sector and to increase the number of branches of large banks, and therefore were rarely granting licenses to new banking institutions.
- considerable government involvement in financial and capital markets affected the efficient allocation of capital in the financial markets.
- boycott of the Arab world of the state of Israel in the world deterred foreign banks from entry to Israel.

The concentration of the banking system in Israel has been diminishing but it still has a high degree of concentration. The market share of the two large banks (bank HaPoalim and bank Leumi) is about 55%, along with the increase of the market share of the middle-size banks like bank Mizrahi-Tefahot and Israel Discount Bank.

Since 2013 until 2018, the Herpindel-Hirschman Index (HHI) in Israel has declined, but, since 2018, the index began to rise, and this is because Dexia Bank merged into Discount Bank and Union Bank merged with Mizrahi Tefahot Bank. (see Figure 21).

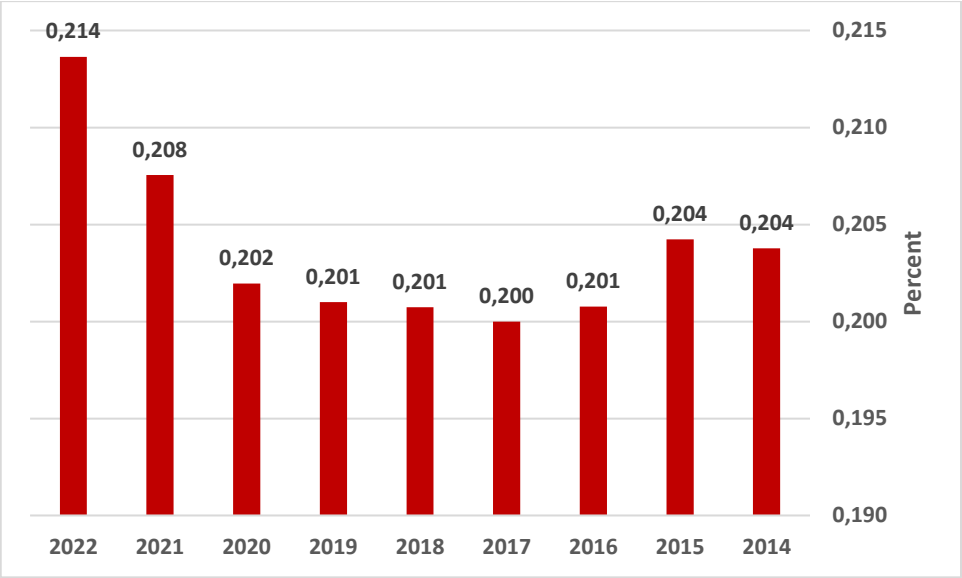


Figure 21. The Harpindel-Hirschman Index (HHI) in Israel, 2014-2022 1st Q (in percent)

Source: Israel's Banking System, Survey, June 2022, https://www.boi.org.il/media/shmdron3/20000.pdf.

4.2. Characteristics of banks in Israel

4.2.1. Central bank

The **Bank of Israel** is the central bank of the State of Israel with its head office in Jerusalem and a branch in Tel Aviv. The Bank of Israel was founded on August 24, 1954, after the Knesset passed the Bank of Israel Law. The law transferred the currency issuing and regulatory functions from the Ministry of Finance to the newly formed bank. Control over foreign currency exchange was given to the bank only in 1978. The bank became completely independent in 1985. Since 1992, the bank manages its monetary policy to meet the inflation target set by the Israeli government[5].

The functions of the Bank of Israel are[6][7]:

- to maintain price stability as the primary objective, by setting interest rates and taking measures to supplement the framework of monetary policy;
- supporting other government objectives, such as: economic policy, especially growth, employment and reducing social inequality, and this under assumption that the Monetary Committee believes that this will not hurt the achievement of price stability

[5] Today, the target is the range between 1 and 3 percent per year, considered as price stability.
[6] According to the Bank Israel Law, 2010.
[7] Functions of Bank Israel from Bank Israel internet site.

over time;

- regulation of operations of financial system and ensure its stability;
- to manage monetary policy;
- holding, management, regulation and supervision of banks and the national foreign exchange reserves;
- regulation and supervising of activity of the foreign exchange market in Israel.
- act as a banker of the government;
- regulation of the payment and settlement systems in the economy to ensuring their efficiency and stability;
- regulating the cash system.

Additionally, the Bank of Israel has the exclusive right to issue a currency (e.g. Israeli Shekel banknotes and coins).

The Bank of Israel has the exclusive right to grant licenses to operate as a banking company. Furthermore, any entity, private or business, that wishes to acquire more than five percent of the shares of one of the existing banks in Israel must obtain approval from the Bank of Israel.

The Bank of Israel includes Banking Supervision Unit, which is the regulatory authority of the banking system. The functions of the Unit are:

- supervision of banking institution stability relentless protection of depositors' money;
- maintaining the proper management of the banks;
- encouraging competition and efficiency in the banking system;
- maintaining fairness in the business relations between banks and their customers;
- ensuring the continuity of banking services for public.

4.2.2. Commercial banks

Bank Hapoalim

Bank Hapoalim was founded in 1921 by the central institutions of the settlement at that time - the Zionist Organization and the Histadrut[8]. The idea behind the foundation of Bank

[8] The Histadrut or the General Federation of Laborers in the Land of Israel - Israel's National trade union center, representing the majority of trade unionists in the State of Israel.

Hapoalim is that it should be a bank that is managed by workers, serve the interests of workers and help workers when needed. In 1928, the bank prevented the collapse of Solel Boneh company, when it granted a loan of 5000 Israeli lira.

Since 1968, bank Hapoalim started accelerated development. Most of the important Histadrut factories began to work with bank Hapoalim and as result, more than 90 percent of the workers' enterprises transactions being done through Bank Hapoalim. Thus, within 10 years the bank reached the status of the largest bank in the country, passing the bank Leumi that held this place earlier. During this period, bank Hapoalim acquired the control of many small banks, for example Zrubavel bank, Israeli American bank, bank Masad, etc.

In 1971 bank Hapoalim started international activities by opening a branch in London and a representative office in Zurich. In 1974 a branch was opened in New York. Additionally, the Continental bank was founded in Israel, as a partnership between bank Hapoalim and the Bank of Trade Unions in Germany. This trend continued with the opening of more branches around the world. In 1971, the bank jumped to second place (by balance sheet size) in Israeli banking sector, pushing bank Discount to third place.

The Histadrut was the owner of bank Hapoalim until 1983, when the bank was nationalized following the banks stock crisis, along with other banks. The bank was held by the Israeli government until 1995, when the State of Israel published a tender to purchase the bank. The tender was approached by two groups: a first group of investors included George Soros, Ted Arison and Goldman Sachs Bank. A second group of investors was led by Israeli businessman Eliezer Fishman. In September 1997, the controlling interest was finally sold to a group of investors headed by Ted Arison.

Today, bank Hapoalim is Israel’s largest commercial bank (by total assets) (Annual financial statement, Bank Hapoalim, 2018). In Israel it has 225 bank branches, 7 regional business centers, 22 business branches and industry desks for major corporate customers and over 600 ATMs (automated teller machines). The bank's stock is traded on the Tel Aviv Stock Exchange. In addition, the bank has a significant presence in global financial markets via subsidiaries in Turkey, USA (New York City, Los Angeles, Beverly Hills and Aventura), Zurich and Luxembourg.

Bank Leumi

Bank Leumi was founded on February 27, 1902, in Jaffa as the Anglo Palestine Company.

It was founded as a subsidiary of the Jewish Colonial Trust (Jüdische Kolonialbank) Limited, formed before in London by members of the Zionist movement[9] to promote the industry, construction, agriculture, and infrastructure of the land.

The bank opened its first branch in Jaffa in 1903. Its activities included land purchase, imports and obtaining concessions. Later, branches were opened in Jerusalem, Beirut, Hebron, Safed (Tzefat), Haifa, Tiberias and Gaza.

The Anglo-Palestine Bank offered a long-term loan to farmers. Also, the bank provided loans to the "Ahuzat Bayit" association which built the first neighborhood in Tel Aviv. During World War I, the Ottoman government declared the bank to be an enemy institution, because it was registered in England, and began to wind down it activity and to confiscate its assets.

After the World War I, the bank expanded its activity. In 1932, the main branch moved from Jaffa to Jerusalem. During the World War II, the Anglo-Palestine Bank helped to finance the establishment of industries that manufactured and supplied different products for the British Army.

In 1948, after the establishment of the State of Israel, the bank won the concession to issue new banknotes. In 1950, the bank was renamed Bank Leumi Le-Israel (National Bank of Israel). Bank Leumi played a role of a central bank until 1954, when Bank of Israel - the central bank, was founded. After establishment of the Bank of Israel, Bank Leumi became a commercial bank. During the years of operation, Bank Leumi acquired a number of small banks, enabling it to grow and expand its operations in Israel.

In 1983, as other banks, Bank Leumi was nationalized by the Government of Israel, as a result of the bank stock crisis. From 2006, under the privatization policy introduced by the Ministry of Finance, the government gradually sold most of its shares.

Bank Leumi has been operating in the United Kingdom since 1902. Today Bank Leumi UK is a subsidiary of Bank Leumi, and it offers to customers a comprehensive range of commercial, general and private banking services.

In the United States Bank Leumi has been operating for more than 50 years. Bank Leumi began its activity in New York in 1951 through local representation “Bank Leumi Trust

[9] Zionism movement - political and ideological movement emerged in the 19th century to espouse support for the establishment of a homeland for the Jewish people in Palestine, a region roughly corresponding to the Land of Israel in Jewish tradition. Following the establishment of Israel, Zionism became an ideology that supports "the development and protection of the State of Israel".

Company of New York". Today the bank operates in USA through it subsidiary - Bank Leumi USA (BLUSA).

In August 2006, Bank Leumi acquired Romanian Eurom Bank for about USD 60 million. After the acquisition, Eurom Bank continued its activity as Bank Leumi Romania - a subsidiary of Bank Leumi. Bank Leumi Romania is engaged in banking activities including receiving deposits, credit, international trade and foreign exchange operations. At the starting point, Bank Leumi Romania operated with 37 branches, but during period 2010-2015 the bank closed 22 branches and remained only with 15. Ten years later Bank Leumi has signed a sale Bank Leumi Romania to British investment fund "Argo Capital Management", but the sale did not receive the approval from the Romanian regulator authority.

Leumi Switzerland was founded in 1953. The bank is engaged in private banking and included thousands of affluent clients. In 2011, Bank Leumi acquired Geneva-based Banque Safdie SA for CHF 143m. In 2012, Banque Safdie was merged with Bank Leumi Switzerland Ltd to Leumi Private Bank Ltd. On 13th March 2015 Leumi Private Bank Ltd. wind-down its business activities and transferred the majority of its private banking customers to Bank Julius Baer Bank.

Leumi Luxembourg was founded in 1991 and has been mainly engaged in private banking and assets management. On 23 November 2015, Bank Leumi (Luxembourg) S.A., a subsidiary in Luxembourg was sold to Banque J. Safra Sarasin (Luxembourg) S.A. for a sum of 3.5 million dollars.

Today, Bank Leumi is the oldest bank in Israel and second largest bank (by total assets, Annual financial statement, Bank Leumi, 2018) with 208 offices in Israel. Bank Leumi has overseas banking subsidiaries in USA (New York, Los Angeles, Palo Alto, Chicago), United Kingdom (London), Romania (14 branches in 12 cities) and China (Shanghai)[10]. More than 90% of the bank's stocks are held by the public and traded on the Tel Aviv Stock Exchange.

Bank Mizrachi - Tefahot

Bank Mizrahi Tefahot is the third largest bank in Israel by value of assets. The bank operates in and outside Israel. The bank's activities are: commercial, business and retail banking, and mortgage operations in Israel. Today Bank Mizrahi Tefahot has 180 branches and business

[10] Leumi China is a representative office.

centers[11] in Israel. The Bank's activities abroad are conducted through a number of subsidiaries, three branches and four offices in Europe, the United States and South America.

Bank Mizrahi Tefahot was created in 1980 as a merger of two banks – the Mizrahi bank and the Tefahot bank**. Bank Mizrahi** was founded in 1923 by "Tnuat HaMizrahi[12]", a religious Zionist Organization[13]. The main activity of the Mizrahi bank was to provide financial aid and financial instruments for the enterprise of individuals and institutions belonging to the Mizrahi Organization[14]. In addition, the bank was assigned the task of serving as a public national bank for all localities. In April 1925 the bank started to provide services to the public. In 1927, bank Mizrahi opened its branch in Tel Aviv. The banks head office was in Jerusalem. At the same time of the Mizrahi bank establishment, the "Hapoel Mizrachi bank" was established. In 1928 "Hapoel Mizrachi bank" was renamed to the "Hapoel Hamizrachi escort fund". In 1935 was established the Mizrachi Land Development Company Ltd and the bank opened new branch in Haifa.

In 1963, bank Mizrahi had 14 branches. In 1969, the heads of management of Mizrahi Bank and Hapoel-Mizrahi Bank decided to merge and establish the united Mizrahi Bank. The united Bank had 42 branches across the Israel and assets worth over 400 million Israeli pounds. In 1980, bank Tefahot was acquired from the government by Mizrahi bank and began to operate as the bank's subsidiary.

In 1983, following the banks stock crisis, the bank was nationalized by the State of Israel. In addition, as a result of the banks stock crisis, bank Mizrahi was one step ahead of its collapse. Only 100 million dollars of credit, granted by the State of Israel, saved it from default. In 1995, bank Mizrahi was partially privatized by Ofer-Vertheim Investment group.

Tefahot was established in 1944 by the Jewish Agency of Israel as a secondary mortgage lending company, where funds were invested by the Keren Hayesod. Bank Tefahot borrowed money for housing projects as another lender. In 1949 the Amidar, a state-owned housing company, was founded and became as Tefahot subsidiary. Tefahot activities in 1950 were

[11] Annual financial statement, Bank Mizrahi Tefahot, 2018.

[12] The Mizrachi movement is a non-government religious Zionist political movement, founded in 1902. The main occupation is the religious education of Jews all over the world.

[13] The Zionist Organization is a non-governmental organization that promotes Zionism. It was founded in 1897 August 1897 in Basel, Switzerland and in 1960 renamed to The World Zionist Organization.

[14] Mizrahi Organisation is a religious-Zionist organization and movement foundedin Vilnius in 1902 at an international conference of religious Zionists. According to their ideology, the principles of the Torah should be at the center of the Zionist movement.

limited because the government increased the mortgage rates for the first mortgage, which in most cases would satisfy the need for a second mortgage. In early 1954 Tefahot started to finance different projects to create new work vacancies. The company provided loans to local authorities for various development projects, such as connecting localities to the electricity grid, roads developing and schools establishing. Additionally, the company provided loans for the purpose of building another room in private homes. At the end of 1961, Tefahot became a mortgage bank. In 1965, the bank opened a branch in Jerusalem.

In 1975 the bank Tefahot became a public company, where a major part of it owned by the Israeli government. In 1978, the government held 52% of the shares, Israel's investors held 16% and the "Clal" company held 20%. 22% of the shares were traded on the Tel Aviv Stock Exchange.

In 1978, the government initiated the sale of its shares in the bank Tefahot to private investors. In February 1980, bank Mizrahi made the highest bid and won the tender. The acquisition completed in March 1980.

In 2005, the united Mizrahi Bank and Bank Tefahot merged. Today the bank is known as "Mizrahi Tefahot Bank" or "Mizrahi Tefahot".

Israel Discount Bank

Israel Discount Bank is a public company, which shares are traded on the Tel Aviv Stock Exchange. All shares of the bank are held by the public. The bank offers to its customers comprehensive banking services in all areas of financial activity, through a nationally branched network and through direct and online banking. The Bank has operations abroad through its affiliates and is focused on business-commercial and private banking.

The bank was established on April 5, 1935, as "Eretz Yisrael Discount Bank" also known as "Palestine Discount Bank" by Leon Recanati and his partners Joseph Albo and Moshe Karso. The bank's equity has grown from about GBP 60,000 at the time of its establishment to GBP 170,000 in its second year of itself activity. Discount Bank activity was founded with a focus on foreign trade and with a deliberate Sephardic orientation so as to fill what Recanati perceived as a Sephardic void in the banking industry. The unique of the bank was in that it was open to private customers, whereas most other banks in Palestine at the time had provided services only to merchants and institutions.

The Discount Bank became widely known to the public when borrowers, who were

residents of the country, were given favorable conditions, while the mandate government enforced strict laws to withdraw bank deposits to prevent economic collapse.

In 1944, Discount Bank acquired the Mercantile Bank in Haifa. After the establishment of the State of Israel in 1948, Ottoman Bank, one of five large foreign banks active at the time, was merged into Discount Bank. In 1952, Discount became Israel's second largest bank with over 40 branches across the country. It retained that position until the merger of bank Hapoalim with the credit and saving funds of the Histadrut in 1957.

In the early 1950s, the bank opened branches in Europe and began investing in Israeli companies through the "Israeli Finance and Investment Company" that was acquired before. In 1962 Discount opened its first commercial bank in the United States called Israel Discount Bank of New York, or IDB Bank.

In the 1970s, Bank Discount was the first to computerize its activities: the bank invested in advanced technology, a modern computer system and ATMs. In addition, it was the first bank to issue its shares to the public.

In 1983, bank Discount was nationalized by the State of Israel, along with other banks, as a result of the banks' stock crisis. In 2006 control of the bank was sold to private hands. In 2010 additional 5 percent of of the 25 percent bank's stock, owned by Israeli government at the time was sold to privet market.

Today, is the fourth largest bank (by total assets). The bank provides services to over one million private and business customers through a network of about 100 branches belonging to Discount Bank, 80 branches of the Mercantile Discount Bank Ltd. subsidiary, mainly located in the periphery. The IDB New York, a full owned subsidiary of bank Discount is the largest Israeli bank operating overseas and maintains branches in New York, Florida, California and the Cayman Islands.

Bank Ha-Benleumi (First International Bank in Israel)

Bank Ha-Benleumi was founded on June 25, 1972, and began banking operations on August, 4 of that year, after receipt of the license from the Bank of Israel. The aim of the foundation of the new bank was to increase competitiveness in the banking industry and to provide additional financial source for funding the industrial sector.

Bank Ha-Benleumi was formed from the merger of a number of financial institutions that operated as separate entities at that time into the new banking institution: Bank for Craft

(founded in 1954), Bank for Export (founded in 1935), Bank for Foreign Trade (founded in 1956), Israeli Bank for Industry (founded in 1932) and three other small financial institutions.

In 1983, there was a banking crisis in Israel that developed as a result of the manipulation of the stock exchange rates of banks shares on the stock exchange. As a result of the crisis, the shares of all the largest banks in Israel were nationalized by the State of Israel, their share prices dropped sharply, and caused great financial damage to investors and the Israeli economy as a whole. The Bank Ha-Benleumi was the only one of the big banks that did not participate in the stock prices manipulation process for all the years, and after the execution of the stock arrangement in the banks remained the only large privately owned bank.

In 1981, Bank Ha-Benleumi began its international activity by establishing a branch in London. Later, in 1984, the bank established the branch in Zurich. In 2014, the bank sold its banking activity in London and in 2016 sold its activity in Switzerland, eliminating its international operations. Thus, the Bank Ha-Benleumi became the only Israeli bank among the large banks that since then has not conducted direct international operations outside of Israel, through its subsidiaries.

Since 2004, the Bank Ha-Benleumi has made a number of acquisitions and mergers with small banks. Thus, small banks were merged into the bank, ceased to exist as independent banks and began to operate as Bank Ha-Benleumi subsidiaries.

The unique of Bank Ha-Benleumi among Israeli banks for a long time was that service was offering complete paperwork in English even to ordinary customers, not for English-speaking only.

Today Bank Ha-Benleumi is the fifth largest bank in Israel (by total assets, Annual financial statement, Bank Ha-Benleimi, 2018). The bank has 158 branches in Israel. The bank's operations are based on large business customers as well as on private customers. The bank's main areas of activity are private banking, business banking, capital and foreign exchange markets. About fifty percent of the Bank's shares are traded in the Tel Aviv Stock Exchange.

Bank of Jerusalem

The Bank of Jerusalem (previously known as the "Jerusalem Bank for Development and Mortgages Ltd.") is an Israeli bank that has been operating as a commercial bank since 1998, and specializes in credit for real estate, the capital market, savings and international banking. The bank provides trading services in foreign and Israeli securities, and investment house

services.

The idea of establishing a bank in Jerusalem that would focus on financing economic activity in Jerusalem first came up in the late 1950s of the 20th century, at the initiative of a number of Jerusalem businessmen. At the same time, the Workers' Loan and Savings Fund in Jerusalem also sought to become a bank. The Bank of Israel initially opposed the establishment of new banks at the time, but in 1963 agreed to the establishment of a mortgage bank in Jerusalem. In December 1963, the bank was given a license under the name "Jerusalem Development and Mortgage Bank Ltd." The mayor of Jerusalem, Mordechai Ish Shalom, was appointed president of the bank. Later the bank changes its name to Bank of Jerusalem.

"Bank of Jerusalem" was the second bank that operated under this name. In 1928, the businessmen of the old ultra-Orthodox settlement, including Moshe Parosh, established the "Bank of Jerusalem Ltd.". This bank was sold and merged with the Feuchtwanger Bank in 1938.

The bank's shareholders at the beginning were: the Wolfson Clair Meir company, the government housing and development company, Export Investment Company (which was owned by the Meir brothers), the Jerusalem Loan and Savings Bank, the Jerusalem Municipality and the Histadrut[15]. Isaac Wolfson was appointed as chairman of the board of directors and Charles Claure and Moshe Meir were appointed as his vice. The bank was mainly engaged in financing residential construction in Jerusalem and took part in the establishment of Kiryat Wolfson[16] and the Ramat Sharet[17].

Over the years, the Meir brothers purchased the majority of the bank's shares (after purchasing the full ownership of the Wolfson Color Meir company, which was the largest shareholder in the bank, in addition they also owned an export company which was a shareholder in the bank. In 1989, the brothers decided to separate their businesses and Moshe Meir took control of the bank. Moshe Meir appointed Zalman Shovel, as chairman of the bank. At the time Shuvel was also serving as a member of the Knesset and this provoked criticism for a conflict of interest. After the death of Moshe Meir in 1993, the bank came

[15] Histadrut, or the General Organization of Workers in Israel - Israel's national trade union center and represents the majority of Israel's trade unionists.
[16] District in Jerusalem.
[17] District in Jerusalem.

under the control of Zalman and Kena Shuvel.

In 1992, the bank offered its shares to the public on the Tel Aviv Stock Exchange. In 1996 the name of the bank was changed to its current name. In the 1990s, he significantly expanded his activity in the field of financial support for real estate up to 40% of his total credit, this scope, together with the repayment difficulties of some borrowers, led the supervisor of banks at the Bank of Israel to intervene and order a temporary halt in the granting of credit to this field.

In 1997, the bank received a financial institution license from the Bank of Israel in accordance with the Banking Law. As part of the license, the bank was allowed to engage in all activities allowed for a banking corporation with a "bank" license, with the exception of payment by checks upon demand. In 1998, it received a commercial bank license as part of the bank's effort to enter the field of business credit, loans and savings for the private sector, and with its receipt, the bank completed its transformation into a commercial bank.

In 2002, the bank began issuing credit cards to its customers in cooperation with the Israel Credit Card Company (CAL Israel Credit Cards).

In 2010, the bank's board of directors decided on a turnaround in the business strategy centered on controlled growth while focusing on retail activity specializing in mortgages and the continued development of consumer credit, while maintaining a low risk profile that is reflected in the mix of business activities, alongside the diversification of customers and sources of financial and operational income. In an attempt to balance considerations of return and risk and is intended to lead to maintaining the stability and strength of the bank, achieving adequate profitability and measured growth. About NIS 20 million was invested in upgrading the computer systems and cyber protection, a call center and digital archive were established, a customer relationship management system was implemented, the bank's website was upgraded, and ATMs with the ability to withdraw cash, deposit cash and deposit checks were installed in all bank branches.

In 2011, following the social protest, the bank decided to change the method of interest on bank deposits that had been used until that time. While the banks offer their customers 20% of the Bank of Israel interest and keep 80% of it, the Bank of Jerusalem offered to give customers 80% of the interest and keep 20% of it. The Bank of Jerusalem called the change of method a transition from the minimum method to the maximum method. Beginning in the second half of 2013, the bank reduced this generous policy, offering its customers only half

of the Bank of Israel interest.

As part of the effort to increase the market share of households, in 2012 the bank offered a current account without fees and was the first bank to offer customers of all banks the option of opening a deposit online through a website it established, without opening a current account at the bank and without the need to visit a bank branch. In 2017, the bank started charging fees.

During the year 2013, the bank acquired the company "Kelal Finances-Betuha Investment Management". Thus, the bank significantly increased his activity in the local capital market. But he sold this activity 4 years later to "Meitav Dash Investment".

In 2017, the bank launched a loaded debit card service, intended mainly for employees without a bank account, who receive their monthly salary in cash, to receive a salary by credit card.

During 2018, the Bank of Jerusalem tried to purchase Municipal Bank (which was then owned by the Belgian-French banking and finance group Dexia), but its purchase offer was rejected in favor of a competing offer from Discount Bank.

The Bank of Jerusalem has a number of subsidiaries, including "Eir Shalem Insurance Agency Ltd. (1996)" which deals in mortgage and life insurance, "Jerusalem Financing and Issuances (2005) Ltd." which deals in the field of underwriting and public issues as well as in the activity of private capital raising and Tomer Jerusalem Ltd. M. In the field of real estate, the bank focuses on financial support for residential construction projects. The bank has a significant market share in this area relative to its size, and the bank's estimates are that it holds about 10% of the market.

The bank has about 24 branches throughout Israel. Starting from the second decade of the 21st century, the bank began operating in the field of consumer credit. Part of the bank's strategy for increasing its activity is to grant credit to customers of other banks without the need to open a current account, while establishing a friendly digital platform that will examine eligibility for a loan according to several criteria and provide digital approval in principle without human contact.

4.2.3. Significant events affecting Israeli banking system

1983 Israel banks stock crisis

During the 1970's, Bank Hapoalim and its dominant manager, Jacob Levinson, began operation for taking control the exchange rates of the bank's shares on the Tel Aviv Stock Exchange. As part of the operation, the bank recommended to its clients to invest their money in the purchase of the bank's shares (Blass and Grossman, 1996). Such customers purchases enabled the bank to increase the available capital for providing new loans to customers, for new investments, and so on. In order to keep the bank's customers to continue to invest in the bank's shares - that is, in order for the shares to continue to be an attractive investment opportunity for purchasers - the bank also engaged in the self-acquisition of its shares through its controlled funds and companies, so that there seemed to be a higher and constant demand for its shares, and their value rose or kept constant. By granting loan to its customers for the purchase of the shares, bank also made a profit from the interest on the credit.

This operation of manipulation with stock prices through the flow of unnatural demand seemed to banks an easy and straightforward way to raise large sums of money from the public. In time, other banks such as bank Leumi, bank Discount, bank Mizrahi, Union Bank joined to bank Hapoalim. The only one bank that did not join the stock prices manipulation was bank Benleumi (Blass and Grossman, 2001).

The manipulation of share prices encouraged the public to invest in the shares of the banks and at the same time allowed the banks to increase their business activity. In 1977, such manipulation led to a large public interest in the shares of the banks and consequently a sharp rise in its rates. Banks wanted to avoid such a sharp rise, made the mass decline in the rates in June 1977 to avoid losing control on the banks (Sargent and Zeira, 2011).

Following a requirement of Israel Security Authority (ISA), the banks included in their quarterly and annual reports a paragraph stating the execution of the share prices manipulation, but the reports on the manipulations were partial, misleading, and sometimes false. However, the manipulation was well known to the public and widely discussed in the newspapers. For example, during the stock market declines in August 1980, which were exempt from bank shares because of the regulation, "Maariv" published: "Bank shares continued to hold thanks to constant support from the banks, and other institutional investors notwithstanding."

In the middle of 1983, the public began to suspect that share prices manipulation was a bubble that may soon burst. As result, the public lost confidence in the banks 'shares and began a massive selling the banks' shares and buying foreign currency instead. Shortly thereafter, banks began to have difficulty acquiring the public's stock offering and on October 6, 1983, reached their capability and a crisis broke out. The loss of the ability to absorb the supply could have brought many bank customers into bankruptcy because they purchased the shares that they could not sell, and bring the banks themselves into bankruptcy, as the collateral for the great credit they gave was only their shares.

In order to prevent this snowball effect, which would lead to the economic crisis, trading on the shares of the four big banks (bank Ha-Poalim, bank Leumi, bank Discount and Union bank) was stopped. Within two weeks a "bank share arrangement" was formulated, in which the government undertook to redeem the banks shares at different dates, relative to their value before closing the stock exchange. All four banks were nationalized. Israeli government took the control of the banks, but their new managers were left with full business independence, in order to enable the banks to maintain their ability to operate in the financial markets.

When stock trading resumed, their rate fell 17%. The value of the Treasury's share buy-back commitment was estimated at $ 6.9 billion, where the damage caused to the state following the stock crisis was estimated at $ 10 billion (Blass and Grossman, 2001). For instance: in 1983 GDP was approximately $27 billion.

Regulatory requirements restricted the exposure of Israeli banks to risky activity. This step helped the Israeli banks to avoid many of the problems, faced by banks in many other western countries at the end of the economic crisis of the 2000's. Additionally, it helped to ensure a stability in local banking sector, which contributed significantly to the relative strength of the Israeli economy in the face of the recession of the late 2000’s.

On the administrative side, the banks should be separated from the Pension Funds and Trust Funds. This step is fully completed by the end of 2006.

From the accounting side: banks were required to accounting reports according to the double standard. The implication of this principle is that not only do the financial statements comply with generally accepted accounting rules, but they must also correctly reflect the business situation of the corporation.

Blass and Grossman (2007) compare bank share manipulation in Israel with that in the United States before the passage of the Glass-Steagall Act and Eastern Europe countries with

transition economies (EIT). They argue that many of the techniques of and motivations for manipulation in Israel were similar to manipulations and motivations in the United States and Western Europe during 1927–1929 years (Blass and Grossman, 2007; Ofer, 2004).

The hyperinflation or the "lost decade"

Since the founding of the state until today, inflation in Israel has known ups and downs. The peak of inflation was between 1980 and 1985. Since 1980, inflation started to jump to three digits: 100% and up per year. Such inflation is called "galloping inflation" or "hyperinflation." The government has taken several actions against it but without success. Figure 22 shows the inflation in Israel since 1952 until 2018.

In October 1983, the banks' shares collapsed due to stock manipulations, which the bank's management had taken for many years. The government had to take on the ownership of the banks and the responsibility for their stocks to prevent their collapse, which could seriously damage the entire country's economic system. The result was a significant increase in the country's internal debt, due to government commitment to bank shareholders. The public lost confidence in banks and the capital market and began to accumulate foreign currency amounts, prompting a rapid erosion of the shekel.

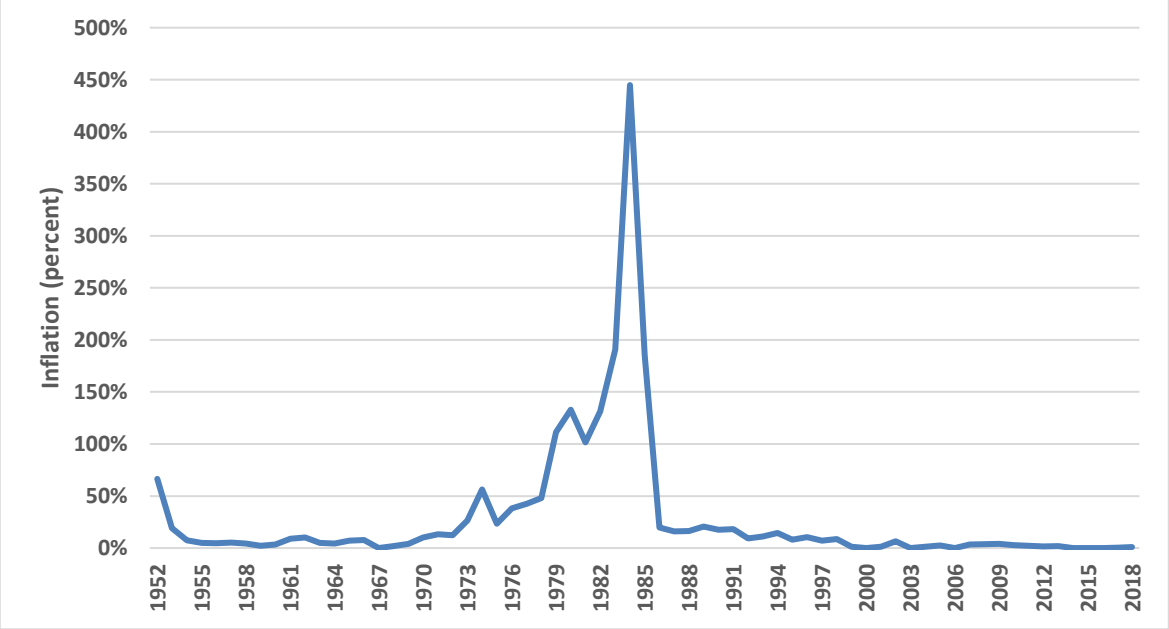


Figure 22. Inflation in Israel (1952-2018)

Source: Central Bureau of Statistics.

The combination of stagnation in most sectors of the economy, the "galloping inflation", the banking crisis, the worsening balance of payments problems and the state budget deficit - all have led the economic situation to a dead end. In 1984 the annual rate of inflation peaking to the new unprecedented record: 444,88%. In other words, prices rose five and a half times on average in just one year. The highest monthly Consumer Price Index (CPI) growth was recorded in July 1985 at 27,49 %. The rapid and uncontrolled increase in prices was the reason that the state budget was calculated and presented in US dollars instead shekels, for several years, because at the beginning of the year it was impossible to know what the rate of shekel at the end of the year will be. In addition, a very large external debt was created, which threatened to exacerbate the economic crisis, and Israel 's foreign exchange reserves fell sharply.

This period is known in Israel as the **"lost decade" or "the Depression**". Inflation eventually stopped after the 1985 Economic Stabilization Plan. Since 1999-year inflation has been below 4 percent in a year.

- The control of the main inflationary instrument, the interest rate, was transferred to the exclusive control of the Bank of Israel.
- The Bank of Israel was forbidden to print money to cover government budget deficits.
- Currency exchange - The New Shekel officially replaced the shekel on January 1, 1986. A conversion ratio was: one New Shekel was equal to 1,000 shekels[18].

The embezzlement in the Trade Bank

The embezzlement at the Trade Bank took place in 1997–2002. During this period, the Trade Bank employee, Etti Alon, embezzled huge amounts of bank money which led to the bank's bankruptcy and later liquidation. In total, Alon embezzled NIS 254,199,600 (approximately $ 72 million). As part of the embezzlement, Alon opened 206 fictitious bank accounts which equivalent to approximately 1,300 bank customers, which provided back-to-back loans. The loan funds she withdrawn for her disposal. Also, she broke costumers' deposits and took the money.

The extensive embezzlement went on for a long period without being revealed. Due to its role as Banking Supervisor, the Bank of Israel has initiated several changes in the bank's

[18] Bank of Israel, Israel's currency system.

supervision, in the working procedures of bank's employees and in reporting formular to their customers. Thus, Bank of Israel obliged the banks to change and update a number of procedures which, according to Bank of Israel, constituted breaches that allowed the embezzlement in the Trade Bank. For example, clear rules were set for the computer system that used by banks and for permissions and passwords. All banks in Israel are required to use in each branch computerized information station, which will enable to each client to obtain information about his account independently and without the need for any of the bank's officials.

In addition, the Bank of Israel Division for Banking Supervision issued a directive on rotation and continuous vocation for bank employees. Thus, an employee of banking corporation must be on continuous vocation for at least six working days. Holders of sensitive positions must be on continuous vocation at least ten working days (Bank of Israel Press Releases,27.04.2004). Such step assigned to assist the internal control of a banking corporation and may make it difficult for certain techniques to commit embezzlement and fraud or to help in its early detection.

Most of the Trade Bank customers received back their money due to a voluntary guarantee provided by the Bank of Israel. In simple word, the Bank of Israel "bought" the Trade Bank's debt towards its customers by paying customers the value of the deposits they had in the Trade Bank and filing a debt claim with the bank for this payment. Payments began in September 2002 and continue until this day. As on January 2008, the Bank of Israel paid a total of approximately NIS 600 million to the Trade Bank's customers.

4.3. Risks of Israeli banking system

The banking system, not only in Israel, by nature, is exposed to a variety of risks, including well known financial risks, most notably credit risk, and also liquidity risk and market risk. Alongside financial risks, the banking system is exposed to a variety of other risks - including risk from cross-border activity and compliance risk, geopolitical risk, legal risk and operational risk.

The main risks of the banking system in Israel vary from year to year. In last years the financial risks are declining, while operational risks are on the rise. Thus, operational risks in Israel banking system, basically cyber and technological risks, arising from the technological

improvement that goes through all areas of our lives, has risen during last years. Even through financial risks have been reduced, most notably credit and liquidity risks, banks still treat them as major risks (Israel's Banking System - First Half of 2022).

Credit risk

Credit risk is the risk arising from the probability that a borrower or a group of borrowers will not meet in their obligations to the bank. Its realization will be reflected in non-payment of principal and/or interest, and consequently, the bank's expected profits will erode. This risk is usually divided into three components: quantity, quality and credit portfolio concentration (Rothenberg, 2010).

Since 2015-year, credit card companies have expanded their lending activities, increasing their market share at the expense of banks. In addition, other companies such as investment houses and other private companies that have been licensed to engage in lending have started grant loans to companies and households[19]. This situation created in the credit market can exacerbate competition between banks and other players. Furthermore, a dangerous situation may arise in which loans can be approved for individuals or companies, with very low ability to meet debt payments.

The consumer credit risk has expanded at very high rates in recent five years, resulting in increased risk. Consumer credit is personal debt taken on to purchase goods and services. In 2018, there was a continued slowdown in consumer credit growth, which began in 2017. Thus, it grew by only 1.2%. For instance, during the same period last year the growth was about 3.8%, and about 6.4% on average in years 2012-2016. The downturn in consumer credit was uneven among banks: while the large banks, "Leumi" and "Hapoalim", showed a reduction in this credit by an average of 2.6%. The middle-sized banks, "Discount", "Mizrahi-Tefahot" and small-sized bank, "HaBenleumi", expanded their activities in it. The average growth in these three banks was about six percent (Bank of Israel Annual Survey, 2021).

Despite the rapid growth of consumer credit over the years, the level of households leverage in Israel is not high in international comparison (Figure 23).

[19] According to Israeli law, a business entity that wishes to engage in loans must obtain a license from the Ministry of Finance.

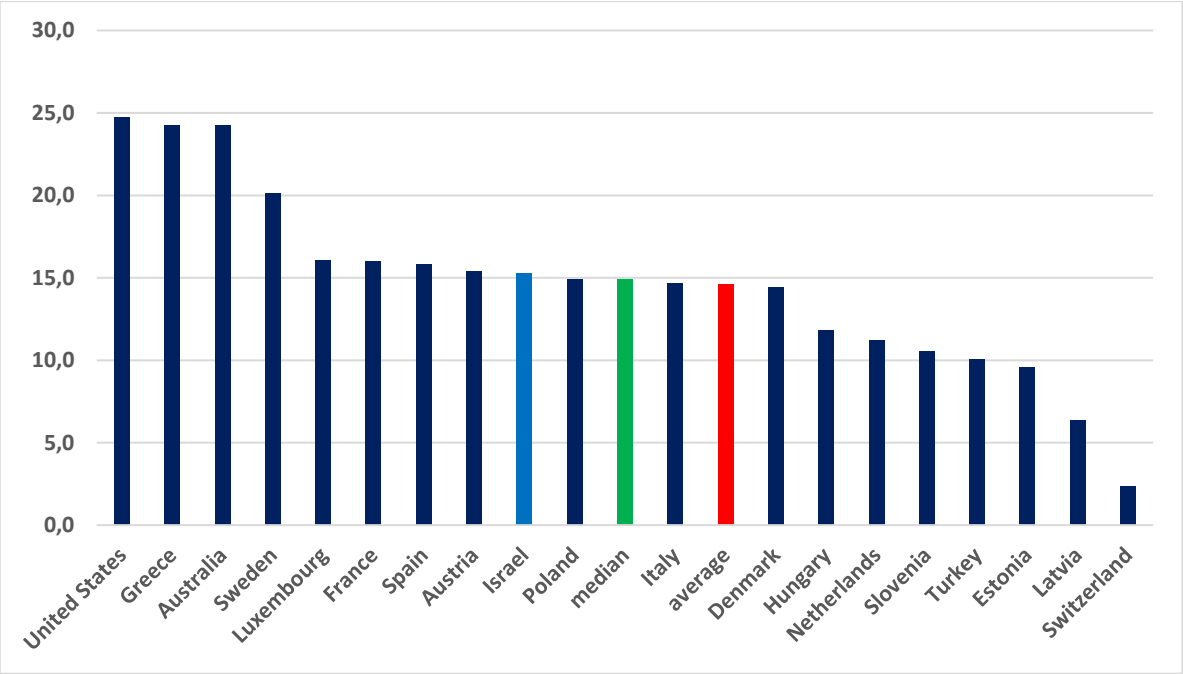


Figure 23. Leverage level of households in Israel compared to the global and average level, 2018

Source: Israel – data from banks annual financial statements, foreign countries – data from OECD.

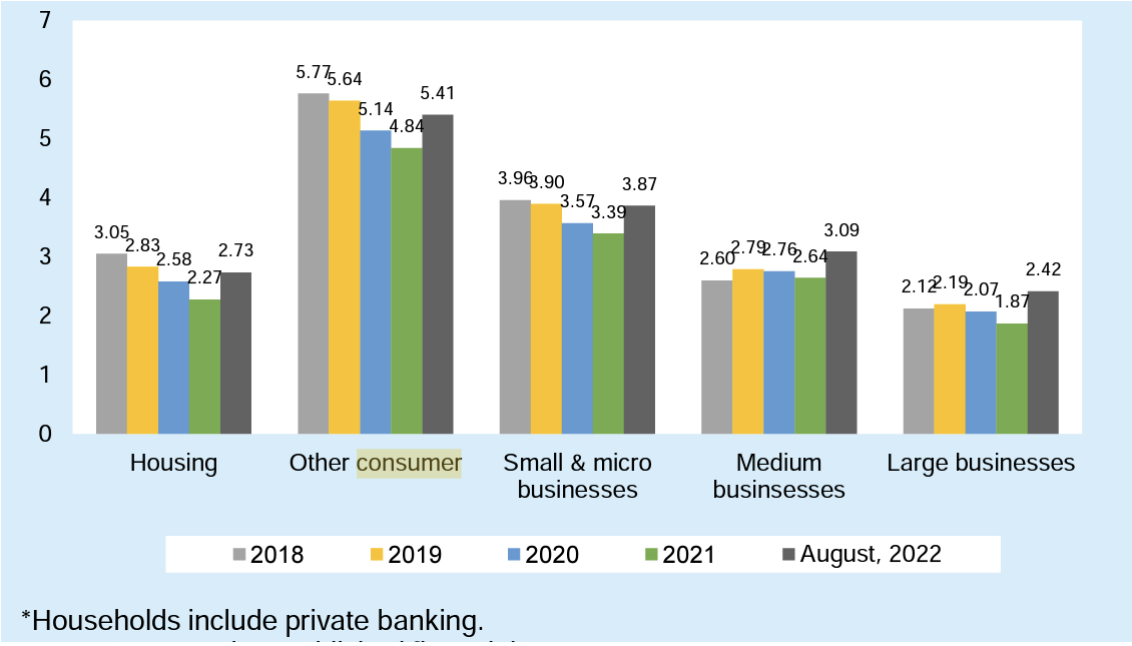


Figure 24. Leverage level of households and business sector in Israel, 2018-2022 (in percent)

Source: Israel's Banking System, Survey, June 2022, https://www.boi.org.il/media/shmdron3/20000.pdf.

According to the Bank of Israel, there are expectations that problematic (bad) credit rates with consumer credit will also grow in the coming years. Thus, banks credit losses will also

grow.

The business credit growth began in 2017 and continued in 2018 (Figure 25). The business credit grew by seven percent during 2018 (compared with 4.7% last year and zero growth rates between 2012-2016 years). Such growth is mainly due to increase of credit to the large business sector, which grew about 9.6%, and credit to the medium-sized business sector, which grew by about 7.2%. In contrast, credit for the small business sector grew by approximately 6.2% (compared to 6.6% last year). Similar to consumer credit, the differences between the large and medium banks are significant. Thus, in 2018 credit grew in the medium-sized banks at an average rate of about 10.2%, while in large banks it grew at an average rate of about 4%.

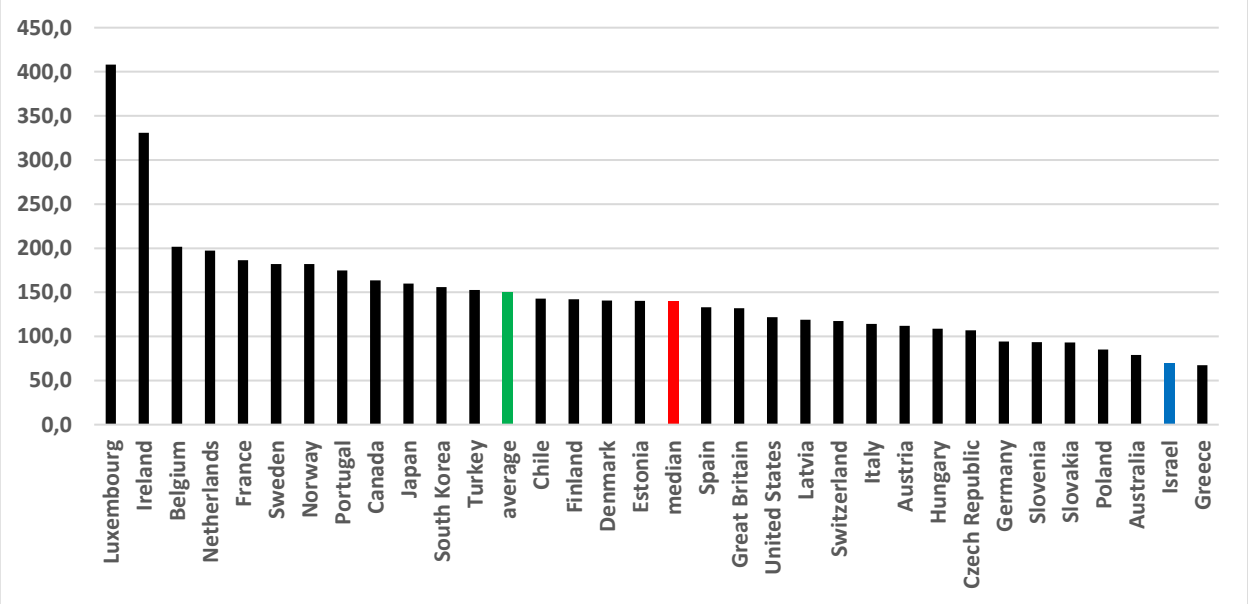


Figure 25. Business credit to GDP ratio, International Comparison, 2018 (in percent)

Source: Israel – data from banks annual financial statements, foreign countries – data from OECD.

Credit loss rate is higher in consumer credit than in business credit. The risk banks recognize in providing retail credit has even increased in recent years relative to the large and medium-sized business sectors, due to a certain increase in household leverage and legislative changes. In 2018, these loss rates narrowed. Higher risk in households and small business sector than large companies is not unique to Israel. It stems, among other things, from the information asymmetry between the banking corporation and the business owners or households - a result of the lack of quality and available information about the borrower's financial situation.

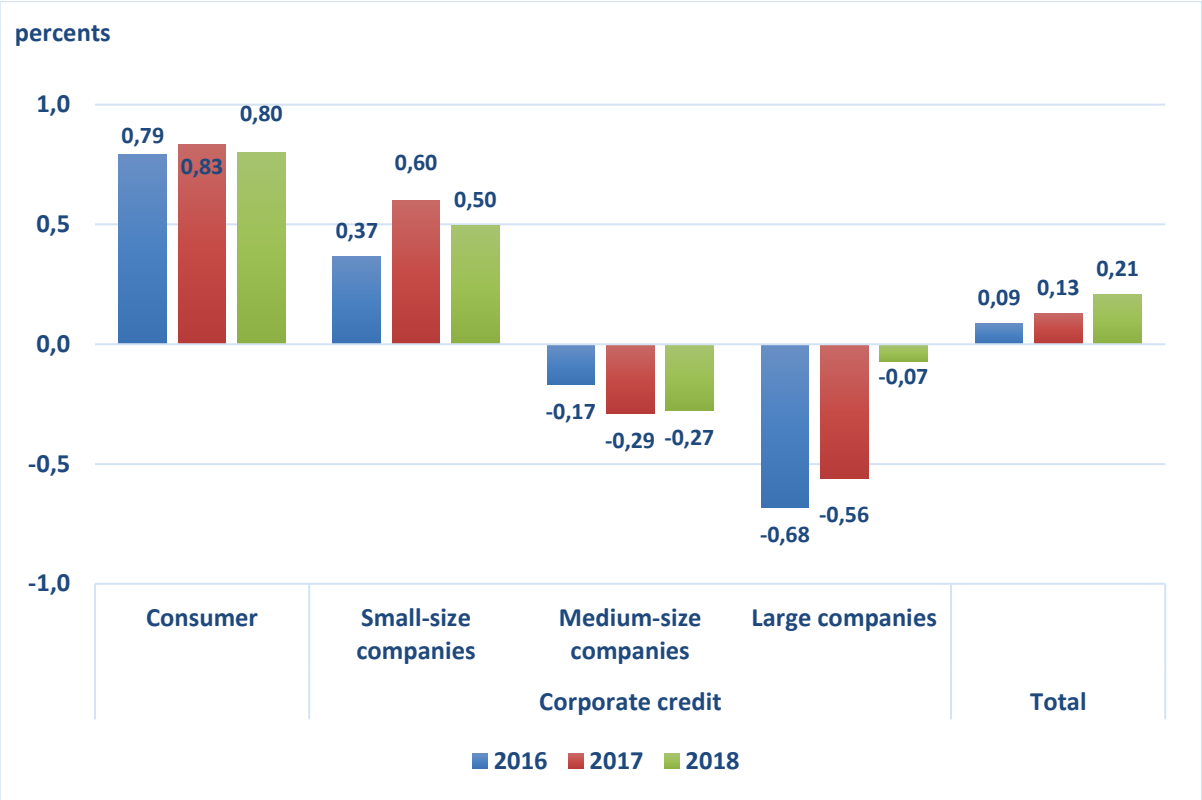


Figure 26 – Credit losses on credit (end of period), five banks, 2016 - 2018

Source: Israel – data from banks annual financial statements

In order to address the information asymmetry problem, the Bank of Israel has established the *Credit data pool*. Credit data pool is a new database that includes the extended credit picture for a person and concentrate their data from most financial institutions. The idea of the database was born out of the understanding that the banks' control of credit for households stems from the vast knowledge they have of their customers, who manage their bank account. This knowledge enables banks to accurately analyze the client's risk and know whether granting him a loan is worth. The database is open to all credit lenders in Israel, who will be able to price their loans better and improve their ability to compete with banks. The credit data pool began operating on April 2019. Today, alongside all banks and credit card companies that report to the credit data system, 18 non-banking entities that offer credit to the public have also joined the system, and the number continues to rise.

The banking loan portfolio indicates, in most, on good quality of loans. Thus, loan loss provision (LLP) remains to be on low level. In 2018 the loan loss provision (LLP) increased to 0.21%, compared to 0.13% in 2017. Most of this increase was due from the individual provision for credit losses, which was affected by a reduction in total debt collection from

medium-size and large companies. Such losses were previously written-off. Write-off to total credit ratio declined to 0.15%, relative to 0.19% in 2017.

The bad debt to total debt decreased to 2.15% in 2018 from 2.30% in 2017. Arrears decreased to 1.24%, compared to 1.36% in 2017. The coverage ratio continued to rise in 2018 as well, reaching 95.4%, compared to 86.7% in 2017.

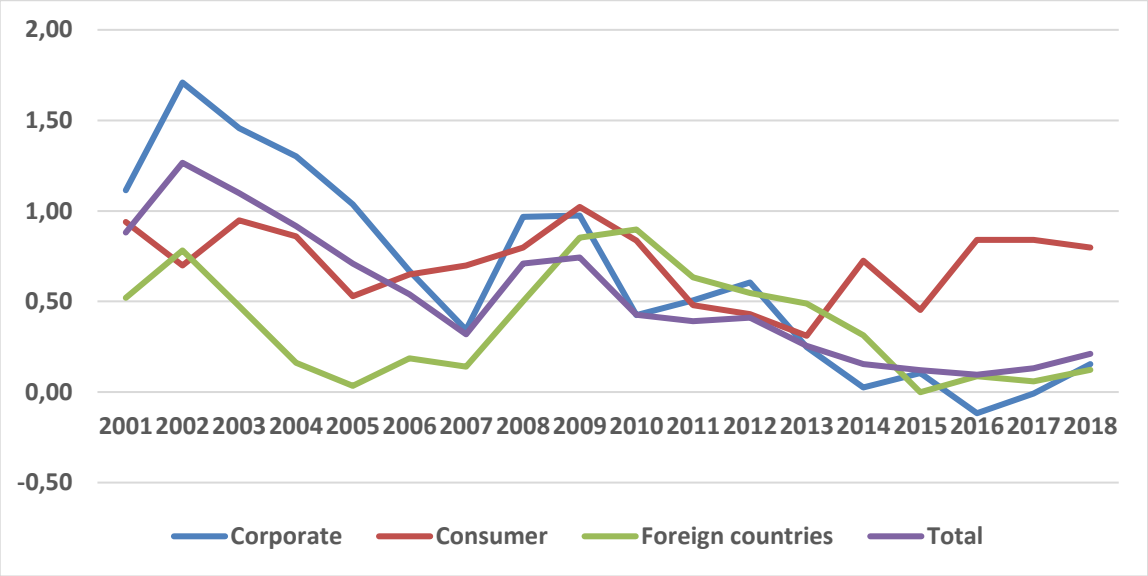


Figure 27 – Loan Loss Provision (LLP), five banks, international comparison, 2001 - 2018

Source: Israel – data from banks annual financial statements, foreign countries – data from OECD

One of the sources of credit risk in banking institutions is the concentration of the credit portfolio. Due to the recognition of the effect that the extent of the credit portfolio's concentration has on the extent of its exposure the credit risk, Bank of Israel has set limits on the debt of a large borrower and group of borrowers. That is the reason for the decrease in the loan loss provision (LLP) and the reduction of credit losses in segment of large companies.

Liquidity risk

Liquidity risk is the risk that arises from uncertainty about unexpected withdrawal of deposits and unexpected demand for credit that the bank must provide immediately. During 2018-year liquidity coverage ratio (LCR) in banking institutions slightly increased. Thus, its aggregate value was approximately 128%, compared with approximately 125% in December 2017 and about 103% in June 2015. The reason for this increase is that supervision has demanded the banks raise the liquidity ratios and the quality of the liquid assets they hold (Rothenberg, 2010). This step is due to the adoption of recommendations of Basel Committee

regarding liquidity coverage ratio (as part of Basel III) and its graded implementation in 2015-2017 years.

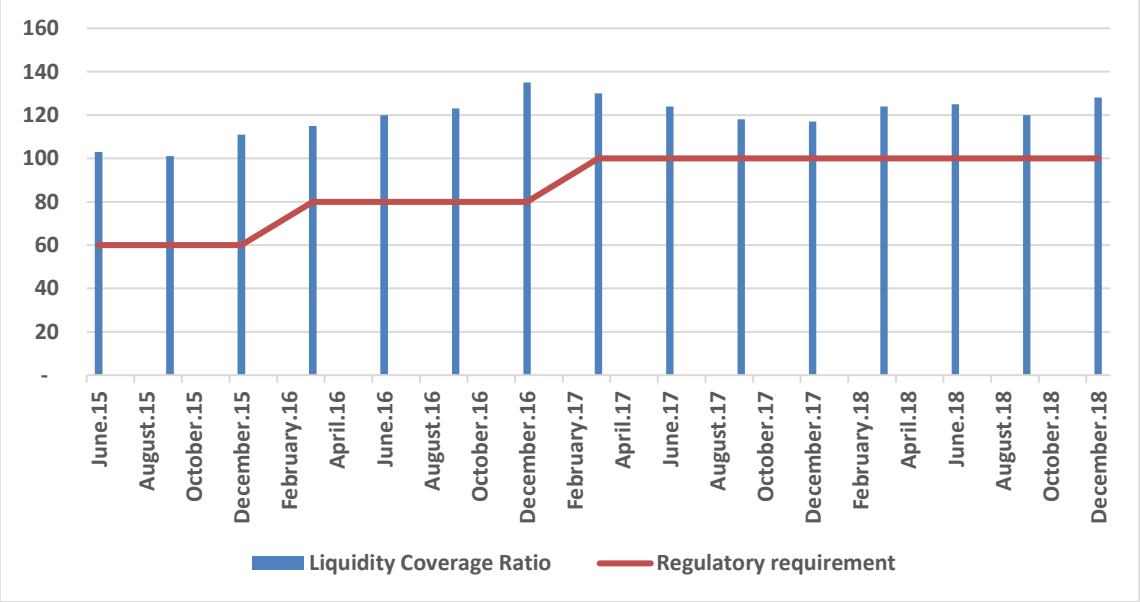


Figure 28 – Loan Coverage Ratio (LCR), five banks, 2015 - 2018

Source: data from banks annual financial statements

Market risk

Market risk is the risk arising from the probability that unexpected changes in market prices - interest rates, price indices, exchange rates, stock prices and more - will hurt bank income, in its profitability and capital value. Market risks arise from both the trading portfolio and the banking portfolio (Rothenberg, 2010).

In order to reduce or avoid this risk, the Banking Supervision Department required all banks to allocate and hold capital as "buffer" and audited its quality and management. As of 2018, commercial banks in Israel have met this regulatory requirement[20].

Other risks

In recent years, a several changes have taken place in the financial sector, and with them, a newest risk has grown, originating from technology development, regulation and accelerated legislation in Israel and around the world, changes in global banking and changes in consumer

[20] Bank of Israel - Israel's Banking System - Annual Survey, 2018.

preferences and behavior. Such risks include cyber risk, technology risk, business model risk, and behavioral risk.

In 2017, there was a change in consumer behavior. As of this year, customers have begun to do more operations using technology (e.g., ATM, Internet, information station, etc.) than through a local branch (Figure 3.9). It is estimated that this trend will continue in the future, so today banks invest a lot of resources in technology and digital innovation to adapt banking services and developing new products.

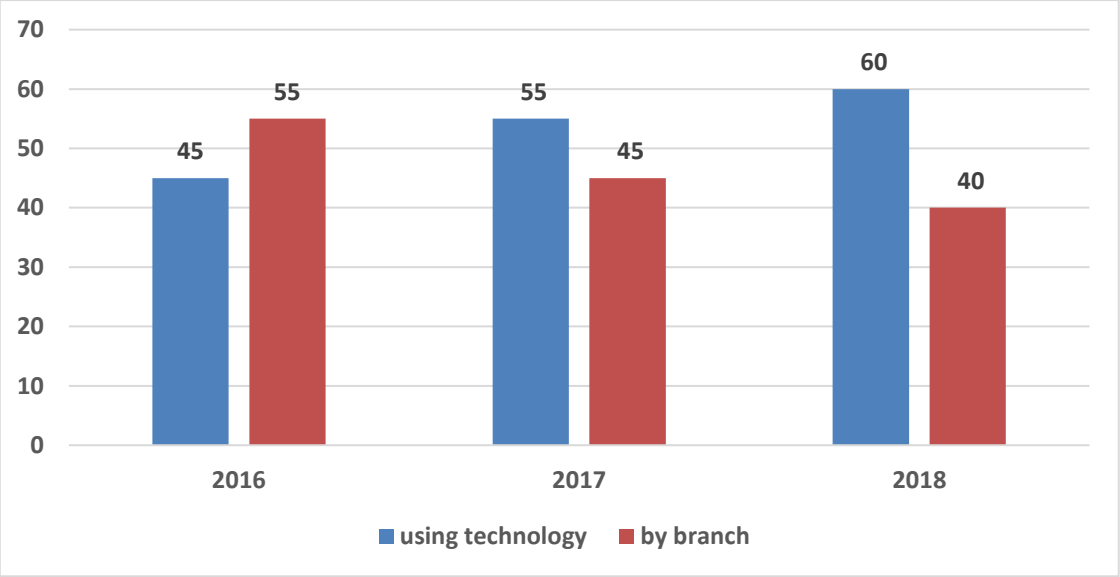


Figure 29 – Rate of customers operations using technology vs operations by branch (in percent), 2016-2018

Source: data from banks annual financial statements

Due to the unique characteristics of the newest risks that arise in the new business environment, it is difficult to completely identify them. Therefore, not always it is possible to quantify and assess the damage that is expected and the likelihood of the event. The magnitude of the risk and consequences of its occurrence can be understood from the cyber events and information leakage from banks around the world.

4.4. Efficiency of Israeli banking system

In recent years banks around the world have been struggling with decrease in the profit sources - partly because of the increased competition derived from the entry of non-banking

entities e.g., FinTech companies in the banking sector. Thus, traditional banks decline the status and competitive advantage. Therefore, Israeli banks, similar to banks in other countries, are required to look for new sources of growth and make difficult decisions about whether and how to change their activity so that it will respond to changes in the banking world.

To improve the spending structure, banks in Israel, as well as around the world, implements the optimization programs (e.g., personnel, process, real estate, non-profitable activities and more). Such programs are intended to avoid profit reduction or to increase it. Last years the banks in Israel have performed significant optimization processes, which were manifested in a large reduction of manpower and real estate. Since 2011, the number of closed branches has fallen by a cumulative rate of only 8%, less than average in the EU and the US - a decrease of approximately 20% (Figure 30).

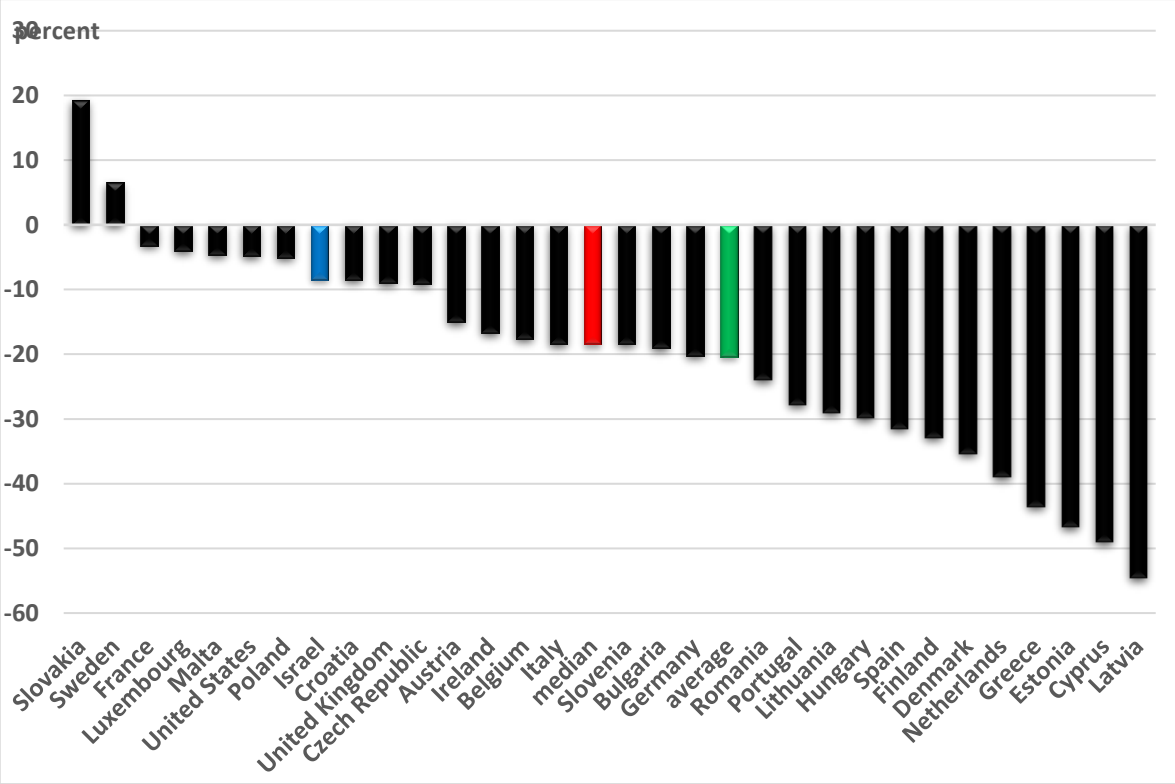


Figure 30 – The rate of change in the number of banks branches, 2011-2018

Source: Israel: data from annual statements of banks and data from Bank of Israel, Europe: data from European Central Bank, United States: data from FDIC.

In addition to reduction of the number of branches, banks also reduce the number of

employees. Thus, in 2011 In Israel was a high number of banks employees. Between 2011-2018 jobs in the banking system decreased by 15% (about 6,000 jobs) (Figure 31).

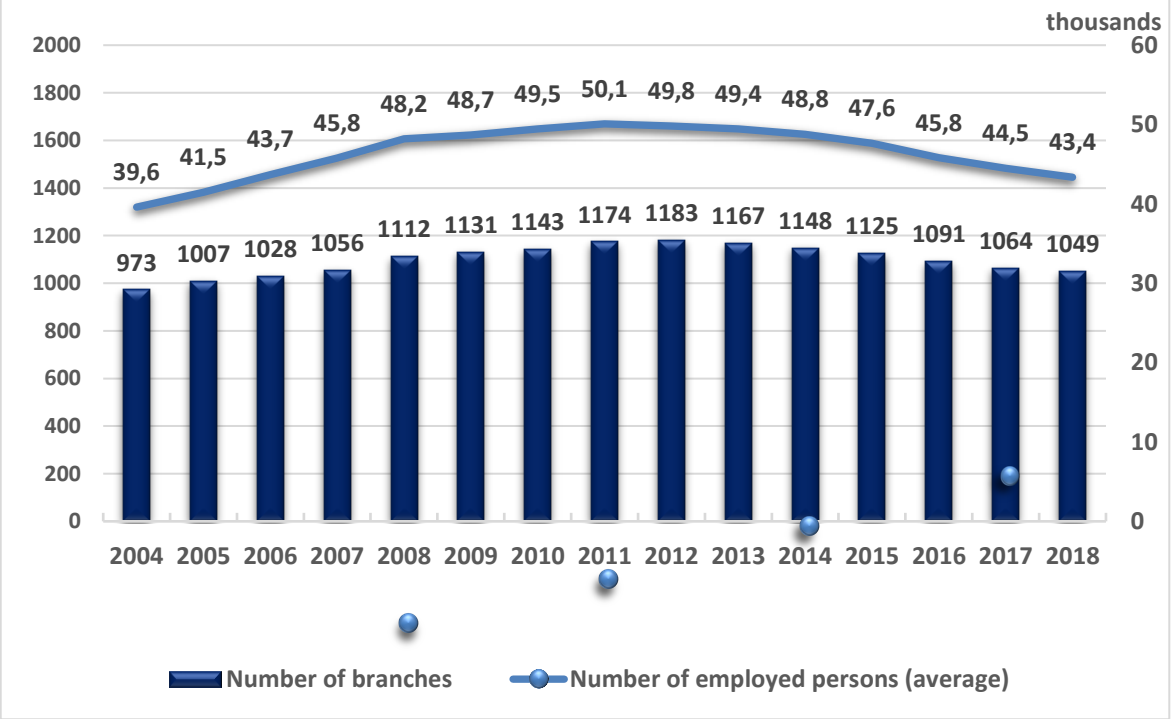


Figure 31 – The number of employees and number of branches, 2014-2018

Source: data from annual statements of banks.

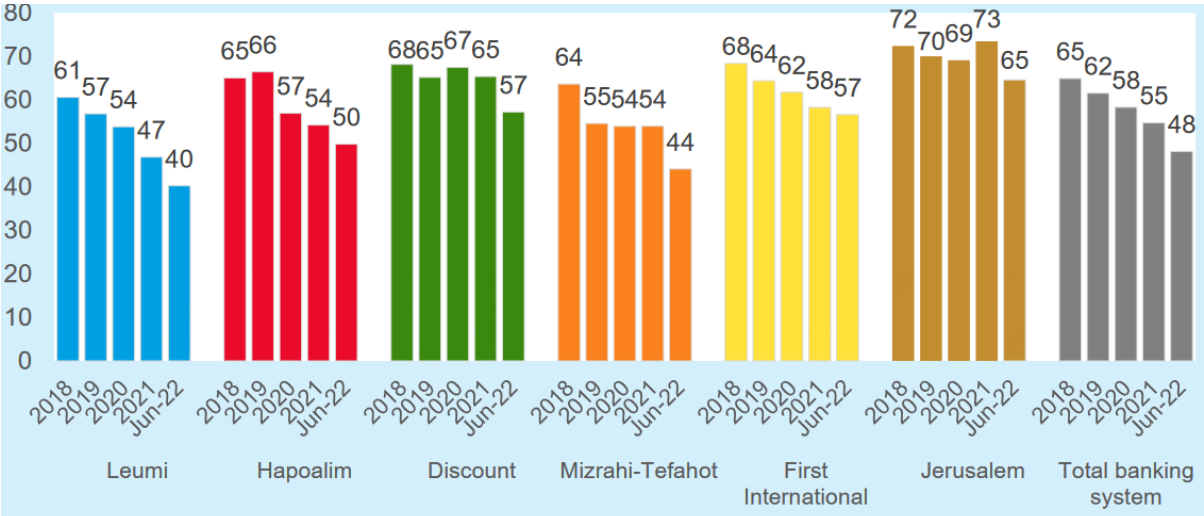
The improvement in effectiveness of Israeli banks was reflected in a reduction of personnel, the number of branches and real estate expenses. However, such improvement is not evident in the value of the efficiency operational ratio[21], because the business results of some banks were negatively affected in 2018 by various exceptions - in particular the expenses for investigations of two banks (Bank Hapoalim and Bank Mizrahi-Tefahot) by US authorities - which have significantly raised operating expenses.

Efficiency ratios, also known as activity ratios, are used to measure the performance of a company's short-term or current performance. All these ratios use numbers in a company's current assets or current liabilities, quantifying the operations of the company. For a bank, an efficiency ratio is an easy way to measure the ability to turn assets into revenue. Efficiency ratio in banks is calculated as:

[21] The ratio of total operating and other expenses to total net interest income and non-interest income (cost to income).

$$Efficiency\ Ratio = \frac{Expences\ (without\ interest\ rates)}{Revenue} \qquad 4.1.$$

The efficiency ratio of five Israeli banking institutions in 2018 was approximately 64.4%, lower than its average value in the last five years (about 67.8%) (Figure 31). Without provisions for the purposes of investigations mentioned before, the efficiency ratio in 2018 was 61.1%, compared to 63.1% in 2017. In other words, the ratio calculated without expenses of investigations indicates an improvement in effectiveness after 2017.



*The ratio of total operating and other expenses to total net interest and noninterest income (cost to income).
SOURCE: Based on published financial statements and reports to the Banking Supervision Department.

Figure 26. The efficiency ratio, six banks, 2018-2022 1st Q (in percent)

Source: Israel's Banking System, Survey, June 2022, (https://www.boi.org.il/media/shmdron3/20000.pdf.)

Despite the efforts of banks, the efficiency of the banking system in Israel is still lower than that of OECD countries. Improving the operational efficiency of the Israeli banks and adjusting them to the standard used in the banks similar in developed countries are some of the main targets set by the Bank of Israel for the local banks.

Loan granting is a traditional activity of the banks. Banks lend money to loan seekers and in return receive interest. On the other hand, banks borrow money from the central bank or use deposits of their customers as a source for loan granting. The remaining margin between interest paid by the bank on a loan or a deposit and the interest that bank received from a borrower is a profit of the bank from the loan activity. Both income from interest on public

credit and interest rate gap were on the decline until 2015. From 2015 both have been on a slowness upward trend (Figure 33).

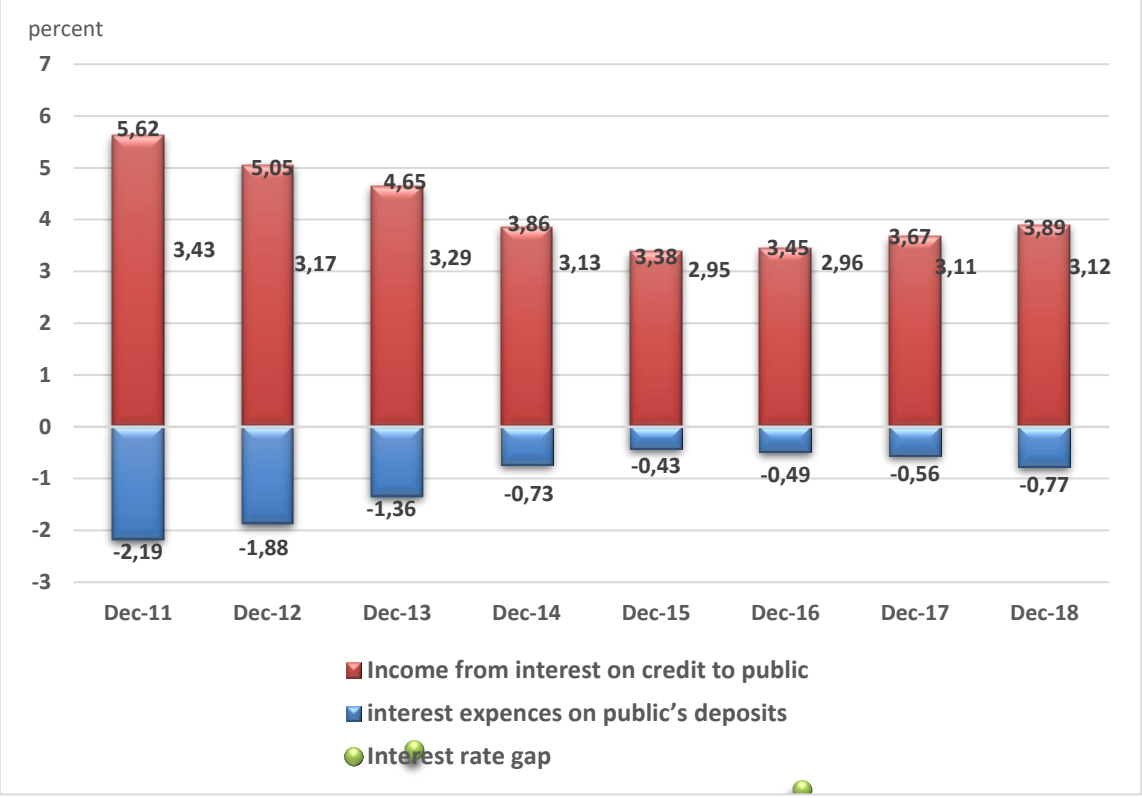


Figure 33 – Income from interest on credit to public, interest expenses on public's deposits and interest rate gap, five banking, 2011-2018 (in percent)

Source: data from annual statement of banks.

Net interest margin is one of the profitability indicators of a company, reflects its ability to earn on interest from its credit products: loans in case of bank. Net interest margin after 2006 is also on the slow rise (Figure 34).

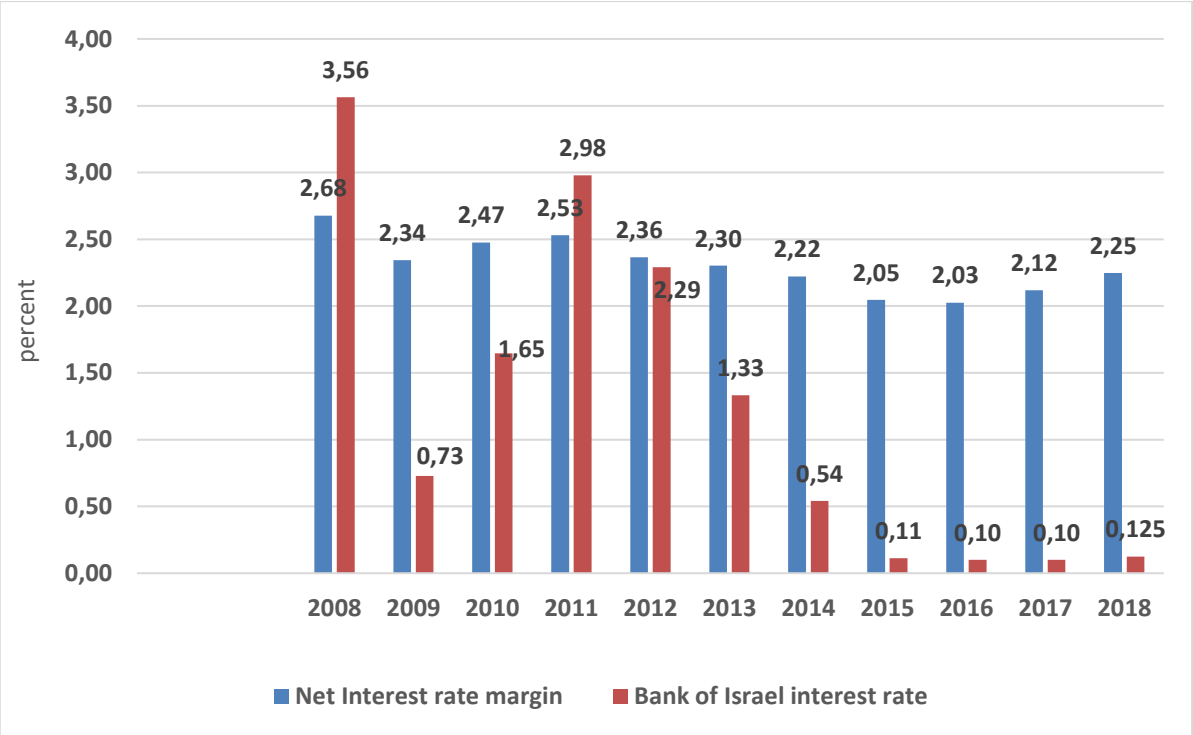


Figure 34 – Net interest margin and the Bank of Israel Interest Rate, 2008-2018 (in percent).

Source: data from annual statement of banks.

The reasons for the increase in the net interest margin, among other, are:

- An allocation of assets into lending funds which are higher-yielding investment channels.
- rise in CPI - Consumer Price Index (inflation) to 1.2% after about five years of low inflation rates.

The Return on equity ratio (ROE) is also important as it measures the efficiency of the company in generating profits from its net assets. 2006 was a peak year in the ROE index of five banks in Israel. Since the ROE has fallen by about 50% compared to 2018. However, in recent years the situation has balanced and the decline of this index in 2018 relative to 2017 is the same as the average of the previous few years (Figure 35).

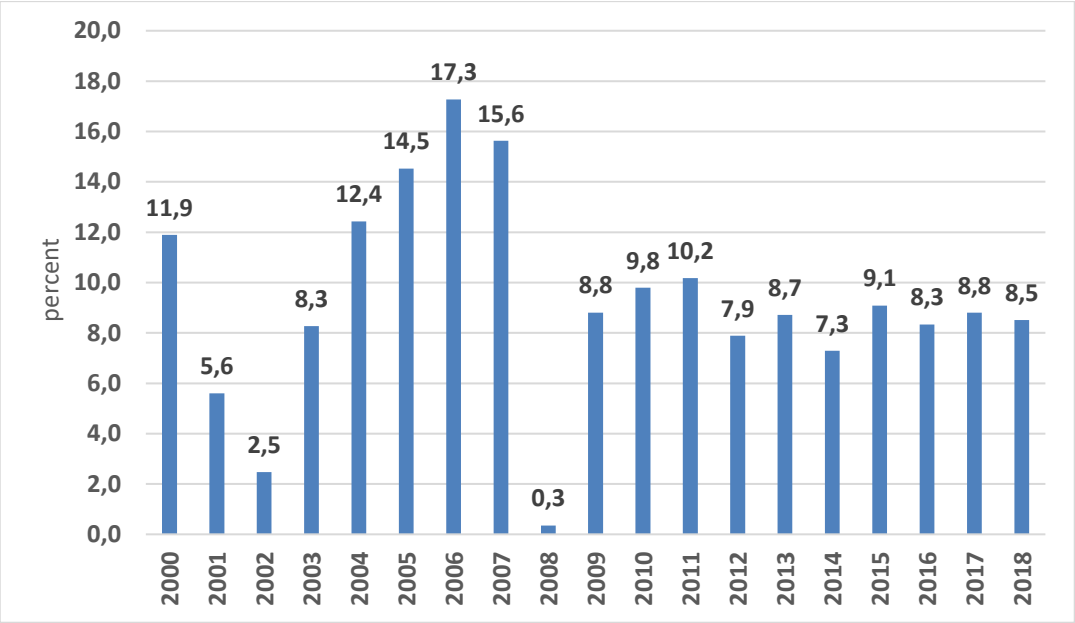


Figure 35 – Return on Equity (ROE), after tax, six banks, 2000-2018

Source: data from annual statement of banks.

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Banking system in Israel is healthy but in the last few years it has been facing many challenges caused by external and internal factors. In the first half of 2020 Covid-19 pandemic caused shocks in the economy and the concerns about the development of the crisis, reflected among the banks by high credit loss allowances and among customers by preferring liquid assets—among other things, by notable use of bank credit lines while selling securities portfolios and depositing the redemptions in the banks, which over many years have a reputation for stability. With the outbreak of the crisis, Bank of Israel examined all the tools available to it and began to use them in order to prevent an adverse impact on the supply of credit in the economy and to allow the continued sound activity and provision of services for households and the business sector, alongside maintaining the stability of the banking system. The steps taken were numerous, varied, and in some cases unprecedented in Israel's banking system, but they increased the efficiency and enhanced the competition of the banks (Bank of Israel, 2021).

Just after the Covid-19 pandemic as well as the interest rates and inflation rise were stopped, on October 7, 2023 Israel declared a war with Hamas. The next day, the Tel Aviv Banking Index (TA-Banks5), which contains five largest Israeli banks, fell by 8%, and in the next two weeks 20%. It has started to recover since then but the challenge to keep the

banking system in stability remains. Similar military escalations in Israel in recent years, such as the 2006 Israel-Hezbollah War, had little impact on the country's wider economy and banking sector. However, the scale of the current war is significantly larger and no one knows how long it will last. That is the reason the Bank of Israel has directed the banks to set aside additional provisions to account for the cost of war in their results (Euromoney, 2023). The banks have done it so according to the Bank of Israel they are in a reasonable shape. Therefore until today the banking system in Israel remains stable and efficient.

Chapter 5.

Analysis of a loan decision making model using real options

Existing scientific literature on banking theory covers more fields, such as transaction costs (Benston and Smith, 1976) production functions (Sealey and Lindley, 1977), informational asymmetry and financial decisions (Leland and Pyle, 1977; Talmor, 1981), as well as financial intermediary (Diamond, 1984). In the author's opinion, the subject of real options in the banking field does not receive enough attention. This is the main reason for the research and the loan decision making model using real options proposed in this chapter. Below the author of this PhD thesis presents the background of his model, explains the methodology and discussed the results he obtained.

5.1. Background

In decision-making process related to investment, the real options-based approach is very useful (Dixit, 1989; Pindyck, 1991; (Pindyck, 1993; Ingersoll and Ross, 1992; Grenadier, 1996b). Based on real options approach, Choi and Smith (2002) proposed a new bank lending approach. In their study, Choi and Smith (2002) put the focus on lending decision making process under uncertainty. Without uncertainty, investment process can be based on one or more of the most common traditional methods, such as DCF, NPV, IRR, ROI and payback. But in fact, uncertainty can take place at any stage of investment and traditional methods that are not dynamic or flexible enough to capture it (Myers 1984; Hodder and Riggs, 1985; Trigeorgis and Manson, 1987; Ingersoll and Ross, 1992; Ross, 1995). According to Choi and Smith (2002), the main sources for uncertainties for the assets and liabilities of the banks and other financial institutions are interest rate changes and risk of loan default. Loan default can cause an increase of major risk of banks - the credit risk. Credit risk hinders the growth of bank performance (Zheng et. al., 2018). To evaluate loan default risks, banks use quantitative methods, such as financial statement lending, assets-based lending, credit scoring or more qualitative methods (Berger and Udell, 2006). Credit scoring is lending technology for individuals which helps banks to approve and extend credit, to evaluate how much credit to extend and when to take action against clients with repayment problems (Rosenberg and

Gleit, 1994).

Choi and Smith (2002) model illustrates and explains the relationship between loan granting, loan-to-assets, and the uncertainties regarding interest income and expenses (Choi and Smith, 2002, p. 25). Thus, without uncertainty, loan grating can be based only on Net Present Value (NPV) criteria, but uncertainty may take place during the period of a loan repayment. Therefore, it is necessary to use an instrument that takes into account the uncertainty. Such tool is real options.

As presented in Chapter 2, real option is defined as the right, but not the obligation, to take an action (e.g., deferring, expanding, contracting, or abandoning) at a predetermined cost called the exercise price, for a predetermined period, which is the life of the option (Copeland and Antikarov, 2003). Ragozzino, Reuer, and Trigeorgis (2016) define real option as ability to change course of investment decision, when uncertainty exists. To be in line with the research topic, this definition will be used during current research.

Does real option can be used in this case?

To use real options, a several conditions must be met:

- uncertainty regarding the outcome which can be limited: in case of loan, some level of uncertainty exists about partial or full loan repayment.
- the managerial flexibility: for a loan life period, a bank has ability to take some actions to maintain a profit or to prevent losses.
- totally or partially irreversible investment: loans can by characterized by a high degree of irreversibility (e.g., partial or total loss of loan).
- asymmetric payoffs: expected returns on loans can be asymmetric.

Among all bank activities, the loan granting process entails effort to assess accurately all risks related to loan seeker. It is difficult to reach accurate assessment due to the following reasons:

- availability and quality of information.
- loan granting process in banks is based on many different factors and characteristics that cannot always be weighted in a normative way using a formal model (Crouhy et al., 2001), therefore, some level of flexibility in loan granting process is required;
- dual nature of risk (Lueg and Knapik, 2016), in simple words the risk can be overestimated or underestimated then in fact.

In addition, Tversky and Kahneman (1974 and 1979) in their prospect theory showed that decision-making process sometimes includes a number of cognitive errors, such as risk aversion and overestimation of small probabilities (Kahneman et. al., 1982). Thus, loan officer may give an incorrect assessment regarding the granting of a loan.

Similar to Choi and Smith (2002), author of this thesis proposes to consider loan as an investment. That is, granting loan can be seen as a bank make investment today (granting a loan) to get the profit (the interest rate) in the future. But, in contrast to Choi and Smith (2002), the author of this PhD thesis suggests that it is more correct to use ambiguity instead of uncertainty. In the loan granting process, as well as in other decision-making processes, it is very important to have a deep understanding of the difference between risk, uncertainty and ambiguity:

- **Risk** in loan granting process refers to situations under which all potential outcomes (growth forecast, forecast for interest rate changes, expected inflation, etc.,) and their probability of events are known to the decision-maker (loan officer).
- **Uncertainty** in loan granting refers to situations under which either the outcomes or their probabilities of events are unknown to the decision-maker (loan officer). Thus, a decision-maker (loan officer) cannot know with certainty regarding future outcomes from loans (that is, whether a loan will be repaid in full or in part), but it is possible to estimate probabilities for certain events (non-payment of a loan, for example, etc.).
- **Ambiguity** in loan granting process refers to situations under which decision maker (loan officer) can prevent from giving two or more viable *options* (for example two loan seekers) equal consideration. As a result, decision making process may be ineffective. The loan officer may automatically reject one of existing (and possibly good) *options* based solely on their intuition, believing that trusting an unknown event is very risky.

A brief explanation is needed in the decision-making process in granting loans. When a loan seeker contacts a bank for a loan request, a loan officer asks for documents that show a loan seeker's financial situation. Loan officer uses a model, for example a five Cs' model: **C**haracter, **C**apacity, **C**apital, **C**onditions and **C**ollateral (Beaulieu, 1994). In fact, models that are used by one bank may be differ from other banks, what makes it difficult to compare between banks. A loan officer needs to analyze information that was received to form the opinion about (Wright and Davidson, 2000):

- ability of loan applicant to meet loan repayment (capacity),
- sufficient funds to meet loan payments and manage normal (routine) activity (capital),
- additional (alternative) sources that will help to meet loan payments in case that loan applicant can't (collateral).

Ambiguity as well as uncertainty can create a lot of challenges for a loan officer because of the unknown or uncertain outcome, incomplete or a conflict information (Eliaz & Ortoleva, 2016). Loan granting decision making is characterized by some *ambiguous* information that was presented by loan seeker and that needed to be checked and verified by a loan officer. According to Wright and Davidson (2000), there are two sources of ambiguity in banking lending decision:

- the fundamental uncertainty: the information that was presented by loan seeker corresponds the true, actual financial situation.
- risk that information and financial statement that submitted by the loan seeker does not meet with generally accepted accounting rules (GAAP).

The author of this PhD thesis proposes and tests a model that is based on the banks' accounting reports, i.e. accounting reports that comply with accepted accounting standards and rules GAAP. In addition, a model allows a simple comparison between the banks. According to the model, a decision-maker is not directly influenced by the personal information of a loan applicant. Instead, **they make decisions based on the bank's financial reports as well as macroeconomic data**. **The use of the bank's financial reports is also intended to neutralize the cognitive influence and ambiguity preferences** (for example, ambiguity neutral or ambiguity averse) of a decision-maker.

Additionally, it will be very interesting to investigate ambiguity in banking sector for the following reason: according to Caballero and Krishnamurthy (2008), rise of ambiguity that has affected investors behavior was one of the major reasons of financial crisis in 2008. Thus, loans given to one large borrower were cut by almost half at the height of the financial crisis (Ivashina and Scharfstein, 2010).

5.2. Model development

The model proposed by the author of this thesis is a modification of the model of Choi and Smith (2002). The model is based on same assumptions as described below:

- risk neutrality - bank is risk neutral;

- equal sensitivity - bank assets and liabilities are equally sensitive to changes in interest rate.

The bank decision to accept a loan is based on the net present value (NPV) of the loans (Choi and Smith, 2002). NPV is the discounted net interest revenue which is calculated as interest income minus the interest expense and loan losses. A bank pays C (cost) to fund a loan (investment) which yields a cash flow of P (interest payment) per unit time (Choi and Smith, 2002). The uncertainty stemming from the stochastic variables, P and C appears for each bank. Thus, a bank can delay granting loan from its own perspective by rejecting loan application until the economic condition will be more favorable to the bank (Choi and Smith, 2002).

Choi and Smith (2002) assume that interest payment cash flow, P, of the asset (e.g., loan) follows a geometric Brownian motion of the next form:

$$\frac{dP}{P} = \mu_P dt + \sigma_P dZ_P \qquad 5.1$$

The liability to fund the loan, C, also follows the geometric Brownian process, similarly to P (Choi and Smith, 2002):

$$\frac{dC}{C} = \mu_C dt + \sigma_C dZ_C \qquad 5.2$$

where μ is the expected drift (i.e., growth rate), σ is the diffusion (volatility) of the process. dZ refers the increment of a standard Wiener process.

The optimal timing of investment (loans) will determine option value to grant a loan (Choi and Smith, 2002). By comparison of potential and outstanding loan, Choi and Smith (2002) determine the trigger point when a bank grant the actual loans. They define $V(P, C)$ as the value of an opportunity to grant a loan. When no actual return on the potential loan, the value of the opportunity to grant the loan, $V(P, C)$, is derived from its expected capital gains. Choi and Smith (2002) use Ito's lemma and equate $E[dV(P, C)]$, the expected capital gain over dt, to $rV(P, C)dt$, from the asset equilibrium condition, where r is the bank's constant normal return (or discount rate), they receive the following differential equation:

$$\frac{1}{2}\sigma_P^2 P^2 V_{PP} + \rho\sigma_P PCV_{PC} + \frac{1}{2}\sigma_C^2 C^2 V_{CC} + \mu_P PV_P + \mu_C CV_C - rV = 0 \qquad 5.3$$

where ρ is the instantaneous correlation coefficient between the Wiener processes dZ_P and dZ_C. The correlation coefficient describes price and cost behavior over time.

Through the changes in variables that $X(Q) \equiv \frac{V(P,C)}{C}$, $Q \equiv \frac{P}{C}$, equation (5.3) can be transformed into:

$$\frac{1}{2}(\sigma_P^2 - 2\rho\sigma_P\sigma_C + \sigma_C^2)\, Q^2\, X_{QQ} + (\mu_P + \mu_C)QX_Q - (r - \mu_C)X = 0 \quad 5.4$$

Under assumption that interest rates have directly affect both the stochastic nature of the price of the loan and the sources for loan, the first term of equation (5.4), $\sigma_P^2 - 2\rho\sigma_P\sigma_C + \sigma_C^2$, means the interest rate risk plus risk of default that the bank will face (Choi and Smith, 2002). Thus, this equation is very important for loan granting under uncertainty.

$$X(Q) = A_0 Q^{-\alpha} + BQ^{\beta} \quad 5.5$$

where:

$$-\alpha = \frac{(a-b) - \sqrt{(b-a)^2 - 4ac}}{2a} < 0, \quad 5.6$$

$$-\beta = \frac{(a-b) - \sqrt{(b-a)^2 - 4ac}}{2a} > 1, \quad 5.7$$

(for the solution of the partial differential equation see appendix 1)

$$\alpha = \frac{1}{2}(\sigma_P^2 - 2\rho\sigma_P\sigma_C + \sigma_C^2), b = \mu_P - \mu_C = \mu_C - r \quad 5.8$$

A_0 and B are constants derived from the boundary conditions (Choi and Smith, 2002).

According to Choi and Smith (2002), for a very low price-cost ratio, Q, the option to grant a loan should be approximately worthless (e.g., deep out-of-money). Therefore, the solution for equation (4.5) should be $A_0 = 0$.

The outstanding loan generates both interest income and capital gain. Therefore, the value of an outstanding loan $W(P, C)$ must fulfill the following:

$$\frac{1}{2}(\sigma_P^2 P^2 W_{PP} + \rho\sigma_P\sigma_C PCW_{PC} + \frac{1}{2}\sigma_C^2 C^2 W_{CC} + \mu_P PW_p + \mu_C CW_C - rW + P = 0 \quad 5.9$$

By comparing between equation (5.3) and equation (5.9), Choi and Smith (2002) find that the difference between these two equations is only unit income P. As in the case of equation (5.3), using $Y(Q) \equiv \frac{W}{C}$ and $Q \equiv \frac{P}{C}$ allows equation (5.9) to be:

$$\frac{1}{2}(\sigma_P^2 - 2\rho\sigma_P\sigma_C + \sigma_C^2 Q^2 Y_{QQ} + (\mu_P - \mu_C Q Y_Q - (r - \mu_C)Y + Q = 0 \quad 5.10$$

The condition for convergence is $r > \mu_P$, therefore, the solution is:

$$Y(Q) = AQ^{-\alpha} + B_1 Q^{\beta} + \frac{Q}{r - \mu_P} \quad 5.11$$

where: Q is the effective yield of the loan when the loan's market value is equal to the loan cost. The term $\frac{Q}{r-\mu_P}$ is expected perpetuity of a unit interest income per unit cost. Thus, $AQ^{-\alpha} + B_1 Q^{\beta}$ should be the option value of loan's liquidation. The value of the option decreases as Q increases. Moreover, for a very high Q, the value of the option must be near 0, i.e., $B_1 = 0$ (Choi and Smith, 2002).

To set up the value to wait, Choi and Smith (2002) define $M(Q) = Y(Q) - X(Q)$. From equations (5.4) and (5.10), $M(Q)$ satisfies the following equation:

$$0 = \frac{1}{2}\left(\sigma_P^2 - 2\rho\sigma_P\sigma_C + \sigma_C^2\right)Q^2 M_{QQ} + (\mu_P - \mu_C)QM_Q - (r - \mu_C)M + Q \quad 5.12$$

After evaluation of equation (5.12) at the investment (loan) trigger point, Q_H, Choi and Smith (2002) receive:

$$Q_H = -\frac{1}{2}(\sigma_P^2 - 2\rho\sigma_P\sigma_C + \sigma_C^2)Q_H^2 M_{QQ}(Q_H) + (r - \mu_C) \quad 5.13$$

Since $M(Q_H) = 1$, $M_Q(Q_H) = 0$, $M_Q(Q_H) = M_Q(Q_L) = 0$ and $M(Q_H) > M(Q_L)$, therefore, $M(Q)$ must be concave at Q_H and convex at Q_L (see appendix 2). From this $MQQ(QH) < 0$.

The last equation, (5.13). is very important, because it shows the relationship between the value to wait and the uncertainty. In simple words, Q_H, the loan trigger (e.g., granting more loans) is a function of future uncertainty that is presented as $-\frac{1}{2}(\sigma_P^2 - 2\rho\sigma_P\sigma_C + \sigma_C^2)Q_H^2 M_{QQ}(Q_H)$, and net benefits from loan granting, are represented by $(r - \mu_C)$.

The real option model for lending decisions developed by Choi and Smith (2002) notes that the uncertainty regarding to interest income and loan expenses has effect on granting loan decision. And this is in addition to loan expenses. In their research, **Choi and Smith (2002) presented empirical proof that high uncertainty decreases banks loan activities**. Choi and Smith (2002) **suggest that correlation between interest income and loan expenses has influence on the value of waiting loan decision**. This was an inspiration for the author of this

PhD thesis to conduct a similar study for banks in Israel, but with a modification to their model, such that instead of uncertainty he uses ambiguity. More details below.

5.3. Empirical model framework

According to Choi and Smith (2002) investment (i.e., banks loan activity) is a function of uncertainty and loan benefits as described below:

$$LA_i = \alpha + \beta_1 Uncerainty_i + \beta_2 LoanBenefit_i + \mathrm{e_i} \qquad 5.14$$

Loan to Asset ,LA_i, is independent variable. This ratio is in fact a kind of a basic measure of composition assets of the bank. Loan to Asset shows the percentage of assets dedicated to loans. As the value of the ratio is higher, the liquidity of the bank is lower. Moreover, high ratio shows that bank has high exposure to default in case of non-payment of loans. In simple words, LA_i is the difference between existing loan and potential loan that can be granted in the future or, in other words, it is bank's loan activity.

The author of this PhD thesis uses **real options as an analytical tool**. Bank's loan activity can be described within the real option framework as compound options that consists of **option to wait, option to growth and option on abandon**. The higher the uncertainty - the greater the losses from the existing loans - the higher the value of the option (option to wait) and thus a bank will prefer to wait before granting a new loan (Choi and Smith, 2002).

As the gap between existing loans and future loans increases - a bank can increase lending activity and vice versa - as the gap is smaller - a bank can reduce and even stop providing new loans until the conditions are ripe to resume lending activity.

$LoanBenefit_i$ is dependent variable. In fact, it is a set of dependent variables that describes the net profit from granting a loan.

Choi and Smith (2002) in their model tested effect that has uncertainty (*UNC*) on loan granting process by measuring uncertainty by two ways: variance or correlation. They used regression as described below:

$$LA_i = \alpha + \beta_1 UNC_i + \beta_2 NIIAA_i + \beta_3 LPAA + \mathrm{e}_i \qquad 5.15$$

where:

UNC is $CORR$ or VAR;

$ALAA$ - ten years average of loan-to-asset ratio;

$CORR$ – correlation between interest revenue and interest expense plus loan loss provisions for ten years;

VAR - variance of net interest income divided by average assets;

$NIIAA$ - 10-year average of net interest income divided by average assets,

$LPAA$ – ten years average of loan loss provision divided by average assets;

Choi and Smith (2002) pointed that, according to existing scientific literature, such as Fazzari, Hubbard, and Peterson (1988), Hoshi, Kashyap, and Scharfstein (1991), there is a measurement error problem in analyzing the effect of liquidity on investment decision. This problem is known in the scientific literature as "omitted variable". This problem takes place when regression specification assumes liquidity as exogenous. In fact, liquidity can be a proxy for unobservable determinants of investment - the investment profitability (Choi and Smith, 2002). The problem causes an inaccuracy in the liquidity coefficient assessment. Choi and Smith (2002) adopted the approach that is accepted in the investment literature mentioned before. But in their case the situation is different from the one that is described in the investment literature. Choi and Smith (2002) argue that in their case, the source of biased estimation problem is in the endogeneity problem and not in the omitted variable problem. Thus, uncertainty can be endogenous and not exogenous, so correlation with the dependent variables may take a place. That causes a bias of the beta coefficient of uncertainty variable. Thus, a loan-to-assets variable may affect the uncertainty variable and it can lead to its correlation with disturbance. To deal with the endogenous problem, Choi and Smith (2002) divided the sample into two groups by loan-to-asset size. The idea behind this action is expectation of different relationship between loan-to-assets and net interest margin variance for high and low loan-to-assets sample.

In decision making process uncertainty refers to situations in which outcomes or its probabilities of occurrences are unknown. This can be caused by several factors such as political changes, changes in government policies and market and economic changes. To be closed to the subject of the thesis, in loan granting decision making process factors that inflict uncertainties are unknown or unpredictable, such as economic condition, competition banks actions, regulatory changes, etc.

In terms of Knightian distinction, according to SEU (Subject Expected Utility) theory, all uncertainty can be reduced to risk (Rustichini et al, 2005). Therefore, equation 5.14 can be written as:

$$LA_i = \alpha + \beta_1 Risk_i + \beta_2 LoanBenefit_i + \mathrm{e}_i \quad 5.16$$

On the other hand, uncertainty can be divided into risk and ambiguity(Dannenberg et al, 2014). Therefore, uncertainty can be also defined as in equation:

$$Uncertainty = Risk + Ambiguity \quad 5.17$$

An alternative version of the regression model is thus obtained::

$$LA_i = \alpha + \beta_1 (Risk + Ambiguity)_i + \beta_2 LoanBenefit_i + \mathrm{e}_i \quad 5.18$$

According to Arend (2020) ambiguity refers to a situation where the possible outcomes are known, as well as the possible actions that can take place and the payoff for each action in each outcome. However, the absolute probabilities of these outcomes cannot be known at the decision-making point. **The author of the thesis argues that it is more correct to use ambiguity rather than uncertainty because**:

- It is possible to calculate the expected future returns from a given loan,
- It is possible to calculate/build a plan and ensure as much as possible the repayment of a loan by the loan applicant (linkage of loan to index/expected inflation),
- despite the previous two points, there is no absolute probability about future repayments of the loan. Thus, for example, a regulatory change in the interest rate can cause a bank to have to change its decisions on the amount of new loans. Insolvency or bankruptcy of several borrowers can also cause the bank to reach a similar decision.

When such information arrives (changes in interest rates, changes in demand for loans, bankruptcy of borrowers, etc.), the bank must have the flexibility to adapt to the changes.

The author of the thesis uses the measure of ambiguity proposed by Yitzhakian (2012). In his research, Ytzhakian (2012) concluded that **ambiguity can be measured as four-time variance**. The author of the thesis assumes that **four-time variance of Loan Loss Provision is the best suitable variable that can describe ambiguity**. This measure is closer to the classical calculation of uncertainty used by Choi and Smith (2002),

To deal with endogeneity problem, the author of the thesis differentiates banks in the study according to their total asset. Total assets present the bank size. The idea behind such decision is that the large banks have more assets and, as result - more loans that bank can

grant. That is, the loan-to-assets ratio in large banks will be greater than in medium and small banks. The author examines each group of banks (large banks, medium-sized banks and small banks) separately. The author expects different relationship between loan-to-assets and net interest margin variance due to banks size. For small banks, he expects a more significant relationship than for medium and large banks. It is consistent with Choi and Smith (2002) study.

In addition, data regarding the banking sector is aggregated, and it is not possible to analyze individual credit decisions based on it. This can only be done at the macro level. Therefore, transition from micro-level analysis (i.e., individual loan approval) to macro-level analysis (i.e., expanding/constricting credit actions) would be helpful. Real options framework can help in decisions about whether to grant credits or not. Thus, the author examines the entire banking industry (all banks together) in addition to three groups divided by asset size. **Banking loan activity (which is related to compound real option) can be described as the function of ambiguity, risk and loan benefits**.

5.3.1. Goals and hypotheses of the analysis

As previously stated, lack of information or unqualified information can increase ambiguity and thus negatively affect decision-making. Wrong decisions can result in a bank giving loans but not getting its money back. This situation becomes dangerous when the amount of bad loans is large. This situation endangers the bank and could put it into bankruptcy. Because banks are an economic engine, banks bankruptcy can seriously damage the economic situation. From this point, the main goal of the thesis is to propose and to test a model explaining banks loan activity, based only on the banks' financial reports and macroeconomic data only. The purpose of use of dry numbers is intended to prevent as much as possible cognitive errors that can be made in the decision-making process. In the author's opinion, this can solve the problem of lack of information or low-quality information as well as reduce cognitive errors in the decision-making process and be a guide for a loan officer.

The study includes four stages as described in the scheme 5.1. In the first stage author defines all necessary variables. This is crucial for understanding the model. In the second stage of the study the author uses OLS regression to test the hypotheses. In the third stage the author compares results for three different types of banks (small banks, medium banks and large banks). In addition, results obtained at the level of the entire banking industry are

presented. In the final stage the author summarizes and discusses the results and presents conclusions.

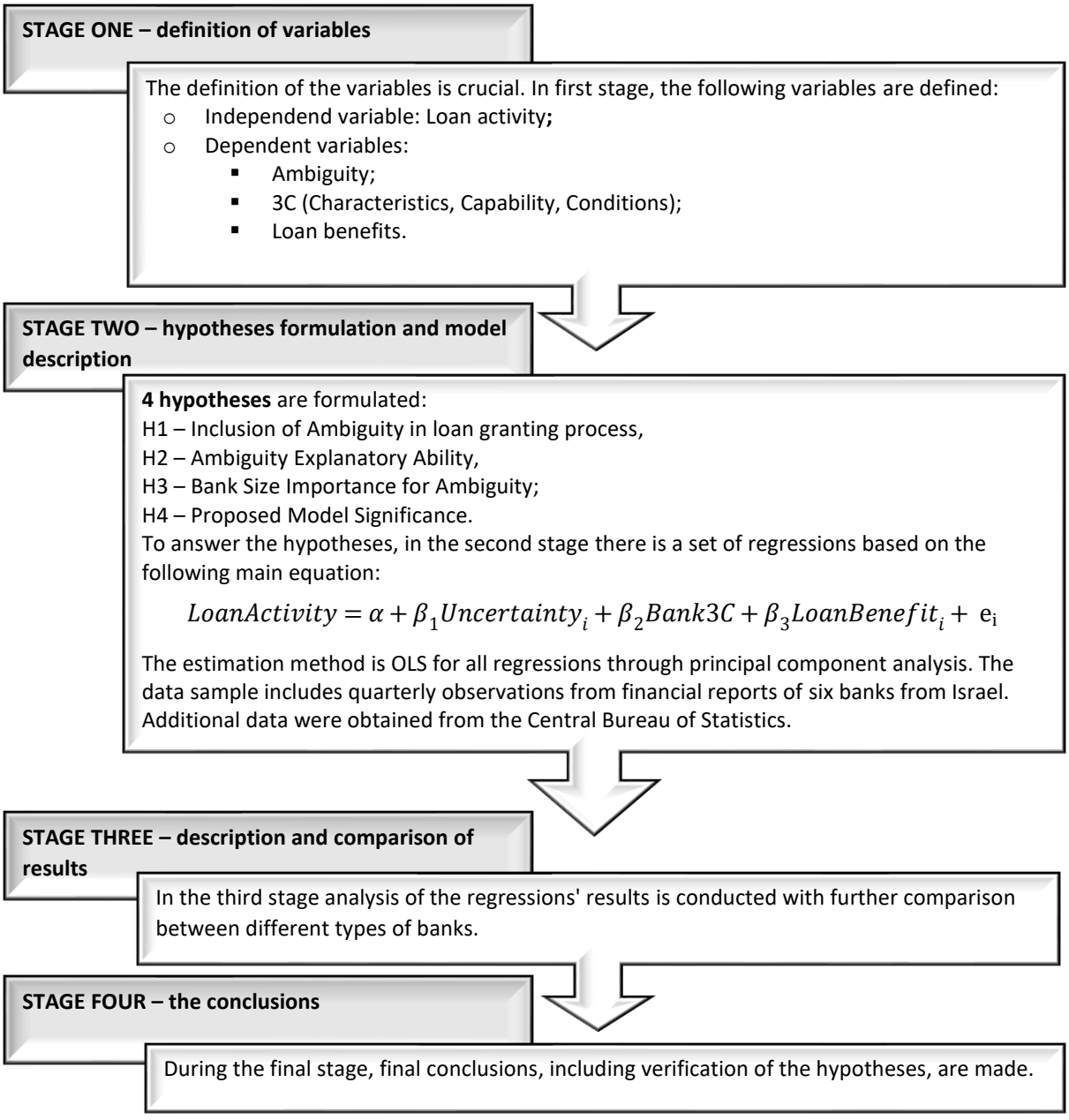


Figure 27. Procedure of the research

Source: Author's own work.

Loan activity can be measured using $\boldsymbol{CFPTA}$ – Credit For Public to ln Total Assets. This set of variables presents the loan trigger for the bank. In fact, this is related to a **real compound option.**

Instead of uncertainty of a loan activity used in the Choi and Smith (2002) model the author

of this PhD thesis proposes **ambiguity**. This set of variables presents ambiguity in loan granting process.

Bank 3C are elements of a group of variables that consist of a bank's attributes. Total Assets (***TA***) are used as bank characteristics. This set of variables presents total assets of the bank. As **Capability** Real Weighted Revenue (***RWR***) is used. And as **Conditions**: GDP per capita **(*GDPpC*.)** and Interest Rate ***InR*** are used.

As **Loan benefits** the authors uses:

- ***NetIn* –** Net Interest Income Neto. Profit that a bank receives from interest paid on a loan.
- ***LLPTA*** – Loan Loss Provision to Total Assets. The ratio expresses the bank estimation of lose from loans given, from its total assets

Since the author in the research uses time series data - there is a concern of unit root. Therefore, the author decided to perform a first-order difference on each variable. Therefore, the econometric model is described follow:

For testing three groups of banks separately, according to the size of the banks, the author of the thesis constructed the following regression:

$$d_1 CFPTA = \alpha + \beta_1 d_1 AMB + \beta_3 d_1 lnTA + \beta_3 d_1 NetIn + \beta_4 LLPTA \qquad 5.17$$

where:

$\boldsymbol{d_1 CFPTA}$ – the difference between **Credit For Public** to **Total Assets**. It is dependent variable. As the ratio ***CFPTA*** increases, bank can grant more loans. In fact, this variable is a bank's loan trigger, or, in simple words, bank's decision to approve more loans (loan activity). In fact, this is related to a **real option – option to wait**, similar to LA_i in Smith and Choi (2002) research.

$\boldsymbol{d_1 AMB}$ - the difference between **Ambiguity**, where the difference is calculated as the difference between the current quarter and the previous quarter. **Ambiguity** is calculated as four-time variance of Loan Loss Provision. The author of the thesis expects negative relationship between ambiguity (dependent variable) and loan activity.

$\boldsymbol{d_1 lnTA}$ - the difference between the natural logarithm of bank's **Total Assets**. This variable indicates the change in the banks capitalization, or, in other words, bank size. Positive coefficient is expected. The author assumes that as the bank has access to more funds, more loans can be granted.

$\boldsymbol{d_1 NetIn}$ - the difference between **Interest Income (Net),** where the difference is calculated

as the difference between the current quarter and the previous quarter. The author expects positive coefficient, because the greater a bank's net profit from a loan, the more profitable it is for the bank to grant more loans.

$\boldsymbol{d_1 LLPTA}$ – the difference between **Loan Loss Provision** to **Total Assets**. As $\boldsymbol{LLPTA}$ increases a bank loses more money, that is, the decision-making process in loan granting is wrong. Therefore, negative coefficient is expected here.

For testing all three group of banks together (as one group) and the effect of macroeconomic factors on loan granting process, the author of the thesis built the following regression:

$$d_1 CFPTA = \alpha + \beta_1 d_1 AMB + \beta_3 d_1 lnTA + \beta_3 d_1 NetIn + \beta_4 LLPTA + \beta_5 d_1 lnRWR + \beta_6 \%\Delta \mathrm{GDPpC} + \beta_7 d_1 lnR \quad 5.18$$

where:

$\boldsymbol{d_1 lnRWR}$: the difference between natural logarithm of **Real Weighted Revenue**. A high value of variable indicates the high ability to cover the loan by income. Therefore, the author expects here positive coefficient.

$\%\Delta \boldsymbol{GDPpC}$ - percentage change in GDP per capita. This variable shows economic growth and macroeconomic trends in the overall economy. Positive coefficient is expected.

$\boldsymbol{d_1 lnR}$ – the difference between the natural logarithm of the **Interest Rate**. The interest rate is the price of money. The variable indicates market conditions for both the borrower and for the bank: the higher interest rate - more expensive loans. Negative coefficient is expected.

There are **4 hypotheses** the Author wants to test in this PhD thesis. They are described as follows:

H1 – ***Inclusion of Ambiguity in loan granting process***: Apart from the 3 bank characteristics: capital, capacity and character and profit from loan the banking loan activity can be explained in terms of ambiguity in loan granting process.

H2 - ***Ambiguity Explanatory Ability***: The proposed method of ambiguity estimation in loan decision-making process has better explanatory ability than uncertainty measuring method, presented in Choi and Smith (2002) study.

H3 -***Bank Size Importance for Ambiguity***: Large banks are less cautious in decision-making process of loan activities than medium and small banks.

H4 – ***Proposed Model Significance***: All the components of the proposed model are

statistically significant.

5.3.2. Data

The author of the thesis collected data on loan activities (Credit for Public to Total Assets), total assets, loan loss provisions, interest income, and interest expense for the Top Retail Banking holding companies: bank Ha-Poalim, bank Leumi, bank Mizrahi-Tefahot, bank Discount, The First International Bank in Israel (FIBI) and Bank of Jerusalem (as of March 31, 2023) for the period from first quarter of 2000 to first quarter of 2023. The data were from the Bank of Israel (the Central bank) and annual and quarterly financial statements of six listed banks. These banks were divided into three groups according to its assets. This criterion is sufficient for comparison among banks for examining decision-making process in granting loans. Thus, the author got three groups of banks: small banks, medium banks and large banks, where in each group there are two banks, which are close to each other in terms of total assets. Each sample consist of 168 observations (84 observations for each bank).

Additional to three samples (small banks, medium banks, large banks), the study includes fourth sample – same observations listed before (credit for public to total assets, total assets, loan loss provisions, interest income, and interest expense) of all six banks together, with macroeconomic observations: Real Weighted Revenue, GDP per capita and Interest Rate. Macroeconomic observations were taken from the Central Bureau of Statistics and Bank of Israel. The data from period of first quarter of 2000 to the first quarter of 2023 as well as reports.

5.3. Results

The initial steps of the empirical analysis are the test for stationarity, heteroskedasticity, and autocorrelation. The first test was Dickey–Fuller test. According to the results (Table 9) – all variables are stationary. To test for heteroskedasticity in a linear regression model, the Breusch–Pagan test was used. Additionally, the Hausman test is used to check whether the fixed effects and random effects are significantly different. Finally, the Wooldridge test for serial autocorrelation was conducted. According to the results (Table 10), the most suitable model of linear regression is the Random Effects Panel.

Table 9. Panel data Unit Root test

	PANEL DATA UNIT ROOT TESTS								
	Levin–Lin–Chu			Harris-Tzavalis			Breitung		
	adj T	PROB	RESOLUTION	Z	PROB	RESOLUTIO	lambda	PROB	RESOLUTIO
d1lnTAl	-6.7518	0.0000	STATIONARY	-37.0901	0.0000	STATIONAR	-5.4947	0.0000	STATIONAR`
d1CFPTAl	-4.9261	0.0000	STATIONARY	-37.0634	0.0000	STATIONAR	-7.7895	0.0000	STATIONAR`
d1NETINl	-13.4002	0.0000	STATIONARY	-45.1361	0.0000	STATIONAR	-6.3258	0.0000	STATIONAR`
d1LLPTAl	-8.8677	0.0000	STATIONARY	-44.2346	0.0000	STATIONAR	-9.6594	0.0000	STATIONAR`
d1AMBl	-8.0979	0.0000	STATIONARY	-38.3924	0.0000	STATIONAR	-3.6385	0.0000	STATIONAR`
d1lnTAm	-6.5492	0.0000	STATIONARY	-30.7071	0.0000	STATIONAR	-7.5174	0.0000	STATIONAR`
d1CFPTAm	-5.9601	0.0000	STATIONARY	-32.6597	0.0000	STATIONAR	-6.6827	0.0000	STATIONAR`
d1NETINm	-6.4498	0.0000	STATIONARY	-41.9153	0.0000	STATIONAR	-6.6666	0.0000	STATIONAR`
d1LLPTAm	-9.4466	0.0000	STATIONARY	-38.9291	0.0000	STATIONAR	-8.5170	0.0000	STATIONAR`
d1AMBm	-7.8942	0.0000	STATIONARY	-30.7775	0.0000	STATIONAR	-5.3788	0.0000	STATIONAR`
d1lnTAs	-6.3620	0.0000	STATIONARY	-39.6803	0.0000	STATIONAR	-6.7330	0.0000	STATIONAR`
d1CFPTAs	-5.1119	0.0000	STATIONARY	-42.8883	0.0000	STATIONAR	-5.6912	0.0000	STATIONAR`
d1NETINs	-7.4923	0.0000	STATIONARY	-44.9823	0.0000	STATIONAR	-5.3860	0.0000	STATIONAR`
d1LLPTAs	-7.8864	0.0000	STATIONARY	-37.1084	0.0000	STATIONAR	-5.6401	0.0000	STATIONAR`
d1AMBs	-6.9258	0.0000	STATIONARY	-36.1941	0.0000	STATIONAR	-6.5788	0.0000	STATIONAR`

Source: Author's own work.

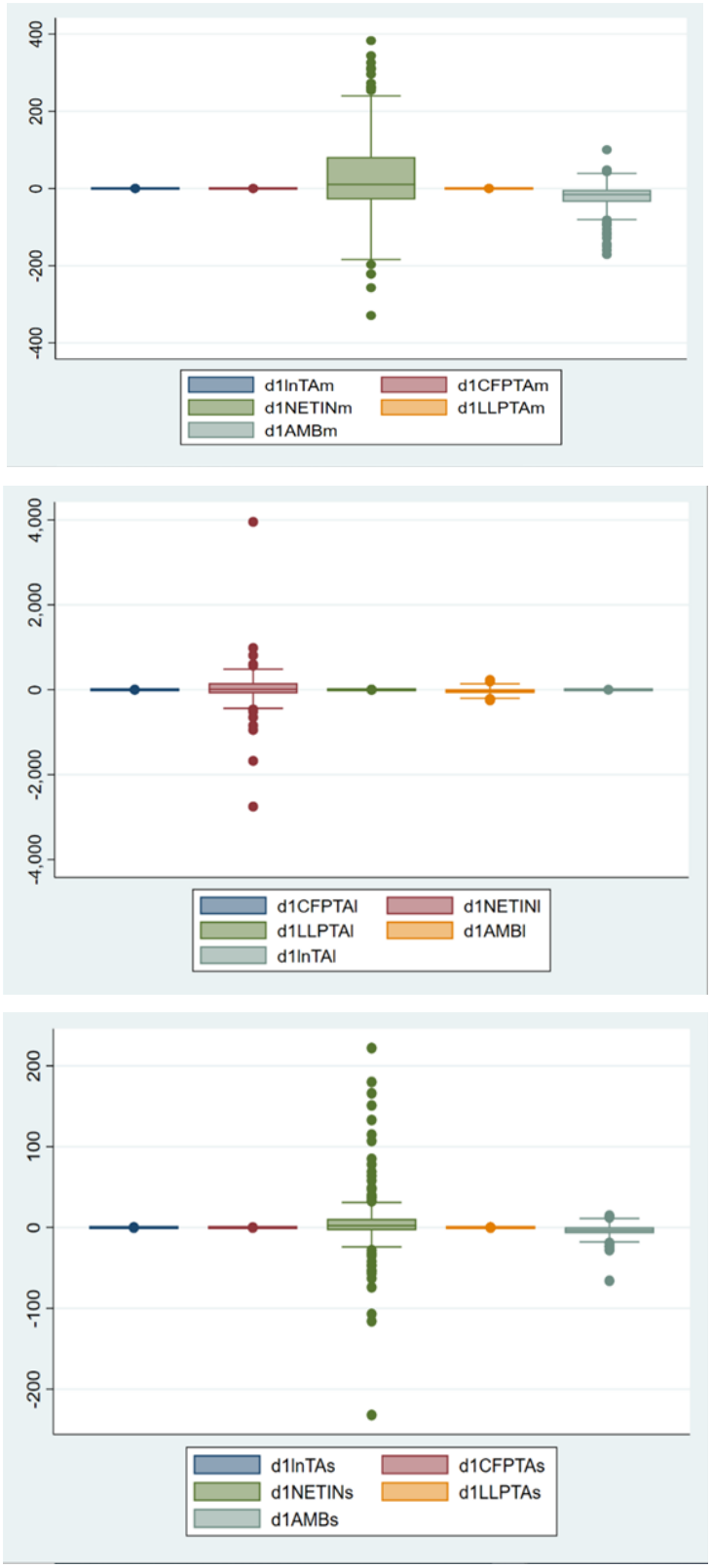
Table 10. Test for choosing the suitable model

		TESTS FOR CHOSING RE vs FE vs POOLED OLS		
		LARGE	MEDIUM	SMALL
Hausman	CHI2	0.22	0.02	0.96
	PROB	0.8976	0.9876	0.6186
	RESOLUTION	RANDOM EFFECT	RANDOM EFFECT	RANDOM EFFECT
Breusch-Pagan LM	CHI2	0.00	0.00	0.00
	PROB	1.0000	1.0000	1.0000
	RESOLUTION	RANDOM EFFECT	RANDOM EFFECT	RANDOM EFFECT
Wooldridge	F	4.426	0.843	0.14
	PROB	0.2825	0.5272	0.7722
	RESOLUTION	NO AUTOCORRELATION	NO AUTOCORRELATION	NO AUTOCORRELATION

Source: Author's own work.

The existence of outliers is checked. Since the sample contains very large numbers (millions of shekels), when there is no change, the difference is 0, resulting in a significant deviation. Hence, the author performs a **Box plot**. The **Box plot** outputs are shown on Figure 27. Based on the Box plot, there is a problem of outliers, and the sample is relatively small. Since it is not possible to remove data to handle outliers, the author uses Robust Mode. Robust Mode handles both heteroskedasticity and outliers.

Figure 28. Outliers



Source: Author's own work.

The results for the model, obtained for the small, medium and large banks as well as for all six banks together from the study sample, are presented in Table 11 (for small-sized banks), Table 12 (for medium-sized banks), Table 13 (for large-sized banks) and Table 14 (for all six banks together with macroeconomic variables).

Table 11. Regression results - small banks

```
. xtreg d1CFPTAs d1lnTAs d1NETINs d1LLPTAs d1AMBs, re robust

Random-effects GLS regression                   Number of obs     =       168
Group variable: LEUMI                           Number of groups  =         2

R-squared:                                      Obs per group:
     Within  = 0.4014                                         min =        84
     Between = 1.0000                                         avg =      84.0
     Overall = 0.3980                                         max =        84

                                                Wald chi2(1)      =         .
corr(u_i, X) = 0 (assumed)                      Prob > chi2       =         .

                                    (Std. err. adjusted for 2 clusters in LEUMI)
------------------------------------------------------------------------------
             |               Robust
    d1CFPTAs |      Coef.   Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
     d1lnTAs |  -.0536583   .0025982   -20.65   0.000    -.0587506   -.048566
   d1NETINs  |   2.98e-06   9.14e-08    32.63   0.000     2.80e-06    3.16e-06
   d1LLPTAs  |   -.007796   .0268356    -0.29   0.771    -.0603928    .0448009
     d1AMBs  |  -.0000655   8.51e-06    -7.69   0.000    -.0000822   -.0000488
       _cons |   .0003322   .0001539     2.16   0.031     .0000305    .0006338
-------------+----------------------------------------------------------------
     sigma_u |           0
     sigma_e |  .00115844
         rho |           0   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Source: Author's own work.

As can be seen from the results, the **variable that is statistically insignificant**, especially in the case of small banks, is d_1LLPTA. This variable represents the bank's risk. Since risk is something that is known, it can be quantified and banks have analytical tools to deal with it. The author of the thesis assumes that this is the reason why especially small banks are not sensitive to it. According to the author this is an oligopolistic industry, where large banks control it and set "playing conditions" for medium-sized banks as well as small banks. Small and medium-sized banks actually work on accumulating capital (capitalization), similar to

large banks.

Table 12. Regression results– medium banks

```
. xtreg d1CFPTAm d1lnTAm d1NETINm d1LLPTAm d1AMBm, re robust

Random-effects GLS regression                   Number of obs     =       168
Group variable: LEUMI                           Number of groups  =         2

R-squared:                                      Obs per group:
     Within  = 0.3685                                         min =        84
     Between = 1.0000                                         avg =      84.0
     Overall = 0.3711                                         max =        84

                                                Wald chi2(1)      =         .
corr(u_i, X) = 0 (assumed)                      Prob > chi2       =         .

                                    (Std. err. adjusted for 2 clusters in LEUMI)
------------------------------------------------------------------------------
             |               Robust
    d1CFPTAm |      Coef.   Std. err.      z    P>|z|     [95% conf. interval]
-------------+----------------------------------------------------------------
     d1lnTAm |  -.0201458   .0007597   -26.52   0.000    -.0216348   -.0186567
    d1NETINm |   8.30e-07   4.23e-08    19.62   0.000     7.47e-07    9.13e-07
    d1LLPTAm |    .024934   .0429795     0.58   0.562    -.0593042    .1091722
      d1AMBm |   2.06e-06   4.44e-07     4.64   0.000     1.19e-06    2.93e-06
       _cons |   .0004027   7.19e-06    56.03   0.000     .0003886    .0004168
-------------+----------------------------------------------------------------
     sigma_u |           0
     sigma_e |  .00073391
         rho |           0   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Source: Author's own work.

In fact, the variable $\boldsymbol{d_1 lnR}$ is the change in the price of money for the bank, so it is not surprising that it was accepted as **statistically significant**. The other variables did not turn out to be significant, that is, they are not relevant, and it is necessary to find and examine other macroeconomic variables.

Table 13. Regression results– large banks

```
. xtreg d1CFPTA1 d1lnTA1 d1NETIN1 d1LLPTA1 d1AMB1, re robust

Random-effects GLS regression                   Number of obs     =       168
Group variable: LEUMI                           Number of groups  =         2

R-squared:                                      Obs per group:
     Within  = 0.4439                                         min =        84
     Between = 1.0000                                         avg =      84.0
     Overall = 0.4431                                         max =        84

                                                Wald chi2(1)      =         .
corr(u_i, X) = 0 (assumed)                      Prob > chi2       =         .

                                  (Std. err. adjusted for 2 clusters in LEUMI)
```

d1CFPTA1	Coefficient	Robust std. err.	z	P>|z|	[95% conf.	interval]
d1lnTA1	-.0302608	.0019054	-15.88	0.000	-.0339954	-.0265263
d1NETIN1	1.65e-08	1.84e-08	0.90	0.370	-1.96e-08	5.27e-08
d1LLPTA1	-.020263	.0666393	-0.30	0.761	-.1508737	.1103477
d1AMB1	-7.14e-07	6.18e-07	-1.16	0.247	-1.93e-06	4.96e-07
_cons	.0002394	.0000275	8.71	0.000	.0001856	.0002933
sigma_u	0					
sigma_e	.000791					
rho	0	(fraction of variance due to u_i)				

Source: Author's own work.

Table 14. Regression results for the relationship between loan activities, ambiguity and macroeconomic conditions – all six banks together

```
. reg d1CFPTA d1lnTA d1NETIN d1LLPTA d1AMB d1lnR d1lnRWG GDPpC, robust

Linear regression                               Number of obs     =         84
                                                F(6, 76)          =          .
                                                Prob > F          =          .
                                                R-squared         =     0.4647
                                                Root MSE          =    .00052
```

d1CFPTA	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
d1lnTA	-.028301	.0086194	-3.28	0.002	-.0454681	-.011134
d1NETIN	6.55e-11	9.65e-11	0.68	0.499	-1.27e-10	2.58e-10
d1LLPTA	-.043582	.0667107	-0.65	0.516	-.1764479	.0892839
d1AMB	-5.99e-07	1.32e-06	-0.45	0.651	-3.23e-06	2.03e-06
d1lnR	.0012459	.0004071	3.06	0.003	.000435	.0020567
d1lnRWG	.0007898	.0038305	0.21	0.837	-.0068394	.0084189
GDPpC	.0000566	.0000442	1.28	0.204	-.0000314	.0001447
_cons	.0002339	.0001045	2.24	0.028	.0000259	.000442

Source: Author's own work.

5.4. Discussion and conclusions

The main empirical purpose of this PhD thesis was to introduce and test a model, based on the concept of a real option explaining banks loan activities (i.e., granting loan). The dependent variable in the model is Credit for Public. This variable expresses a ratio between granted loans and the bank's total assets. Let's imagine a round cake (total assets of the bank), where Credit for Public is a piece of the cake that was cut and took away. The smaller this piece, the larger the remaining pie portion. To be more closely related to the topic of the thesis, the smaller Credit for Public to Total Assets ratio, the more funds the bank has for providing new loans. In fact, it can be described as a real option such as the option to wait. The model assumes that a real option (option to wait) is affected by ambiguity and benefits from loans (interest paid on a loan). The author of the thesis expected that the relationship between ambiguity and Credit for Public on total Assets would be negative, because when there is more ambiguity, the bank prefers to wait before granting new loans. Table 14 presents results of the model regression. As can be seen from Table 14 - the coefficient of ambiguity is negative, that support authors expectation.

Now let's move to Benefits from Loans. This part consists of two variables: the author

expected that the coefficient of Net Interest Income would be positive because the more profitable loans are to the bank - the bank has an incentive to offer more loans. Regarding to Loan Loss Provision on Total Assets - this is a variable that describes a ratio of expected losses from loans as a part of the bank's total assets. The author expected a positive coefficient of the total assets, but as can be seen from Table 14 - a negative coefficient was obtained. The author assumes that an explanation for this discrepancy is the size of the sample, that is, the sample is relatively small. This assumption is also supported by the results obtained in Table 11, Table 12, Table 13 that even in these regressions the coefficient is negative, even though the expectation was positive.

Capacity group of variables describes a loan applicant's ability to meet its repayments. In this group there is only one variable - real weighted revenue. As the author of the thesis expected - the obtained coefficient was positive.

Conditions group of variables - describes macroeconomic and market conditions that may have an impact on the bank's loan activities. In this group there are two variables - GDP and interest rate. GDP - the coefficient obtained here is positive, as the author expected at the beginning of the study. Interest rate - also the expectation regarding the coefficient was realized - the obtained coefficient is positive, as observed. All observations in Table 14 statistically significant.

From all listed above, conclusion about first hypothesis can be derived.

H1 – Ambiguity Inclusion hypothesis

Based on results, statistical significance of observations and Table 14, the author of the thesis concludes that this hypothesis is successfully reached. **Including ambiguity to the model gives a significant result**.

In addition, there are three hypotheses in this thesis which have been verified empirically. The overall results and conclusions are as follows**.**

H2 – Ambiguity Explanatory Ability hypothesis

In order to examine which model has an explanatory best, it is customary to use the adjusted R^2. Choi and Smith's (2002) sample include 77 observations, and the author's sample includes 84 observations, that is, these are two relatively small samples. Choi and

Smith (2002) reported adjusted R^2 at a level of 57.7%, when uncertainty measured as correlation between interest income and loan expenses for the 10-year period and adjusted R^2 at a level of 56.7% when uncertainty is measured as variance of the net interest margin after loan loss provision.

The author of the thesis uses ambiguity instead of uncertainty and measures the ambiguity as four different times of provision for bad debts. The author received $R^2 = 0.4647$. Simple calculation of adjusted R^2 (see formula in Appendix 3) gives a result: adjusted $R^2 = 0{,}4145$. That is, adjusted $R^2 is\ 41.5\%$.

From the results obtained it can be seen that in Choi and Smith's (2002) model adjusted R^2coefficient is higher than adjusted R^2coefficient obtained by the ambiguity model presented by author of the thesis. That is, Choi and Smith's (2002) model has a better explanatory power.

In addition, the standard deviation obtained in Choi and Smith (2002) study is larger in two cases: when uncertainty measured as correlation between interest income and loan expenses for the 10-year period, and when uncertainty is measured as a variance of the net interest margin after loan loss provision. Therefore, **Choi and Smith (2002) has a wider spread than the ambiguity model presented by the author**. All these indicate that this hypothesis is not reached. However, this hypothesis can be improved in the future.

H3 - Bank Size Importance for Ambiguity hypothesis

To test this hypothesis, the author divided the sample into three groups: small banks, medium banks and large banks, with only two banks in each group. The dependent variable is credit to the public on total assets is a trigger to make more loans, that is, it refers to a real option (option to wait). According to table 11 that presents the small banks the coefficient of ambiguity is negative as the author expected. In Table 12, which presents the medium-sized banks, it can be seen that the coefficient of ambiguity is already positive. In table 14 that presents large banks again the coefficient of ambiguity is negative. There is significant difference between the three beta coefficients. From Tables 11, 12 and 13 it can be seen that as the credit for public on total assets is higher (trigger to define size of the bank), over other coefficients become insignificant. In simple words – **when a bank is bigger, it has less sensitivity to ambiguity**. It can be explained by a very strict requirements for credit risk and capital requirement. Such strict requirements cause that loan activities are not sensitive to

the changes in investment environments. This finding is similar to conclusion of Choi and Smith (2002). They argued that large banks may face with some restriction on loan activities, therefore, banks loan decision making may not be sensitive to uncertainty as the model predicts.

Based on findings obtained, **only small banks are sensitive to ambiguity**. The explanation for this phenomenon is the amount of assets: it is difficult for smaller banks to give loans because they have fewer assets compared to medium and large banks. From here, any loss of theirs will be difficult to make up.

The banking market in Israel is an oligopolistic market. Large banks lead it, while small and medium-sized banks align with large banks. Both small and mid-sized banks are trying to increase their assets. This is their way of dealing with ambiguity.

Based on all the information listed above, this hypothesis is successfully supported.

H4 – Proposed Model Significance hypothesis:

There are variables with insignificant coefficients. GDP per capita and Real Weighted Revenue have low values and can be omitted without the negative effect on the explanatory variable. However, the main goal is to create an ambiguity-based model with banking and macroeconomic variables. Therefore, the author of the thesis decided not to drop insignificant coefficients. Hence, this hypothesis is partly reached. Thus, in the future this hypothesis shall be studied more deeply to improve future results.

Final remarks

Since the development of real options, they have gained momentum and found an honorable place not only in science but also in various industrial fields such as the automobile industry, aerospace industry, natural resources exploration and more. Despite the popularity and proof that real options help in risk management, they have not found their place in the banking sector. In the field of banking and especially in the provision of loans, an effective tool is required that will give the bank the required flexibility in making decisions related to the provision of a loan.

Loans are one of the main areas in which banks deal. When a bank gives a loan, each borrower can encounter difficulties and thus it will be difficult to repay all or part of the loan. Banks can absorb some loan losses but not when it becomes a "pandemic". This only highlights the need for a flexible tool to help the bank in these situations. Damage in this area could endanger the entire bank, thus creating a "snowball effect" that could endanger and even harm other banks and even the entire economic situation, as was the case in the sub-prime crisis.

During banking loan activity, banks encounter ambiguity. Not all the necessary information is known and clear at the time of making a decision on granting credit. So, decision making person (loan officer) can make a wrong decision. After a bank has approved loans, the information can change, new information will be required to reach correct decisions. A real option is the type of option to wait that can help the bank by "buying" time until the required information arrives or until conditions become clear.

This thesis, based on the study of Choi and Smith (2002), presents and tests real option-based model, in which variables are: ambiguity, banks characteristic and macroeconomic conditions. Hypothesis that this model to have predictive ability was successfully obtained. Moreover, banks were divided into three groups by its size to investigate influence of ambiguity on these banks' loan activity. According to the results obtained, only small banks are sensitive to ambiguity. The larger the bank, the less sensitivity it shows to ambiguity..

This study is not free from limitations. The first limitation is a relatively small sample - only 168 observations for each group of banks and only 84 observations for a model that includes

banking characteristic, macroeconomic conditions, and borrower characteristics were studied. Another limitation is that, due to the unique nature of the banking system in Israel, the results cannot be generalized to the global market.

As a part of future research, the model can be tested in other countries, where banks are similar to banks in Israel. For example: banks in United States and banks in Islamic countries. It is possible that in these countries a larger sample could be obtained, allowing for a more extensive test of the model. The macroeconomic conditions chosen for the model did not provide an exemplary predictions, so it is worth investigating whether this is a phenomenon unique to Israel or if the chosen variables are not suitable for the model. In such a case, one should choose other macroeconomic variables and examine their predictive form. Ambiguity was calculated by author based on the idea that Loan Loss Provisions is the most appropriate figure to describe ambiguity. Although it was a logical idea presented by author of the thesis, more studies must be conducted in order to state that this measurement method is (the most) accurate for the decision makers of bank loan activity.

References

Abinzano, I., Corredor, P., Manuel Mansilla-Fernández, J., 2022, Sovereign debt holdings and banks' credit risk: Evidence from the Eurozone, Finance Research Letters, Vol. 47, Part A, 102600, https://doi.org/10.1016/j.frl.2021.102600.

Abisoye, B., 2007, Real Options Analysis as a Decision Tool in Oil Field Developments, Master thesis of science in engineering and management, Massachusetts Institute of Technology.

Acharya, V. V., Carpenter, J., N., 2002. Corporate bond Valuation and Hedging with Stochastic Interest Rates and Endogenous Bankruptcy. Review of Financial Studies, Vol. 15, No. 5, pp. 1355-1383.

Acharya, V., Steffen, S., 2015. The Greatest Carry Trade Ever? Understanding Eurozone Bank Risks. Journal of Financial Economics, Vol. 115, No. 2, pp. 215–36.

Adams, M., 2004, Real options and customer management in the financial services sector, Journal of Strategic Marketing, Vol. 12, No. 1, pp. 3–11. doi.org/10.1080/ 0965254032000171573.

Aggarwal, D., Monhanty, P., 2021, Influence of imprecise information on risk and ambiguity preferences: Experimental evidence, Managerial and Decision Economics, Vol. 43, No. 4, pp. 1025-1038. doi.org/10.1002/mde.3436.

Alexander, C., Chen, X., 2012, A General Approach to Real Option Valuation with Applications to Real Estate Investments. ICMA Centre Discussion Papers in Finance DP2012-040.

Almamy, J., Aston, J., Ngwa, L. N., 2015, An evaluation of Altman's Z-score using cash flow ratio to predict corporate failure amid the recent financial crisis: Evidence from the UK, Journal of Corporate Finance, pp. 278-285.

Altman E., Hotchkiss E., 2006. Corporate Financial Distress and Bankruptcy, 3rd ed, John Wiley & Sons, Inc. New Jersey, USA.

Altman, E. I., 1968. Financial Ratios, Discriminant Analysis, and the Prediction of Corporate Bankruptcy. Journal of Finance, Vol. 23, No. 2, pp. 589–609.

Altman, E. I., Brady, B., Resti, A., Sironi, A., 2005. The link between default and recovery rates: Theory, empirical evidence, and implications. Journal of Business, Vol. 78, No. 6, pp. 2203-2227.

Altman, E. I., Narayanan, P., 1997. Business Failure Classification Models: An International Survey. International Accounting, 2nd ed. Wiley, New York.

Altman, E. I., Saunders, A., 1997. Credit risk measurement: Developments over the last twenty years. Journal of Banking and Finance Vol. 21, No. 11-12, pp. 1721-1742.

Amiram, D., Beaver, W.H., Landsman, W.R., Zhao, J., 2017, The effects of credit default swap trading on information asymmetry in syndicated loans, Journal of Financial Economics, Vol. 126, No. 2,

pp. 364-382.

Amram, M., Kulatilaka, N., 1999, Disciplined decisions: aligning strategy with the financial markets. Harvard Business Review. January-February.

Amram, M., Kulatilaka, N., 2000, Strategy and shareholder value creation: the real options frontier. Journal of Applied Corporate Finance, Vol.13, No. 2, Summer, pp. 15–27.

Amram, M., Li, F., Perkins, C., 2006, How Kimberly-Clark Uses Real Options. Journal of Applied Corporate Finance, Vol. 18, No. 2, pp. 40–47.

Anderson, E. J., 2014. Business Risk Management: Models and Analysis. John Wiley & Sons, Ltd, United Kingdom.

Anson, M. J. P., Fabozzi, F. J., Choudhry, M., 2000. Credit Derivatives: Instruments, Applications, and Pricing Hoboken, Wiley, New Jersey, United States.

Arora, N., Bohn, J. R., Zhu, F., 2005. Reduced Form vs. Structural Models of Credit risk: A Case Study of Three Models. Journal of Investment Management, Vol. 34, pp. 43-67.

Artzner, P., Delbaen, F., Eber, J. M. Heath, D., 1999. Coherent Measures of Risk. Mathematical Finance, Vol. 93, pp. 203-228

Atiya, A., F., 2001. Bankruptcy Prediction for Credit Risk Using Neural Networks: A Survey and New Results. IEEE Transactions on Neural Networks, Vol. 12, No. 4, pp. 929-935.

Avenhuis, J.O., 2013, Testing The Generalizability of the Bankruptcy Prediction Models of Altman, Ohlson and Zmijewski for Dutch Listed And Large Non-Listed Firms, Journal of Business Administration, pp. 38-39.

Baker, H. K., Dutta, S., Saadi, S., 2011, Management Views on Real Options in Capital Budgeting, Journal of Applied Finance, Vol. 21, No. 1, pp. 18-29.

Bank of Israel 1984, “Chapter VIII: Money and Capital Markets.” In Bank of Israel Annual Report 1983, Jerusalem: Bank of Israel, May 31, 1984, https://ypfs.som.yale.edu/library/money-and-capital-markets-bank-israel-annual-report1983.

Bank of Israel 2017, Israel's Banking System. Annual Survey 2017.

Bank of Israel 2018, Israel's Banking System. First Half of 2018.

Bank of Israel 2021, Israel’s Banking System. Annual Survey 2020.

Bansal, R., Kiku, D. Yaron, A., 2012, An Empirical Evaluation of the Long-run Risks Model for Asset Prices, Critical Finance Review, Vol. 1, pp. 183–221.

Bartram, S. M., Conrad, J., Lee, J., Subrahmanyam, M. G., 2022, Credit Default Swaps around the World, The Review of Financial Studies, Vol. 35, No. 5, pp. 2464–2524, doi.org/10.1093/rfs/hhab092

Beaver, W., 1966. Financial Ratios as Predictors of Failure. Journal of Accounting Research, Vol. 4, No. 71- 111.

Beaver, W., 1968. Market Prices, Financial Ratios and Prediction of Failure. Journal of Accounting Research, Vol. 62, pp. 179-192.

Beck, U., 2006, Living in the world risk society, Economy and Society, Vol 35, No. 3, pp. 329-345.

Becsky-Nagy, P., 2014, Growth and Venture Capital Investment in Technology-based Small Firms, Annals of the Oradea of Economic Science, Vol. 2, No. 2, pp. 828-836.

Becsky-Nagy, P., Fazekas, B., 2014, Returns of Private Equity – Comparative Analyses of the Returns of Venture Capital and Buyout Funds in Europe and in the US, Annals of the Oradea of Economic Science, Vol. 2, No. 2, pp. 820-827.

Bell, R. A., Brooks, C., Prokopczuk, M., 2013. Predicting Financial Distress of Companies: Revising the Z-score and Zeta® Models. Handbook of Research Methods and Applications in Empirical Finance. Edward Elgar Publishing Limited, Cheltenham, UK.

Benzschawel, T., 2012. Credit Risk Modeling: Facts, Theory and Applications. London: Risk Books.

Berger, Allen N., Udell, G. F., 2006, A more complete conceptual framework for SME finance, Journal of Banking and Finance, Vol. 30, No. 11, pp. 2945-2966.

Berk, J.B., Green, R.C. Naik, V., 1999, Optimal Investment, Growth Options, and Security Returns, Journal of Finance, Vol. 54, pp. 1553-1607.

Bertola, G., 1998, Irreversible Investment, Research in Economics, Vol. 52, pp 3–37.

Besiss, J., 2010, Risk Management in Banking, 3th ed., John Wiley & Sons Ltd.

Bessis, J., 2015. Risk Management in Banking, 4th ed, John Wiley & Sons Inc, New York, United States.

Betz, J., Krüger, S., Kellner, R., Rösch, D., 2020, Macroeconomic effects and frailties in the resolution of non-performing loans, Journal of Banking & Finance, Vol. 112 (105212). doi.org/10.1016/j.jbankfin.2017.09.008.

Bielecki, T. R., Rutkowski, M., 2000. Multiple ratings models of defaultable term structure. Mathematical Finance, vol. 102, 125-139.

BIS, 1999. Principles for the Management of Credit Risk, Risk Management Group of the Basel Committee on Banking Supervision, Bank for International Settlements, July 1999.

Black, F., Cox, J., C., 1976. Valuing Corporate Securities: Some Effects of Bond Indenture Provisions. Journal of Finance, Vol. 31, No. 2, 351-367.

Black, F., Scholes, M., 1973, The Pricing of Options and Corporate Liabilities, Journal of Political Economy, Vol. 81, No. 3, pp. 637 - 654. doi:10.1086/260062.

Blass, A. A., Grossman, R. S., 1996. A Harmful Guarantee? The 1983 Israel Bank Shares Crisis Revisited, Research Department, Bank of Israel, Jerusalem.

Blass, A. A., Grossman, R. S., 2001. Assessing Damages: The 1983 Israeli Bank Shares Crisis, Contemporary Economic Policy, Vol. 191, pp. 49–58. doi:10.1111/j.1465-7287.2001.tb00049.x.

Blass, A. A., Grossman, Richard R. S., 1998. Who needs Glass-Steagall? Evidence from Israel's Bank

Shares Crisis and The Great Depression. Contemporary Economic Policy, Vol. 16, No. 2, 185–196. doi:10.1111/j.1465-7287.1998.tb00511.x.

Block, S., 2012, Are “real options” actually used in the real world?, The Engineering Economist, Vol. 52, pp. 255–267.

Borison, A., 2003, Real Options Analysis: Where are the Emperors Clothes? In Real options conference, pp. 1–30, Washington: N.a.

Borison, A., Triantis, A. J., 2001, Real Options: State of the practice, Journal of Applied Corporate Finance, Vol.14, No. 2, pp. 8–24.

Boyle, P. P., 1977, Options: a Monte Carlo approach, Journal of Financial Economics, Vol. 4, pp. 323–338.

Boyle, P. P., 1988, A Lattice Framework for Option Pricing with Two State Variables, Journal of Financial and Quantitative Analysis, Vol. 23, No. 1, pp. 1-12.

Brach, M., 2003, Real Options in Practice, Hoboken. New Jersey: John Wiley & Sons, Inc.

Brand˜ao, L. E., Dyer, J. S., Hahn, W. J., 2005, Using Binomial Decision Trees to Solve Real-Option Valuation Problems, Decision Analysis, Vol 2, No. 2, pp. 69–88.

Brealey, R. A., Myers, S. C., Allen, F., 2011, Principles of corporate finance, 10th ed., New York: McGraw-Hill/Irwin.

Brealey, R., A., Myers, S., C., Allen, F., 2008, Brealey, Myers, and Allen on Real Options, Journal of Applied Corporate Finance, Vol. 20, No. 4, pp. 58-72.

Brennan, M., Schwartz, E., 1984, Evaluating Natural Resource Investments, Journal of Business, Vol. 58, No. 2, pp. 135-157.

Broll, U., Welzel, P., Wong, K.P., 2018, Ambiguity preferences, risk taking and the banking firm. Eurasian Econ Rev Vol. 8, No. 1., pp. 343–353. doi.org/10.1007/s40822-018-0096-2.

Busaba, W.Y., 2006, Book building, the option to withdraw, and the timing of IPOs, Journal of Corporate Finance, Vol. 12, No. 2, pp. 159-186.

Camara, A., Popova, I., Simkins, B. 2012. A comparative study of the probability of default for global financial firms. Journal of Banking & Finance, Vol. 36, No. 3, 717-732.

Campbell, J. Y., Hilscher, J., Szilagyi, J. 2008. In search of Distress Risk. Journal of Finance, Vol. 63, No. 6, pp. 2899-2939.

Campbell, J. Y., Lettau, M., Malkiel, B. G., Xu, Y., 2001. Have individual stocks become more volatile? An empirical exploration of idiosyncratic risk. Journal of Finance, Vol. 56, No. 1, pp. 1–43.

Cañibano, L., García-Ayuso, M., Sánchez, P., 2000, Accounting for intangibles: a literature review, Journal of Accounting Literature, Vol. 19, pp. 102-30.

Caouette, J. B., Altman, E. I., Narayanan, P., 2008. Managing Credit Risk: The Great Challenge for Global Financial Markets. Hoboken, New Jersey: Wiley.

Capozza, D. R., Sick, G. A., 1994, “The Risk Structure of Land Markets,” Journal of Urban Ecomomics, Vol. 35, No. 3, pp. 297-319. doi:10.1006/juec.1994.1018.

Capozza, D., Sick, G., 1994, Risk Structure of Land Markets, Journal of Urban Economics, Vol.35, No. 3, pp. 297-319.

Castellano, R., Corallo, V., Morelli, G., 2022, Structural estimation of counterparty credit risk under recovery risk, Journal of Banking Finance 140 (106512).doi.org/10.1016/j.jbankfin.2022.106512.

Castro, V., 2013, Macroeconomic determinants of the credit risk in the banking system: The case of the GIPSI, Economic Modelling, Vol. 31, 672 -683.

Casu, B., Girardone, C., Molyneux, P., 2006. Introduction to Banking, Pearson Education Ltd, Harlow, England.

Chen, Z., Li, H., Wang, T., Wu, J., 2023, How digital transformation affects bank risk: evidence from listed Chinese banks, Finance Research Letters, 104319, doi.org/10.1016/j.frl.2023.104319.

Chernov, M., Creal, D., Hördahl, P., 2023, Sovereign credit and exchange rate risks: Evidence from Asia-Pacific local currency bonds, Journal of International Economics, Vol. 140, 103692, doi.org/10.1016/j.jinteco.2022.103692.

Cheung, J. 1991. A Review of Option-Pricing Theory in Accounting Research. Journal of Accounting Literature, Vol. 10, 51–84.

Choi, Yoon K; Smith, Stanley D., 2002, Real options: A commercial bank lending application, Managerial Finance, Vol. 28, No. 12, pp. 25-43.

Collin-Dufresne, P., Goldstein, R. S., 2001. Do Credit Spreads Reflect Stationary Leverage Ratios? The Journal of Finance, Vol. 56, No. 5, pp. 1929-1958.

Copeland, T. E., 2002, What Do Practitioners Want? Journal of Applied Finance, pp. 7–14.

Copeland, T. E., Antikarov, V., 2003, Real Options: A Practitioner’s Guide, New York: Texere Publishing.

Copeland, T., Keenan, P.T., 1998, How much is flexibility worth?, The McKinsey Quarterly, 2, pp. 38-49.

Copeland, T. E., Tufano, P., 2004, March, A real-world way to manage real options, Harvard Business Review, Vol. 82, No. 3, pp. 90–99, 128.

Coppola, M., D’Amato, V., Levantesi, S., 2018, An option pricing approach for measuring Solvency Capital Requirements in Insurance Industry, Physica A: Statistical Mechanics and its Applications, Vol. 509, No. 1, pp: 717-728. doi.org/10.1016/j.physa.2018.05.113

Courtney H. G., Kirkland J., Viguerie S. P., 1997, Strategy under uncertainty, Harvard Business Review, Vol. 75, No. 3, pp. 67–79.

Cox, J. C., Ross, S. A., Rubinstein, M. 1979, Option pricing: a simplified approach, Journal of Financial Economics, Vol. 7, pp. 229–263.

Dannenberg, A., Löschel, A., Paolacci, G., Reif, C., Tavoni, A., 2015, On the Provision of Public Goods

with Probabilistic and Ambiguous Thresholds, Environmental and Resource Economics, Vol. 61, No. 3, pp 365–383.

Das, S. R., Freed, L., Geng, G., Kapadia, N., 2006. Correlated Default Risk, Journal of Fixed Income, Vol. 162, pp. 7-32.

Davis, G. A., 1998, January, Estimating volatility and dividend yield when valuing Real Options to invest or abandon, The Quarterly Review of Economics and Finance, Vol 38, No. 3, pp. 725–754.

Dembo, A., Deuschel, J., Duffie, D., 2004. Large portfolio losses, Finance and Stochastics, 81, 3-16.

Dhaliwal, D. S., Trezavant, R., Wang, S., 1992. Taxes, investment-related tax shields and capital structure. Journal of the American Taxation Association, Vol. 14, No. 1, pp. 1–21.

Dixit, A. K., Pindyck, R. S., 1994, Investment under Uncertainty, New Jersey: Princeton University Press.

Dixit, A. K., Pindyck, R. S., 1995, The Options Approach to Capital Investment. Harvard Business Review, Vol. May-June, pp. 105–115.

doi.org/10.1016/j.elerap.2010.04.005.

Driouchi, T., Bennett, D. J., 2012, Real Options in Management and Organizational Strategy: A Review of Decision-making and Performance Implications, International Journal of Management Reviews, Vol. 14, No. 1, pp 39–62.

Du, S., Suo, W., 2007. Assessing Credit Quality from Equity Markets: Is a Structural Approach a better Approach? Canadian Journal of Administrative Studies, Vol. 24, No. 3, 212-228.

Duan, J. C., Sun, J., Wang, T., 2012. Multiperiod Corporate Default Prediction – A Forward Intensity Approach. Journal of Econometrics, Vol. 170, No. 1, 191–209.

Duffie, D. S., Saita, L., Wang, K., 2007. Multi-period corporate default prediction with stochastic covariates. Journal of Financial Economics, Vol. 83, No. 3, pp. 635-665.

Duffie, D., Singleton, K. J., 1999. Modeling the Term Structures of Defaultable Bonds. Review of Financial Studies, Vol. 12, No. 4, pp. 687-720.

Duican, E. R., Pop, A., 2015. The implications of credit activity on economic growth in Romania, Procedia Economics and Finance, Vol. 30, pp. 195-201.

Eliaz, K., Ortoleva, P., 2016, Multidimensional ellsberg. Management

Eom, Y. H., Helwege, J., Huang, Jing-Zhi, 2004. Structural models of corporate bond pricing: An empirical analysis. Review of Financial Studies, Vol. 17, No. 2, pp. 499-544.

Euromoney, 2023, Israel's banks prepare for conflict, November, 13, https://www.euromoney.com/article/2cg4jirsshfpxqapdt1xc/opinion/israels-banks-prepare-for-conflict.

Ewald, Ch. O., Taub, B., 2022, Real options, risk aversion and markets: A corporate finance perspective, Journal of Corporate Finance, Vol. 72, 102164. doi.org/10.1016/j.jcorpfin.2022.102164.

Fama, E. F., French, K. R., 1992, The Cross-Section of Expected Stock Returns, Journal of Finance, Vol.

47, No. 2, pp. 427–465.

Fama, E. F., French, K. R., 1995, Size and Book-to-Market Factors in Earnings and Returns,The Journal of Finance, Vol. 50, No. 1, pp. 131–155.

Fenyves V., Tarnóczi T., Vörös P., 2014, Financial Indicators in Managerial Decision Making, Annals of the University of Oradea Economic Science, Vol. 23, No. 1, pp 893-904.

Finger, C., 1999. Conditional Approaches for CreditMetrics® Portfolio Distributions", CreditMetrics® Monitor, April.

Fons, J. S., 1994. Using Default Rates to Model the Term Structure of Credit Risk. Financial Analysts Journal, Vol. 50, no. 5, pp. 25-32.

Frye, J., 2000. Collateral Damage, Risk, April, pp. 91-94.

Gamba, A., 2002, Real Options Valuation: A Monte Carlo Approach, Working Paper 2002/3, presented on European Finance Association, meeting of Berlin, 2002.

Gennaioli, N, Alberto, M., Stefano R., 2014a. Banks, Government Bond, and Default: What Do the Data Say? Manuscript, Center for Economic and Policy Research, Washington, DC.

Gennaioli, N, Alberto, M., Stefano R., 2014b. Sovereign Default, Domestic Banks, and Financial Institutions. Journal of Finance, Vol. 69, No. 2, pp. 819–66.

Geske, R., 1966. The Valuation of Compound Options. Unpublished manuscript, University of California, Berkeley.

Geske, R., 1977. The Valuation of Corporate Liabilities as Compound Options. Journal of Financial and Quantitative Analysis, Vol. 12, No. 4, pp. 541-552.

Gibson, W., Morrell, P., 2004, Theory and practice in aircraft financial evaluation, Journal of Air Transport Management, Vol. 10, No. 6, pp. 427-433.

Gómez-Puig, M., Pieterse-Bloem, M., Sosvilla-Rivero, S., 2023, Dynamic connectedness between credit and liquidity risks in euro area sovereign debt markets, Journal of Multinational Financial Management, Vol. 68, 100800, doi.org/10.1016/j.mulfin.2023.100800.

Gong, J. J., Van der Stede, W. A., Young, S. M., 2011, Real options in the motion picture industry: Evidence from film marketing and sequels. Contemporary Accounting Research, Vol. 28, No. 5, pp. 1438–1466. doi.org/10.1111/j.1911- 3846.2011.01086.x.

Gordy, M. B., 2000. Credit VaR Models and Risk-Bucket Capital Rules: A Reconciliation. Working Paper, Federal Reserve Board, March.

Graham, J. R., Harvey, C. R., 2001, The theory and practice of corporate finance: evidence from the field, Journal of Financial Economics, Vol. 60, pp. 187–243.

Hackbarth D., Jonson T., 2015, Real Options and Risk Dynamics, Review of Economic Studies, Oxford University Press, pp. 1-34.

Haenlein, M., 2015, Real options and customer lifetime value. In Kumar, V., D. Shah, D., (Eds.),

Handbook of research on customer equity in marketing, pp. 118–136, Edward Elgar Publishing. doi.org/10.4337/9781781004982.

Haenlein, M., Kaplan, A. M., Schoder, D., 2006, Valuing the real option of abandoning unprofitable customers when calculating customer lifetime value, Journal of Marketing, Vol. 70, No. 3, pp. 5–20. doi.org/10.1509/jmkg.70.3.5

Hand, D.J., Henley, W.E., 1997, Statistical classification methods in consumer credit scoring: a review, Journal of The Royal Statistical Society, Vol. 160, No. 3, pp. 523-41.

Hantonio, H., 2019, Predicting Financial Distress Using Altman Score, Grover Score, Springate Score, Zmijewski Score (Case Study on Consumer Goods Company, Vol. 8, No. 1, pp.1–16.

Hartmann, M., Hassan, A., 2005, Application of real options analysis for pharmaceutical R&D project valuation – Empirical results from survey, Research Policy, Vol. 35, No. 3, pp. 343-354.

Hartmantzis, F.C., Trigeorgis, L., Tanguturi, V.P., 2006, Flexible Investment Decisions in the Telecommunications Industry: Case Applications using Real Options, Working paper #06-06, The Networks Electronic Commerce, and Telecommunications "NET" Institute.

Haslett, W., V., 2010, Risk Management: Foundations for a Changing Financial World, USA: John Wiley & Sons, Inc.

Hatefi, M.A., Balilehvand, H. R., 2022, Risk assessment of oil and gas drilling operation: An empirical case using a hybrid GROC-VIMUN-modified FMEA method, Process Safety and Environmental Protection 170, pp. 392-402. doi.org/10.1016/j.psep.2022.12.006.

Haushalter, G. D., 2000, Financing Policy, Basis Risk, and Corporate Hedging: Evidence from Oil and Gas Producers, The Journal of Finance, Vol. 55, No. 1, pp. 107-152.

Hempel, G. H., Simonson, D. G., 1999. Bank Management: Text and Cases. 5th ed., John Wiley, New York, United States.

Henderson, V., Hobson, D.G., 2002, Real options with constant relative risk aversion, Journal of Economic Dynamics and Control 27(2), pp. 329-355, https://doi.org/10.1016/S0165-1889(01)00052-5.

Hertz, D. B., 1979, Risk Analysis in Capital Investment, Harvard Business Review. Vol. 57, No. 5, pp. 169-181.

Hevert, K. T., 2001, Real Options Primer: A Practical Synthesis of Concepts and Valuation Approaches, Journal of Applied Corporate Finance, Vol 14, No. 2 Summer, pp. 25–39.

Hillegeist, S., Keating, E., Cram, D., Lundstedt, K., 2004. Assessing the probability of bankruptcy. Review of Accounting Studies, Vol. 91, 5-34.

Hoang, D.P., Chu, L.K., To, T.T., 2023, How do economic policy uncertainty, geopolitical risk, and natural resources rents affect economic complexity? Evidence from advanced and emerging market economies, Resources Policy 85 (Part A), 103856.

doi.org/10.1016/j.resourpol.2023.103856.

Hodder, J. E., Riggs, H. E., 1985, Pitfalls in Evaluating Risky Projects, Harvard Business. Reviews, Vol. 63, No. 1, pp. 128-135.

Holloway, S., 2003, Straight and Level: Practical Airline Economics, 3rd ed., Ashgate Publishing Ltd., New York, United States.

Horn, A., Kjærland, F., Molnár, P., Wollen Steen, B. 2015, The use of real option theory in Scandinavia's largest companies, International Review of Financial Analysis, Vol. 41, No. 1 (November 2015), pp: 74-81. doi.org/10.1016/j.irfa.2015.05.026

Houe, A., 2016, Real Option Valuation in Real Estate Development: A Case Study Of FREDERICIAC, Aarhus University, School of Business and Social Science, Denmark.

Hsu, J. C., Saa-Requejo, J., Santa-Clara, P., 2010. A Structural Model of Default Risk. The Journal of Fixed Income, Vol. 19, No. 3, 77-99.

Hughes, J. E., MacDonald, S. B., 2002. International Banking, Addison Wesley, Boston, MA, United States of America.

Hugonnier, J., Morellec, E., 2007, Corporate control and real investment in incomplete markets, Journal of Economic Dynamics and Control Vol. 31, No. 5, pp. 1781-1800, https://doi.org/10.1016/j.jedc.2006.09.001.

Hull, C. J., 2011, Options, Futures, and Other Derivatives, 9th ed., Pearson Education, Inc., New Jersey.

Hull, C. J., 2012 Risk Management and Financial Institutions, 3rd ed. John Wiley & Sons, Inc, Hoboken, New Jersey.

Husein, M. F., Pambekti, G. T., 2014., Precision of the Models of Altman, Springate, Zmijewski, and Grover for Predicting the Financial Distress, Journal of Economics, Business, and Accountancy Ventura, Vol. 17, No. 3, pp: 405–416.

Ige, O., 1995, Information Technology in a deregulated telecommunication environment, Keynote address presented at INFORTECH 95, First International Conference on Information Technology Management, Lagos.

Ingersoll, J., Ross, S., 1992, Waiting to Invest: Investment and Uncertainty, Journal of Business, Vol. 65, No. 1, pp. 1-29.

Ipsmiller, E., Brouthers, K. D., and Dikova, D., 2019, 25 Years of Real Option Empirical Research in Management, European Management Review 16, pp. 55–68. https://doi.org/10.1111/emre.12324.

Istrate, L.G., Ionescu, B.Ș., Haralambie, M., 2016. Aspects of the impact of interest rate development on the probability of default, Audit Financiar Journal, Vol. 14, No. 142, pp. 1149-1156.

Jameson, R., 2001. Between RAROC and a hard place. Erisk.com, New York, United States.

Jarrow, R. A., Lando, D., Turnbull, S. M., 1997. A Markov Model for the Term Structure of Credit Risk

Spreads. Review of Financial Studies, Vol. 102, pp. 481-523.

Jarrow, R. A., Turnbull, S. M., 1995. Pricing Derivatives on Financial Securities Subject to Credit Risk. Journal of Finance, Vol. 50, No. 1, pp. 53-85.

Jarrow, R. A., Yu, F., 2001. Counterparty risk and the pricing of defaultable securities. Journal of Finance, vol. 56, No. 5, pp. 1765-1799.

Jones, P. E., Mason, S. P., Rosenfeld, E., 1984. Contingent Claims Analysis of Corporate Capital Structures: An Empirical Analysis. Journal of Finance, Vol. 39, No. 3, pp. 611-625.

Jones, S. L., Yeoman, J. C., 2009, The promoter's role in ticket pricing: Implications of real options for optimal posted prices and rationing. Journal of Business Research, Vol. 62, No. 11, pp. 1187–1192. doi.org/10.1016/j.jbusres.2008.09.002.

Joppien, M. G., 2006, Strategisches Airline Management, 2nd ed., Bern: Haupt Verlag.

Jorion, P., Zhang, G., Y., 2007. Good and Bad Credit Contagion: Evidence from Credit Default Swaps. Journal of Financial Economics, Vol. 84, No. 3, pp. 860-883.

Chung, K., Charoenwong, C., 1991, "Investment Options, Assets in Place, and Risk of Stocks," Financial Management, Vol. 20, No. 3, pp. 21-33. doi:10.2307/3665748.

Kellogg, D, Charnes, J.M, 2000, Real-Options Valuation for a Biotechnology Company, Financial Analysis Journal, Vol. 56, pp. 76-87. doi:10.2469/faj.v56.n3.2362.

Kester, W. C., 1984, Today's Options for Tomorrow's Growth, Harvard Business Review, Vol. 62, No. 2, pp. 153–160.

Kim, I. J., Ramaswamy, K., Sundaresan, S., 1993. Does Default Risk in Coupons Affect the Valuation of Corporate Bonds? A Contingent Claims Model. Financial Management. Vol. 223, Autumn, 1993, 117-131.

Kiyosi, I., 1944, Stochastic Integral, Proceedings of the Japan Academy, Series A, Mathematical Sciences, Vol. 20, No. 8, pp. 519–524, Tokyo.

Knight, F., H., 1921, Risk, Uncertainty and Profit, Boston, MA: Hart, Schaffner & Marx; Houghton Mifflin Co.

Koju, L., Koju, R. and Wang, S., 2020, Macroeconomic determinants of credit risks: evidence from high-income countries, European Journal of Management and Business Economics, Vol. 29 No. 1, pp. 41-53. doi.org/10.1108/EJMBE-02-2018-0032.

Koller, T., Goedhart, M., Wessels, D., 2010, Valuation: Measuring and Managing the Value of Companies, 5th ed., Hoboken, NJ, USA: John Wiley & Sons, Inc.

Koosha, H., Albadvi, A., 2015, Customer lifetime valuation using real options analysis. Journal of Marketing Analytics, Vol. 3, No. 3, 122–134. doi.org/10.1057/ jma.2015.12

Kulatilaka, N., Marks, S. G., 1988, "The Strategic Value of Flexibility: Reducing the Ability to Compromise, "American Economic Review, Vol. 78, No. 3, pp. 574-580.

Lambrecht, B.M., Myers, S.C., 2012, A Lintner model of payout and managerial rents, Journal of Finance, Vol. 67, No. 5, pp. 1761–1810, doi.org/10.1111/j.1540-6261.2012.01772.x.

Lambrecht, B.M., Myers, S.C., 2017, The dynamics of investment, payout and debt, Review of Financial Studies 30 (11), 3759–3800, doi.org/10.1093/rfs/hhx081.

Lando, D., 1998. On Cox processes and credit risky securities. Review of Derivatives Research, Vol. 22, No. 3, pp. 99-120.

Langdon and Langdon, 2006, Managing Digital Firms, MIS Review.

Laudon, D. P., Laudon, J. P., 1991, Business Information System: A Problem-Solving Approach, New York, HBJ, College Publishers.

Lee, C., 2010, Handbook of Quantitative Finance and Risk Management. New York: Springer.

Leggio, K.B., Bodde, D. L., Taylor, M. L., 2006, Managing Enterprise Risk, What the Electric Industry Experience Implies for Contemporary Business, Elsevier Ltd., Oxford, UK.

Leland, H. E., 1994. Corporate Debt Value, Bond Covenants, and Optimal Capital Structure. Journal of Finance, Vol. 49, No. 4, pp. 1213-1252.

Leland, H. E., Toft, K. B., 1996. Optimal Capital Structure, Endogenous Bankruptcy, and the Term Structure of Credit Spreads. Journal of Finance, Vol. 51, No. 3, 987-1019.

Levett, P., Page, M., Nel, D., Pitt, L., Berthon, P., Money, A., 1999, Towards an application of option pricing theory in the valuation of customer relationships, Journal of Strategic Marketing, Vol. 7, No. 4, pp. 275–284. doi.org/10.1080/ 096525499346387

Lewis, M. K., Davis, K., T., 1987. Domestic and International Banking, Philip Allan, Oxford, United Kingdon.

Li, D., X., 2000. On default correlation: A copula function approach. The Journal of Fixed Income, Vol. 94, pp. 43-54.

Li, S., Yang, Y., Zongfang Z., 2014, Research on Impact of Moral Hazard on Individual Credit Risk, Procedia Computer Science, Vol. 31, pp: 577-586. doi.org/10.1016/j.procs.2014.05.304.

Lin Chung-Gee, Wang Yu-Shan, 2012, Evaluating natural resource projects with embedded options and limited reserve, Journal of Applied Economics, Vol. 44, pp. 1471-1482.

Lin, Z., Xiaoyong, L., 2023, Bank credit and corporate innovation investment: The role of government risk sharing." Managerial and Decision Economics, Vol. 44, No. 5, pp: 2615-2625. doi.org/10.1002/mde.3837.

Liu, Z., Huoqing, T., Chengsi, Z., 2023, Corporate governance, moral hazard, and financialization., International Review of Economics & Finance, Vol. 88, pp: 318-331.

Lobo, G. J., 2017. Accounting Research in banking – A review. China Journal of Accounting Research, 101, March 2017, 1-7.

Longstaff, F. A., Schwartz, E. S., 1995. A Simple Approach to Valuing Risky Fixed and Floating Rate Debt.

Journal of Finance, Vol. 50, No. 3, pp. 789-819.

Longstaff, F. A., Schwartz, E. S., 2001, Valuing American Options by Simulation: A Simple Least-Squares Approach, The Review of Financial Studies, Vol 14, No. 1, pp. 113–147.

Luehrman, T. A., 1998, Strategy as a portfolio of real options. Harvard Business Review, Vol. 76, No. 5, pp. 89–99, 187.

Luehrman, T. A., 1998. Investment Opportunities as Real Options: Getting Started on the Numbers, Harvard Business Review, July-August, pp. 3–15.

Luftman, J., N., 2003, Competing in the Information Age: Align in the Sand, 2^{th}ed., Oxford University Press Inc, New York, United States.

Makri, V., 2015. What triggers loan losses? An empirical investigation of Greek financial sector, SPOUDAI Journal of Economics and Business, Vol. 65, No. 2, pp. 119 - 143.

Makri, V., Papadatos, K., 2016. Determinants of loan quality: Lessons from Greek cooperative banks, Review of Economic & Business Studies, Vol. 91, pp. 115-140.

Mark R., Bishop W., 2017. The flexibility of RAROC. The many values of risk adjusted return on capital approach. Teradata Magazine, March, NCR Corporation.

Marki, V., Tsagkanos, A., Bellas, A. 2014. Determinants of non-performing loans: The case of eurozone, Panoeconomicus, Vol. 61, No. 2, pp. 193-206.

Mathews, S., Datar, V., Johnson, B., 2007, A Practical Method for Valuing Real Options: The Boeing Approach, Journal of Applied Corporate Finance, Vol. 19, No. 2, pp. 95-105.

McDonald, R., Siegel, D., 2002, The Value of Waiting to Invest, Quarterly Journal of Economics, Vol. 101, No. 4, pp. 707-728.

McGowan, D., Nguyen, H., 2023, To Securitize or to Price Credit Risk? Journal of Financial and Quantitative Analysis, Vol. 58, No. 1, pp: 289-323. doi:10.1017/S0022109022000552

Mendez-Suarez, M., Crespo-Tejero, N., 2021, Why do banks retain unprofitable customers? A customer lifetime value real options approach, Journal of Business Research, Vol. 122 (2021), pp. 621–626. doi.org/10.1016/j.jbusres.2020.10.008

Merton R., Perold A., 1993. Theory of risk capital in financial firms. Journal of Applied Corporate Finance, Vol. 63, No. 1, pp. 16-32.

Merton, R. C., 1973, Theory of Rational Option Pricing, The Bell Journal of Economics and Management Science, Vol. 4, No. 1, pp. 141–183.

Merton, R. C., 1974. On the Pricing of Corporate Debt: The Risk Structure of Interest Rates. Journal of Finance, Vol. 29, No. 2, pp. 449-470.

Mileris, R., 2012. The effects of macroeconomic conditions on loan portfolio credit risk and banking system interest income, Ekonomika, Vol. 91,No. 3, pp. 85-100.

Mileris, R., 2014. Macroeconomic determinants of loan portfolio credit risk in banks, Inzinerine

Ekonomika-Engineering Economics, Vol. 23, No. 5, pp. 496-504.

Milne, A., Onorato, M., 2009. Risk-Adjusted Measures of Value Creation in Financial Institutions, European Financial Management, 18November.

Mishkin, F. S., Eakins S. G., 2009, Financial Market and Institutions, 5th ed., Ney York, Pearson.

Modigliani, F., Miller, M. H., 1958, The cost of capital, corporation finance and the theory of investment. The American Economic Review, 48, No. 3, pp. 261–297.

Mohsin, A., Mudeer, A. K., Nafis, A., 2023, Credit risk in dual banking systems: does competition matter? Empirical evidence." International Journal of Emerging Markets, Vol. 18, No. 4, pp: 822-844.

Moon, Y., Kwon, C., 2011, Online advertisement service pricing and an option contract, Electronic Commerce Research and Applications, Vol. 10, No. 1, pp. 38–48.

Morris, A. P., Teisberg, E. O., Koble, A. L., 1991, "When Choosing R&D Projects, Go with the Long Shots," Research Technology Management, Vol. 34, No. 1, pp. 35-40.

Mun, J., 2006, Modelling Risk, Jhon Wiley & Sons, Inc, Hoboken, New Jersey.

Myers, S. C., 1977, Determinants of corporate borrowing, Journal of Financial Economics, Vol 5, pp. 147–175.

Myers, S. C., 1984, Finance Theory and Financial Strategy, Interfaces, Vol. 14, No. 1, pp. 126-137.

Myers, S. C., 2004, Real options after 27 years, Keynote address presented at the Real Options Conference, June 16–19, Montreal.

Nadarajah, S., Secomandi, N., 2023, A review of the operations literature on real options in energy, European Journal of Operational Research 309(2), pp. 469-487, https://doi.org/10.1016/j.ejor.2022.09.014.

Nagy, P., 2002, Adventure capital, International conference on Evolution of Institutions and Knowledge Economy, Debrecen, Magyarország, University of Debrecen, pp 1-10.

Nichols, N. A., 1994, "Scientific Management at Merck: An Interview with CFO Judy Lewent," Harvard Business Review, Vol. 72, No. 1, pp. 88-99.

Nur, G.N., MacKenzie, C.A., Min, K.J. 2023, A Real Options Analysis model for generation expansion planning under uncertain demand, Decision Analytics Journal 8, 100263, https://doi.org/10.1016/j.dajour.2023.100263.

Nwafor, Ch. N., Nwafor, O. Z., 2023, Determinants of non-performing loans: An explainable ensemble and deep neural network approach, Finance Research Letters 56 (104084). doi.org/10.1016/j.frl.2023.104084.

Odom, M. D., Sharda, R., 1990, A Neural Network Model for Bankruptcy Prediction. IJCNN International Joint Conference on Neural Networks. San Diego, CA.

Ofer, E., 2004, Glass-Steagall: The American Nightmare That Became the Israeli Dream. Fordham

Journal of Corporate & Financial Law, Vol. 9, No. 2, pp: 527–81.

Ogden, J., 1987, An Analysis of Yield Curve Notes. Journal of Finance, Vol. 42, No. 1, pp/ 99-110.

Ohlson, J., A. 1980, Financial ratios and the probabilistic prediction of bankruptcy, Journal of Accounting Research, Vol. 18, No. 1, pp. 109-131.

Oppi, C., Campanale, C. and Cinquini, L. 2022, Ambiguity in public sector performance measurement: a systematic literature review, Journal of Public Budgeting, Accounting & Financial Management, Vol. 34, No. 3., pp. 370-390. doi.org/10.1108/JPBAFM-09-2020-0167.

Orth, W., 2013, Multi-period credit default prediction with time-varying covariates, Journal of Empirical Finance, 21 March 2013, pp. 214–222.

Panayi, S., Trigeorgis, L., 1998, Multi-stage real options: The cases of information technology infrastructure and international bank expansion. The Quarterly Review of Economics and Finance, Vol. 38, pp. 675–692.

Parlour, C. A., Winton, A., 2013. Laying off credit risk: Loan sales versus credit default swaps, Journal of Financial Economics, Vol. 107, No. 1, pp. 25-45.

Perotti, E., Rossetto, S., 2007, Unlocking value: Equity carve outs as strategic real options, Journal of Corporate Finance 13(5), pp. 771-792, https://doi.org/10.1016/j.jcorpfin.2007.03.007.

Pindyck, R. S., Majd, S., 1987, Time to Build, Option Value, and Investment Decisions, Journal of Financial Economics 18, pp. 7–27.

Posen, H. S., Leiblein, M. J., Chen, J. S. 2017, Toward a behavioral theory of real options: Noisy signals, bias, and learning, Strategic Management Journal Vol. 39, No. 4, doi.org/10.1002/smj.2757.

Power, M. 2005, The Invention of Operational Risk, Review of International Political Economy, Vol. 124, 577-599.

Pozo, J., 2023, Bank risk-taking in emerging economies: Empirical evidence and theory, Journal of Financial Stability, Vol. 67, 101136, doi.org/10.1016/j.jfs.2023.101136.

Prabowo, S. C. B., 2019, Analysis on The Prediction of Bankruptcy of Cigarette Companies Listed in the Indonesia Stock Exchange using Altman (Z-score) model and Zmijewski (X-score) model. Journal of Applied Management, Vol. 17, No. 2, pp. 254–260. doi.org/10.21776/ub.jam.2019.017.02.08.

Purinsh, I., Reizinsh, T., Braslinsh, G., Svitlika, N., 2012, Decision-making process in credit granting, Regional Formation and Development Studies, Vol. 1, No. 6, pp. 104-113.

Putri, D. P., S., 2018, Comparison of Bankruptcy Prediction Models Analysis (Altman, Springate, Grover, Ohlson and Zmijewski) on Pt. Asuransi Harta Aman Pratama, TBK, Economics and Accounting Journal, Vol. 1, No. 2, pp. 156–165.

Putten, A. B. Van, MacMillan, I. C., 2004, Making real options really work, Harvard Business Review, Vol 82, No. 12, pp. 134–150.

Quigg, L., 1993, Empirical Testing of Real Option-Pricing Models, The Journal of Finance, Vol. 48, No.

2, pp. 621-640. doi:10.2307/2328915.

Ragozzino, R., Reuer, J. J., Trigeorgis, L., 2016, Real Options in Strategy and Finance: current gaps and future linkages, Academy of Management Perspectives, Vol. 30, No. 4, pp. 428–440.

Richhild M, William A. Allen, 2011, Banking crises and the international monetary system in the Great Depression and now. Financial History Review, Vol 18, pp. 1-20.

Rose, P., 2002. Commercial Bank Management. 5th ed, Mc Graw-Hill/Irwin, Boston, USA.

Rothenberg, D., 2010, Bank Management in Israel - Assets Management, Liabilities and Risk, Keter Books, The The Hebrew University of Jerusalem, Jerusalem.

Rózsa, A., 2007, Possibilities and Limitations in the evaluation of real options in the strategic investments, Szakmai Füzetek 19, pp 50-63.

Ruggeri, D., Leotta, A., Rizza, C., 2018, The Bank Lending Process: Accounting Information Role in Constructing Realities or Illusions, International Journal of Business and Management, Vol. 13, No. 2, pp. 53-64.

Rustichini, A., Dickhaut, J., Ghirardato, P., Smith, K., Pardo, J. V., 2005, A brain imaging study of the choice procedure, Games and Economic Behavior, Vol. 52, No. 2, pp. 257-282.

Salamero S. A., Tarradellas E. J., Martínez C. C., 2008, A Real Option-Based Model to Properly Value Aircraft Purchase Rights: Impact of the coming EU Legislation on Aircraft CO2 emission levels, II International Conference on Industrial Engineering and Industrial Management, September 3-5, Burgos, Spain, pp. 575-584.

Sargent, T. J., Zeira, J., 2011, Israel 1983: A Bout of Unpleasant Monetarist Arithmetic, Review of Economic Dynamics, Vol. 14, No. 3, pp: 419–31.

Sathye, M., 1999, Adoption of Internet banking by Australian consumers: an empirical investigation, International Journal of Bank Marketing. 17(7), pp. 324-334.

Saunders, A., 2007, Credit Risk Measurement: New Approaches to Value at Risk and Other Paradigms, John Wiley & Sons Inc., New York, United States.

Saunders, A., Cornett, M. M., 2011, Financial Institutions Management: A Risk Management Approach, 7th ed., New York: McGraw Hill.

Schönbucher, P. J., 2003, Credit derivatives pricing models: models, pricing and implementation. John Wiley & Sons. Chichester, England.

Schwart E. S., Moon, M., 2000, “Rational Pricing of Internet Companies,” Financial Analysts Journal, Vol. 56, No. 3, pp. 62-75. doi:10.2469/faj.v56.n3.2361.

Schwartz, E. S., Trigeorgis, L., 2004, Real Options and Investment under Uncertainty: Classical Readings and Recent Contributions, The MIT Press.

Schwartz, E., 2002, Patents and R&D as Real Options, Working Paper, Anderson School at UCLA.

Science, Vol. 62, No. 8, pp. 2179–2197. doi.org/10.1287/mnsc.2015.2240.

Shanuka, S., Copp, R., 2015, Credit Default Swaps and the Global Financial Crisis: Reframing Credit Default Swaps as Quasi-Insurance, Global Economy and Finance Journal, Vol. 8, No. 1, pp. 137-149. doi:10.21102/gefj.2015.03.81.10.

SIiamni, G., Majid, M. S., A., Siregar, W. V., 2018, Bankruptcy Prediction Models and Stock Prices of the Coal Mining Industry in Indonesia. Etikonomi, Vol. 17, No. 1, pp: 57–68.

Skała, D., 2014, Credit policy in small polish banks - Is there room for income smoothing? Collegium of Economic Analysis Annals, Warsaw School of Economics 34, 183-196.

Smit, H. T. J., Moraitis, T., 2010, February, Serial Acquisition Options. Long Range Planning Vol. 4, No. 1, pp. 85–103.

Smit, H. T. J., Trigeorgis, L., 2004, Corporate Finance and Strategic Planning: A Linkage, Princeton University Press.

Smit, H. T. J., Trigeorgis, L., 2006, Strategic planning: valuing and managing portfolios of real options. R&D Management, Vol. 36, No. 4, pp. 403–419.

Smith, J. E., McCardle, K. F., 1999, Options in the real world: lessons learned in evaluating oil and gas investment, European Journal of Operational Research 47, pp. 1-15.

Smith, K. W., Triantis, A. J., 1995, The Value of Options in Strategic Acquisitions. Real Options in Capital Investment, pp. 135–149.

Stulz, R., M., 2010, Credit Default Swaps and the Credit Crisis. Journal of Economic Perspectives, Vol. 24, No. 1, pp. 73-92.

Suzuki, H., Goto, M., & Ohno, T., 2015, A model of purchase behavior under price uncertainty: A real options approach. International Journal of Real Options and Strategy, Vol. No.3, pp. 1–12. doi.org/10.12949/ijros.3.1.

Tapen, S., Macmillan, P., 2004, Strategy, Value, and Risk -- The Real Options Approach, Journal of Risk and Insurance, Vol. 71, No. 2 (June 2004), pp. 345-346.

Tarantino, A., Cernauskas, D., 2009, Risk Management in Finance: Six Sigma and Other Next-generation Techniques, USA: John Wiley & Sons, Inc.

Thijssen, J.J.J., 2010, Irreversible investment and discounting: an arbitrage pricing approach. Annals of Finance, Vol. 6, pp. 295–315, doi.org/10.1007/s10436-008-0108-4

Timan, S., 1985 “Urban Land Prices Under Uncertainty.”, American Economic Review, Vol. 75, No. 3, (June 1985), pp. 505-514.

Titman, S., 1985, Urban Land prices Under Uncertainty, The American Economic Review, Vol. 75, No. 3, pp. 505-514.

Triantis, A. J., 1999, A View Through a Real Options Lens. Real Options and Business Strategy: Applications to Decision-Making, pp. 39–58.

Triantis, A. J., 2000, Real Options and Corporate Risk Management. Journal of Applied Corporate

Finance Vol. 13, No. 2, pp. 64-73.

Triantis, A. J., 2005, Realizing the Potential of Real Options: Does Theory Meet Practice Journal of Applied Corporate Finance Vol. 17, No. 2, pp. 8–16.

Triantis, A., Borison, A., 2001, Real options state of the Practice, Journal of applied corporate Finance, Vol 14, pp. 8-24.

Trigeorgis, L., 1988, A conceptual options framework for capital budgeting, Advances in Futures and Options Research, Vol 3, pp. 145–167.

Trigeorgis, L., 1993, The Nature of Option Interactions and the Valuation of Investments with Multiple Real Options, The Journal of Financial and Quantitative Analysis, Vol 28, No. 1, pp. 1–20.

Trigeorgis, L., 1993, Topics in real options and applications: Real Options and Interactions with Financial Flexibility, Financial Management, Vol. 22, No. 3, pp: 202-223.

Trigeorgis, L., 1995, Real options in capital investment: models, strategies, and applications, Praeger Publisher, an imprint of Greenwood Publishing Group, Inc, Westport, USA.

Trigeorgis, L., 1999, Real Options: Managerial Flexibility and Strategy in Resource Allocation, Cambridge, Massachusetts: MIT Press.

Trigeorgis, L., 2005, Making use of real options simple: An overview and applications in flexible/modular decision making, The Engineering Economist, Vol 50, June 2012, pp. 25–53.

Trigeorgis, L., Baldi, F., 2016, Valuing brand strategies with real options. Brand Strategies.

Trönnberg, C., C., Hemlin, S., 2012, Banker's lending decision making: a psychological approach, Managerial Finance, Vol. 38, No. 11, pp.1032-1047.

Turnbull, S., M., 2000. Capital allocation and risk performance measurement in a financial institution, Financial Markets, Institutions & Investments, Vol. 95, pp. 325-357.

Ullrich, C., 2015, Valuation of IT Investments Using Real Options Theory. Springer Science & Business Media, Vol. 5, pp. 331-341.

Vasicek, O., A., 1984, Credit Valuation. KMV Corporation.

Vionea, G., Anton, S.G., 2009, Lessons from the current financial crisis. A Risk Management Approach, Review of Economic and Business Studies REBS, Vol. 3, pp. 139-147.

Wang, H., Mao K., Wu W., Luo H., 2023, Fintech inputs, non-performing loans risk reduction and bank performance improvement, International Review of Financial Analysis 90 (102849), https://doi.org/10.1016/j.irfa.2023.102849.

Willigers B.J.A., Hansen, T.L., 2008, Project valuation in the pharmaceutical industry: a comparison of least-squares Monte Carlo real option valuation and conventional approaches, R&D Managment, Vol. 38, No. 5.

Wright, M. E., Davidson, R. A., 2000, The effect of auditor attestation and tolerance for ambiguity on commercial lending decisions. Auditing: A Journal of Practice & Theory, Vol. 19, No. 2, pp. 67-81.

Yeo, K. T., Qiu, F., 2003, The value of management flexibility - a real option approach to investment evaluation, International Journal of Project Management, Vol. 21, No. 4, pp 243-250.

Yoewono, H., 2018, Bankruptcy Prediction Models Applied on Companies Listed on the Indonesian Stock Exchange (IDX). Journal of Management and Leadership, Vol. 1, No. 2, pp. 1–19.

Zamore, S., Djan, K. O., Alon, I., Hobdari, B., 2018, Credit Risk Research: Review and Agenda, Emerging Markets Finance and Trade, Vol. 54, No. 4, pp. 811-835, DOI: 10.1080/1540496X.2018.1433658.

Zheng, C., Sarker, N., Nahar, S., 2018. Factors affecting bank credit risk: An empirical insight. Journal of Applied Finance & Banking, Vol. 82, 45-67.

Zhu, X., Chu, Q., Song, X., Hu, P., Peng, L., 2023, Explainable prediction of loan default based on machine learning models, Data Science and Management, Vol. 6, No. 3, pp. 123-133, https://doi.org/10.1016/j.dsm.2023.04.003.

Zmijweski, M. E., 1984, Methodological Issues Related to the Estimation of Financial Distress Prediction Models. Journal of Accounting Research, Vol. 22, pp. 59–82. https://doi.org/10.2307/2490859.

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Appendix 1

Change the variables following Grenadier (1995):

$$\boldsymbol{Q \equiv \frac{P}{Q}, X(Q) \equiv \frac{1}{C} V(P, C), Y(Q) \equiv \frac{1}{C} W(P, C)}$$

Since $\mathrm{V(P, I)} = \mathrm{IX(Q)}$,

$$\boldsymbol{V_P = C X_Q \frac{1}{C} = X_Q}$$

$$\boldsymbol{V_C = X + C X_Q \left(\frac{-P}{C^2}\right) = X - X_Q \frac{P}{C}}$$

$$\boldsymbol{V_{PP} = \frac{\partial}{\partial C} V_P = X_{QQ} \frac{1}{C}}$$

$$\boldsymbol{V_{CC} = \frac{\partial}{\partial C} V_C = X_Q \left(\frac{P}{C^2}\right) - \left[X_Q \left(\frac{P}{C^2}\right) + X_{QQ} \frac{P}{C} \left(-\frac{P}{C^2}\right)\right] = X_{QQ} \frac{P^2}{C^3}}$$

$$\mathbf{V_{PC} = \frac{\partial}{\partial C} V_P = X_{QQ}(-\frac{P}{C^2})}$$

Appendix 2

$$\boldsymbol{(a) V(P_H, C_H) = W(P_H, C_H) - C_H}$$

$$\boldsymbol{(b) V_P(P_H, C_H) = W(P_H, C_H)}$$

$$\boldsymbol{(c) V_C(P_H, C_H) = W_C(P_H, C_H) - 1}$$

Lets divide both sides on C_H and than reorganize it:

$$\boldsymbol{(a') X(Q)_H = Y(Q_h) - 1}$$

$$\boldsymbol{(b') X_Q(Q)_H - Y_Q(Q_h)}$$

$$\boldsymbol{(c') X(Q)_H - X_Q(Q_h) Q_H = Y(Q_H) Y_Q(Q_H) Q_H - 1}$$

Appendix 3

$$\boldsymbol{R^2_{Adjusted} = 1 - \frac{(1 - R^2)(N - 1)}{N - p - 1}}$$

where:

$R^2 - sample\ R^2$

N – total sample size

p – number of independent variables