THE RISK CHANNEL IN THE TRANSMISSION MECHANISM OF MONETARY POLICY IN THE EUROPEAN MONETARY UNION BASED ON GERMAN DATA

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I ABSTRACT

This research answers the call of de Groot (2014) to explore the risk channel in the transmission of monetary policy by identifying the operating mechanism. The importance of that topic arises because central bankers are increasingly confronted with fluctuations in the business cycle that result from an unnoticed pile up of risk in the balance sheet of commercial banks. Decision makers of monetary policy need to understand this kind of risk-related business cycle fluctuations in order to respond appropriately with their monetary policy measures. This Post-Positivist research contributes theoretical and empirical insights on the underlying mechanism of the risk channel in the European Monetary Union. The theoretical findings consist in a theoretical representation of the risk channel, which explains the effect of monetary policy on risk perception and risk-taking of commercial banks. The strength of the mechanism depends on the liquidity multiplier as well as macroeconomic and financial background conditions. Macroprudential bank regulation affects the risk channel through the capital framework effect and the capital threshold effect. The empirical findings are based on a regression analysis on regulatory data of German commercial banks in the period between 2002 and 2019. The empirical evidence supports the hypotheses on the risk channel mechanism: First, low ECB interest rates on main refinancing operations have a statistically significant, positive effect on credit risk perception of German IRBA banks. Second, low ECB interest rates on main refinancing operations have a statistically significant, negative effect on credit risk-taking of German banks. Third, the ECB interest rate on main refinancing operations has a statistically significant, negative effect on interest rate risk-taking of German banks. Fourth, the evidence points to a nonlinear nature of the risk channel in monetary transmission. The implication for monetary policy makers is that monetary policy measures aimed to stabilise inflation can under certain circumstances have undesired side effects on the accumulation of risk in the balance sheet of commercial banks and hence the stability of the bank sector.

KEYWORDS: risk channel of monetary policy, risk-taking, financial stability, macroprudential bank regulation

II AUTHOR'S DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of the University of Gloucestershire and is original except where indicated by specific reference in the text. No part of the thesis has been submitted as part of any other academic award. The thesis has not been presented to any other education institution in the United Kingdom or overseas.

Any views expressed in the thesis are those of the author and in no way represent those of the University.

SIGNED …[redacted]……………………………

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1 INTRODUCTION

1.1 CHAPTER INTRODUCTION

This research relates to the field of monetary economics by investigating the link between monetary policy and risk-taking of commercial banks in order to explain the risk channel of monetary policy in the European Monetary Union (EMU) by identifying the operating transmission mechanism. This chapter preludes the research by providing an overview on the research context and the research motivation along with a justification of the importance and originality of the research. Furthermore, it presents the research aim and questions, the paradigm of research as well as the structure of the thesis.

1.2 RESEARCH CONTEXT

Conducting monetary policy for the 19 member states of the European Monetary Union (EMU) is the main concern of the European Central Bank (ECB). According to Article 127(1) of the Treaty on the Functioning of the European Union, the primary objective of the European System of Central Banks (ESCB) is to ensure price stability in the Euro area, which is interpreted as inflation under but close to 2% in the medium term. Furthermore, the secondary objective of the ESCB is the support of real economy targets such as full employment and growth of the gross domestic product (GDP). Monetary instruments include the base rate of interest, the money supply and reserve requirements. The use of these instruments triggers a variety of mechanisms, which finally affect macroeconomic variables like output and prices. This process is of high complexity and is termed the transmission mechanism of monetary policy (TMMP).

The transmission mechanism that drives the effect of monetary impulses through the economy comprises a variety of mechanisms and behaviours of economic actors in different stages of the transmission process (Kuttner & Mosser, 2002). Hence, monetary measures have an impact on the development of prices with a considerable delay in time. The relevant literature developed continually over decades with respect to improvement of the conceptual framework as well as adjustments towards a changing environment, resulting from a change in the financial system as well as institutional change. While a consensus is reached in theory on the fundamental operation of the transmission mechanism, there is still dissent on the details. Depending on the pathway of effects, various “traditional” channels in the transmission mechanism were identified in the existing research (Kuttner & Mosser, 2002). Empirical evidence points to the existence of another, largely unexplored mechanism referred to as the risk channel (de Groot, 2014). This risk channel in the TMMP is the subject of this research.

1.3 RESEARCH MOTIVATION

The theoretical and empirical literature on the traditional channels in the transmission mechanism of monetary policy (TMMP) emerged decades ago and experienced continuous improvements and extensions. Monetary theory on the interest rate channel, which is considered the main channel of monetary transmission, came up at the time when massive restrictions on the portfolio of banks on credit allocation and credit policies were in place (Taylor, 1995). The underlying mechanism explains monetary transmission with relocations in the portfolios of households and firms between capital market instruments (bonds) and reservable deposits. With the change towards the regulation of minimum capital requirements, the focus of monetary theory shifted towards the bank capital channel, which is based on cost differences of equity funding (Van den Heuvel, 2007). Beyond these and other traditional channels of monetary transmission, empirical evidence points to the existence of a largely unexplored mechanism, which Borio and Zhu (2008) coined the risk-taking channel. The risk-taking channel refers to the link between monetary policy and the risk-taking of commercial banks.

Some empirical studies approached the risk channel of monetary transmission. De Groot (2014) found for the United States of America (USA) that monetary policy can affect the amount of risk in the balance sheet of the financial sector through changes in the monetary policy rate of interest. Related empirical research on banks in the USA and the EU presents evidence in support a risk channel as well, among them Gambacorta (2009), Jiménez, Ongena, Peydró and Saurina (2012), Dell'Ariccia, Laeven and Suarez (2017), Paligorova and Santos (2017) as well as Adrian, Estrella and Shin (2019). Empirical studies of the risk channel in Germany seem to be absent. This research study addresses this gap by contributing new empirical insights on the risk channel of monetary policy in the EMU for German commercial banks.

The mechanism that facilitates the risk channel of monetary transmission remains nebulous. In theoretical literature on the TMMP, the element of risk is often neglected or only touched peripherally so far. Moreover, the link between macroprudential bank regulation and monetary policy is barely subject of theoretical literature. Altogether, a comprehensive theoretical representation on the underlying mechanisms of the risk channel is missing. Therefore, it makes sense to follow up on the empirical findings of de Groot (2014) and others. This research gap provides much space for further investigation on the mechanism behind the risk channel of monetary policy.

IMPORTANCE: The change in the financial system, the increase in macroprudential regulation as well as the low-interest environment in the EMU made the risk channel become more important within the monetary transmission mechanism, that means in relation to the traditional channels (Altunbas, Binici & Gambacorta, 2018). Central bankers are increasingly confronted with fluctuations in the business cycle, resulting from a long-lasting increase in risk-taking followed by a sudden recession, where long periods of apparent stability give way to sudden, potentially highly disturbing financial tensions (Borio & Zhu, 2012). The financial crisis that emerged in 2007 is the latest reminder of this evolution (Baily, Litan & Johnson, 2008). Decision makers of monetary policy need to understand this kind of business cycle fluctuations in order to respond appropriately with their monetary policy measures. Consequently, the analysis of the interaction between monetary policy and risk-taking is a necessary step for providing political decision makers with a sounder analytical base for their response to business cycle fluctuations that relate to the accumulation of risk.

ORIGINALITY: This study investigates the underlying mechanism that drives the risk channel of monetary transmission and contributes a theoretical representation of the risk channel to the theoretical literature that explains the link between monetary policy and risk-taking of commercial banks. This research highlights the dimension of risk and the role of macroprudential bank regulation in the TMMP. Furthermore, this study contributes empirical insights on the link between monetary policy in the EMU and risk-taking of German commercial banks. Hence, this study will narrow the gap in the research on monetary transmission through the risk channel by both a theoretical and empirical contribution.

1.4 RESEARCH AIM AND QUESTIONS

The main concern of monetary economics is the transmission of monetary policy impulses through the economy induced by the central bank. Literature on the risk channel of monetary transmission is still comparatively rare. The link between monetary policy and risk-taking of commercial banks requires further research.

RESEARCH AIM: The real economy is vulnerable to disturbances of the financial system, which can arise from an unnoticed pile up of risk in the balance sheet of commercial banks in association with monetary policy. The aim of this research is to explain the risk channel of monetary policy in the European Monetary Union (EMU) by identifying the operating transmission mechanism in a conceptual representation and to complement this with empirical insights of the German bank sector. The risk channel represents the effect of a change in the monetary policy rate of interest controlled by the central bank on risk-taking of commercial banks, as reflected by the amount of risk in their balance sheets as well as price and non-price conditions of credit extension.

RESEARCH QUESTIONS: To achieve that research aim, this study addresses the following research questions:

RQ1: What is the underlying mechanism of the risk channel in the transmission of monetary policy within the EMU?

RQ2: What is the role of macroprudential bank regulation in the risk channel in the transmission of monetary policy within the EMU?

RQ3: What are the implications of the risk channel for the decision makers of monetary policy for the EMU?

The scope of this research is delimited to monetary transmission through the risk channel in the EMU and therefore to the transmission of monetary policy conducted by the European Central Bank (ECB) through the economies of the

19 member states[1]. Consequently, the theoretical analysis focuses on explaining the risk channel mechanism of monetary transmission in contrast to that of other traditional channels of monetary policy such as the interest rate channel or the credit channel. Furthermore, the empirical analysis focuses on commercial banks in Germany as a member state of the EMU and covers the time period between 2002 and 2019, whereby the starting point corresponds to the early beginning of the EMU with the introduction of the Euro as common cash money.

[1] With the start of the EMU on 01.01.1999, the ECB became responsible for the common monetary policy (ECB, 2022a). As of 2022, the member states of the EMU include: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden.

1.5 PARADIGM OF RESEARCH

The research on the risk channel is conducted under the research paradigm of Post-Positivism. The researcher is objective and takes a neutral, outside standing position throughout the whole research process. The paradigm of Post-Positivism has its foundations in the Positivist paradigm and integrates some elements of the Interpretivist paradigm (Grix, 2004). Throughout this research, the researcher takes the ontological starting point of one reality, which originates from the Positivist paradigm. The epistemological position of the researcher is to understand a reality of limited visibility, which originates from the Interpretivist position. The reasons for approaching the risk channel under the Post-Positivist paradigm are outlined in what follows.

The ontological view of one reality seems reasonable for explaining the risk channel mechanism because there is no reason to assume that different realities exist. The underlying mechanism relies on macroeconomic relations between interest rates, asset values, capital, liquidity, risk that are considered in the context macroprudential bank regulation. The existing economic and financial literature investigates these variables standardly under the ontological position of one truth. The consideration of the context is important because the legal framework affects the mechanism. However, the ontological starting point of different realities has more relevance at the microlevel and for research questions where subjective interpretations of individuals do matter. In this research the context is limited to the EMU and Germany, so that tracing only one reality of the risk channel mechanism seems reasonable.

The Positivist epistemological attempt to explain one fully visible truth would be too limited for explaining the risk channel mechanism. First, the development of a theoretical representation requires the consideration of a highly complex process, which involves many economic and financial relationships. In this context, the truth is likely not fully visible for example due to lacks in theoretical and empirical research on single aspects that contribute to the mechanism of the risk channel. Second, the empirical analysis on German banks is subject to data restrictions because bank data is generally highly sensitive and protected by German law. Moreover, some variables that affect the mechanism are not directly observable and hence must be proxied by suitable variables that are observable. Therefore, the researcher accepts the epistemological view of limited visibility and chooses a research design that is consistent to the available data and the aim of investigating the effect of a change in the monetary policy rate of interest on risk perception and risk-taking of commercial banks. The circumstance that the reality is not fully visible affects in particular the methodological approach including the choice of the empirical method, the specification of econometric models and the application of confidence intervals.

To sum up, the researcher takes the Post-Positivist position, because the risk channel requires to some extent the Interpretivist elements of interpretation and the consideration of the context, which can contribute to a more comprehensive understanding of the research subject. The Post-Positivist paradigm opens up the necessary space in the development of the theoretical representation of the risk channel as it allows for the integration of elements from different disciplines and theories as well as the consideration of the context, in particular with respect to the institutional framework of macroprudential bank regulation as well as macroeconomic and financial background conditions. As typical for the Post-Positivist approach, this research starts out with a theoretical part, in which a literature review leads to the research gap and brings out a theoretical concept of the risk channel. In the subsequent empirical part, a quantitative method is applied to test the hypotheses derived of the economic model based on data of German commercial banks. As typical for the Post-Positivist paradigm, the methodology of this research builds up on a quantitative method in the form of a regression analysis.

1.6 STRUCTURE OF THE THESIS

The thesis builds up on 3 components that are driven by the research aim and questions, as shown in Figure 1.1.

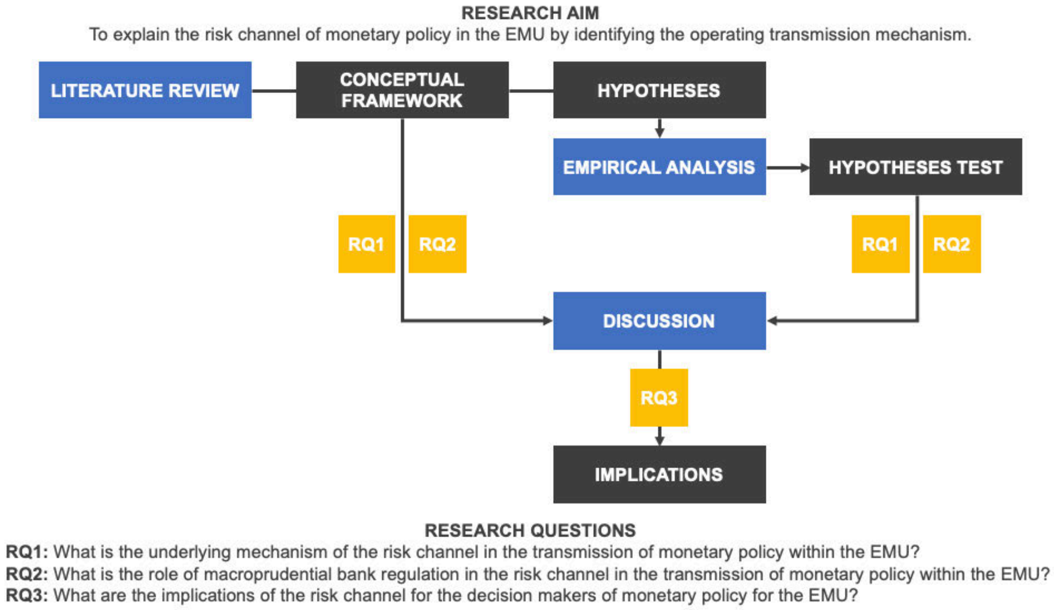

FIGURE 1.1:
RESEARCH DESIGN

Source: author's illustration

The first component "Literature Review" (chapter 2) relates to the theory and results in a theoretical representation of the risk channel in monetary transmission which implies the economic model. The second component is the "Empirical Analysis" (chapter 4) including the "Methodology" (chapter 3), in which the hypotheses of the risk channel are tested based on data of German commercial banks. These two components relate to the research questions of explaining the underlying mechanism of the risk channel in the TMMP within the EMU (RQ1) including the role of macroprudential bank regulation (RQ2). The theoretical and empirical results both build the foundation for the "Discussions" (chapter 5) and "Conclusion" (chapter 6) on the implications of the findings on the risk channel for the decision makers of monetary policy in the EMU (RQ3).

The structure of the thesis subsequent to this introductory chapter 1 is outlined in the following sections. Each chapter contains a chapter introduction and chapter conclusion.

Chapter 2 presents the findings of the literature review. The versatile nature of the risk channel with its micro and macros aspects requires the consideration of the intersections of theory from different disciplines. Chapter 2.2 examines the economic theory on monetary transmission including the theories on money, interest and credit from different schools of thought, the traditional channels of monetary policy as well as the academic debate and research gap. Chapter 2.3 is dedicated to the perspective of finance theory on bank risk. The focus is on bank risk management, bank risk measurement, bank risk pricing and the implication for the risk channel. Chapter 2.4 puts the emphasis on the institutional context of macroprudential bank regulation in the EMU and how that regulation affects monetary transmission through the risk channel. The focus is on the institutional framework, the requirements on the measurement of credit risk and the requirements on capital, leverage and liquidity. Chapter 2.5 presents the theoretical representation of the risk channel in the TMMP that explains the path of effects from a change in the monetary policy rate of interest on risk-taking of commercial banks. It covers the key insights on risk-taking, liquidity and capital regulation, the monetary transmission mechanism as well as the background conditions that affect the risk channel.

Chapter 3 introduces the empirical part of the research by outlining the methodology of the empirical analysis. Chapter 3.2 presents the research paradigm with an emphasis on ontology, epistemology and methodology. Chapter 3.3 outlines the research approach. Chapter 3.4 derives the hypotheses from the economic model implied by the theoretical representation of the risk channel and presents the identification strategy. Chapter 3.5 outlines the collection of the secondary data. Chapter 3.6 presents the applied research methods with respect to regression model specification, regression method and statistical inference. Chapter 3.7 addresses ethical considerations of the research.

Chapter 4 is concerned with the empirical analysis of data and builds up on a regression analysis. Chapter 4.2 presents the data samples along with the data preparation. Chapter 4.3 presents the descriptive statistics. Chapter 4.4 outlines the specification of the econometric models. Chapter 4.5 refers to the time series diagnostics. Chapter 4.6 outlines the regression model diagnostics. Chapter 4.7 is dedicated to the test of the hypotheses. Chapter 4.8

summarises the regression results. Chapter 4.9 refers to the regression evaluation.

Chapter 5 is focused to the discussions of the research findings. Chapter 5.2 evaluates the empirical findings of the empirical analysis in the light of the theoretical findings of the literature review. Chapter 5.3 compares the results of the current research to that of the previous related studies.

Chapter 6 completes the research with the conclusion. Chapter 6.2 summarises the research with an overview. Chapter 6.3 highlights the main findings of the research. Chapter 6.4 outlines the implications and recommendations that follow from the research findings. Chapter 6.5 elaborates on the research contributions. Chapter 6.6 addresses the limitations of this research. Chapter 6.7 offers suggestions for further research.

1.7 CHAPTER CONCLUSION

This introductory chapter outlines monetary policy as the context of the research along with the research gap of the risk channel in the transmission of monetary policy. It presents the research aim of explaining the underlying mechanism of the risk channel as well as the corresponding 3 research questions that lead this study. Furthermore, Post-Positivism is introduced as the paradigm under which this research is conducted. Finally, it presents a brief overview on the structure of the thesis along with an indication on the interplay between the chapters and the research questions.

2 LITERATURE REVIEW

2.1 CHAPTER INTRODUCTION

This chapter constitutes the theoretical starting point of this research and aims to shed light on the various aspects of the risk channel in monetary transmission from different perspectives. The literature review examines the theory of economics and finance with the emphasis on monetary policy transmission and its link to risk in the balance sheet of commercial banks. In addition, the institutional framework of macroprudential bank regulation in the EMU is investigated with regard to its role in the transmission mechanism. The objective of this chapter is to develop a theoretical representation of the risk channel in the TMMP, which allows to derive and economic model along with hypotheses for the empirical analysis of this research.

2.2 ECONOMIC THEORY ON MONETARY TRANSMISSION

This chapter is dedicated to the economic theory on the transmission of monetary policy, investigating how monetary policy might affect the risk-taking behaviour of banks. The first subchapter examines the economic theory on money, interest, and credit from different schools of thought. The second subchapter investigates the traditional channels of monetary policy. The third subchapter summarises the corresponding academic debate and points out the identified gap in research.

2.2.1 THEORY ON MONEY, INTEREST AND CREDIT

This subchapter is dedicated to the economic theory on money, interest, and credit in different schools of thought including classical theory, Keynesian theory, and Post-Keynesian theory with a focus on the role of banks, risk, capital liquidity as well as monetary policy interventions.

2.2.1.1 CLASSICAL THEORY

The classical quantity theory of money goes back to Irving Fisher (1896) and became influential in the 1970s, that is the era of Monetarism with well-known advocates like Milton Friedman (1956), Karl Brunner (1976), Allan Meltzer (1976) and Phillip Cagan (1958). The central belief is that prices, hence the value of money, and the nominal money stock are directly interrelated.

Monetarists regard money as a special asset that plays a key role in portfolio allocation due to its special function (Fisher, 1896; Friedman, 1959). In the classical model, money is defined as assets that are widely used and accepted as payment. It functions as a medium of exchange, a unit of account and a store of value. The supply of money is the amount of money available in the economy, which can be influenced by the central bank through open market operations and the issuance of government bonds. The expected return is defined as the rate of return, this is an asset's increase in value per unit of time. Investors want assets with the highest expected return (ceteris paribus), the returns are not known in advance, so people estimate their expected return.

In classical theory risk is regarded as the degree of uncertainty in an asset's return (Fisher, 1896). People are risk-averse, so they prefer assets with low risk (ceteris paribus). Risk relates to money as increased riskiness in the economy may increase money demand, in times of erratic inflation risk in holding money is increased, so money demand declines. Another central determinant is liquidity, which is defined as the ease and quickness with which an asset can be traded. Money is very liquid, assets like automobiles and houses are rather illiquid since it takes long time and large transaction costs to trade them. Stocks and bonds are seen as fairly liquid. Investors prefer liquid assets (ceteris paribus). Liquidity relates to money as financial deregulation, competition and innovation have given alternative assets more liquidity, reducing the demand for money. The time to maturity refers to the amount of time until a financial security matures, and the investor is repaid the principal. According to the expectations theory of the term structure of interest rates, investors compare returns on bonds with differing times to maturity (Modigliani & Sutch, 1966; Modigliani & Shiller, 1973). In equilibrium, holding different types of bonds over the same period yields the same expected return. Because long-term interest rates usually exceed short-term interest rates, a risk premium exists: the compensation to an investor for bearing the risk of holding a long-term bond. The demand for assets, including money, bonds, stocks, houses and consumer durable goods, is characterised by a trade-off among their expected return, risk, liquidity and time to maturity (Fisher, 1896). Money has a low return, but low risk and high liquidity.

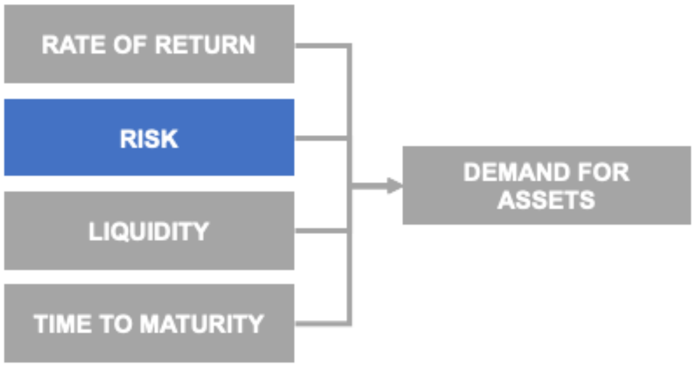

FIGURE 2.1:
ASSET DEMAND AT THE MICRO LEVEL

Source: author's illustration

According to Friedman (1959), the demand for money is described by the money demand function, in which the aggregate nominal money demand (M^d) is dependent from the price level (P) and the money demand function (L), which is in turn conditional to real income or output (Y) and the nominal interest rate on nonmonetary assets (i).

$$M^d = P * L(Y, i) \tag{2.1}$$

When the nominal interest rate on nonmonetary assets (i) is replaced by the real interest rate on nonmonetary assets (r) and expected inflation (π^e) an alternative expression becomes:

$$M^d = P * L(Y, r + \pi^e) \tag{2.2}$$

Velocity (V) is a measure for the turn-over of money in each period and depends on the nominal GDP (PY) and the nominal money stock (M). This yields the quantity theory of money, which represents the classical dichotomy, that is the idea that nominal and real variables are independent of each other (Friedman, 1956).

$$MV = PY \tag{2.3}$$

That means real output (Y) is determined solely by real factors such as the size of the capital stock and the labour force as well as the state of technology.

The economy is assumed to be at its full employment level. The nominal variable of money supply (M) is exogenously[2] determined by the central bank, while velocity (V) is predetermined by the payment and expenditure practices in the economy. Hence, the price level (P) is the only endogenous variable in the system. In the long run, variations in the nominal money stock (M) are reflected in proportionate changes in the price level (P). That implies in the long-run money does not matter – the classical neutrality of money. The quantity theory of money assumes a constant velocity, where velocity is not affected by income or interest rates and hence states that real money demand is proportional to real income:

$$M^d/P = kY \tag{2.4}$$

The asset market equilibrium condition is that real money supply equals real money demand:

$$(M/P) = L(Y, r + \pi^e) \tag{2.5}$$

Money supply (M) is determined by the central bank, π^e is expected inflation, income Y depends on the labour market, which determines the level of employment by using employment in the production function. For a given Y, the goods market equilibrium condition determines r (assuming π^e to be fixed). That means the asset market equilibrium condition determines the price level (P):

$$P = M/L(Y, r + \pi^e) \tag{2.6}$$

The price level is the ratio of nominal money supply to real money demand. That means for example that doubling the money supply would double the price level. The inflation rate is closely related to the growth rate of the money

[2] In economic modeling, the distinction between exogenous and endogenous variables is that exogenous variables are determined by factors outside the model, while endogenous variables are determined within the model, that is by their relationship to other variables in the model (Orcutt, 1960).

supply (Friedman, 1959). Rewriting the asset market equilibrium condition in growth-rate terms gives:

$$\frac{\Delta P}{P} = \frac{\Delta M}{M} - \frac{\Delta L(Y, r + \pi^e)}{L(Y, r + \pi^e)} \quad (2.7)$$

If the asset market is in equilibrium, the inflation rate equals the growth rate of the nominal money supply minus the growth rate of real money demand. Therefore, forecasting inflation requires forecasting both money supply growth and real money demand growth. The relation between expected inflation rate and the nominal interest rate can be derived from:

$$i = r + \pi^e \quad (2.8)$$

For a given real interest rate (r), expected inflation (π^e) determines the nominal rate of interest (i). In the classical view, monetary policy affects the real economy only in the short run. As prices adjust, the real effects are offset as reflected by the classical proposition of the neutrality of money. Table 2.1 highlights the fundamental assumptions of the classical quantity theory of money (Friedman, 1956; Brunner and Meltzer, 1976).

TABLE 2.1:
CLASSICAL ECONOMIC THEORY ON ASSETS, MONEY AND PRICES

ELEMENT	ASSUMPTION
Money supply	Exogenous
Monetary policy instrument	Money supply
Main concern	Assets, money
Banks	No explicit role (merely financial intermediaries)
Reserve mechanisms	Multiplier
Reason for credit rationing	Asymmetric information
Interest rates	Arise from market laws
Liquidity preference	Determines the interest rate
Risk	Arises from the degree of uncertainty in an asset's return,

	holding money reduces risk (exception: high inflation risk)
Capital (equity)	No role, investment of firms is fully debt financed
Collateral[3]	No role
Schumpeter's distinction[4]	Real analysis (money is neutral in the long run)
Financial disturbances	Short-run effects only (price rigidities)
Inflation causality	Price inflation is caused by an excess supply of money
Macroeconomic causality	Saving determines investment
Monetary causality	Deposits allow loans

In the classical model the supply of money is exogenously determined by the central bank, while the consideration of the monetary policy instruments is restricted on changes in the supply of money. Commercial banks function rather as financial intermediaries, who do credit rationing for reasons of imperfect information, while the credit market and collateral in general have no explicit role. Interest rates arise from market laws, driven by liquidity preference at the asset market. Monetary interventions have real effects only in the short run. As soon as prices adjust, the real effects are offset, hence money is neutral in the long run. This conclusion arises from the assumptions of perfect markets, rational agents, and full information, which excludes the possibility of imperfect outcomes and market failure. In the classical model, risk is associated to uncertainty regarding the return on assets, holding money reduces uncertainty under normal conditions. In the classical theory on money there is no explicit role for the link between monetary policy and risk-taking of commercial banks.

[3] In lending agreements, collateral is a borrower's pledge of assets to a lender, to secure repayment of a loan (Tian, 2017).
[4] Schumpeter (1954) made the distinction between "real analysis" and "monetary analysis". In "real analysis" the equilibrium values of the economic system, that is output, employment, distribution and growth, can be determined without any reference to monetary variables.

2.2.1.2 KEYNESIAN THEORY

The IS/LM model of Hicks (1937) is known as the baseline model for most of the conventional macroeconomic textbooks. It is intended as a graphical representation of "The General Theory of Employment, Interest, and Money" of Keynes (Keynes, 1936). The model explains the adjustments between the asset market, the good market and the labour market towards the general equilibrium, including the impact of a monetary policy intervention in the event of a disequilibrium. The following section outlines the theoretical foundations of the basic IS/LM framework in order to illustrate the economic response to a monetary policy intervention by the interplay of the asset market, the goods market and the labour market.

The full employment line (FE) shown Figure 2.2 represents the equilibrium at the labour market, which adjusts employment and output towards the full-employment level (Abel, Bernanke & Croushore, 2011). The FE line is vertical since it does not depend on the real interest rate. The full-employment level of output is determined by the full-employment level of employment and the levels of capital and productivity. An increase (decrease) in these factors will shift the FE line to the right (left). Capital in the sense of this model refers to capital as means of production, for example machinery, which is not to be confused with capital in finance theory in the means of equity capital in the balance sheet.

The investment-saving curve (IS) represents the equilibrium at the goods market (Abel, Bernanke & Croushore, 2011). It shows the relationship between the real interest rate and output for which desired national investment (I^d) equals desired national saving (S^d) at the goods market (Keynes,1936). The saving curve slopes upward because a higher real interest rate increases saving. An increase in output shifts the saving curve to the right because people save more when their income is higher. The investment curve slopes downward because a higher real interest rate reduces the desired capital stock, thus reducing investment.

The LM curve represents the equilibrium at the asset market (Abel, Bernanke & Croushore, 2011). It indicates the relationship between the real interest rate and output, where real money demand (liquidity L) equals real money supply

(M) at the asset market (Keynes, 1936). Consistent with classical theory, as outlined by the asset market equilibrium condition $(M/P) = L(Y, r + \pi^e)$, for a given level of expected inflation, the price of a nonmonetary asset is inversely related to the real interest rate: a fall in the price of a non-monetary asset means an increase in the rate of return, ceteris paribus (Hicks,1936). At the asset market, real money supply (M) is a vertical line since it is determined by the central bank and not affected by the real interest rate. Real money demand (M^d) slopes downward because it falls as the real interest rate (r) rises and rises as the level of output (Y) rises. This negative relationship between the demand for money and the rate of interest provides a link between changes in the supply of money and the level of economic activity. In contrast to classical theory, the IS/LM model simplifies in the categorisation of assets by the distinction between only two assets: money and non-monetary assets. That means in terms of bank loans, that they are put together with all other asset market instruments.

The general equilibrium IS/LM model shown in Figure 2.2 considers the interaction between the 3 markets: the labour market via the vertical FE line, the goods market via the downward sloping IS curve and the asset market via the upward sloping LM curve (Abel, Bernanke & Croushore, 2011). The relative time of markets to adjust differs: the financial markets respond most quickly to changes in economic conditions, that means the asset market responds first to monetary interventions. The labour market responds most slowly due to the time effort in job matching and wage negotiation.

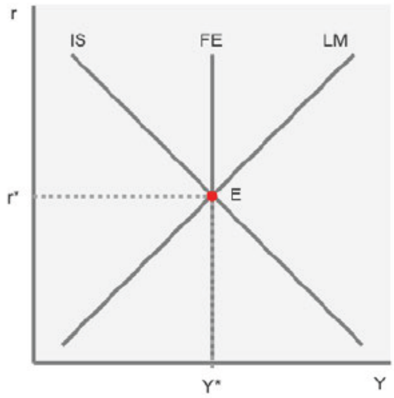

FIGURE 2.2:
THE GENERAL EQUILIBRIUM IN THE IS/LM MODEL

Source: author's illustration

The IS/LM model allows to analyse the effects of monetary policy interventions on the economy, for example in reaction to a disequilibrium with real output falling below full employment output. In this situation, the central bank increases the nominal supply of money, as reflected by a right shift of the real money supply (M/P) line. The price level remains unchanged in the short run due to price rigidities. At the asset market, the demand for nonmonetary assets increases, which increases asset prices and reduces the real interest rate (r). In turn, the fall in the real interest rate increases demand for consumption of households and demand for investment by firms at the goods market. In the short run, the expansionary monetary intervention leads to a new general equilibrium with output being back to full employment output. In the long run, the increase in the nominal money supply (M) causes the price level (P) to change proportionally, which shifts the LM curve back to the left. This reflects the neutrality of money in the long run. Table 2.2 highlights the main characteristics of the Keynesian theory on the IS/LM model (Keynes, 1936; Abel, Bernanke & Croushore, 2011).

TABLE 2.2:
KEYNESIAN THEORY AND THE IS/LM MODEL

ELEMENT	ASSUMPTION
Money supply	Exogenous
Monetary policy instrument	Money supply

Main concern	Asset market, labour market, goods market
Banks	No explicit role (merely financial intermediaries)
Reserve mechanisms	Multiplier
Reason for credit rationing	Asymmetric information
Interest rates	Arise from market laws
Liquidity preference	Determines the interest rate
Risk	Arises from uncertainty, no explicit role
Capital (equity)	No role, investment of firms is fully debt financed
Collateral	No role
Schumpeter's distinction	Real analysis
Financial disturbances	Effects in both short-run and long-run (rigidities in prices and wages)
Inflation causality	Price inflation is caused by an excess supply of money
Macroeconomic causality	Saving determines investment
Monetary causality	Deposits allow loans

There is consensus between classical and Keynesian economists on the general idea of the IS/LM general equilibrium framework. However, the two schools of thought differ in the underlying assumptions. One debate is on the speed of adjustment of the price level (Abel, Bernanke & Croushore, 2011). While both classical economists see rapid adjustment in the price level, advocates of the Keynesian school assume much more time up to several years before prices and wages fully adjust. When not in general equilibrium, output is determined by aggregate demand at the intersection of the IS and LM curves, while the labour market is not in equilibrium. That means, depending on the assumptions, the IS/LM model leads to different results in terms of the economic response. Money is neutral if a change in the nominal money supply changes the price level proportionately but has no effect on real variables (Keynes, 1936). While classical and Keynesian economists agree on the neutrality of money in the long-run, there is dissent in the short-run. The classical view is that a monetary expansion affects prices quickly with at most a transitory effect on real variables such as real wages and real output. Keynesians take the position that the economy may spend a long time in disequilibrium, so a monetary expansion increases output and employment and causes the real interest rate to fall.

In the Keynesian IS/LM framework, the money supply is exogenously determined by the central bank. The focus of that framework is on the interplay between the asset market, the labour market, and the goods market. Just as in the classical theory, banks have no explicit role. For that reason, there is no indication on the role of bank behaviour with respect to risk-taking in monetary transmission. The equilibrium rate of interest is determined by the demand for and supply of money through liquidity preference. The IS/LM framework provides an explanation for regular business cycle movements and the effects of a monetary or fiscal intervention in reaction to a disequilibrium. What remains nebulous is the link between monetary policy and the risk-taking of banks.

2.2.1.3 POST-KEYNESIAN THEORY

The Post-Keynesian macroeconomic theory on money, interest and credit goes back to the ideas of Richard Kahn (1931, 1972), Nicholas Kaldor (1957) and Joan Robinson (1956, 1962), which were further developed by Michal Kalecki (1937) and Piero Sraffa (1960). The Post-Keynesian school differs radically from the classical school of thought regarding the underlying assumptions (Lavoie, 2022). One of those assumptions is fundamental uncertainty. The Post-Keynesian theory builds up on the ideas of Keynes (1936), who considered money as wealth in its most liquid form. That means holding money means to be able to respond to unforeseen payment requirements and investment opportunities. Hein (2008) characterises the Post-Keynesian model as follows: Money has a liquidity premium. The rate of interest is the price for parting with money and holding wealth in a less liquid form. Forward contracts are seen as means of reducing the degree of uncertainty and introduce rigidity as anchor for expectations, for example money wage contracts and credit contracts. Institutions have the role of contract enforcement. Scarcity of money is necessary due to its function as value, means of payment and store of value. Money is generated when commercial banks grant credit and then demand reserves from the central bank.

The Post-Keynesian monetary system is a hierarchical system with the central bank at the top. At the money market, the central bank sets base rate of interest (or monetary policy rate of interest, synonymously), defines the standards for creditworthiness and supplies central bank money to commercial banks, acting as the lender of last resort. At the credit market, commercial banks mark-up the central bank's base rate of interest (Hein, 2008). The mark-up (m_B) is determined by the costs of banking, uncertainty, risk premia (default risk, liquidity premium), profits in banking, and the degree of competition in the banking sector. Commercial banks do credit rationing, that means they check the creditworthiness of firms and households and supply credit to those who are creditworthy (Palley, 1994).

$$m_B = cost + risk\ premium\ (default, liquidity) + profit\ (competition) \tag{2.9}$$

In this framework, credit and money are endogenously determined by the economic process (Hein, 2008). The interest rate is an exogenous distribution parameter for income generation and the growth process. In the notion of Lavoie (1992, p. 170):

> *“Money is credit-driven; loans make deposits; deposits make reserves. The supply of and the demand for credit money are interdependent. The control instrument of the central bank is not a quantity but a price, the rate of interest.”*

In order to hit the target interest rate, the central bank applies a corridor system with the lending facility rate as upper floor and the deposit facility rate as lower floor (Lavoie, 2014).

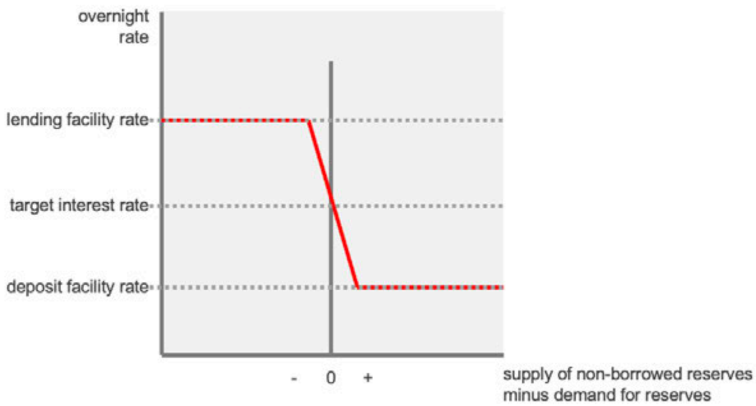

FIGURE 2.3:
INTEREST RATE TARGETING WITH THE CORRIDOR SYSTEM

Source: author’s illustration following Lavoie (2014)

On the credit supply by commercial banks, it is assumed that commercial banks obtain reserves at the money market only, that means the model does not account for deposits by households. The interest rate offered by commercial banks at the credit market (i_B) exceeds base rate of interest demanded by the central bank at the money market (i_{CB}) by the mark-up (m_B):

$$i_B = (1 + m_B) i_{CB} \tag{2.10}$$

Banks do credit rationing depending on the creditworthiness of firms at the credit market. Figure 2.4 shows the distinction between the notional demand of firms (L^{Dn}) and effective demand (L^{D}) for loans as banks do credit rationing (Lavoie, 2014).

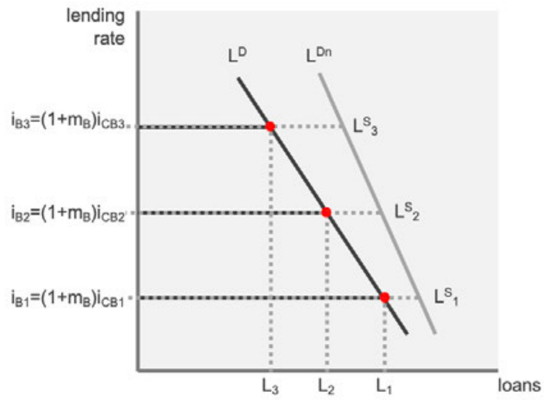

FIGURE 2.4:
DEMAND FOR LOANS AT THE CREDIT MARKET

Source: author's illustration following Lavoie (2014)

The Post-Keynesian horizontalist perspective on endogenous money and credit was pioneered by Kaldor (1982), Lavoie (1984) and Moore (1989). Figure 2.5 visualises the general equilibrium following the approach of Palley (1994). The supply of loans is a horizontal line (L^S), meaning commercial banks provide any level of loans because of a complete accommodation by the central bank as indicated by the horizontal money supply line (M^S). In contrast, the Post-Keynesian structuralist perspective assumes an upward sloping supply of loans (L^S) with incomplete accommodation of the central bank (Palley, 1994). The rate of interest determines the stock of capital, which is assumed to be exclusively debt financed by firms. In this general equilibrium framework, banks supply loans (L^S) only to the creditworthy demand for loans (L^D) by credit rationing. Therefore, effective demand (L^D) is below notional demand (L^{Dn}) for loans. Loans create deposits, as represented by the loan-deposit curve (LD). These deposits translate into reserves at the central bank, represented by the deposit-reserves curve (DM). The reserves in turn correspond to the money supplied by the central bank (M^S).

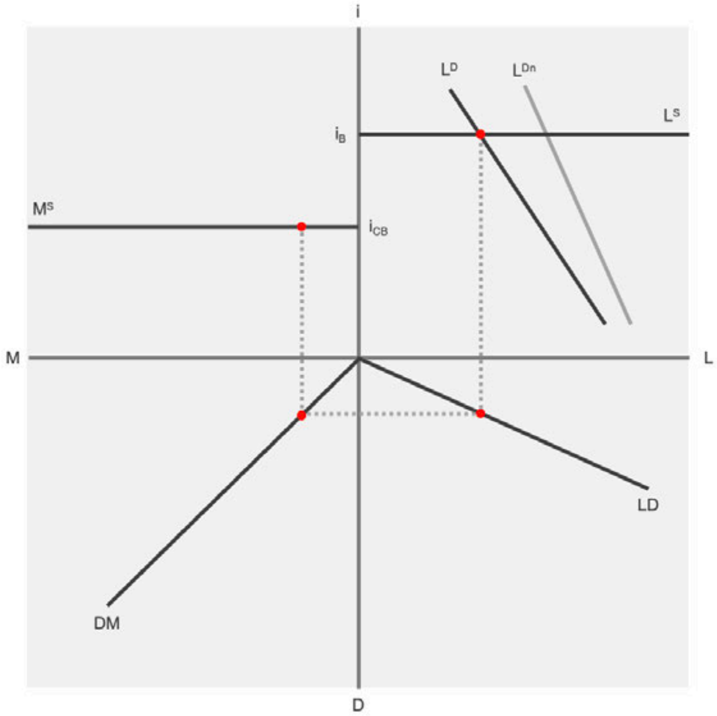

FIGURE 2.5:
THE GENERAL EQUILIBRIUM IN THE PK MODEL

Source: author's illustration

An expansionary (contractionary) monetary policy intervention starts with a decrease (increase) in the base rate of interest at the money market (i_{CB}). Given an unchanged mark-up, banks lower (raise) the rate of interest at the credit market (i_B), as well. Firms demand more (less) credit as the price of credit declines (rises) and increase (decrease) investments. The result is an increase (decline) in economic activity. This theory of endogenous money follows the inverse idea of the classical theory: The bank makes a new loan that appears as an asset in the balance sheet of the bank, the corresponding deposit of the borrower shows off in the liabilities of the bank. Due to reserve requirements, the new deposit requires additional reserves at the central bank (assuming the bank starts from an initial excess reserve of zero), which the bank borrows at the money market to the price the central bank defines (i_{CB}). As the borrower withdraws the deposit, the bank needs to borrow additional money at the money market in order to comply with the reserve requirements. In the words of Lavoie (1992), in this model "the central bank is a price maker and a quantity taker" (p. 170).

In the Post-Keynesian model, the central bank controls the short-term rate of interest at the money market, while the long-term rate of interest at the credit market is affected by central bank policies (applying the corridor system). The framework unveils a potential asymmetry: the central bank can increase the interest rate in any case, but a decrease is not possible if commercial banks simultaneously increase their mark-ups, for example due to an increase in liquidity preference or perceived risk of credit default. The volume of credit and quantity of money are endogenously determined by economic activity, credit demand and payment conventions. Changes in the long-term rate of interest may affect credit demand and hence the volume of credit and money if credit demand is interest elastic. Another potential asymmetry applies for monetary policy: increasing the base rate of interest will finally choke credit demand and economic activity; whereas decreasing the base rate of interest may not be sufficient to stimulate credit demand and economic activity. The limit of monetary expansion via the monetary policy rate is the zero-lower bound, which the ECB reached between 2016 and 2022 (ECB, 2021). Table 2.3 presents an overview on the key features of the Post-Keynesian perspective on money, interest and credit (Kaldor, 1982; Lavoie, 1984; Moore, 1989; Palley, 1994; Hein, 2008).

TABLE 2.3:
POST-KEYNESIAN THEORY ON MONEY, INTEREST AND CREDIT

ELEMENT	ASSUMPTION
Money supply	Endogenous and demand-led
Monetary policy instrument	Base rate of interest
Main concern	Debt, credit
Banks	Creators of credit flows
Reserve mechanisms	Divisor
Reason for credit rationing	Lack of confidence
Interest rates	Distribution variables
Liquidity preference	Determines the differentials relative to the base rate

Risk	Arises from fundamental uncertainty and is reduced by credit rationing, forward contracts and institutions
Capital (equity)	No role, investment of firms is fully debt financed
Collateral	Determined by central bank, implemented by commercial banks via credit rationing
Schumpeter's distinction	Monetary analysis
Financial disturbances	Effects in both short-run and long-run
Inflation causality	The growth in money aggregates is mainly caused by the growth in output and prices
Macroeconomic causality	Investment determines saving
Monetary causality	Loans make deposits

The Post-Keynesian perspective differs radically from classical theory on money. In the Post-Keynesian model, money supply is an endogenous variable, which is determined by effective demand for loans. The base rate of the central bank is the monetary instrument for the control of the price level though the price of money. Banks have a central role as the creators of credit flows, which do credit rationing due to a lack of confidence. Interest rates act as distribution variables. The liquidity preference affects the difference between the base rate at the money market and the interest rate at the credit market as part of the mark-up of commercial banks. The element of risk is more in the focus of attention compared to classical theory and the Keynesian IS/LM model. Risk arises from fundamental uncertainty and is reduced by institutions and forward contracts. Commercial banks are assumed to supply loans solely to creditworthy demand by credit-rationing. However, this simplified assumption neglects restrictions capital, liquidity and leverage that macroprudential bank regulation imposes on commercial banks. The expected risk is priced in through the risk premia component of the mark-up. The central bank affects risk by defining the standards of creditworthiness in terms of the accepted collateral. In the horizontalist model, the central bank provides a full accommodation of money for the supply of loans. That means this model does not consider a liquidity shortage of commercial banks that might impede loan supply. There is no role for equity capital, since firms are assumed to be fully debt financed, while equity capital of commercial banks is not considered at all. In contrast to the theories of other economic paradigms, the Post-Keynesian framework builds up on the notion of effective demand along with a macroeconomic causality, in which investment determines saving and credit creates deposits.

2.2.2 TRADITIONAL CHANNELS OF MP

The previous subchapter points out that the theoretical frameworks on money, interest, and credit of the classical, Keynesian and Post-Keynesian perspectives rely on different assumptions and consider neither the variety of channels in monetary transmission nor risk as an endogenous variable. The following subchapters outline the debate on the traditional channels of monetary policy.

In the EMU, the ECB applies 3 main instruments for monetary policy (ECB, 2021): (1) the quantity of money by open market operations, (2) the monetary policy rate of interest by a set of ECB interest rates on ECB facilities that banks may use at any time in order to borrow or deposit money and (3) reserve requirements on reservable liabilities of banks or voluntary deposits at the ECB. By using the inflation targeting strategy, the ECB determines a target for the change in the price level. In order to reach that target, the ECB uses the monetary policy rate of interest for controlling the price of money, while complementary open market operations aim to affect the quantity of money. At the money market for short-term facilities, the ECB uses a corridor system[5] in order to target the long-term rate of interest at the credit market by an upper lending facility rate (MLF) and a lower deposit facility rate (DFR). In order to control the overnight rate of interest at the money market (MLF), the necessary demand for facilities of banks is generated by minimum reserve requirements or incentives for voluntary reserve deposits. Hence, the instruments of reserve requirements and the short-term central bank rate relate to each other, as minimum reserve requirements constitute the precondition for the demand of central banks facilities by commercial banks, thus promoting the control of the central bank on inflation through the price of money.

[5] The ECB sets three rates: (1) MRO … the interest rate on main refinancing operations, to which banks can borrow funds from the ECB against collateral on a weekly basis at a pre-set rate, (2) DFR … the rate on deposit facility, which banks may use to make overnight deposits at a pre-set rate lower than the main refinancing operations rate, and (3) MLF … the rate on marginal lending facility, which offers overnight credit to banks at a pre-set interest rate above the main refinancing operations rate.

Depending on the pathway of effects, various channels transport the monetary impulse simultaneously through the economy. The traditional channels of monetary transmission include the interest rate channel, the exchange rate channel, the Tobin's q channel, the wealth channel, the balance sheet channel, the bank lending channel and the bank capital channel (Kuttner & Mosser, 2002), as illustrated in Figure 2.6.

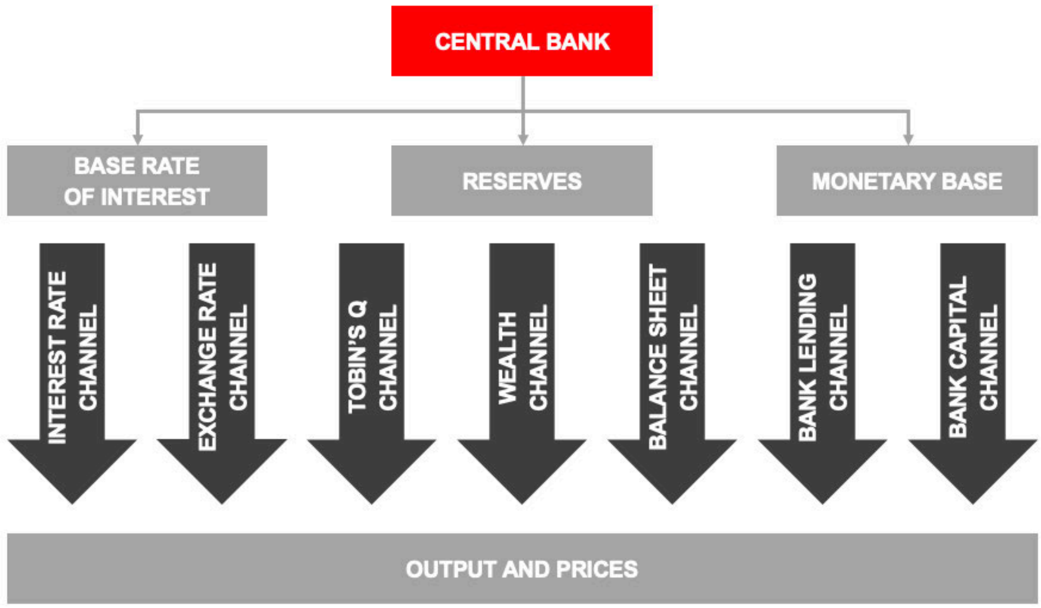

FIGURE 2.6:
TRADITIONAL CHANNELS OF MONETARY POLICY

Source: author's illustration

Bernanke and Gertler (1995) describe the TMMP as a "black box". They investigated the credit channel and got results for a macroeconomic response that is considerably larger than implied by conventional estimates of the interest elasticities of consumption and investment. Hence, other channels must be at work at the same time.

2.2.2.1 INTEREST RATE CHANNELS

One view of monetary transmission builds up on the interest rate channels of monetary policy, including the interest rate channel and the exchange rate channel. The Keynesian interest rate channel is seen as the key channel in the transmission of monetary policy and builds the basis for the standard Keynesian macroeconomic textbook model (Rotemberg & Woodford, 1997). Closely related to the interest rate channel, the exchange rate channel extends the view to an open-market economy.

INTEREST RATE CHANNEL: The channel builds up on the Keynesian view, that a change in short term interest rates affects long term interest rates in the same direction, which ultimately affects real activity (Keynes, 1936; Clarida, Galí, & Gertler, 1999). This The scheme of expansionary monetary transmission to the real economy works on the following mechanism: Expansionary monetary policy (M) causes a fall in the real interest rate (r), which triggers a rise in investment spending (I) and hence the increase in real aggregate demand and output (Y), and vice versa:

$$M \uparrow \Longrightarrow r \downarrow \Longrightarrow I \uparrow \Longrightarrow Y \uparrow \tag{2.11}$$

The Keynesian IS/LM model explains that due to sticky prices in the short run, the excess money supply (M) raises the demand for assets, driving the real interest rate (r) down, which in turn lowers the cost of capital for firms. This leads to a revival in investment (I) and output (Y). While Keynes originally considered exclusively the decision of firms on investment spending, later research pointed out that household decisions on expenditures on consumer durables and housing qualify as investment decisions as well (Keynes,1936; Mishkin, 1978). Hence, the transmission of the interest rate channel applies to both firm investment and household consumption spending on durable goods, as represented by investment (I).

EXCHANGE RATE CHANNEL: Closely related to the interest rate channel, open-market macroeconomic models build up on the exchange rate channel (Mishkin, 1995). The monetary transmission mechanism links the rate of interest to the rate of exchange by the uncovered interest rate parity condition, which relates interest rate differentials to expected exchange rate movements. Thus, a rise in the domestic rate of interest, relative to the foreign rate of interest, would lead to a stronger currency and a reduction in both net exports and the overall level of aggregate demand. The scheme that describes the mechanism explains the effect of expansionary monetary policy (M) through a fall in the domestic real interest rate (r), domestic currency deposits become less attractive relative to deposits in foreign currency, which leads to fall in the value of domestic currency deposits, that is a domestic currency depreciation (E). The lower value of the domestic currency makes domestic goods less expensive than foreign goods, causing net exports (NX) and hence domestic output (Y) to rise:

$$M \uparrow \Longrightarrow r \downarrow \Longrightarrow E \downarrow \Longrightarrow NX \uparrow \Longrightarrow Y \uparrow \quad (2.12)$$

The exchange rate channel highlights the effect of monetary policy on international trade rather as opposed to that on the balance sheet of domestic banks. In contrast, the interest rate channel refers to the domestic economy, but does not indicate effects of monetary policy on risk-taking of commercial banks.

However, there is empirical evidence that increases in the monetary policy rate are not always associated to the expected increase in long term interest rates. A recent study of Adrian, Estrella and Shin (2019) on the USA outlines that as the Fed Funds target was raised by 425 basis points between June 2004 and June 2006 from 1% to 5.25%, the lagged 10-year Treasury yield increased only by 38 basis points over that same time period from 4.73% to 5.11%. Earlier, Greenspan (2005) already referred to this behaviour of longer-term yields as a “conundrum of monetary policy makers”. This is a strong implication that other channels must be at work in the transmission of monetary policy, as well.

2.2.2.2 ASSET PRICE CHANNELS

The asset price channels have its roots in Monetarism, which is closely allied with the classical school of thought and can be regarded as an extension of classical theory that developed in the 1960s and 1970s with the aim to explain a new economic phenomenon called stagflation. The Monetarist channel of monetary policy is not part of the current New Keynesian macroeconomic models. Monetarists criticise the Keynesian model by questioning the assumption that monetary policy is completely facilitated by the movements in the short-term nominal interest rate. The Monetarist perspective is generally reluctant to commit on a specific transmission mechanism, since the consideration of a large set of relative asset prices and real wealth relates to various mechanisms that change during the business cycle, as outlined in Mishkin (1995).

Monetarists explain the economic response to monetary policy interventions with the direct effect of changes in relative quantities of assets, rather than interest rates. In contrast to Keynesian theory, Monetarists apply a much larger set of assets (Meltzer, 1995). Assets are seen as imperfect substitutes in the portfolios of investors. Monetary policy changes the composition by issuing outstanding assets, which causes changes in relative asset prices and can in turn result in real effects (Friedman, 1959; Brunner & Meltzer, 1976). The two mechanisms that dominate in the Monetarist view are the Tobin's q theory on investment that goes back to Tobin (1969) and the wealth effect on consumption developed by Ando and Modigliani (1963).

TOBIN'S Q CHANNEL: The Tobin's q channel offers an approach on the effect of monetary policy on the economy through the valuation of equities (Tobin, 1969). The q represents the market value of firms divided by the replacement cost of capital.

$$q = \frac{market\ value\ of\ assets}{replacement\ cost\ of\ capital} \tag{2.13}$$

A high q indicates a high market price of firms relative to its replacement cost of capital, hence the purchase of new capital is relatively cheap. That means with a high q, firms can issue equity for a high price relative to the cost of capital, that is the plant and equipment they buy. In result, investment spending of firms with a high q is high, because they can buy a lot of capital goods with only a small issue of capital, as compared to firms with a low q. Monetary policy affects equity prices as expansionary monetary policy (M) leads households to increase spending at the stock market. The increase in demand for equities at the stock market leads to an increase in equity prices (P_e) that correspond to a higher Tobin's q and thus higher investment (I) and output (Y).

$$M \uparrow \Longrightarrow P_e \uparrow \Longrightarrow q \uparrow \Longrightarrow I \uparrow \Longrightarrow Y \uparrow \tag{2.14}$$

The Tobin's q channel highlights the effect of monetary policy on firm investment.

WEALTH CHANNEL: The wealth channel relates to the life cycle model of consumption, in which consumption spending is determined by lifetime resources of consumers, which include human capital, real capital and financial wealth (Modigliani, 1971). A main component of financial wealth is common stocks. Hence, wealth is linked to monetary policy through the rate of interest and asset prices: Expansionary monetary policy (M) causes the demand at the stock market to increase, which in turn increases the value of long-term assets, such as stocks (P_e). This corresponds to a rise in the wealth of consumers and causes consumption (C) and output (Y) to rise.

$$M \uparrow \Longrightarrow P_e \uparrow \Longrightarrow wealth \uparrow \Longrightarrow C \uparrow \Longrightarrow Y \uparrow \tag{2.15}$$

The wealth channel highlights the effect of monetary policy on household consumption. Both Monetarist channels explain monetary transmission through stock market effects. Generalising, this view relies on the effect of monetary policy on relative asset prices of firms and households.

2.2.2.3 CREDIT CHANNELS

The neoclassical credit channels go back to Bernanke and Blinder (1988, 1992), who criticise the predominance of interest rate and exchange rate effects while stressing the importance of relative quantities in the financial market, such as the relative cost of credit. The credit channels include the broad notion of the credit channel and its decompositions into the balance sheet channel and the bank lending channel.

CREDIT CHANNEL: According to the neoclassical credit channel, monetary transmission builds up on the assumption that asymmetric information and a costly enforcement of contracts create principal agent problems and hence credit market frictions. Following Bernanke and Gertler (1995), the direct effect of monetary policy is amplified by endogenous changes in the external finance premium (EFP), defined as the difference between the cost to a borrower of raising funds externally by issuing equity or debt ($cost_{ef}$) and the opportunity cost of internal funds by retaining earnings ($opportunity\ cost_{if}$).

$$EFP = cost_{ef} - opportunity\ cost_{if} \tag{2.16}$$

External finance by raising funds from lenders is virtually always more expensive than internal finance by using internally generated cash flows, because of the costs that outside lenders bear of evaluating borrowers' prospects and monitoring their actions. Thus, the external finance premium is generally positive. The size of the external finance premium is driven by credit market imperfections, which result in a wedge between the expected return of lenders and the costs faced by borrowers. Typical costs reflected by the external finance premium include the costs of evaluation, monitoring and collection of the lender. Expansionary monetary policy (M) by a decrease in the monetary policy rate of interest causes the external finance premium (EFP) to fall, which stimulates aggregate spending (I) and the real economy (Y).

$$M \uparrow \Longrightarrow EFP \downarrow \Longrightarrow I \uparrow \Longrightarrow Y \uparrow \tag{2.17}$$

Bernanke and Gertler (1995) further decompose the credit channel into the balance sheet channel and the bank lending channel.

BALANCE SHEET CHANNEL: The balance sheet channel or broad credit channel can be imagined as the effect of changes in the monetary policy rate of interest on the balance sheet of both borrowers and lenders at the credit market (Bernanke & Gertler, 1995). The emphasis of that channel is on the effect of monetary policy on the net worth of borrowers at the credit market through their balance sheets. However, Bernanke and Gertler (1995) point out that the mechanism covers the effect on the balance sheet of lenders at the credit market, that is the value of bank assets, in the same way. This is in line with the empirical findings of Adrian and Shin (2010a), who emphasise that in a financial system where balance sheets are continuously marked to market, changes in asset prices show up immediately on balance sheets and have an instant impact on the net worth of all constituents of the financial system. The net worth of financial intermediaries is especially sensitive to fluctuations in asset prices given the highly leveraged nature of such intermediaries' balance sheets.

The theoretical link between the credit channel and the balance sheet channel is that the external finance premium faced by the borrower depends on its financial position. The net worth of a borrower is given by the sum of liquid assets and collateral in its balance sheet. A lower borrower net worth means that lenders have in effect less collateral for their loans, which corresponds to a higher external finance premium for the borrower, thus the losses from adverse selection are higher. A decline in net worth leads to an increase in adverse selection problems, which results in a decrease in lending to finance investment spending and vice versa. Furthermore, a lower net worth of firms increases the moral hazard problem because it means that owners have lower equity stake in their firms, which provides more incentive to engage in riskier investment projects. Such risky investment projects increase the likelihood that lenders will not be paid back, which again is associated to a decrease in lending and investment spending. That means fluctuations in the borrower net worth affect decisions on investment spending through problems of adverse selection and moral hazard. The balance sheet channel arises because the central bank does not only affect the market rate of interest, but also the borrower's net worth (directly and indirectly).

According to the balance sheet channel, monetary policy can affect the balance sheet of firms in several ways (Bernanke & Gertler, 1995). A direct effect of contractionary monetary policy (M) brings asset prices in general and equity prices (P_e) in particular to fall, thus lowering the net worth and collateral (nw & c) of firms. The corresponding increase in the external finance premium for the borrower (EFP) raises problems of adverse selection and moral hazard (as & mh), which leads to a decrease in loan supply (L^S) for investment spending (I) and hence lower output (Y).

$$M \downarrow \Longrightarrow P_e \downarrow \Longrightarrow nw \,\&\, c \downarrow \Longrightarrow EFP \uparrow \Longrightarrow as\&mh \uparrow \Longrightarrow L^S \downarrow \Longrightarrow I \downarrow \Longrightarrow Y \downarrow \qquad (2.18)$$

If contractionary monetary policy is accompanied by an unanticipated decline in the price level, an additional reinforcement in the balance sheet channel occurs (Bernanke & Gertler, 1995). Since debt payments are fixed by contract in nominal terms, an unanticipated decline in the price level increases the value of the liabilities of firms in real terms, meaning a higher burden of debt, without raising the real value of the firm's assets. Hence, the real net worth of the borrower falls. This rationale goes back to the debt deflation view of Fisher (1933). The second direct effect of tight monetary policy (M) is the deterioration of the balance sheet of firms through the increase in interest expenses (i) along with a reduction in net cash flows (ncf), which weakens the financial position of borrowers, as well.

$$M \downarrow \Longrightarrow i \uparrow \Longrightarrow ncf \downarrow \Longrightarrow nw \,\&\, c \downarrow \Longrightarrow as \,\&\, mh \uparrow \Longrightarrow L^S \downarrow \Longrightarrow I \downarrow \Longrightarrow Y \downarrow \qquad (2.19)$$

Although most of the literature on the balance sheet channel of monetary transmission focuses on the effect on the balance sheet of firms and investment spending, Bernanke and Gertler (1995) suggest it should apply equally well to the balance sheet of households and consumption spending on durable goods and housing: Consumers are analogously affected by the negative effect of tight monetary policy (M) on asset prices (P_e) through housing prices and other household durable assets. This reduces the households' net worth of assets and collateral ($nw \,\&\, c$), raises adverse selection problems ($as \,\&\, mh$), and finally results in adverse effects on consumption spending (C) and output (Y).

$$M \downarrow \Longrightarrow P_e \downarrow \Longrightarrow nw \,\&\, c \downarrow \Longrightarrow as \,\&\, mh \uparrow \Longrightarrow L^S \downarrow \Longrightarrow C \downarrow \Longrightarrow Y \downarrow \qquad (2.20)$$

Additionally, contractionary monetary policy (M) causes a deterioration in the balance sheet of households by reducing their net cash flows (ncf) due to higher interest expenses (i), which reduces the net worth of household assets and hence collateral ($nw \,\&\, c$). The corresponding increase in the problems of adverse selection and moral hazard ($as \,\&\, mh$) cause a decline in bank lending (L^S), leading to a fall in consumption spending on durable goods and housing (C) and a decline output (Y).

$$M \downarrow \Longrightarrow i \uparrow \Longrightarrow cf \downarrow \Longrightarrow nw \,\&\, c \downarrow \Longrightarrow as \,\&\, mh \uparrow \Longrightarrow L^S \downarrow \Longrightarrow C \downarrow \Longrightarrow Y \downarrow \qquad (2.21)$$

In this view of Bernanke and Gertler (1995), the indirect effect of tight monetary policy arises from changes in the net worth of borrowers by the negative effect of lower aggregate consumption of customers on the revenues of firms because quasi-fixed costs, such as wage and interest payments, do not adjust in the short run. A financing gap arises as the difference between the source and use of funds, eroding the net worth and creditworthiness of firms over time.

The balance sheet channel highlights the link between asset prices and the net worth and collateral borrowers: Asset prices determine the value of collateral (Bernanke & Gertler, 1995). In an imperfect credit market with frictions and asymmetric information, a fall in collateral values increases the external finance premium borrowers need to pay for obtaining loan, which causes consumption and investment to fall. A higher external finance premium associated to higher problems of adverse selection and moral hazard corresponds to lower credit risk-taking because the marginal firm is of better quality, and vice versa. The notion that endogenous procyclical movements in borrower's balance sheets amplify business cycles is termed the “financial accelerator”, as discussed in Bernanke, Gertler and Gilchrist (1996).

BANK LENDING CHANNEL: The bank lending channel or narrow credit channel represents the impact of monetary policy on the balance sheet of lenders through loanable funds and hence the supply of loans by banks at the credit market. This channel was already described by Roosa (1951) and developed further since then, in particular by Bernanke and Blinder (1988) as well as Bernanke and Gertler (1995). Commercial banks are seen as the predominant source of intermediate credit that specialise in overcoming credit market frictions, such as problems on asymmetric information. A reduction in the supply of loans is associated with an increase in the external finance premium and a decline in real activity.

In the model of Bernanke and Blinder (1988), the central bank affects the supply of loans (or its relative pricing) through changes in the access of banks to loanable funds. A tight monetary policy conducted by open market sales drains reserves and hence deposits from the banking system, which limits the supply of loans by reducing the access of banks to loanable funds. This effect is transmitted through the level and composition of bank assets. The underlying assumption is that the different sources of funds (deposits, certificates of deposit and issued equity) are no perfect substitutes, so that banks are not able to replace the losses in deposits easily. Similarly, Kashyap and Stein (1994), among others, argue that banks do not face a perfectly elastic demand in their open-market liabilities, so that monetary policy affects the cost of funding for a bank. That means banks rely on reservable fund deposits as an important source of fund. As the central bank reduces the aggregate volume of reservable deposits, the supply of loans by banks declines. Since a considerable share of households and firms relies heavily on external financing, aggregate demand is caused to fall. In the model of Bernanke and Blinder (1988), a tight monetary policy raises the relative costs of funding for banks since banks must pay a higher rate of interest to sell certificates of deposit, which causes the supply of loans to fall and raises the external finance premium for borrowers. In turn, expansionary monetary policy (M) increases bank reserves and deposits (R & D), raising the supply of loans (L^S), which promotes the access of borrowers to external finance accompanied with a lower external finance premium (EFP) and causes investment (I) and output (Y) to rise.

$$M \uparrow \Longrightarrow R \,\&\, D \uparrow \Longrightarrow L^S \uparrow \Longrightarrow EFP \downarrow \Longrightarrow I \uparrow \Longrightarrow Y \uparrow \tag{2.22}$$

The credit channels of Bernanke and Blinder (1988, 1992) explain the effect of monetary policy with the external finance premium at the credit market, highlighting the effect on the balance sheets of borrowers, and on the reserves and deposits in the balance sheets of banks, respectively. While the credit channels implicitly consider credit risk for the demand side by effects on borrower's balance sheets, there is no explicit role for the supply side by endogenous changes in risk-taking of banks.

2.2.2.4 BANK CAPITAL CHANNEL

The bank capital channel goes back to Van den Heuvel (2007) and emphasises the effect of monetary policy on bank lending through its impact on bank capital. The model incorporates risk-based capital requirements, an imperfect market for bank equity and a maturity mismatch on the bank's balance sheet. These assumptions imply a failure of the Modigliani-Miller theorem[6] for the bank as its lending depends on the bank's financial structure, as well as on lending opportunities and market interest rates. This mechanism is distinct from the bank lending channel because it does not rely on any particular role of bank reserves.

$$M \uparrow \Longrightarrow CAP \Longrightarrow L^S \uparrow \Longrightarrow I \uparrow \Longrightarrow Y \uparrow \tag{2.23}$$

The mechanism implies that the macroeconomic effect of monetary policy (M) on bank lending (L^S) depends on the capital adequacy of the banking sector (CAP) because poorly capitalised banks are less likely to lend compared to well-capitalised banks. Bank capital affects lending even when the regulatory constraint is not momentarily binding, and shocks to bank profits, such as loan defaults, can have a persistent impact on lending. Bank capital requirements may therefore interact with monetary policy in subtle and hard-to predict ways. Moreover, to the extent that it affects banks' exposure to interest rate risk, the maturity distribution of bank assets will also affect the transmission of monetary policy.

[6] The Modigliani-Miller theorem states that the market value of a company is correctly calculated as the present value of its future earnings and its underlying assets, and is independent of its capital structure (Modigliani & Miller, 1958; Miller & Modigliani, 1961).

2.2.3 ACADEMIC DEBATE AND RESEARCH GAP

This subchapter synthesises the key insights of the literature review of economic theory on monetary transmission by pointing out in how far the element of risk is considered in the academic debate on monetary transmission, which leads to the identified research gap.

ECONOMIC THEORY: The literature of economic theory on money, interest and credit emerged already decades ago and experienced continuous improvements and extensions. While there is a consensus between Monetarists and Keynesian economists on the general functioning of the transmission mechanism, dissent exists on the details of the various mechanisms involved. Both schools of thought rely on the monetary causality that deposits allow for credit. They highlight the asset market and explain the effect of monetary policy on aggregate expenditures with relative yields from imperfectly substitutable assets. The views are divided regarding the degree of relative substitutability between money and other assets and the related question of the size of the set of assets necessary to capture the effects. Monetarists like Friedman (1959), Tobin (1961), Brunner and Meltzer (Brunner & Meltzer, 1976; Meltzer, 1995) argue for a lower interest elasticity of money demand and a much larger set of assets than Keynesian economists, including real assets and possibly human wealth. In contrast, the Keynesian IS/LM model in its simple version (Keynes, 1936; Hicks, 1937) makes the distinction only between money as an asset with an exogenously fixed nominal return, and bonds. The Post-Keynesian theory on money, interest and credit relies on the monetary causality that loans make deposits (Lavoie, 1992). The model is focused on the credit market and explains the effect of monetary policy on aggregate outcomes with the mark-up pricing of banks that deal with fundamental uncertainty and credit risk by credit rationing, forward contracts, and institutions. The classical, Keynesian and Post-Keynesian models have in common that they relate risk to uncertainty, but they restrict the mechanism that allows for endogenous changes of risk-taking in the bank system.

TRADITIONAL CHANNELS: Various traditional channels of the monetary transmission mechanism were identified, including the Keynesian interest rate channels, the Monetarist asset price channels as well as the neoclassical credit and bank capital channels (Kuttner & Mosser, 2002). Due to differences in their fundamental underpinnings and historical background, the channels offer different explanations of the monetary transmission mechanism. The conventional Keynesian interest rate channel evolved at the time when massive restrictions on the portfolio of banks on credit allocation and credit policies were in place (Laidler, 2002). The mechanism that transfers monetary impulses through the economy works through relocations in the portfolios of households and firms between monetary and non-monetary assets (Keynes, 1936; Hicks, 1937). The US monetary policy in the late 1990s and early 2000s generated a low-risk environment that incentivised banks to take on more risk, make greater use of short-term debt, and leverage up their balance sheets. This shifted the attention of classical economists towards the balance sheet channel of Bernanke and Gertler (1995). The mechanism builds up on the link between asset values and the balance sheet of borrowers with respect to their creditworthiness and collateral (Bernanke & Gertler, 1990) as well as their leverage and debt (Gertler & Kiyotaki, 2010; Gertler & Karadi, 2011). Related research of Bernanke and Gertler (1989) as well as Kiyotaki and Moore (1997) denotes the balance sheet channel as financial accelerator of monetary transmission, meaning the composition of the balance sheet of banks determines the strength of the transmission mechanism. The balance sheet channel implicitly includes credit risk through the demand side effects at the credit market: monetary contraction increases the external finance premium, causes higher agency problems, and lowers borrowers net worth, which corresponds to lower risk-taking since the marginal firm is of better quality. However, the mechanism does not incorporate the endogenous response of risk-taking of the bank system as implied by the risk channel, that is the supply side effect at the credit market. As the regulation of minimum capital requirements evolved, the focus of monetary theory shifted to the bank capital channel put forward by Van den Heuvel (2007), which is based on cost differences of equity funding. The empirical study of Zsámboki (2007) investigated the effect of bank regulation on bank behaviour and points to an increase in risk sensitivity of banks as well as procyclicality of capital requirements. Martinez-Miera and Repullo (2017) analysed risk premia though the business cycle and confirm a countercyclical movement. It is to note that these models do not question the effect of monetary policy on risk-taking of banks, but rather highlight the role of capital in monetary transmission.

RESEARCH ON THE RISK CHANNEL: After the emerge of the global financial crisis in 2007 the research on the risk channel extended the balance sheet channel by considering risk-taking of commercial banks as an endogenous variable. The term risk channel was coined by Borio and Zhu (2008), who emphasise the highly disturbing potential of boom-and-bust cycles from an unnoticed pile up of risk in the bank sector for the real economy. They argue that the current models of monetary policy were not able to capture that kind of risk, which requires a better understanding of the mechanism behind the risk channel of monetary policy. Chmielewski, Lyziak and Stanislawska (2020) assess the status of research on explaining the risk channel as follows:

"The literature so far has offered neither a convincing theoretical model explaining this channel of monetary transmission, nor consensus about the economic processes behind it".

This statement coincides with the finding of the author: Before this research, no comprehensive theoretical representation on the mechanism that facilitates the risk channel was proposed. However, there are endeavours in empirical research to capture the effects of monetary policy on risk-taking of commercial banks. Related studies point to the existence of the risk channel in the USA and the EMU and offer various clues on the mechanism as well as indications on bank characteristics that affect the strength of the mechanism. The following sections summarise the main contributions.

USA RESEARCH: The empirical research on US banks indicates the existence of the risk channel in the USA. Related studies find that a fall in interest rates leads to a decline in lending standards (Delis & Kouretas, 2011; Maddaloni & Peydro, 2011; Angeloni & Faia, 2013; Abbate & Thaler 2015, Paligorova & Santos, 2017), a rise in leverage (Adrian & Shin, 2014; de Groot, 2014), a fall in risk premia (Drechsler, Savov & Schnabl, 2018), and increased asset risks (Angeloni, Faia & Duca, 2015). In addition, other papers contribute theoretical foundations for the link between risk-taking and the capital structure (Dell'Ariccia, Laeven & Marquez, 2014) or regulatory capital (Van den Heuvel, 2007; Borio & Zhu, 2012) of banks. The empirical evidence identifies inverse effects from the capitalisation of banks: On the one hand, a low capitalisation can limit the effect on risk-taking due to a risk-shifting[7] effect (Dell'Ariccia, Laeven & Suarez, 2017). On the other hand, a low capitalisation can promote risk-taking due to the search for yield effect in association with a relatively higher degree of competitive pressure and an inferior ability of these banks to adjust the capital structure (Gambacorta, 2009; Altunbas, Gambacorta & Marques-Ibanez, 2014; Buch, Eickmeier & Prieto, 2014). Low short term interest rates interact with sticky profit targets, triggering a search for yield (Rajan, 2006; Buch, Eickmeier & Prieto; 2014) and increase competition in the bank sector (Maudos & de Guevara, 2004). The corresponding flattening of the yield curve affects the profitability of banks by further compressing net interest margins (Adrian & Shin, 2011, Meaning & Zhu, 2011; Alessandri & Nelson, 2015; Adrian, Estrella & Shin, 2019).

EMU RESEARCH: The empirical research on the risk channel in the EMU is rather scarce but growing. Related studies find that low interest rates correspond to an increase in risk tolerance of banks (Altunbas, Gambacorta & Marques-Ibanez, 2014; Jimenez, Ongena & Peydro, 2014), a fall in lending standards (Maddaloni & Peydro, 2011; Neuenkirch & Nöckel, 2018), higher risk-taking of lowly capitalised banks (Jimenez, Ongena & Peydro, 2014) and in the long run to a decrease in interest margins (Claessens, Coleman & Donnelly, 2018). Other papers also identify effects of higher risk-taking from quantitative easing (Giannone, Lenza & Reichlin, 2012; Kandrac & Schlusche, 2021).

The related research to the risk channel that touches upon relevant aspects of the mechanism focusses on the relationship between asset values and risk measures; interest rates and net interest margins; profits and search for yield; as well as liquidity, moral hazard and risk-shifting.

[7] Risk-shifting refers to the shift of risk from shareholders onto debtholders by paying out safe cash flows. As Jensen and Meckling (1976) outline: For bank shareholders it can be optimal to pay out safe cash flows to themselves, shrinking the bank's capital cushion and exposing the bank to greater default risk. This effectively transfers more risk onto debtholders who hold a claim on the remaining assets after the capital distribution in the event of bank default. Government guarantees on deposits and expectations of government bailouts in times of crisis increase the incentives for risk-shifting.

ASSET VALUES AND RISK MEASURES: A reduction of interest rates boosts the value of assets and collateral (Bernanke & Gertler, 1995; Adrian & Shin, 2010a), which results in lower measures of risk in balance sheets as well as an improvement in risk assessment of potential borrowers (Borio & Zhu, 2008). Hence, the perception of risk of commercial banks declines with a magnitude that depends on the regulatory capital framework effect, while risk-taking increases with a magnitude that depends on the regulatory capital wedge effect, and vice versa (Zsámboki 2007; Borio & Zhu, 2012).

INTEREST RATES AND NET INTEREST MARGINS: The net interest margin (NIM) constitutes an important part of banks' profit. In a low interest rate environment, the NIM might be squeezed due to the zero lower bound for bank financing sources. That means as market interest rates go low, commercial banks cannot further decrease interest rate costs for some instruments while interest income further declines (Claessens et al., 2018; Adrian, Estrella & Shin, 2019; Eggertsson, Juelsrud, Summers & Wold, 2019). In 2021 for example, nonfinancial sector deposits in Germany have interest rates already very close to zero, while the interest income of loans is still decreasing. Bank business lines might have quite different NIM elasticities with respect to changes in the level of interest rates, as pointed out by Claessens et al. (2018). Since safer business lines, such as mortgage lending, tend to be associated with lower interest rate spreads due to lower inherent credit risk than more risky types of bank activity, such as consumer loans, the former ones are more vulnerable to profitability deterioration in the low interest rate environment. For a bank with relatively large importance of low-risk business lines, this could imply a lower probability of bank executives receiving bonus payments (Chmielewski, Lyziak & Stanislawska, 2020). To restore the previous level of expected bonus payments, the bank management might be forced to allocate more resources to higher-risk higher-return business lines. A related debate concerns the question whether long lasting, exceptionally low monetary policy rates provide the ground for the next financial crisis, for example in Rajan (2010), Krishnamurthy and Vissing-Jorgensen (2011), Farhi and Tirole (2012), and Chodorow-Reich (2014).

PROFITS AND SEARCH FOR YIELD: Another strand of research places the emphasis on the behaviour of banks with respect to risk-taking from a search for yield motive. Rajan (2005) defines search for yield as a reaction to lower earning opportunities that consists in an increase in risk-taking as a means to enhance profitability. Shareholders of commercial banks usually require managers to attain pre-set nominal rates of return, which tend to be relatively stable over time. A declining monetary policy rate of interest triggers a decrease in the rates of return on risk-free assets and makes them less attractive. Therefore, to attain the profit target, financial intermediaries with short-term time horizons seek riskier assets, ones that would generate higher yields (Rajan, 2006; Adrian & Shin, 2009). Bank senior executives are driven by performance-based bonuses, which are a widespread phenomenon in the banking sector (Fahlenbrach & Stulz, 2011). However, inherent uncertainty related to future outcome of bank business activities implies that the "performance" is to a large extent a realisation from some stochastic process. Hence, it is not fully a signal about an effort or competence. This randomness, however, is quite often neglected in contracts between shareholders and hired bank executives, resulting sometimes in adverse incentives for the latter (Chmielewski, Lyziak & Stanislawska, 2020). Moreover, contracts between shareholders and bank managers often stipulate that a lump sum bonus payment is triggered if certain targets, set in terms of return on equity, are met (Cai, Cherny & Milbourn, 2010). Such a framework incentivises the managers to achieve some profitability level within the constraints of bank equity as the scope for risk-taking is limited by bank equity. Due to the risk-return trade-off, a higher profitability target implies the necessity to increase the risk-taking. However, higher risk of bank operations implies higher volatility of bank profits (DeYoung & Roland, 2001), affecting the probability of bank executives receiving a bonus payment. On the other hand, a low realisation of bank profits might imply reputational losses for the bank managers and a deterioration in prospects for future income. Therefore, the bank executive decision problem is to construct the bank risk profile in such a way that expected bonus payments are maximised (Chmielewski, Lyziak & Stanislawska, 2020). Memmel, Seymen and Teichert (2018) present a theoretical model on the search for yield effect along with empirical evidence in support. Dell'Ariccia, Laeven and Marquez (2014) present a model in which a steepening yield curve, implying a widening in the spread between long-term and short-term interest rates, generates two opposing effects: While a fall in risk-return results in higher risk-taking, it reduces incentives for risk-taking due to an inverted search for yield through risk-shifting. In their framework, the leverage of the bank determines the relative strength of these effects. The empirical study of Maddaloni and Peydró (2011) identifies evidence of search for yield for the USA and the EMU by showing that lower short-term rates, which are generally associated with a steeper yield curve, lead to increased credit risk-taking of banks.

LIQUIDITY, MORAL HAZARD AND RISK-SHIFTING: The empirical research on liquidity in the balance sheet of banks and the incentives of moral hazard from monetary policy includes the studies of Diamond and Rajan (2009) as well as Acharya and Naqvi (2012), who present a model in which monetary policy is time inconsistent. Open market operations lower short-term rates and as result liquidity increases in the form of deposits. Thus, expansionary monetary policy is associated with a lower probability of punishment in the form of a bank run or of a penalty to the manager. Hence, banks get the incentive to increase leverage and fund more illiquid projects. The model of Farhi and Tirole (2012) shows second order effects of banks correlating their risk exposures in order to be bailed-out in the event of failure. Empirical evidence on Germany supports the moral hazard effect from the bail-out of German banks (Heppke-Falk & Wolff, 2007). Other studies find that an increase in funding liquidity causes an increase in risk-shifting in lending, as banks face strong moral hazard problems, especially low capitalised banks who do not fully internalise loan defaults (Jensen & Meckling 1976, Allen & Gale, 2000; Allen & Gale, 2004; Borio & Zhu, 2008; Adrian & Shin, 2011; Allen & Rogoff, 2011; Diamond & Rajan, 2012; Jiménez, Ongena, Peydró & Saurina, 2014). However, the idea that the liquidity provided by central banks is important in driving excessive risk-taking is not new: “Speculative manias gather speed through expansion of money and credit or perhaps, in some cases, get started because of an initial expansion of money and credit” (Kindleberger, 1978). Acute agency problems combined with a strong reliance on short-term funding may thus lead the short-term monetary interest rate, more than the long-term interest rate, to encourage bank risk-taking. On the other hand, higher interest rates may increase the risk-taking incentives of borrowers due to moral hazard

(Stiglitz & Weiss, 1981), increase the opportunity costs for banks to hold cash, thus making risky alternatives more attractive (Smith, 2002), or even reduce the banks' net worth enough to make a "gambling for resurrection" strategy attractive (Keeley, 1990). This implies the risk channel mechanism might be of nonlinear nature.

The determinants that affect the strength of the risk channel discussed in the previous studies include bank capital, bank size, bank source of funding and bank liquidity, as outlined in what follows.

BANK CAPITAL: The bank capital channel indicates an impact of bank capital on the macroeconomic effect of monetary policy (Van den Heuvel, 2007). The capital buffer, that is bank capital above the regulatory capital threshold, is a necessary condition for increasing risk exposure by a bank due to macroprudential bank regulation and the associated capital threshold effect (Borio & Zhu, 2012). Banks with low capital buffers might be restricted in their capacity to take more risk. On the other hand, lower interest rate levels might result in lower credit risk for existing borrowers as they have to use smaller fractions of their cash flows to service debt, therefore releasing some economic capital for new risk-taking.

BANK SIZE: Big banks might enjoy implicit "too big to fail" subsidy, making it easier for them to move to more risky activities (Davies & Tracey, 2014). Moreover, large banks are more likely to finance large infrastructure projects for which financing might be not viable when interest rates are high. Therefore, larger banks might be more likely to have a change in borrower structure when interest rates decline. On the other hand, big banks might have access to a wider spectrum of potential funding sources, allowing them to have better control over interest costs, which counteracts the incentive to increase risk-taking to restore profitability (Chmielewski, Lyziak & Stanislawska, 2020).

BANK SOURCE OF FUNDING: The source of funding, including the importance of deposit funding, might be another variable influencing bank reaction to low market interest rates. On the one hand, banks with a large share of non-financial sector deposits might encounter problems with further lowering of interest costs when deposit interest rates are already close to zero (Eggertsson, Juelsrud, Summers & Wold, 2019). On the other hand, banks with dominating market-based funding sources might have initially lower net interest margins, so might be more sensitive to any negative profitability shocks (Chmielewski, Lyziak & Stanislawska, 2020). Hence, the net effect of a given amount of deposit funding on the potential occurrence of a bank's risk-taking is ambiguous.

BANK LIQUIDITY: Bank liquidity is often a factor considered among determinants of bank reaction to different shocks, including monetary policy shocks. A larger share of liquid instruments in bank assets might be a signal of high-risk aversion of the bank management as liquid assets reduce liquidity risk in association to various shocks, even if it worsens bank ability to generate profits. In this case, risk averse bank executives would be less willing to take additional risk to improve profitability. Moreover, valuation of fixed coupon financial instruments such as liquid government bonds will increase with interest rates going down, hence improving profits and mitigating incentives to increase profits by taking more credit risk (Diamond & Rajan, 2009; Borio & Zhu, 2012; Kiyotaki & Moore, 2019; Chmielewski, Lyziak & Stanislawska, 2020).

RESEARCH GAP: A tremendous amount of theoretical and empirical literature on the transmission of monetary policy evolved within the last decades. While the mechanism of the traditional channels of monetary policy including the interest rate channel, the asset price channel, the credit channels and the bank capital channel is already comprehensively explained in literature, the underlying mechanism of the risk channel remains rather nebulous: Despite the occurrence of risk-related disturbances in the financial sector, the existing research has provided empirical studies on the USA and some EMU countries, but not a comprehensive understanding of the link between monetary policy and the risk-taking of commercial banks.

As outlined above, some literature on the transmission mechanism highlights the role of banks as financial intermediary, some empirical studies have paid attention on risk in the balance sheet of banks. However, the traditional channels of monetary policy are not able to explain the potentially highly disturbing boom and bust cycles, where economic growth is accompanied by an unnoticed pile up of risk, in particular from excessive risk-taking of banks.

One reason for that is that the role of banks, their attitude towards risk and their balance sheet composition is not in the foreground. The review of economic literature yields three findings: There is a lack of research with an explicit focus on (1) the relationship between monetary policy and risk-taking, (2) the interaction of bank regulation and risk-taking and (3) on the interrelation of accounting and risk-taking. Hence, research seems not focused enough on the risk channel in monetary transmission, that emphasises the link between monetary policy and risk-taking of commercial banks, the role of liquidity and the role of macroprudential bank regulation. In the current generation of theoretical monetary policy models, the risk-taking of banks is either neglected or treated as exogenous. It is not that the element of risk is absent in economic theory: asymmetric information is crucial and investment projects can fail. But the analysed models restrict the mechanisms through which risk perceptions and risk tolerance of banks affect decisions on their lending and risk-taking. A comprehensive understanding on the underlying mechanism that drives monetary transmission through the risk channel is absent so far. Empirical research on the risk channel in the EMU is rare and almost absent for Germany. The existing empirical research on the link between monetary policy and risk-taking of banks strongly points to the need for explaining the risk channel mechanism. This is a reason to follow up on these findings by investigating the path of effects through which monetary policy affects the risk-taking of banks.

To address this research gap, this study aims to explain the risk channel of monetary policy in the EMU by identifying the operating transmission mechanism. The first step towards that objective is to derive a theoretical representation of the risk channel of monetary transmission. The multifaceted nature of the risk channel requires the complementation of economic theory with the perspective of finance theory on risk as well as the institutional context of macroprudential bank regulation in the EMU. Accordingly, the following subchapters extend the view on these subjects.

2.3 FINANCE THEORY ON BANK RISK

One finding of the preceding review of economic literature on monetary transmission is the lack of economic theory on the relationship between monetary policy and risk-taking of commercial banks. Explaining the risk channel in monetary transmission requires the emphasis on the risk-taking behaviour of banks in a more subtle way. Therefore, this subchapter follows the objective of investigating risk in the balance sheet of commercial banks from the perspective of finance theory with a focus on risk management, risk measurement and risk pricing of banks. The question is on the factors that drive the risk-taking of commercial banks in order to draw conclusions on the effect of monetary policy on the risk-taking of commercial banks.

The first subchapter investigates the risk management of commercial banks along with the nexus to their decisions on the amount of risk in their balance sheets. The second subchapter puts the emphasis on methods of risk measurement and their impact on the risk perception of commercial banks. The third subchapter explores the risk pricing of commercial banks. Finally, the fourth subchapter synthesises the findings from finance theory on risk and derives the implications for monetary transmission through the risk channel.

2.3.1 BANK RISK MANAGEMENT

In monetary theory, risk is associated to uncertainty. The definition of risk in finance theory relates closely to the economic view, as outlined in Bessis and Bessis (2015, p. 2):

"In finance practice, risk is seen as the negative deviation from an expected outcome, which results from uncertainty and is associated to adverse consequences on earnings. The uncertainty cannot be eliminated but the exposure to uncertainty can be changed".

In particular, this notion of risk corresponds to the perspective of financial risk managers and bank regulators. In banking practice, differences exist on the inclusion of expected losses. In a study of the German Central Bank (2019a) on Less Significant Institutions (LSI) it was found that both the definition and classification of risk is rather heterogeneous in the German financial sector.

For example, in the group of Savings banks 41.9% of the banks apply a risk concept that includes expected losses, while the majority of 58.1% defines only unexpected losses as risk. From a regulatory perspective, banks must report their risk according to their individual classification, that means there is no compulsory delimitation of risk in bank supervision. The regulatory guidelines require the indication of each bank on whether the own concept to risk covers the expected loss in addition to unexpected loss and to follow a broad and common classification of risk BCBS (2022). In general, the classification of risk follows the source of uncertainty: Depending on specific events that cause losses, subclasses further divide each class of risk (Bessis & Bessis, 2015). The following classification outlines the distinction of classes and subclasses of risk.

2.3.1.1 RISK CLASSIFICATION

In finance theory, the risk in bank business is distinguished by different classes. The main classes of risk in the balance sheet of commercial banks include counterparty default risk, market risk, liquidity risk and operational risk (Tian, 2017; BCBS, 2022) as outlined in what follows.

COUNTERPARTY DEFAULT RISK: Counterparty default risk covers the danger that one of those involved in a transaction might default on its contractual obligation. This includes losses in value due to default or deterioration of the creditworthiness of business partners, the default of state creditors and restrictions on payment transactions as well as losses from a shortfall of income from the liquidation of collateral (Guégan & Hassani, 2019). The subclass credit risk covers losses from default and deterioration of the credit standing of the borrower. On the one hand, credit risk includes default risk, which occurs when the counterparty fails to meet payment obligations and is associated with total or partial loss of the amount lent. On the other hand, credit risk includes migration risk, which arises from the downgrade of the counterparty's credit rating and does not imply default, but a higher likelihood of default. That means the book value of a loan does not change when the credit quality of the borrower declines, but its economic value is lower because the likelihood of default increases (Bessis & Bessis, 2015). For a traded debt, an adverse migration triggers a decline of its quoted price. Credit risk is the main type of risk in lending business of a commercial bank (Kuritzkes & Schuermann, 2010). The subclass counterparty risk arises when both parties of a transaction are potentially exposed to a loss when the other party defaults. It occurs when exposures are market driven. The subclass spread risk arises from losses due to a change in market spreads. The spread is the difference in yield of an asset relative to its risk-free benchmark, that is an asset of same maturity but different credit quality. Hence, the spread covers the risk primum and the liquidity premium of a traded asset (Kiesel, Perraudin & Taylor, 2001). An increase in credit spreads decreases the market value of an asset. The subclass recovery risk denotes uncertain values of recovery under default and depends on the seniority of debt, collateral, and the workout efforts to the counterparty.

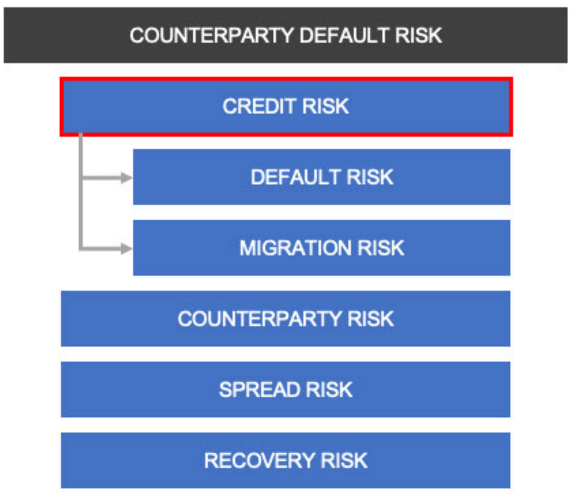

FIGURE 2.7:
SUBCLASSES OF COUNTERPARTY DEFAULT RISK

Source: author’s illustration

MARKET RISK: Market risk is the category for impairments in assets due to the change of interest rates, equity indexes and foreign exchange rates (Guégan & Hassani, 2019). Market risk is a price risk and includes losses in value from changes in interest rates, credit spreads, prices in shares, in foreign exchange, in commodities as well as in volatilities. It can also arise from problems to close a larger market position at short notice at market value. The distinction of subclasses generally covers interest rate risk, equity position risk, settlement and counterparty risk, foreign exchange rate risk, spread risk, commodity price risk and option risk. Market risk depends positively on the liquidation period, that is the period required to sell assets (Miller, 2019). The subclass interest rate risk arises from a decline in net interest income, that is the difference of interest earnings minus interest costs, due to movements of interest rates. Most positions in the balance sheet of a bank, including loans, belong to the so-called interest book, meaning they create revenues and costs that are interest rate driven. Bessis and Bessis (2015) argue that in lending business both parties, borrowers and lenders, are always subject to interest rate risk: For floating rate loans revenues and costs are indexed to short-term market rates. But also fixed rate loans are subject to interest rate risk due to the opportunity costs for borrowers and lenders arising from market movements in the rate of interest.

FIGURE 2.8:
SUBCLASSES OF MARKET RISK

Source: author's illustration

LIQUIDITY RISK: Liquidity risk relates to the threat of insolvency due to insufficient liquid assets. It materialises when the bank has a problem to meet payment obligations which fall in the short term (Guégan & Hassani, 2019). The subclass funding liquidity risk arises from the inability to borrow money. The subclass market liquidity risk, also termed asset liquidity risk, refers to the sale of assets and arises from negative price movements as a result of the trade or the inability to raise liquid funds from trading assets (Zopounidis & Galariotis, 2015). The subclass call risk is a sort of refinancing risk and refers to the threat that borrowers unexpectedly make use of credit lines or unexpectedly withdraw deposits in high volumes. In the extreme case, a lack of liquidity results in bank failure. This scenario is often seen as a result from the materialisation of other classes of risk, that means losses for example from counterparty credit risk or market risk.

FIGURE 2.9:
SUBCLASSES OF LIQUIDITY RISK

Source: author's illustration

OPERATIONAL RISK: Operational risk is defined as losses due to the failure of human, machine, or external factors (Miller, 2019). The subclass human failure might occur from error, negligence, fraud, breaking rules, or incompetency. The subclass failure of machines, technology or systems can for example concern data security and system security as well as internal processes in terms of the effectiveness of control processes, work processes and project management. The subclass external factors includes, among others, uncertainty arising from the legal system, compliance, infrastructure and politics.

FIGURE 2.10:
SUBCLASSES OF OPERATIONAL RISK

Source: author's illustration

In bank practice, risk is seen as potential loss that arises from the interaction with uncertainty. This uncertainty is attached to the exposure of a bank, which measures the extent to which a bank could be affected by certain factors that could have a negative impact on expected earnings. Uncertainty cannot be eliminated but it can be changed, which is the purpose of risk management. The element of uncertainty builds an intersection between economic theory on monetary transmission and finance theory.

2.3.1.2 RISK IN THE BUSINESS LINES

The business lines of banks are associated to different products and services a bank offers to its customers and hence differ in the predominant classes of risk. Cecchetti, Schoenholtz and Fackler (2006) note that regardless of the business lines, the portfolio of a bank is subject to liquidity risk and operational risk. The three main business lines are commercial banking, investment banking and trading, as visualised in the Figure 2.11 adapted from Bessis and Bessis (2015, p. 6).

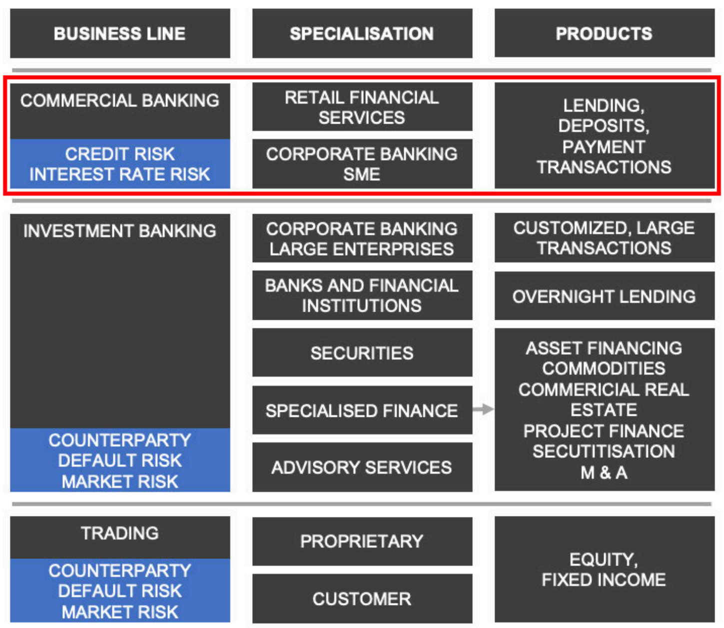

FIGURE 2.11:
RISK IN BUSINESS LINES OF BANKS

Source: author's illustration adapted from Bessis & Bessis (2015)

COMMERCIAL BANKING: The business line commercial banking covers the traditional bank activities of lending, deposits, and payment transactions (Tian, 2017). In commercial banking the further distinction is on the type of counterparty: retail banking refers to business with private customers, whereas corporate banking refers to business with small- and medium sized enterprises (SME). Corporate activities include typically overnight loans, short-term loans (less than one year), revolving facilities, term loans, committed lines of credit or large commercial and industrial loans. Commercial banking relates predominantly to credit risk but also interest rate risk and the applied methods are characterised by “mass” and “automation” (Bessis & Bessis, 2015).

INVESTMENT BANKING: The business line investment banking is the area for large transactions customised to the needs of large enterprises and financial institutions (Tian, 2017). Corporate investment banking involves a variety of products and services, such as lending facilities, hedging instruments, the issuance of securities, trading as well as mergers and acquisitions. The services of specialised finance include in particular asset finance (ships or aircrafts), project finance, commodities finance, commercial real estate, exports, securitisations as well as mergers and acquisitions (Bessis & Bessis, 2015). The products and services are rather customised and of high dimension. Investment banking relates predominantly to market risk as well as counterparty default risk for investment products such as stocks, options, bonds, and derivatives.

TRADING: The business line trading covers both traditional proprietary trading and trading for third parties. As Tian (2017) outlines, proprietary trading refers to the buy and sale of assets by a bank for itself and in order to realise earnings. It is also used for liquidity purposes. Those short-term positions that follow a speculative motive were held in the so-called trading book. For a commercial bank, proprietary trading relates predominantly to market risk and counterparty default risk. The other aspect of trading is trading conducted by the bank in the name of its customers. Bessis and Bessis (2015) point out, that common types include equity trading, which refers to the trade of stocks and securities at stock markets and involves relatively high risk on return arising from fluctuation in prices. The other type is fixed-income trading, which refers to the trade of securities that yield a fixed return like interest earnings and is less risky compared to equity trading.

For understanding the risk channel mechanism, the conclusion is that credit risk and interest rate risk dominate the lending business associated to the business line of commercial banking. The applied methods for lending decisions and risk assessment are comparatively more sophisticated for loans to enterprises in contrast to retail loans, which arises from the sophistication of products, the loan volume, and the input information of borrowers.

2.3.1.3 RISK IN THE BALANCE SHEET

Commercial banks are economic intermediaries with only little equity capital in relation to total liabilities with a relationship of 1 to 9 between capital and debt funding as investigated in a study of Gambacorta and Shin (2018) based on 105 banking institutions in advanced economies that hold over 70% of worldwide banking assets. The business of banks is to generate profits from taking risks. This is predominantly debt financed by customers or the issuance of external capital. The types of risk in the balance sheet of a bank depend on the mix of financial products, which is driven by the business lines. In the typical portfolio of commercial banks, the predominant types of risk are credit risk and interest rate risk that arise from the core business of credit lending.

The balance sheet offers information for different addressees like shareholders, outside creditors, the supervisory board as wells as the works council, and builds the basis for the determination of taxable income. In Germany, the breakdown of the balance sheet of commercial banks relies on legal provisions on accounting of the German Commercial Code (HGB) in conjunction with the Financial Institutions Accounting Regulation (RechKredV)[8]. The key components of the balance sheet consist in bank assets, liabilities, and capital:

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[8] The legal basis for the annual account is given by the third book of the German Commercial Code (§§ 238 - 342a HGB). The first and second chapter (§§ 238 - 335b HGB) cover general provisions on accounting. Additional special provisions apply for financial institutions, regulated in the fourth chapter (§§ 340 - 341p HGB) in conjunction with form 1 RechKredV to account for the peculiarities of the banking business.

$$bank\ assets = bank\ liabilities + bank\ capital \tag{2.24}$$

The simplified balance sheet of commercial banks in Figure 2.12 serves as an analytical basis for developing the concept of the risk channel of monetary transmission.

FIGURE 2.12:
SIMPLIFIED BALANCE SHEET OF COMMERCIAL BANKS

Source: author's illustration

ASSETS: Assets reflect the use of funds from which the bank earns revenue, and which differ in their degree of liquidity (Cecchetti, Schoenholtz & Fackler, 2006). Deviant from the general legal breakdown of balance sheet assets in the German Commercial Code (HGB), which builds up on the distinction between fixed and current assets, the balance sheet breakdown of commercial banks in Germany requires the liquidity principle[9]. That means the typical bank balance sheet shows assets in decreasing order of liquidity, which typically consist in liquidity reserves, loans, bonds, securities, shares and other

[9] For provisions on the breakdown of the balance sheet compare § 266 HGB and §§ 340 - 340o HGB.

securities, investments in associated companies and tangible fixed assets (property, plant and equipment). The simplified balance sheet shows at the asset side the position “liquidity reserve”, which refers to cash and cash equivalents of the bank. Cash money is held to supply cash on demand to customers and as liquidity reserve a bank holds obligatory due to reserve requirements or voluntary with the central bank. Cash equivalents include short-term investment instruments like demand deposits, T-bills and commercial papers of high liquidity and low credit risk. In classical economic theory, free liquidity reserves constitute the precondition for loan supply (Bernanke & Gertler, 1995). In Post-Keynesian theory, the causality is of reverse nature as deposits are assumed to create reserves (Palley, 1994). The position “claims towards financial institutions” mainly relates to banks' overnight lending towards other financial institutions and is dominated by credit risk. The position “claims towards customers” refers to bank assets towards households and firms including in particular loans, which is subject to credit risk and interest rate risk (Bessis & Bessis, 2015). The positions “proprietary investment” and “proprietary trade” refer to long term and short-term assets like stocks, bonds, securities, commodities, derivatives and other financial assets that the bank holds in addition for generating income for investment purposes or with a speculative motive. These positions bear mainly interest rate risk and counterparty default risk (Bessis & Bessis, 2015). For a bank, the primary source of repayment are cash flows generated by assets through its operations or sale.

LIABILITIES: Liabilities reflect the sources of funds and are distinguished in external debt and capital (Cecchetti, Schoenholtz & Fackler, 2006). According to the legal accounting provisions for commercial banks in Germany, the liability breakdown also relies on the liquidity principle. Therefore, the order of the balance sheet consists in liabilities of ascending maturity followed by capital. The simplified balance sheet shows on the liability side the position of “external debt”, which includes deposits, bonds and borrowed money for refinance. The main liabilities of commercial banks are those towards customers and other credit institutions. This position reflects the strong interrelation between assets and liabilities in the balance sheet of commercial banks. Deposits differ from other debt in that the size of deposits (addition or withdrawal) is at discretion of the customer rather than set by contract (Tian, 2017). Commercial banks borrow additional funds from the central bank at the money market, from other commercial banks at the interbank market or from non-depository institutions such as insurance companies and pension funds. The lower positions reflect equity capital, which is distinguished between "external capital" that consists in issued share capital that pays dividends out of profits, and "internal capital" that relates to reserves and retained earnings. Since external debt finance is generally less expensive than capital, it is economically reasonable for commercial banks to rely on debt funding (Bernanke & Gertler, 1995). Therefore, commercial banks face a permanent trade-off between capital (protection of confidence) and debt (profitability).

LEVERAGE: The position of "external debt" reflects the leverage of the bank. The leverage ratio is calculated from capital in relation to the total exposure. A low leverage ratio indicates that a bank has a high level of debt in relation to its capital (Cecchetti, Schoenholtz & Fackler, 2006). Banks leverage their balance sheet in order to fund additional assets, with the aim of raising profits. Leverage exposes the bank to a funding liquidity risk from maturity transformation, which is insured by holding liquidity buffers in asset positions such as "liquidity reserve". Moreover, excessive leverage is associated to systemic risk to the stability of the financial sector and the real economy (BCBS, 2022). Contradictory to the intuition, leverage is lower during economic expansions due to rising asset values and net worth, and higher during economic contractions. Adrian and Shin (2010a) present empirical evidence of procyclical leverage as a consequence of the active management of balance sheets by financial intermediaries who respond to changes in prices and measured risk. Avgouleas (2015) analysed the impact of bank leverage on financial stability and identifies higher risk from debt funding related to contagion in the banking system that exacerbates the transmission of risks from the financial system to the real economy. As the study points out, one reason is that leverage gives rise to credit and asset price cycles, therefore excessive leverage contributes to macroeconomic booms and busts. In the event of the materialisation of risk, capital needs to cover the unexpected losses. In the worst-case scenario, a so-called "low probability - high cost" scenario, various types of risk materialise simultaneously and cause unexpected losses higher than the capital buffer. In this case, the only way out is the increase of external capital issuance, possibly accompanied by support of the central bank acting as lender of last resort. Otherwise, the bank is insolvent due to insufficient liquid assets in order to meet liabilities, implying the default of the bank.

Based on that simplified balance sheet model of commercial banks, the theoretical representation of the risk channel in the TMMP in this research will put liquidity, capital and leverage as well as loan assets into the focus, along with the corresponding credit risk and interest rate risk.

2.3.1.4 RISK IN BANK MANAGEMENT

The general bank management of a commercial bank in the EMU is in particular influenced by current market activity, competition, macroprudential bank regulation and further provisions from national regulation, which is for example the German Banking Act that applies for banks in Germany. The general concern of bank managers is profit maximisation under risk mitigation in compliance with regulatory requirements. Bessis and Bessis (2015) point out that risk management is of great importance for a bank in reaching its targets. Risk managers see their role as being accountable for identifying, assessing, and controlling the likelihood and the consequences of adverse events for the bank. Risk in the portfolio arises from uncertainty on the rate of return, a view that finance has in common with economic theory (Fisher, 1896). This uncertainty cannot be eliminated, but it can be changed by risk management. Risk management instruments for the credit portfolio include risk identification and measurement, risk pricing and collateral requirements in association with the credit decision, risk limitation and risk control (Bessis & Bessis, 2015). The limitation of risk is specified in the bank strategy by the bank management and can for example refer to the credit quality as indicated by the rating of borrowers. Risk control consists of regular monitoring and reporting as well as the ad hoc risk status towards the bank management.

The scheme in Figure 2.13 indicates the trade-off between risk mitigation and profit maximisation: since return and risk relate positively, a bank naturally takes on risk and generates profit out of it, as outlined in Acosta-Smith, Grill and Lang (2020). Excessive risk-taking can in the worst-case result in the default of the bank with possible contagion effects to other commercial banks (Avgouleas, 2015; BCBS, 2022). When setting up the bank strategy, the bank management determines a profit target that corresponds to a certain degree of risk in the portfolio. This is a decision on the risk tolerance of the bank. Grable (2000, p. 625) defines financial risk tolerance as “the maximum amount of uncertainty someone is willing to accept when making a financial decision”. Hence, risk tolerance is a decision of the bank that is grounded on the trade-off between profit and risk mitigation (Cecchetti, Schoenholtz & Fackler, 2006; Borio & Zhu, 2012). The choice on the degree of risk tolerance in turn affects risk management, which controls for the classes and amount of risk in the portfolio. The finance view is consistent to economic theory, in that the demand for (risky) assets is determined by the rate of return and risk, while the former emphasises the role of risk tolerance in the decision of banks on the portfolio composition (Fisher, 1896; Bessis & Bessis, 2015).

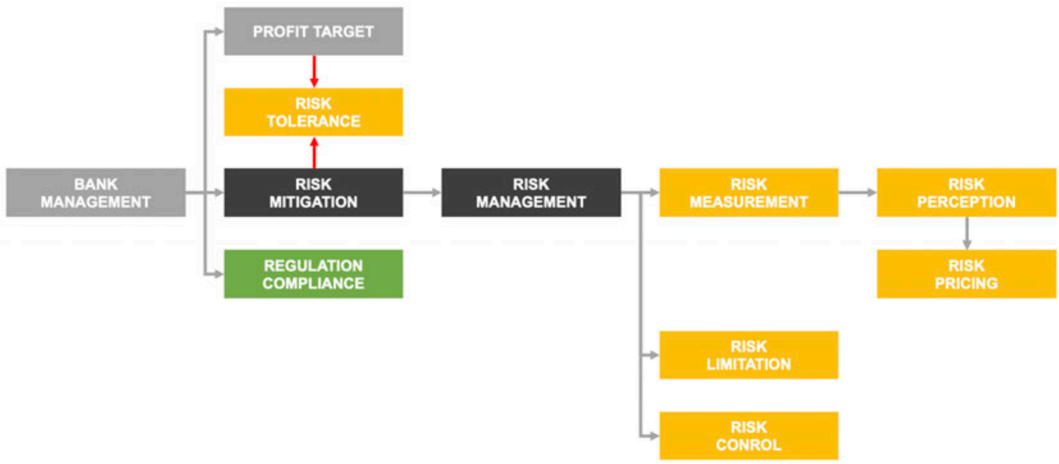


FIGURE 2.13:
RISK IN BANK MANAGEMENT

Source: author’s illustration

With respect to the risk channel of monetary transmission, it is essential to understand how monetary policy affects the balance sheet of banks through changes in the monetary policy rate. Finance theory highlights the trade-off between profit and risk mitigation and implies that balance sheet effects of monetary policy might be driven by changes in risk tolerance of commercial banks (Bessis & Bessis, 2015).

2.3.2 BANK RISK MEASUREMENT

Measuring risk is an integral part of a bank's risk management. The applied methods of risk measurement heavily determine how much of the risk a bank actually perceives in its balance sheet. Hence, given the degree of risk tolerance, risk perception of a bank influences its decision on how much additional risk it takes. This subchapter investigates the nexus between risk measurement, risk perception and risk-taking.

2.3.2.1 RISK BEARING CAPACITY

A crucial instrument in a bank's risk management is the assessment of its risk-bearing capacity. This is the comparison of risk and risk coverage potential and therefore an estimator for the maximum amount of risk that a bank can take according to the size of its capital (Guégan & Hassani, 2019). It is the highest and most comprehensive level of assessment on the risk situation of a bank. The risk-bearing capacity is given if all significant risks are continuously covered by risk coverage potential (BCBS, 2022).

Following the German Central Bank (2007) the risk-bearing capacity analysis comprises (1) the choice of approach, (2) the calculation of the risk coverage potential and (3) the identification and measurement of the significant risks. The first step of calculating the risk-bearing capacity is the choice of the approach, which differs among German commercial banks (German Central Bank (2019a): In the gone-concern approach, the bank would no longer be able to operate when all of the risk in the portfolio identified within the risk-bearing capacity analysis materialise (insolvency). In a fictious liquidation, the creditors could be served. In contrast, with the going-concern approach, the bank is still able to meet the regulatory requirements as all of the risk in the portfolio materialise. The second step is to calculate the risk coverage potential, which is determined by the capital employed for risk protection. In order to distribute the available risk cover to the risk exposure, the third step in the risk-bearing capacity analysis consists of the identification and measurement of the significant risks according to the individual bank portfolio, which are generally distinguished by the classes credit risk, market risk, operational risk, liquidity risk and other risks. The risk-bearing capacity analysis is an important measure that affects the risk perception of the bank. In addition, it provides the foundation for decisions on future risk management of the bank, in particular the decision on risk tolerance.

From the perspective of the general bank management, it is the business strategy that contains the targets on the general direction of the bank, including the profit target, as visualised in Figure 2.14. The results of the risk-bearing capacity analysis build the basis for the subordinated specification of the risk strategy, which indicates the bank's risk tolerance (Bessis & Bessis, 2015). It covers principles and guidelines as well as targets for each class of risk, which in turn translate into a framework and organisational guidelines for single organisational units, positions or functions.

FIGURE 2.14:
RISK STRATEGY

Source: author's illustration

2.3.2.2 CREDIT RISK MEASUREMENT

The method of risk measurement differs for the different classes of risk. Credit risk as the predominant risk in commercial banking is measured based on the probability of default, the exposure at default and effective maturity (Tian, 2017). The probability of default indicates the relative frequency of the occurrence of a (previously defined) credit event within a certain period of time. It translates into a rating for the purpose of risk management, for which it is distinguished between internal ratings calculated by own methods of the bank and external ratings calculated by independent rating agencies such as Moody's, Fitch Rating and Standard & Poor's (Allen, 2012). The exposure at default is a credit equivalent which indicates the use of commitment at default date. For the customer business, it is derived from the commitment and use of a credit line. In terms of the maturity, financial transactions were generally classified into short-term (up to 1 year), middle-term (1 to under 4 years) and long-term (from 4 years) positions. The loss given default is the loss ratio and derived from the return ratio, that is the loss ratio allowing for collateral (Allen, 2012). This loss ratio indicates the loss after work out efforts and is an estimator for the expected need for depreciation and value adjustment at default date. The expected loss (EL) measures the average expected loss and is covered by calculated risk premia and depends on the exposure at default (EAD), the probability of default (PD) and loss given default (LGD) (Allen, 2012).

$$EL = EAD * PD * LGD \tag{2.25}$$

Hence, the expected loss increases with exposure, such as commitments and the use of a credit lines, while it is negatively related to quality and quantity of securities and value adjustments. The value at risk estimates the maximum loss of a portfolio under normal market conditions within a certain period of time that occurs with a certain probability, that is a confidence interval 1-α (Allen, 2012). Tian (2017), Guégan and Hassani (2019) as well as Miller (2019) outline the common approaches for estimating the value at risk for counterparty default risk, including the variance-covariance-approach as analytical model for the products of commercial banking such as loans and simulation models like the historical simulation and the Monte-Carlo-simulation for the products of proprietary investments and trade such as stocks, bonds and derivatives. Miller (2019) outlines that in models applied in the customer business, the value at risk depends on the quantile, correlations, exposure at default, the probability of default and loss given default. For assets of own business, the value at risk depends on the number of simulation-runs, the quantile, the characteristics of the portfolio (maturity, realisation period, exposure, rating) as well as correlations.

FIGURE 2.15:
EXPECTED LOSS, UNEXPECTED LOSS, VALUE AT RISK

Source: author's illustration following Miller (2019)

The unexpected loss (UL) is an estimator for the negative deviation of actual loss from expected loss (EL). This measure is the residual from the value at risk (VAR) decremented by the expected loss, as apparent in Figure 2.15. The unexpected loss indicates the actual risk in terms of uncertainty, which needs to be covered by economic capital in the event of the materialisation of that risk. The so-called tail events refer to the right side of the probability density distribution that reflects events of low probability and high loss.

Since the calculation of the loss given default allows for the recognition of collateral, a collateral assessment needs to precede the risk assessment (Tian, 2017). The creditworthiness of borrowers is in particular determined by the probability of default of the borrower, as expressed by ratings, and the quantity and quality of the collateral provided by the borrower. Various kinds of assets qualify as collateral. Most common assets consist in saving deposits, securitised assets and real estate. Banks assess collateral by calculating the expected proceeds, which finally translate into the loan value. This is the collateral value available to cover potential losses and considered in the measure of expected loss.

Table 2.4 summarises central measures of credit risk following Curcio and Gianfrancesco (2009) and Allen (2012).

TABLE 2.4:
RISK MEASURES AND DETERMINANTS

RISK MEASURE	DETERMINANTS
LGD (loss given default)	Collateral
EL (expected loss)	EAD (exposure at default) PD (probability of default) or rating LGD (loss given default)
VAR (value at risk)	Quantile Correlations EL (expected loss) EAD (exposure at default) PD (probability of default) or rating

Another measure of credit risk is the share of risky loans, which reflects the allocation of risk in the portfolio (German Central Bank, 2020a). It can be derived from various underlying measures. For example, a common view on credit allocation risk is the share of relatively risky loans based on the interest coverage ratio of the counterparty (German Central Bank, 2020a).

The risk-bearing capacity analysis ends with the comparison of the risk coverage potential (RCP) to the value at risk (VAR), which must be sufficient to cover the risk, that is at least unexpected losses arising from the significant risks in the individual portfolio of the bank.

$$RCP \geq VAR \tag{2.26}$$

Figure 2.16 visualises how the risk-bearing capacity analysis and the related measures of credit risk relate to the banks' balance sheet. It shows assets at the left and liabilities at the right side of the figure, pointing out in which way the risk-bearing capacity analysis relates to the attitude of a bank towards risk.

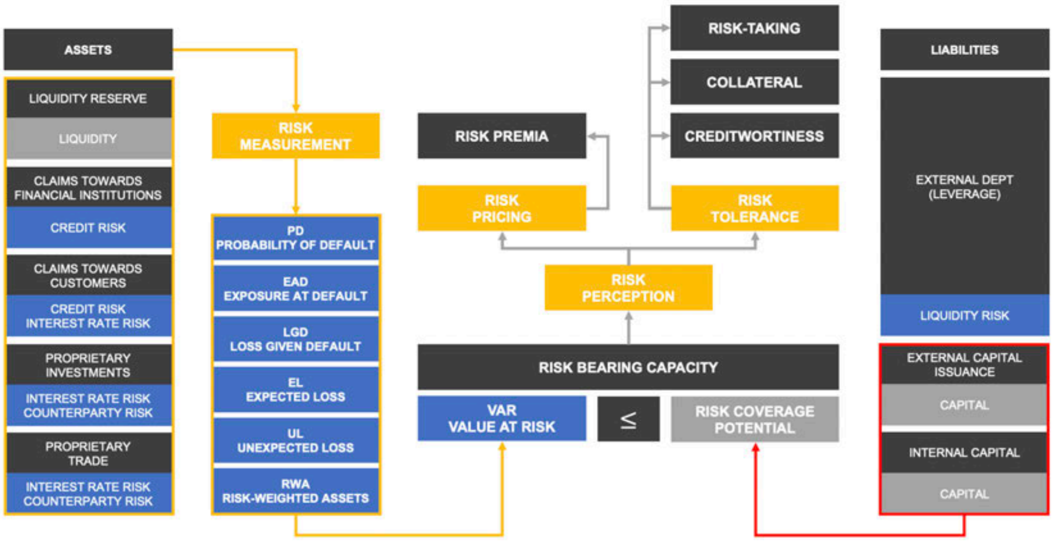


FIGURE 2.16:
RISK BEARING CAPACITY

Source: author’s illustration

The methods of how a bank measures risk determines its risk perception. Pidgeon, Hood and Jones (1992) define financial risk perception as investors’ beliefs, attitudes, judgements and feelings of the risk attributes of the investment product. The more sophisticated the methods of risk measurement, the more of the risk in the balance sheet becomes visible to the bank. This in turn can affect decisions of the bank on the composition of its balance sheet, in particular on holding capital and liquidity as well as on the pricing of risk in terms of the size of risk premia (Tian, 2017). Hence, for a given risk tolerance, the perception of risk affects risk-taking, that is the decision of a bank on taking additional risk, which is reflected in the availability of loans at the credit market and the corresponding credit standards, including the requirements on creditworthiness and collateral. Borio and Zhu (2012) point out that an improvement of methods of risk measurement and hence risk perception tends to enhance the risk sensitivity of the bank, that is the degree to which changes in risk affect bank decisions on capital, liquidity and risk-taking. Risk perception changes throughout the business cycle since measures of risk are lower during economic expansions and higher during economic contractions, which arises from their procyclical nature. Hence, monetary policy affects the risk perception of banks through the effect on economic activity and in turn on procyclical measures of risk.

2.3.3 BANK RISK PRICING

The amount of income from risk premia has to cover the statistical expected losses. The standard method of calculating the rate of interest the borrower pays for a loan at the credit market, that is the price of a loans, is called risk-adjusted pricing (Curcio & Gianfrancesco, 2009). Figure 2.17 shows a simplified scheme of the price components of the interest rate at the credit market as it typically applies for loans. It indicates that the risk premium and capital costs are the risk-related variables in pricing, as they rise with the probability of default of the borrower.

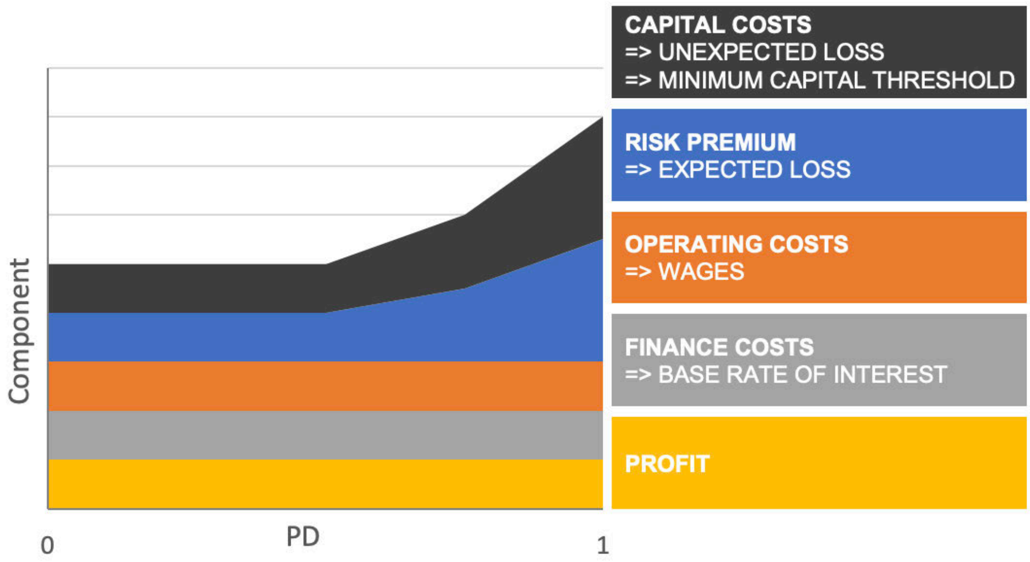


FIGURE 2.17:
RISK ADJUSTED PRICING

Source: author's illustration

The component of profit corresponds to the earnings of the bank from a loan resulting from the applied profit margin. The fraction of finance costs arises from the rate of interest the bank pays at the money market for money procurement. The price of finance costs is determined by the monetary policy rate of interest set by the central bank, which constitutes the lower bound for the pricing of banks at the credit market (Hasan & Zazzara, 2006; Lavoie 2014). Operating costs refer to costs for management and administration, including wages, rent and other overhead costs (Hasan & Zazzara, 2006). These costs arise from real wage negotiation at the labour market and goods market prices (Hein, 2008).

The risk premium is the component that addresses uncertainty and depends positively on risk. Hasan and Zazzara (2006) outline that the risk premium reflects the ex-ante estimated expected loss from credit default, depending positively on the exposure at default, the probability of default of the borrower and hence negatively on the collateral provided by the borrower. Risk premia move countercyclical, since probabilities of default tend to be low during an economic expansion, while they rise in an economic contraction (Martinez-Miera & Repullo, 2017). The risk premium is the spread that reflects the risk in the rate of interest. The measurement of changes in risk premia of assets is done by calculating credit spreads. This is the comparison of the interest rate curve of a particular risky asset, such as loans, to the interest rate curve of a risk-free asset, like a government bond of same maturity (Hasan & Zazzara, 2006). Risk premia indicate changes in risk at the asset market and furthermore are used as indicator for conclusions on changes in risk perception and risk tolerance of banks.

Capital costs relate to risk and market interest rates, as well, and depend on the target size of capital of the bank (Hasan & Zazzara, 2006; Tian, 2017). At the one hand, a bank decides on the amount of capital for economic reasons, in particular considering the need for capital as loss cover from the estimation of unexpected losses. On the other hand, bank regulation determines the capital ratio floor by imposing a minimum capital threshold on risk-weighted assets (BCBS, 2022). Hence, the amount of capital is largely driven by risk at the asset side of the balance sheet, more precisely by risk perception and risk tolerance of a bank. The capital costs consist particularly in the dividends on equity funding, that is the price of issuing external capital. Since the interest rate on equity funding is market driven, capital costs are market driven, as well, and hence volatile throughout the business cycle. Capital costs relate positively to the probability of default, since a higher probability of default implies higher risk, thus a bank needs to hold more capital as cover for unexpected losses and for the compliance to regulatory requirements, which implies higher capital costs for higher risk in the balance sheet.

TABLE 2.5:
RATE OF INTEREST AT THE CREDIT MARKET AND DETERMINANTS

COMPONENT	DETERMINANT
Profit	Profit target
Finance costs	Monetary policy rate of interest (money market)
Operating costs	Wages (labour market), prices (goods market)
Risk premium	Risk measures (EAD, PD), risk perception
Capital costs	Rate of interest (asset market), risk tolerance

Risk pricing is an important element of a banks risk management as it ensures the coverage of expected losses and functions as pre-control of default risk (Curcio & Gianfrancesco, 2009). While Post-Keynesian economic theory already considers a risk component in the mark-up pricing of banks, finance theory adds the more detailed perspective on risk-adjusted pricing based on the components profit, finance costs, operating costs, risk premium and capital costs of the individual rate of interest that a borrower pays for a loan at the credit market. By changes in the base rate of interest, monetary policy affects at least four of the price components of loans: a direct effect arises through finance costs at the money market, and indirect effects relate to operating costs, the risk premium and capital costs. Operating costs are tied to labour market wages and goods market prices. Since risk measures tend to move countercyclical, the monetary policy rate of interest additionally affects risk premia in an indirect way. Capital costs are linked to the rate of interest at the asset market. Finance theory on risk-adjusted pricing of loans relates closely to the Post-Keynesian theory on mark-up pricing but contributes a more in-depth view on how monetary policy affects the interest rate at the credit market.

2.3.4 IMPLICATION FOR THE RISK CHANNEL

This subchapter synthesises the insights of finance theory on risk with respect to their implication for the risk channel of monetary transmission.

Finance theory contributes the perspective on risk, which helps to explain how monetary policy affects risk-taking of commercial banks by changes in the monetary policy rate. Figure 2.18 visualises the relationship between risk-taking in the balance sheet of commercial banks and how it is affected by changes in the monetary policy rate of interest.

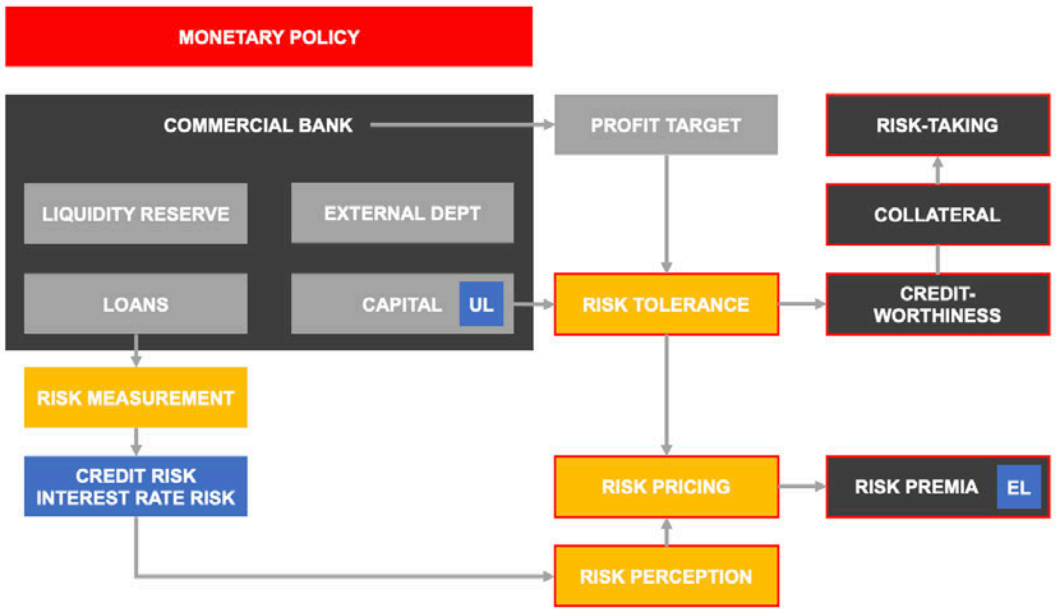


FIGURE 2.18:
RISK IN FINANCE THEORY

Source: author's illustration

Commercial banking with the core business of loan supply to borrowers at the credit market is predominantly associated to credit risk and interest rate risk, other significant classes of risk for banks include liquidity risk and operational risk (Bessis & Bessis, 2015). Credit risk refers to losses from the default or the deterioration of the credit standing of the borrower. Interest rate risk relates to losses in net interest income due to movements of interest rates. The applied methods of risk measurement determine the risk perception of a bank. For the loan portfolio, the measure that indicates the maximum loss from credit risk is the value at risk (Allen, 2012). This and other measures of risk, such as probabilities of default, ratings, expected loss and unexpected loss, move countercyclical and hence exhibit procyclical effects (Borio & Zhu, 2012). In turn, the perception of risk affects risk pricing with respect to the size of the risk premium component of the borrower specific interest rate at the credit market.

How much risk a commercial bank takes depends on its risk tolerance, which is a function of capital in the balance sheet and the profit target in the business strategy (Dell'Ariccia, Laeven & Marquez, 2014). The management decision on the profit target is a trade-off between profit maximisation and risk mitigation. A higher profit target corresponds to higher risk-taking and therefore requires higher risk tolerance. In turn, risk tolerance is conditional to capital, which functions as risk coverage potential for unexpected losses. A higher capital buffer allows for higher risk tolerance. Besides the decision on the amount in the supply of loans, commercial banks control for risk-taking by holding sufficient capital, by applying credit standards, including standards on the creditworthiness of borrowers and collateral requirements, and by risk pricing (Allen, 2012). While expected losses (EL) are covered by the risk premium component of risk-adjusted pricing, capital functions as buffer for absorbing the unexpected losses (UL) from the materialisation of risk (Allen, 2012).

An increase in risk-taking of commercial banks can arise from (1) an increase in the supply of loans that increases the exposure at default, often accompanied by leverage, (2) a decline in the standards on the creditworthiness of borrowers that increases the probability of default and (3) a decline in collateral requirements that increases the loss given default. A growth in loan supply can turn into excessive leverage, which potentially leads to the build-up of systemic risk to the financial stability. High leverage implies that a bank has a relatively small capital buffer for unexpected losses and a great reliance to external debt. The studies of Avgouleas (2015) as well as Alessi and Detken (2018) demonstrate that over-leverage can seriously threaten the soundness of bank's balance sheets as an adverse event, such as an adverse price movement at the asset market, causes the materialisation of interest rate risk in form of a rapid and simultaneous unwind of leveraged positions. During times of distress in the financial sector, highly leveraged banks are more likely to run into liquidity shortages accompanied with the risk for the creditors of the bank of not being repaid, which corresponds to the materialisation of liquidity risk. Therefore, the leverage of bank balance sheets is another indicator for risk-taking from the perspective of systemic risk.

Economic theory offers explanations on the transmission of monetary policy through the traditional channels based on reserve requirements, changes in the quantity of money and the base rate of interest (Bernanke & Gertler, 1995, Kuttner & Mosser, 2002). The endogenous role of the attitude of banks towards risk is rather absent in economic theory on the traditional channels of monetary transmission. For instance, while risk premia are considered in Post-Keynesian theory through the mark up of banks, there is no endogenous role of risk perception and collateral standards, as the latter are assumed to follow exclusively the collateral standard of the central bank in that theoretical framework (Hein, 2008). The integration of economic theory and finance theory reveals the mechanism of the risk channel: Monetary theory implies that a change in the base rate of interest by the central bank alters finance liquidity conditions and affects the size and composition of the balance sheet of commercial banks with respect to assets, external debt and capital. Finance theory unveils how balance sheet positions relate to risk perception, risk pricing and risk tolerance of commercial banks and finally their risk-taking.

The risk channel of monetary transmission extends on the traditional transmission mechanisms by explicitly considering the effect of monetary policy on the risk-taking of banks in monetary transmission. Expansionary monetary policy by lowering the base rate of interest at the money market lifts funding constraints for commercial banks since the price of funding liquidity decreases. As implied by the credit channel of monetary transmission, the monetary stimulus corresponds to a rise in cash flows, asset values and the net worth of borrowers (Bernanke and Blinder, 1992). On the one hand, this translates into an increase in the creditworthiness and collateral values of borrowers (Tian, 2017). In consequence, measures of risk fall countercyclically, lowering the perception of risk in the balance sheets of commercial banks, which is in turn reflected in the pricing of risk by a decline in risk premia. On the other hand, higher cash flows and asset values strengthen the capital position of the bank, which means a higher risk coverage potential that allows for a higher risk tolerance.

Through the rise in risk tolerance accompanied with a fall in risk perception, monetary expansion provides the incentive for banks to increase risk-taking though the extension of loan supply. Credit risk increases as banks decide to lower the standards on creditworthiness of borrowers and collateral requirements (Allen, 2012). Interest rate risk rises as banks intensify maturity transformation by increasing asset durations. Liquidity risk grows as banks increase the leverage of the balance sheet, that is external debt in relation to capital, which bears systemic risk as outlined by Adrian and Shin (2010a). From a macroeconomic perspective, a change in the composition of loan supply has a direct impact on future financial stability and economic growth (Allan & Gale, 2007; Matsuyama, 2007).

Empirical evidence of Adrian, Estrella and Shin (2019), among others, point out that expansionary monetary policy has an adverse effect on profits in a regime of long-lasting, very low interest rates. It causes long term market interest rates to decline and reduces market volatilities, the return from interest and speculation on rising prices. The low interest rates reduce the rate of return in the interest book in the balance sheet. This can exhibit an additional effect the risk tolerance of commercial banks because the gap between the profit target and actual profits widens. In order to reach the profit target further on, commercial banks have an incentive to increase risk tolerance in order to compensate for lower interest-earnings. Empirical evidence of this phenomenon known as search for yield effect is presented in the work of Martinez-Miera and Repullo (2017) as well as Memmel, Seymen and Teichert (2018). Such a low-interest environment occurred in the EMU between 2016 and 2022, as the monetary policy rate reached the zero-lower bound[10].

The danger of an unnoticed pile up of risk in the balance sheet of commercial banks is that the reverse of an economic expansion can potentially start a severe economic downturn as financial disruptions related to the materialisation of risk occur, which threaten the stability of the financial sector. In this scenario the risk channel mechanism works in the opposite direction: Cash flows and asset values decline, risk materialises and capital shrinks in

[10] From March 2016 to July 2022, monetary policy of the ECB touched the zero-lower bound with an ECB interest rate on main refinancing operations of 0% (ECB, 2021).

order to absorb the unexpected losses. The perception of risk increases and simultaneously risk tolerance declines: A formerly increase in leverage corresponds to higher reliance to external debt funding. The balance sheet shows excessive risk on the asset side along with insufficient capital at the liability side. Liquidity risk materialises if commercial banks become unable to meet payment obligations in the short term from selling assets, because losses arise from the sale of assets to a lower price, while liabilities remain of the same magnitude.

In order to prevent such hazardous downward cycles from the pile up of risk in the balance sheet of banks, institutions of the EMU implemented standards on risk measurement and requirements on capital, liquidity and leverage. The following subchapter sheds light on bank regulation in order to evaluate its role in monetary transmission through the risk channel.

2.4 MACROPRUDENTIAL BANK REGULATION

The commercial banks within the EMU are facing a framework of regulatory requirements. This is due to their central role as financial intermediaries for the real economy and the nature of their business activity: the generation of profit out of taking risk. As Alessi and Detken (2018) point out, this risk-based business activity of commercial banks builds up on external funding by around 80 to 85 percent, most of which comes from their customers. The regulatory framework of the Basel Committee of Bank Supervision (BCBS) imposes standards on risk measurement, requirements on capital, leverage, and liquidity as well as standards on risk management and the public disclosure of risk. The aim is to protect the real economy by promoting a stable financial system in terms of sound risk management practices of commercial banks and limitations of their scope for excessive risk-taking (BCBS, 2020).

This subchapter investigates the role of macroprudential bank regulation in monetary transmission through the risk channel. The objective is to identify the impact of the regulatory framework and its requirements on capital, leverage, and liquidity on the transmission of monetary policy. For that purpose, the focus of the analysis is on the effect of macroprudential bank regulation on the attitude of banks towards risk and their behaviour regarding decisions on their balance sheet composition. The first subchapter explores the incentives arising from the institutional framework of macroprudential bank regulation in the EMU, the second subchapter focuses on the impact of regulatory requirements on the measurement of credit risk, the third subchapter investigates the limitations from requirements on capital, leverage, and liquidity in the balance sheet of commercial banks. The fourth subchapter derives conclusions on the role of macroprudential bank regulation in monetary transmission through the risk channel.

2.4.1 INSTITUTIONAL FRAMEWORK

Historical events like the financial crisis that emerged in 2007 have shown the vulnerability of the real economy to the pile up of excessive risk in the bank sector (Baily, Litan & Johnson, 2008). The institutional goal of bank regulation and supervision in the EMU is to protect the functioning, the stability and the integrity of the financial market, that is depositor protection and the protection of the banking system by a legal framework, referred to as prudential regulation (BCBS, 2022; Shaddady & Moore, 2019). In Germany, the origin of that protective idea came up with the German Banking Act ("Kreditwesengesetz", KWG) in 1933. The introduction of the Euro as a common currency in 2002 was accompanied by a constant increase of financial market integration over the years by the development of a standardised legal framework of bank regulation. Nowadays, the specification of that common standard is a supranational issue with a system of financial supervisors at the level of the European Union (EU), while the legislative power remains with the authorities at the national level. In terms of the regulatory objective, there is a distinction between macro-prudential bank regulation, which relates to the stability of the financial system as a whole, and micro-prudential bank regulation, referring to the supervision of single financial institutions (ECB, 2014). In this research the focus is on macro-prudential bank regulation, since this is the framework that applies to all commercial banks within the EMU and hence may affect monetary transmission through the risk channel.

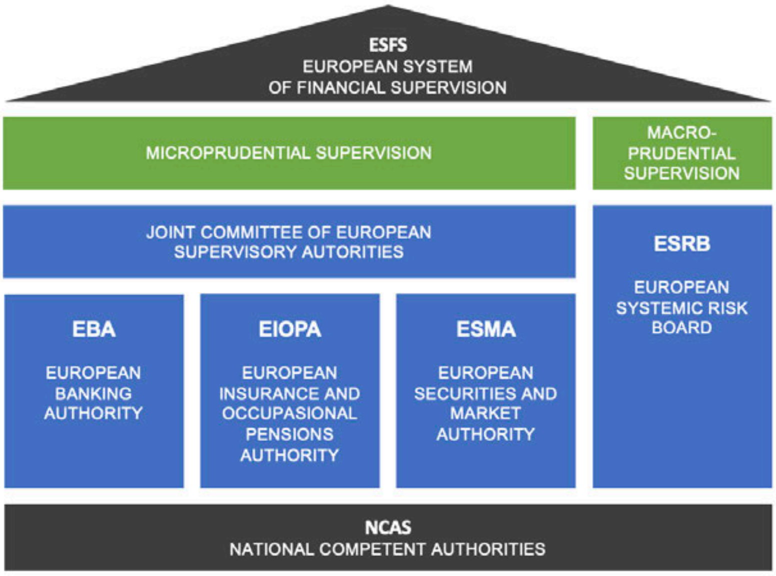


FIGURE 2.19:
EUROPEAN SYSTEM OF FINANCIAL SUPERVISION

Source: author's illustration adapted from the Council of the European Union (2019)

In 2011, the European Banking Authority (EBA) is the agency of the EU for financial market supervision within the European System of Financial Supervisors (ESFS), as shown in Figure 2.19 following the illustration of the Council of the European Union (2019). The European Banking Authority is responsible for the development of a European standard in banking supervision, that constitutes the framework for the national supervisors, which are still primarily responsible for financial market supervision. The framework covers in particular Regulatory Technical Standards, Implementing Technical Standards, non-binding guidelines and recommendations as well as the coordination of stress tests[11].

Another institution for European banking supervision is the Banking Union of the European Union (Figure 2.20). All member states of the EMU are part of the Banking Union, for the remaining member states of the EU the participation is voluntary. The Banking Union was established in 2014 for the ensuring transparency, unity and security after the need for these values emerged with the financial crisis in 2007. It was observed that especially in a monetary union,

[11] EBA/ITS/2017/01 in conjunction with Regulation (EU) 575/2013 (CRR) and Regulation (EU) 680/2014 (Implementing Technical Standards (ITS) on supervisory reporting).

problems can easily spill over national boarders due to the close link between the public sector finances and the banking sector, causing financial disturbances in other member states of the EU. The Banking Union is currently based on two pillars: the Single Supervisory Mechanism (SSM) that aims for a uniform approach of banking supervision and the Single Resolution Mechanism (SRM) that targets uniform rules for banking resolution. The third pillar of a European Deposit Insurance Scheme (EDIS) is envisaged with a gradual implementation until 2024 according to the proposal of the European Commission[12].

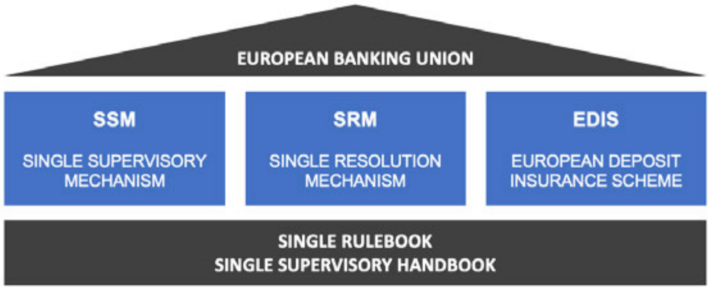


FIGURE 2.20:
EUROPEAN BANKING UNION

Source: author's illustration adapted from the Council of the European Union (2019)

In other words, the Single Supervisory Mechanism represents the system of bank supervision in Europe. It consists of the ECB and the national authorities of the participating countries. The role of the ECB is to perform the duties of a supervisory authority from the perspective of the EU, including the following competences (ECB, 2020):

- conduct supervisory reviews, on-site inspections and investigations
- grant or withdraw banking licences
- assess banks' acquisition and disposal of qualifying holdings
- ensure compliance with EU prudential rules
- set higher capital requirements in order to counter any financial risks
- impose corrective measures and sanctions

[12] COM/2015/0586 final - 2015/0270 (COD) (Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Regulation (EU) 806/2014)

As of 2022, the supervision of the ECB covers 110 Significant Institutions (SI) directly and 5 Less Significant Institutions (LSI) indirectly (ECB, 2022b). The distinction between these two categories depends on the criteria bank size, economic importance, cross-border activities, and direct public financial assistance. In Germany, it is the Federal Financial Supervisory Authority ("Bundesanstalt für Finanzdienstleistungsaufsicht", BaFin) that is responsible for micro-prudential supervision and the German Central Bank ("Deutsche Bundesbank", BBK) that executes the macroprudential supervision of the German financial system as a whole (Figure 2.21).

FIGURE 2.21:
NATIONAL COMPETENT AUTHORITIES IN GERMANY

Source: author's illustration adapted from the Council of the European Union (2019)

The institutional structures of banking supervision in the EU developed over the years towards financial market integration, forming a system of supervising authorities that oversee the financial market and develop a common standardised framework of bank regulation. In order to explore the link between macroprudential bank regulation and the risk channel in monetary transmission, it is crucial to take a closer look at the regulatory requirements within the so-called Basel framework. The Basel framework comprises all applicable standards recommended by the Basel Committee on Banking Supervision (BCBS, 2017).

The foundation of the Basel framework was established already in 1988 with the Basel Accord, that required banks to maintain a minimum of 8 percent of regulatory capital measured in terms of credit risk-weighted assets for the first time. In 2004, a redesign under the title "Basel II" established the three-pillar framework that distinguishes between pillar 1 "requirements on risk measurement and capital", pillar 2 "internal bank supervision of risk management" and pillar 3 "disclosure and transparency" (BCBS, 2004). Figure 2.22 shows the three pillars, that relate to the normative regulatory perspective, the economic bank internal perspective and the market perspective.

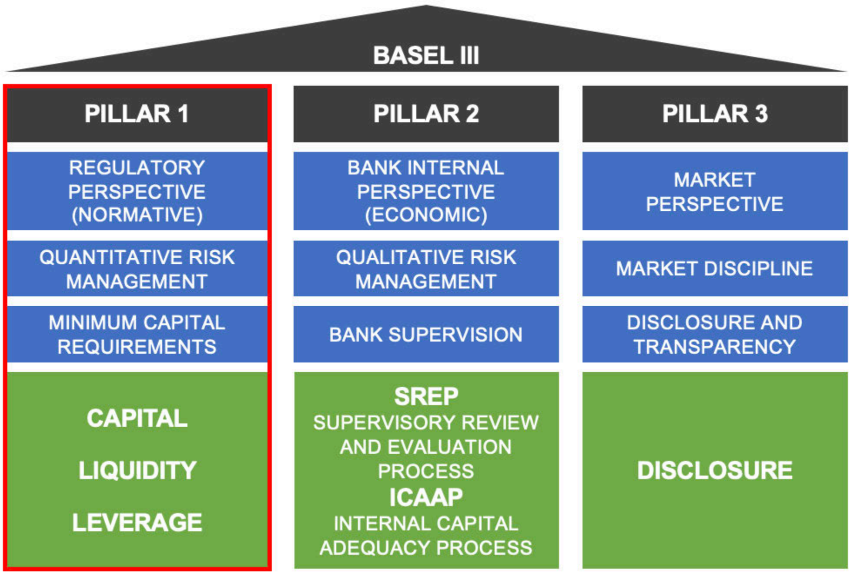


FIGURE 2.22:
3 PILLARS OF THE BASEL III FRAMEWORK

Source: author's illustration adapted from BCBS (2017)

In 2010, the Basel Committee on Banking Supervision published "Basel III: A Global Regulatory Framework for More Resilient Banks and Banking Systems" which was since then continuously augmented and revised. That current framework came with a tightening in the existing requirements as a reaction to the financial crisis of 2007 with the aim to reduce the danger that disruptions in the financial market affect the real economy (Zopounidis & Galariotis, 2015). The latest revision was published in 2017 under the working title "Finalising Basel III" (BCBS, 2017).

The European Commission is responsible for the implementation of the Basel framework into EU law, which includes the translation of the Basel standard into the Capital Requirements Regulation (CRR[13]) or the Capital Requirements Directive (CRD[14]) by making a legislative proposal to the European Parliament and the Council as well as the Implementing Regulation[15] based on the Treaty

[13] CRR (EU) 575/2013
[14] CRD (EU) 36/2013
[15] Instrument: part six TfEU title 1 chapter 2 section 1 article 291

on the Functioning of the European Union (TFEU). While regulations like the CRR have direct binding legal force, directives like the CRD need to be turned into national law by the member states, such as the German Banking Act in Germany. The implementation of the "Finalising Basel III" package at the national level happens successively in stages until 1 January 2027 (BCBS, 2017).

Pillar 1 of the Basel framework[16], which represents the regulatory perspective, refers to the quantitative risk management, that is risk measurement, as well as the requirements on capital, leverage, liquidity and large exposures by the following standards (BCBS, 2022):

- Definition of capital
- Risk-based capital requirements
- Calculation of RWA for credit risk
- Calculation of RWA for market risk
- Calculation of RWA for operational risk
- Leverage Ratio
- Liquidity Coverage Ratio
- Net Stable Funding Ratio
- Large exposure requirements

The regulation on risk measurement (sections CRE, MAR, OPE) affects the decisions of commercial banks on the methods of risk measurement. The requirements on capital (sections CAP, RBC) affect the decisions of commercial banks on capital. This makes pillar 1 highly relevant for the risk channel in monetary transmission. For the purpose of the research, the focus of analysis will be on the measurement of credit risk and the requirements on capital, leverage and liquidity.

Pillar 2 refers to bank supervision from an economic perspective, that is the bank internal risk management. The bank supervisory authority conducts the so-called Supervisory Review and Evaluation Process (SREP) in order to examine the qualitative risk management of the bank against the standards of

[16] Basel framework, sections CAP, RBC, CRE, MAR, OPE, LEV, LCR, NSF, LEX (BCBS, 2022)

pillar 2 (BCBS, 2019). The outcome of this evaluation can result into an additional, individual capital requirement for a bank. With respect to the risk channel, the standards on qualitative risk management in pillar 2 affect the overall risk management of a bank. With the “Minimum Requirements to Risk Management”, the Basel framework requires banks to include at least credit default risk, market risk, liquidity risk and operational risk into the risk-bearing-capacity analysis.

Pillar 3 covers the expanded disclosure[17] and refers in terms of transparency requirements to many of the regulatory measures of pillar 1. It follows that banks are obliged to regulatory reporting to the supervisory authorities at regular frequency and to regulatory disclose to the public (BCBS, 2022).

The regular impact studies of the European Banking Authority for the purpose of Basel monitoring indicate that the influence of macro-prudential bank supervision on the behaviour of banks has been increasing throughout the development and improvement of the institutional framework on bank supervision in the three stages of Basel (EBA, 2020; EBA, 2022). Other studies on the impact of changes in the Basel framework like the cross-country analysis of Cosimano and Hakura (2011) provide evidence in support in that the capital requirements under Basel III correspond to higher lending rates due to the increase in marginal costs of funding with adverse effects on loan growth in the long run. This indicates a tendency of an increasing impact of bank regulation on the risk management of commercial banks and hence on monetary transmission through the risk channel. In order to explore how exactly macroprudential bank regulation affects the risk channel of monetary transmission, the following sections consider the regulatory framework of Basel III with respect to the standards on the measurement of credit risk and the requirements on capital, leverage and liquidity.

[17] Basel framework, section DIS (BCBS, 2022)

2.4.2 REQUIREMENTS ON THE MEASUREMENT OF CREDIT RISK

The section CRE of the Basel framework addresses the method of measurement of risk-weighted assets for credit risk, securitisation, and the measurement of counterparty credit risk[18]. For the purpose of the current research on the risk channel, the focus is on the measurement of credit risk, which is the predominant class of risk in loan supply that builds the core business of commercial banks. In general, the Basel framework (BCBS, 2022) allows banks to apply one of two methods to calculate credit risk-weighted assets: the standardised approach (SA) and the internal ratings-based approach (IRBA).

2.4.2.1 STANDARDISED APPROACH

According to the Basel framework (BCBS, 2022), the standardised approach to the calculation of credit risk applies Credit Risk Mitigation (CRM) techniques, exposure classes and specific risk weights based on external ratings for each exposure class in order to calculate the amount of risk weighted assets (RWA).

The exposure amount[19] of an individual claim is determined by using the applicable Credit Risk Mitigation techniques, which may include, among others, the special consideration of exposures collateralised by first priority claims with cash or securities, guarantees by third parties, credit derivatives or the netting of loans against deposits from the same counterparty (BCBS, 2022). The exposure value after risk mitigation (E^{*}) is calculated from the maximum of zero and the difference of current value of the exposure (E) in consideration of a haircut appropriate to the exposure (H_e) and the current value of the collateral received (C) in consideration of a haircut appropriate to the collateral (H_c) and a haircut for currency mismatch between the collateral and exposure (H_{fx}).

[18] CRR (EU) 876/2019, § 10a KWG
[19] Basel framework, section CRE (BCBS, 2022)

$$E^* = max\{0, E * (1 + H_e) - C * (1 - H_c - H_{fx})\} \tag{2.27}$$

The exposure after risk mitigation is then assigned to the appropriate exposure class:

- Claims on Sovereigns
- Claims on non-central government public sector entities (PSEs)
- Claims on multilateral development banks (MDBs)
- Claims on banks
- Claims on securities firms
- Claims on corporates
- Claims included in the regulatory retail portfolios
- Claims secured by residential property
- Claims secured by commercial real estate
- Past due loans
- Higher-risk categories
- Other assets
- (Off-balance sheet items)
- (Exposures that give rise to counterparty credit risk)

Depending on the exposure class, each exposure is assigned to a standardised risk weight that might correspond to an applicable external rating. The risk-weighted assets are calculated as the product of the exposure value after risk mitigation (E^*) and the standardised risk weight (RW):

$$RWA = E^* * RW \tag{2.28}$$

An exception from that procedure applies to the two exposure classes "off-balance sheet items" and "exposures that give rise to counterparty credit risk". Figure 2.23 provides a schematic overview on the calculation of the RWA for assets exposed to credit risk. The appropriate risk weights are shown for the exposure class of claims towards corporates:

FIGURE 2.23:
STANDARDISED APPROACH TO THE CALCULATION OF CREDIT RISK

Source: author's illustration

Figure 2.23 highlights the fine distinctions of risk-weights depending on the exposure class of assets, which aim for high risk-sensitivity of the credit risk measure RWA in the Basel framework.

2.4.2.2 INTERNAL RATINGS-BASED APPROACH

The internal ratings-based approach (IRBA) on the calculation of credit risk RWA allows banks, conditional to supervisory approval, to use their own internal estimates of risk components in determining the capital requirement for a given exposure (Zopounidis & Galariotis, 2015). The risk components[20] include measures of the probability of default (PD), loss given default (LGD), the exposure at default (EAD) and effective maturity (M). The required risk-weight functions are based on measures of unexpected losses (UL) and expected losses (EL) (BCBS, 2022).

[20] Basel framework, section CRE (BCBS, 2022)

First, exposures to credit risk are assigned to IRBA asset classes, which are at a higher level of aggregation compared to the exposure classes of the standardised approach (BCBS, 2022):

- Corporate
  with 5 sub-classes of specialised lending: project finance, object finance, commodities finance, income-producing real estate, and high-volatility commercial real estate
- Sovereign
- Bank
- Retail
  with 3 sub-classes of exposures secured by: residential properties, qualifying revolving retail exposures and all other retail exposures
- Equity

For each asset class covered under the IRBA framework, there are three specific key elements:

- Risk components
  the estimates of risk parameters ($PD,\ LGD,\ EAD,\ M$) provided by the bank or partly by supervisory estimates
- Risk-weight functions
  the means by which risk components are transformed into risk-weighted assets and finally capital requirements
- Minimum requirements
  the minimum standards that must be met in order for a bank to use the IRBA approach for a given asset class

For many of the asset classes there are two approaches available (BCBS, 2022): (1) a foundation approach where a bank uses own estimates of PD and supervisory estimates for other components, and (2) an advanced approach where a bank uses more of its own estimates of risk. For both of the approaches, banks must use the risk-weight functions of the IRBA framework. These functions are specific to each asset class, but in general cover a correlation function (R), a maturity adjustment (b), the capital requirement function (K) and finally the RWA function. The RWA is for most of the asset classes calculated from the product of the capital requirement (K), the factor 12.5 and the exposure at default (EAD):

$$RWA = K * 1.25 * EAD \tag{2.29}$$

In addition, a scaling factor of 1.06 must be applied to the risk weighted assets calculated for the purpose of minimum capital requirements. Figure 2.24 provides a schematic overview on the calculation of risk-weighted assets in the IRBA approach:

FIGURE 2.24:
IRBA APPROACH TO THE CALCULATION OF CREDIT RISK

Source: author's illustration

The advantage for banks to use the more elaborated internal ratings-based approach is a lower regulatory capital requirement from the finer distinction of risk weights that arise from internal estimates. In order to limit these advantages and to intertwine both the standard and internal ratings-based approach, an output floor is being phased-in gradually until 01 January 2027 (BCBS, 2022). The output floor introduces a lower limit for the applicable risk-weights when RWA are calculated using the internal ratings-based approach. If the internal risk-weight falls below the risk-weight in the standardised approach, a bank must apply the output floor of 72.5% to the standardised risk-weight. Hence, it is a lower limit for internal risk-weights that can be regarded as a middle path between the internally calculated and the standardised risk-weight. According to the impact analysis of the Federal Association of German Banks, this addition to the IRBA framework tends to imply higher capital requirements for banks that apply their internal models (European Banking Authority, 2020; European Banking Authority, 2022).

By imposing a standard on the measurement of risk, the regulatory framework affects bank's decisions on the methods of risk measurement and thereby shapes their risk perception, which in turn affects their risk pricing as well as the non-price conditions in terms of the standards on the creditworthiness of borrowers and collateral requirements.

2.4.2.3 RISK SENSITIVITY

The risk measurement methods in the current Basel III framework introduce a much higher risk sensitivity of capital requirements compared to the previous versions of the Basel framework (European Banking Authority, 2020). The term risk sensitivity refers to the sensitivity of capital requirements to changes in estimated risk parameters and aims to indicate how well the risk weights of different rating classes reflect the underlying risk. In other words, it indicates how precise capital requirements mirror changes in estimators of risk. The empirical studies of Zsámboki (2007), the European Banking Authority (2020) and others indicate, that in the evolution of the Basel framework from Basel I to Basel III (1) the risk sensitivity of risk weights increased and (2) risk sensitivity of the internal ratings-based approach is higher than in the standardised approach.

During the development of the Basel framework, the focus has been shifted noticeably on the measurement of risk and the attitude of banks towards risk, which emphasises the central role of the risk management of commercial banks as financial intermediaries with respect to real economy (European Banking Authority, 2020). The ability of regulatory measures to capture risk increased by a finer distinction of assets of differing credit quality. In addition, the close intertwining of regulatory standards with practical risk management of banks increased. One reason is the introduction of the IRBA approach to risk measurement, that means the option for banks to use their own inputs in the calculation of the required capital (BCBS, 2022). This method is conditional to validation requirements, including that of a fully embedded regulatory standard into the risk management of the bank. Furthermore, constraints on using internal models aim to reduce unwarranted variability in the calculation of risk-weighted assets of banks. An output floor limits the benefits banks can derive from using internal models for the calculation of minimum capital requirements, which aims for a closer alignment between the standard approach and the internal ratings-based approach on risk measurement. Another important advance in regulatory influence on risk sensitivity consists in the supervisory review of pillar 2, which empowers supervisors to require higher capital targets above the minimum capital threshold in pillar 1, depending on the supervisory assessment of a banks risk management (BCBS, 2022). This evolution of higher risk sensitivity of the regulatory standards on methods of measurement and the higher degree of their integration in the daily risk management of banks led to a stronger influence of macroprudential bank regulation on the risk management of commercial banks. Following the notion of Borio and Zhu (2012), this can be termed the capital framework effect, which arises from the pervasive influence of the regulatory framework on the risk management, risk measurement, risk perception and risk pricing of banks. The capital framework effect originates in particular from the normative regulatory perspective of pillar 1, but also from the economic bank internal perspective of pillar 2 and the requirements on disclosure and transparency in pillar 3 of the Basel framework (BCBS, 2022).

2.4.3 REQUIREMENTS ON CAPITAL, LEVERAGE AND LIQUIDITY

This subchapter analyses the link between the requirements on capital, leverage and liquidity arising from pillar 1 of the Basel III framework and the risk channel in monetary transmission.

2.4.3.1 CAPITAL

In the normative perspective of the Basel framework, pillar 1 follows a risk-oriented approach when it comes to the regulation on capital (BCBS, 2022, section RBC). The regulatory intension is to increase the ability of banks to cover unexpected losses from the materialisation of risk and to remain solvent in a crisis. This promotes the macroeconomic objective to increase the stability of the financial system and supports its resistance in a crisis in order to prevent hazard to the real economy.

The regulatory capital requirement refers to the amount of capital a bank has to hold as required by the framework of macroprudential bank regulation (BCBS, 2022). The requirement is expressed as the regulatory capital ratio, which is a risk-related measure that refers to capital components of different quality. According to the respective CRR rules[21], a bank must calculate its total risk exposure as the sum of risk-weighted assets (RWA) coming from credit risk, market risk and operational risk. The regulatory capital ratio is calculated as the ratio of capital and the total risk exposure in the balance sheet of the bank (BCBS, 2022):

$$capital\ ratio = \frac{capital}{risk\ exposure} \tag{2.30}$$

The minimum capital requirements target both the quantity and the quality of capital. According to section CAP of the Basel framework, regulatory capital is defined as capital in terms of own funds of the bank as opposed to external funds, such as deposits of bank customers (BCBS, 2022). In the regulatory view, bank capital is classified into Common Equity Tier 1 capital (CET1) and Additional Tier 1 capital (AT1), which correspond to the going-concern capital

[21] CRR (EU) 876/2019, § 10c – 10i KWG

of the owner that functions as loss absorbing capacity and keeps a bank functioning as risk materialises. In contrast, the Tier 2 capital (T2) corresponds to the gone-concern capital, which is relevant in the case of insolvency for creditor protection as there is no more Tier 1 capital left. This delimitation of the regulatory term "capital" is different to the term "equity capital" in the accounting perspective, since the CRR provides a wider definition of what is considered as capital. With respect to the quantitative dimension, institutions must meet at any time the following capital requirements[22] (BCBS, 2022):

- a Common Equity Tier 1 capital ratio of 4.5%
- a total Tier 1 capital ratio of 6.0%
- a total Tier 1 and Tier 2 capital ratio of 8.0%.

In addition, the CRR requires several capital buffers of the quality of CET 1 capital, that aim to strengthen the general ability of loss-absorbing capacity of a bank. Depending on the specific design, capital requirements follow either a cyclical motive or reflect the structural significance of a bank for the financial system. For the former case, the idea is that a bank builds up a capital buffer when times are good in order to draw from it during bad times of a crisis. For the latter case the objective besides the improvement of the loss-absorbing capacity is also to avoid possible unwarranted advantages in finance costs due to the significance of the bank for the financial system ("too-big-to-fail") and thus to promote equal conditions of competition. The following capital buffers apply depending on the categorisation of a bank (BCBS, 2022):

- A capital conservation buffer of 2.5%
- A countercyclical capital buffer between 0 and 2.5%
- A capital buffer for global systemically important institutions (G-SIIs) between 1 and 3.5%
- A capital buffer for other systemically important institutions (O-SIIs) up to a maximum amount of 2%
- A systemic risk capital buffer of a minimum amount of 1%

[22] CRR (EU) 575/2013, article 92

Figure 2.25 provides an overview on the capital requirements set by Basel III with respect to the quality and the quantity of capital. The mandatory capital requirement that each bank must meet at any time is 10.5% in total. The additional capital buffers might apply depending on the on the macro-financial environment.

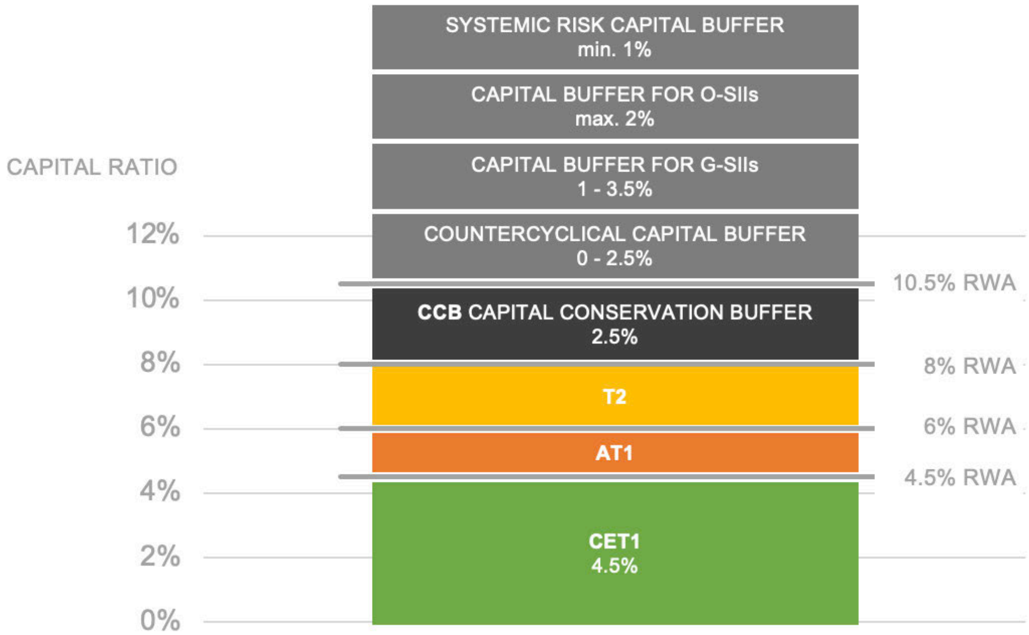


FIGURE 2.25:
CAPITAL REQUIREMENTS

Source: author’s illustration

Capital requirements target credit risk, market risk and operational risk in the banking book, which includes loans. The regulatory requirements on minimum capital affect bank behaviour through the costs associated to prevent breaching the threshold, which is referred to as the capital threshold effect by Borio and Zhu (2012). They outline that the capital threshold is given by the bank’s individual minimum capital requirement, which depends on risk-weighted assets. It affects the composition of the balance sheet of banks through the size of the capital wedge, that is the residual distance between regulatory capital and the capital threshold:

$$capital\ wedge = capital - capital\ threshold \tag{2.31}$$

The capital threshold effect arises from the minimum capital requirements of pillar 1 of the Basel framework and affects the risk tolerance of commercial banks through the capital wedge.

Since the beginning of the Basel framework, the capital ratio has widely been criticised to be procyclical, meaning that capital requirements magnify business cycle fluctuations: They tend to be low under good economic conditions, and high during recessions, which reinforces the economic downturn. Empirical evidence[23] on the degree of procyclicality of the capital threshold for a given portfolio is not unanimous, but on the whole points to an economically significant rise. The extent of the procyclicality depends critically on the methodology, portfolios and samples used. But at least it can be concluded that the greater the reliance on market inputs, the higher is the degree of procyclicality since asset prices and risk premia tend to move with the business cycle (Zsámboki, 2007).

However, the procyclical nature of risk measures highlights the importance of the precautionary increase in capital during economic expansions. The Basel Committee on Banking Supervision assesses the role of capital for the protection of the real economy as follows (BCBS, 2022):

> *"Losses incurred in the banking sector can be extremely large when a downturn is preceded by a period of excess credit growth. These losses can destabilise the banking sector and spark a vicious circle, whereby problems in the financial system can contribute to a downturn in the real economy that then feeds back on to the banking sector. These interactions highlight the particular importance of the banking sector building up additional capital defences in periods where the risks of system-wide stress are growing markedly."*

[23] Notable empirical studies on the degree of procyclicality of the capital threshold include Carling, Jacobson, Linde and Roszbach (2002), Segoviano and Lowe (2002), Corcóstegui et al (2003), Jordan, Peek and Rosengren (2003), Kashyap and Stein (2004), Catarineau-Rabell, Jackson and Tsomocos (2005), Gordy and Howells (2006), Taylor and Goodhart (2006) and Zsámboki (2007).

The procyclicality of risk measures is the reason, why banks retain earnings to build up capital buffers during periods of high economic growth, so that they can draw them down during periods of economic distress.

Borio, Furfine and Lowe (2001) point out, that for a given portfolio, the capital threshold varies over the business cycle. The procyclicality of the capital threshold arises from the natural tendency of risk measures to be procyclical: estimates of probabilities of default, loss given default, asset and default correlations as well as volatilities decline during an economic upswing, while they rise during an economic downturn. Due to the variability of the capital threshold, the bank needs to manage capital actively. This implies a stronger capital threshold effect on its portfolio decisions from the regulatory capital requirement.

2.4.3.2 LEVERAGE

The regulatory intension of the leverage ratio (LR)[24] is to constrain the build-up of bank leverage in order to reduce the risk of a dangerous deleveraging spiral during downturns. In addition, the indicator is designed to reinforce the risk-based capital requirements as a simple, risk-independent backstop measure, which is like the capital ratio designed as a minimum requirement (BCBS, 2022, section LEV).

The leverage ratio is calculated as the ratio of the capital measure to the exposure measure (BCBS, 2022):

$$leverage\ ratio = \frac{capital\ measure}{exposure\ measure} \tag{2.32}$$

The capital measure corresponds to the total of supervisory Tier 1 capital, the exposure measure is composed as the sum of assets:

- On-balance sheet exposures
- Derivative exposures
- Securities financing transaction exposures

[24] CRR 575/2013, CRR (EU) 876/2019, CRD (EU) 62/2015, § 6b KWG

- Off-balance sheet items.

In contrast to the capital ratio, the denominator carries the exposure as opposed to the risk-weighted exposure. A lower leverage ratio implies a higher leverage of the balance sheet. That means the leverage ratio is rather a risk-independent capital ratio than a leverage ratio as the name would suggest. According to the leverage ratio framework, banks must meet a minimum leverage ratio of 3% at all times (BCBS, 2022).

The regulatory leverage ratio limits the ability of excessive leverage for commercial banks. While expansionary monetary policy lifts funding constraints for banks, the regulatory leverage ratio imposes a lower limit on capital that tends to limit the extension of loans based on external finance such as borrowed central bank money.

2.4.3.3 LIQUIDITY

The Basel framework defines two supervisory measures for liquidity[25], the liquidity coverage ratio and the net stable funding ratio. These liquidity requirements aim to force banks to monitor and control liquidity risk on an ongoing basis and further to ensure that banks have sufficient liquid assets at any time in order to meet their liabilities (BCBS, 2022, section LCR).

LIQUIDITY COVERAGE RATIO: The liquidity coverage ratio (LCR) targets the short-term resilience of the liquidity risk profile of a bank by enforcing it to hold sufficient high-quality liquid assets (HQLA) to survive a significant stress scenario lasting 30 days. The stress scenario involves a combined idiosyncratic and market-wide shock that would lead to (BCBS, 2022):

- the run-off of a proportion of retail deposits
- a partial loss of unsecured wholesale funding
- a partial loss of secured, short-term financing with certain collateral and counterparties

[25] CRR (EU) 876/2019, § 11 KWG

- additional contractual outflows that would arise from a downgrade in the bank's public credit rating by up to and including three notches, including collateral posting requirements
- increases in market volatilities that impact the quality of collateral or potential future exposure of derivative positions and thus require larger collateral haircuts or additional collateral, or lead to other liquidity needs
- unscheduled draws on committed but unused credit and liquidity facilities that the bank has provided to its clients
- the potential need for the bank to buy back debt or honour non-contractual obligations in the interest of mitigating reputational risk

The measure liquidity coverage ratio (LCR) is calculated as the quotient of the value of the stock of high-quality liquid assets ($HQLA$) in stressed conditions and total net cash outflows over the next 30 calendar days ($NCO30$) (BCBS, 2022):

$$LCR = \frac{HQLA}{NCO30} \tag{2.33}$$

Assets are considered to be HQLA if they can be easily and immediately converted into cash at little or no loss of value. The liquidity of an asset depends on the underlying stress scenario, the volume to be monetised and the timeframe considered. The fundamental characteristics of HQLA include low risk, ease and certainty of valuation, low correlation with risky assets and listed on a developed and recognised exchange.

The component of net cash outflows ($NCO30$) is defined as the total expected cash outflows ($TECO$) minus total expected cash inflows ($TECI$) in the specified stress scenario for the subsequent 30 calendar days under the scenario up to an aggregate cap of 75% of total expected cash outflows (BCBS, 2022):

$$NCO30 = TECO - \min(TECI, 75\%TECO) \tag{2.34}$$

In the absence of a situation of financial stress, the regulatory standard requires the value of the LCR to be no lower than 100%, meaning the stock of HQLA should at least be equal to the total net cash outflows on an ongoing basis because the stock of unencumbered HQLA is intended to serve as a defence against the potential onset of liquidity stress. During a period of stress, however, it would be entirely appropriate for banks to use their stock of HQLA, thereby temporarily falling below the LCR minimum requirement.

NET STABLE FUNDING RATIO: The net stable funding ratio (NSFR) encourages banks to better match the duration of their assets and liabilities by requiring them to maintain a stable funding profile in relation to the composition of their assets and off-balance-sheet activities. According to section NSF 20.1 (BCBS, 2022),

> *"A sustainable funding structure is intended to reduce the likelihood that disruptions to a bank's regular sources of funding will erode its liquidity position in a way that would increase the risk of its failure and potentially lead to broader systemic stress. The NSFR limits overreliance on short-term wholesale funding, encourages better assessment of funding risk across all on- and off-balance sheet items, and promotes funding stability".*

The net stable funding ratio ($NSFR$) represents the relation between the amount of available stable funding (ASF) and the amount of required stable funding (RSF) (BCBS, 2022):

$$NSFR = \frac{ASF}{RSF} \tag{2.35}$$

The component available stable funding is defined as "the portion of capital and liabilities expected to be reliable over the one-year time horizon considered by the NSFR". The component required stable funding of an institution is "a function of the liquidity characteristics and residual maturities of the various assets held by that institution as well as those of its off-balance sheet exposures" (BCBS, 2022). The calibration of these two components reflects the stability of liabilities in two dimensions:

- Funding tenor:
  longer-term liabilities are assumed to be more stable than short-term liabilities
- Funding type and counterparty:
  short-term deposits (maturity of less than one year) provided by retail customers and funding provided by small business customers are

assumed to be behaviourally more stable than wholesale funding of the same maturity from other counterparties

Banks are required to maintain a net stable funding ratio equal to at least 100% on an ongoing basis.

The regulatory requirements on liquidity force commercial banks to hold sufficient liquidity in their balance sheet. Expansionary monetary policy lifts liquidity constraints for banks by reducing the price of liquidity borrowed at the money market and vice versa.

2.4.4 IMPLICATION FOR THE RISK CHANNEL

This subchapter synthesises the insights of macroprudential bank regulation in the EMU with respect to their implication for the risk channel of monetary transmission.

The regulatory requirements on capital, leverage and liquidity aim to promote the solvency of banks through a sound capital base, the prevention of excessive leverage and sufficient liquidity (BCBS, 2022). While the capital ratio indicates the risk-adequacy of the capital buffer, the leverage ratio adds the perspective on the relative size of capital to external debt. Requirements on liquidity encourage the actual ability to turn assets into liquid assets in order to meet short-term payment obligations. All of these requirements are not only designed to promote the stability of the financial system, but also function as a mean of creditor protection. Borio and Zhu (2012) point out, that capital regulation affects the behaviour of banks and hence monetary transmission in two ways: through the capital threshold effect and the capital framework effect.

2.4.4.1 CAPITAL THRESHOLD EFFECT

Following the notion of Borio and Zhu (2012), the capital threshold effect arises from the costs associated to falling below the minimum capital threshold and hence the costs of the actions to prevent this, primarily through the costs of raising external capital. The regulatory capital requirements impose a lower capital threshold that affects the decisions of banks on their balance sheet composition (BCBS, 2022). The capital threshold effect works through the costs associated with breaking the capital threshold. These costs are severely high and consist in restrictive supervisory actions as well as potential serious reputational costs and adverse market reactions, which are triggered immediately as a bank breaches the threshold (ECB, 2020). Through the prospect of substantial costs associated to noncompliance, the capital wedge has a significant effect on bank behaviour. As a bank approaches the minimum capital threshold, it will take in every respect the necessary countermeasures in order to avoid falling below. The measures against the threat depend on the specific constraint of the capital requirement and the costs of the alternative actions. Measures to increase the capital ratio target either an increase of capital or a decrease of risk in the balance sheet, including (BCBS, 2022):

- Retaining earnings to increase internal capital, possibly accompanied by cutting dividends
- Issuing external capital to increase external capital
- Decreasing risky assets through sale to decrease the RWA
- Raising credit standards in the supply of new loans with respect to the creditworthiness of borrowers and collateral requirements to decrease the RWA

The simplified balance sheet of a commercial bank visualised in Figure 2.26 shows the positions that affect the regulatory capital wedge in red. The smaller the procyclical wedge between risk-related capital and the regulatory capital threshold at the right side of the figure, the more actions a bank will take in order to avoid the costs of breaching the limit. These actions relate to the risk at the asset side as well as the internal and external capital at the liability side of the balance sheet.

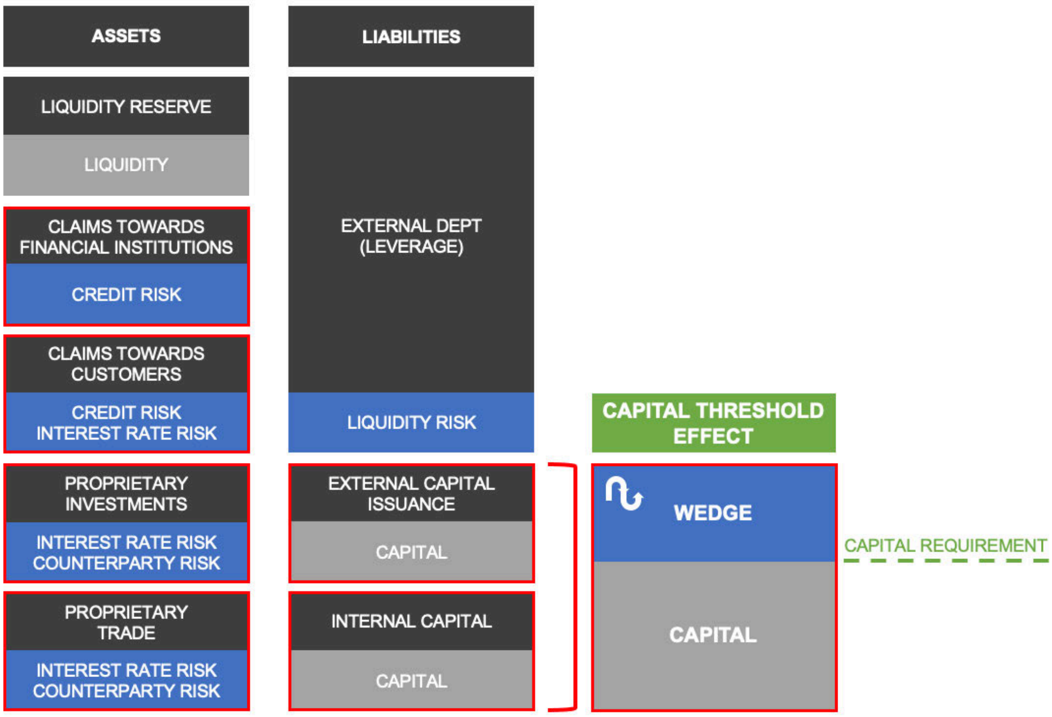


FIGURE 2.26:
BALANCE SHEET COMPOSITION AND CAPITAL WEDGE

Source: author's illustration

A given regulatory capital threshold constitutes a constraint for monetary transmission with respect to the ability of commercial banks to extend credit. This can occur if at the margin increasing the capital ratio is more costly than other sources of funding, that is external debt funding such as deposits and central bank money. Borio and Zhu (2012) identify adverse selection, agency problems, taxation and deposit insurance as reasons of for the existence of differential costs between capital and external debt funding. Due to these differential costs, the regulatory capital threshold affects the availability as well as the price and non-price conditions of loan supply at the credit market. Commercial banks with a capital wedge of small size tend to be limited in loan extension depending on the differential costs between additional capital and external debt funding. Furthermore, those banks tend to set a higher price for loans and to apply higher standards on the creditworthiness of borrowers and collateral requirements (Borio & Zhu, 2012).

The capital wedge tends to vary with the business cycle due to its procyclical nature. Due to this volatility, Borio and Zhu (2012) suggest that the threshold effect also operates in the absence of a threat of falling below the capital ratio. The impact can be imagined as a cost that varies with the size of the wedge and its potential volatility. As analogy, the threshold cost varies with the size of the wedge just like the value of an option varies with the difference between the market price and the exercise price of the option, and the market price volatility. The cost of the option is positive but low, as the price difference (the size of the wedge) is high, while it increases as the market price approaches the exercise price of the option (the wedge shrinks) or as volatility of the market price (of the size of the wedge) increases. Gambacorta and Shin (2018) identify empirical evidence for the option-like nature of the capital wedge. They point out that a higher capital buffer of 1 percentage point corresponds to substantial cost advantages in external debt funding with a reduction of 4 basis points. The smaller the wedge or the greater its volatility, the more restrictive a bank is on the extension of loans depending on the marginal costs of increasing capital in comparison to external debt funding, and vice versa. That means monetary policy itself affects the size of the capital wedge (Borio & Zhu, 2012). Expansionary monetary policy tends to increase the capital wedge, which allows for higher risk tolerance and hence provides an incentive to commercial banks to increase risk-taking, and vice versa. The studies of Chami and Cosimano (2001) as well as Zicchino (2005) contribute empirical evidence in support of the volatility of the size of the regulatory capital wedge. The reasons include exogenous influences, such as the business cycle, and idiosyncratic shocks to the balance sheet. The magnitude depends on the actions of the commercial bank designed to optimise the capital ratio.

2.4.4.2 CAPITAL FRAMEWORK EFFECT

Following the notion of Borio and Zhu (2012), the capital framework effect arises from the provisions on the measurement of credit risk in pillar 1 as well as the standards on risk management in pillar 2 of the Basel framework. Its impact on the behaviour of banks works through the manner the regulatory framework changes how banks manage, perceive, and price risk. This occurs as a bank implements standards of the Basel framework in order to upgrade own methods or to affiliate them more closely to macroprudential bank regulation. The more a bank aims for an integration of the regulatory framework, the greater is the scope for the capital framework effect to operate.

The development of the regulatory framework from Basel I to Basel III implies an increase of the impact of bank regulation on the behaviour of banks both through both the capital threshold effect and the framework effect. The reason is that the evolution of the Basel framework has brought more risk-sensitivity of capital requirements, for example due to (BCBS, 2022):

- much finer graduations of risk
- the possibility to use estimates from internal models conditional to the embedding of regulatory standards in the banks' risk management
- additional capital requirements beyond that in pillar 1 from the supervisory review in pillar 2, which is based on the supervisory assessment of risk in the portfolio and of the effectiveness of risk management systems
- improved public disclosure of these risks in pillar 3 on market discipline

The study of Zopounidis and Galariotis (2015) points out that the increase in risk-sensitivity in the development of the Basel framework and business cycle volatility of the capital threshold has led to a stronger capital threshold effect in Basel III since the bank needs to manage the capital ratio much more actively. That means the capital threshold is more sensitive to economic conditions. The closer integration of regulatory standards into the daily risk management practices of banks has led to a much stronger capital framework effect compared to Basel I. This sensitivity stems not at least of the focus of the amendments in Basel II on (BCBS, 2006):

- the adoption of best-practice risk management into regulatory standards
- promotion of risk assessment at longer time-horizons
- promotion of through-the-cycle rather than point-in-time parameters, such as conservative loss given default estimates or statistical loan provisioning
- the closer alignment of the regulatory standard into bank practice
- the upgrade of banks' databases on credit loss histories
- sounder risk management processes
- the convergence between economic and regulatory capital
- the strengthening of the supervisory review in pillar 2

The implication for monetary transmission is, that this development of the Basel framework towards a stronger capital threshold and capital framework effects is accompanied by a much stronger impact of macroprudential bank regulation on the lending decisions of commercial banks in terms of the availability as well as price and non-price conditions of loans.

2.4.4.3 CAPITAL REGULATION AND BANK BEHAVIOUR

The synthesis of the previous findings from finance theory on risk and from macroprudential bank regulation allows to draw conclusions on how macroprudential bank regulation affects the attitude of commercial banks towards risk, as illustrated in Figure 2.27 with the impact of capital regulation in green.

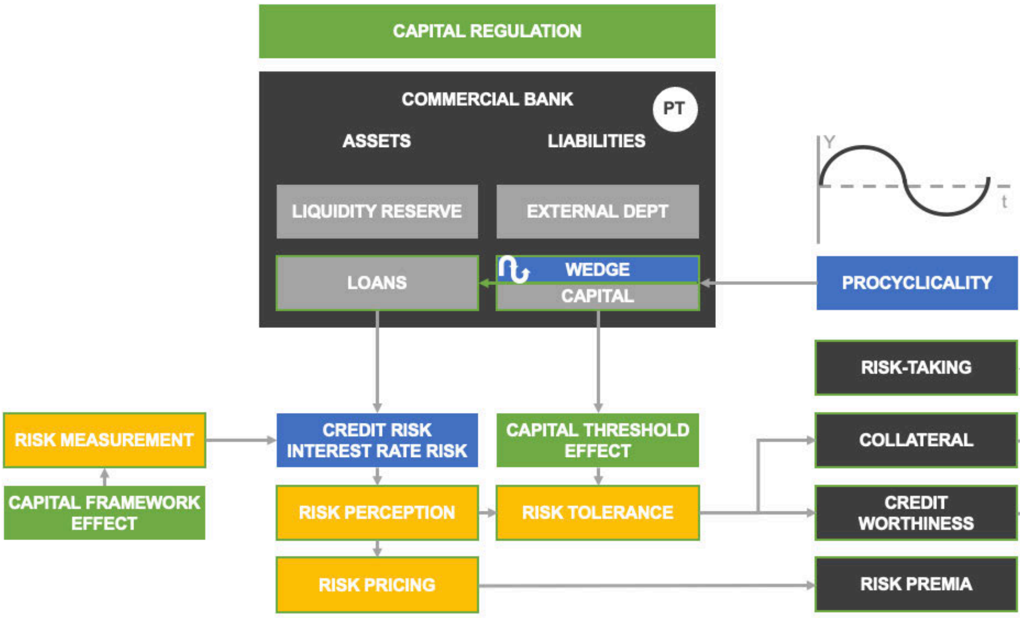


FIGURE 2.27:
CAPITAL REGULATION AND BANK BEHAVIOUR

Source: author’s illustration

First, macroprudential bank regulation affects the methods of risk measurement that commercial banks apply due to the regulatory requirements on risk measurement through the capital framework effect (Borio & Zhu, 2012). The method of risk measurement determines the risk perception of commercial banks and hence their risk pricing and the resulting risk premia at the credit market. Second, the capital threshold effect arises from the regulatory risk-related capital requirements (Borio & Zhu, 2012). The corresponding regulatory capital wedge, that is the difference between capital and the regulatory capital requirement, affects the risk tolerance of commercial banks and hence their risk-taking. This is reflected in the availability of loans along with the price and non-price conditions in lending, including the standards on creditworthiness and collateral requirements. The smaller the regulatory capital wedge, the more commercial banks are limited in the supply of loans and the tighter the price and non-price conditions in lending (and vice versa).

Borio and Zhu (2012) point out that the strength of the impact of capital regulation on bank behaviour is likely to vary substantially with macroeconomic and financial conditions. This arises in part from the option-like nature of the capital threshold effect, which is strongest as capital is at the regulatory threshold (Gambacorta & Shin, 2018). Finance conditions include the bank’s balance sheet composition with respect to the size and volatility of the capital wedge as well as the cost differential between capital and external debt funding. Macroeconomic conditions affect the capital wedge through the effect on risk-weighted assets, capital and funding liquidity. Macroeconomic and financial conditions are also reflected in the capital framework effect, which has contributed to a higher risk sensitivity and therefore a higher sensitivity to changes in macroeconomic and financial conditions. This implies that the impact of capital regulation is stronger if (1) financial conditions of commercial banks are weak since banks operate closer at the capital threshold and if (2) macroeconomic conditions are weak, in which the size of the capital wedge tends to be smaller and the access to liquidity from external debt funding is restricted. Moreover, the impact of capital regulation on the risk channel might be asymmetric in terms of decreases and increases of the monetary policy rate. The reason is again the option-like nature of the capital threshold effect (Gambacorta & Shin, 2018). The capital framework adds to that in terms of the risk sensitivity of the capital wedge (Zopounidis & Galariotis, 2015).

Hence, the regulatory capital wedge builds the link towards monetary transmission: While contractionary monetary policy causes the capital wedge to decline, banks face a stronger capital threshold effect, since the associated costs increase and force commercial banks to restrict the supply loans along with their risk-taking. In contrast, expansionary monetary policy causes the capital wedge to increase, which is associated to a weaker impact of the capital threshold, since the associated costs decline. However, commercial banks do not necessarily need to decide for the extension of loans and risk-taking. While the change in regulatory restrictions corresponds to changing incentives for risk-taking, the actual decision to do so is primarily motivated by the profit target.

2.5 THEORETICAL REPRESENTATION OF THE RISK CHANNEL

The objective of this subchapter is to present a comprehensive theoretical representation of the risk channel in monetary transmission that explains the underlying mechanism and extends the analytical basis for decision makers of monetary policy. Thereby, it refers to the research questions 1 and 2 of this study:

RQ1: What is the underlying mechanism of the risk channel in the transmission of monetary policy within the EMU?

RQ2: What is the role of macroprudential bank regulation in the risk channel in the transmission of monetary policy within the EMU?

This theoretical representation of the risk channel in the TMMP is derived by the analysis of the economic and finance theory as well as the institutional framework of macroprudential bank regulation of the preceding literature review. The risk channel in the EMU represents the link between monetary policy and risk-taking of commercial banks ($RTAK_{CB}$) as an endogenous response of the banking system to monetary policy induced changes in the base rate of interest by the ECB (MPR_{ECB}). In a simplified manner, the nature of the risk channel can be expressed as the functional form:

$$RTAK_{CB} = f(-MPR_{ECB}) \tag{2.36}$$

The equation (2.36) reflects a negative causal relationship between monetary policy and risk-taking of commercial banks as outlined in Borio and Zhu (2008). The underlying mechanism by which monetary policy affects the amount of risk in the portfolios of commercial banks operates through risk perception and risk tolerance of commercial banks, while macroprudential bank regulation as well as macroeconomic and financial background conditions affect the strength of the risk channel.

The risk channel of monetary transmission relates to the credit channel in monetary transmission of Bernanke and Gertler (1995), which operates through demand side effects on borrowers at the credit market. In contrast, the risk channel also captures the supply side effects on commercial banks at the credit market, driven through the attitude of commercial banks towards risk as well as macroprudential capital regulation. In contrast to the traditional channels, the risk channel highlights the element of risk in monetary transmission. This research follows up on the work of Borio and Zhu (2008, 2012), who coined the term "risk-taking channel" as well as de Groot (2014), who identified empirical evidence of the effect of monetary policy on the risk-taking of commercial banks in the USA by investigating their balance sheet.

As typical for monetary transmission, the nature of the risk channel in the TMMP is characterised by complexity and versatility (Kuttner & Mosser, 2002). The underlying mechanism of the risk channel is derived throughout this subchapter, complemented by visualisations in flow chart figures. Figure 2.28 illustrates the corresponding legend that shows the symbolic representation of the variables at work, which aims to facilitate the visualisation of the path of transmission in what follows.

FIGURE 2.28:
LEGEND

Source: author's illustration

The legend indicates that the variables are clustered by colour and form: The variables that refer to financial conditions, that is the composition of the balance sheet of commercial banks, are represented by grey symbols, including capital, leverage and liquidity. These variables build the link to the economic theory. The integration of the element of risk originates from finance theory. The variables that refer to attitude of commercial banks towards risk such as risk perception, risk tolerance and risk pricing are represented by yellow symbols. The black symbols include the standards on creditworthiness and collateral requirements, indicating changes in risk-taking in the balance sheet of commercial banks, as well as risk premia that reflect market perceptions of risk. Since the focus is on monetary transmission and hence the supply of loans, risk is distinguished by three classes: credit risk, interest rate risk and liquidity risk, which are represented by blue symbols. The role of macroprudential bank regulation is incorporated through regulatory requirements on capital, liquidity, and leverage in green symbols. The diamond shapes indicate either macroeconomic background conditions (MBC) such as market interest rates and market liquidity, or financial background conditions (FBC) such as funding liquidity and capital in the balance sheet of commercial banks. The arrows in red symbols indicate the direction of an effect, that is the tendency of an increase or decrease of a variable. The PT symbol represents the profit target of a commercial bank.

In what follows, the first subchapter reflects on risk-taking of commercial banks in the context of loan supply at the credit market. Furthermore, it outlines the role of liquidity and capital regulation in monetary transmission through the risk channel. The second subchapter presents the transmission mechanism of the risk channel of monetary policy. The third subchapter investigates the role of macroeconomic and financial background conditions in monetary transmission through the risk channel.

2.5.1 RISK-TAKING, LIQUIDITY AND CAPITAL REGULATION

This subchapter summarises some fundamental relationships identified in the literature review on economic and finance theory as well as the institutional framework of macroprudential bank regulation. Thereby, the technical focus is on risk-taking of commercial banks, liquidity, and capital regulation, which drive the underlying mechanism of the risk-channel.

2.5.1.1 RISK-TAKING OF COMMERCIAL BANKS

Finance theory indicates that risk-taking of commercial banks relates to the composition of their balance sheet. Figure 2.29 shows in how far leverage and loan assets in the balance sheet of commercial banks relate to their risk-taking.

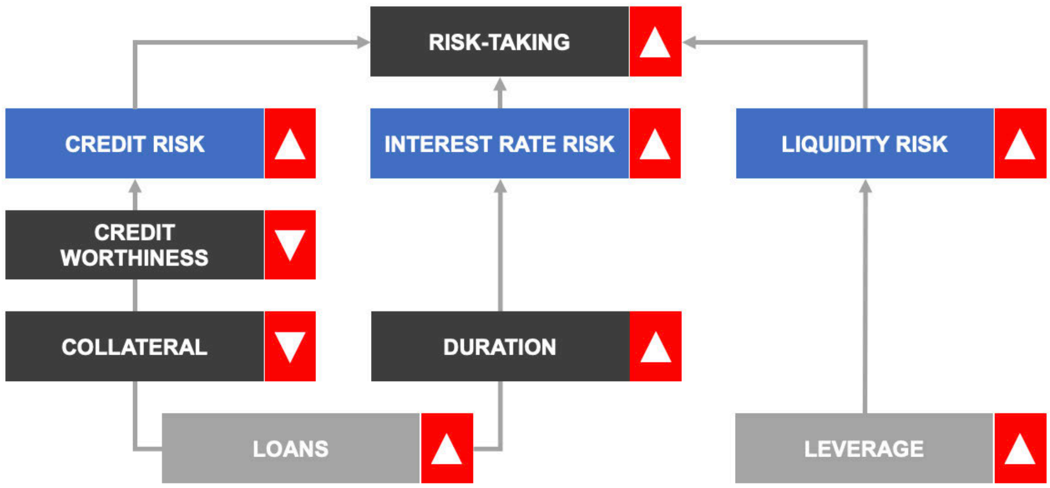


FIGURE 2.29:
RISK-TAKING IN LOAN BUSINESS

Source: author's illustration

LEVERAGE: The liability side of the balance sheet relates to the leverage of banks, that is the degree of reliance on external debt funding (Bessis & Bessis, 2015). As commercial banks make greater use of short-term debt, the leverage of the balance sheet increases. At the microlevel, leverage implies a compositional change between the loss absorbing capital and the reliance on external debt funding that bears a funding liquidity risk (Avgouleas, 2015; Alessi & Detken, 2018). A major fraction of external debt funding consists of customer deposits, a position in the balance sheet that is subject to call risk

(Bessis & Bessis, 2015). Another major fraction consists of borrowed money from the central bank, which reflects the link towards monetary policy. The liquidity risk associated to leverage arises from the maturity transformation and materialises if maturity mismatches between assets and liabilities occur alongside with transferability and funding constraints (Zopounidis & Galariotis, 2015). From the macroeconomic perspective, the studies of Adrian and Shin (2010a) as well as Alessi and Detken (2018) outline that bank leverage bears also systemic risk: Leverage exacerbates the danger of contagion in the banking system and exacerbates the transmission of risks from the financial system to the real economy. Excessive leverage gives rise to credit and asset price bubbles, and hence contributes and macroeconomic boom-bust-cycles. Alessi and Detken (2018) point out that the dynamic feedback properties of leverage, volatility, and asset prices form the so-called leverage cycle, which has the characteristics to give rise to tail-events. The leverage cycle is rising asset prices alongside with rising levels of indebtedness, followed later by falling asset prices and deleveraging. The most important risk associated with leverage is the speed of deleveraging in a downturn. Higher leverage implies higher liquidity risk and higher systemic risk as well as a lower capital ratio that functions as buffer for loss absorption as unexpected risks materialise, and vice versa.

LOANS: Commercial banks increase their leverage for funding assets such as loans, which show up at the asset side of balance sheet and are themselves subject to risk. The extension of loans mainly affects the balance sheet position of claims towards customers, which is subject to credit risk and interest rate risk (Kuritzkes & Schuermann, 2010; Bessis & Bessis, 2015). A rise in credit risk is reflected by a deterioration of ratings of borrowers, that is higher probabilities of default, higher risk weighted assets or a fall in collateralised loan shares (Tian, 2017). Hence, a rise in loan assets, lower standards on the creditworthiness of borrowers or lower collateral requirements imply higher credit risk, and vice versa. Moreover, each increase in assets that are subject to interest earnings like loans and in particular investment and trade positions in the balance sheet bear interest rate risk. Loan assets generate a return out of maturity transformation, which is sensitive to fluctuations in the long-term (investment) or short-term (trade) interest rate. A rise in loan assets, a higher asset duration and a higher interest rate volatility imply higher interest rate risk, and vice versa.

The focus of the theoretical representation of the risk channel in monetary transmission is on the effect of changes on the monetary policy rate of interest on risk-taking of commercial banks. Risk-taking is considered in terms of credit risk, interest rate risk and liquidity risk in the balance sheet of banks because of its associated to the supply of loans (Bessis & Bessis, 2015). Risk-taking relates closely to the attitude of commercial banks towards risk, including their risk perception and risk tolerance (Borio & Zhu, 2012; Nguyen, Gallery & Newton, 2019). Economic and finance theory consistently highlight the positive relationship between risk and the expected return of an asset (Fisher, 1896; Tian, 2017). This trade-off between profits and risk mitigation implies that the strategic decision of a bank on the profit target is conditional to a certain level of risk and therefore relates to the bank's risk tolerance: A higher profit target requires higher risk tolerance (Grable, 2000; Rajan, 2006; Adrian & Shin, 2009; Bessis & Bessis, 2015). Risk perception refers to the amount of risk in the balance sheet that actually becomes visible to the bank, which is heavily determined by the applied methods of risk measurement (Pidgeon, Hood & Jones, 1992; Borio & Zhu, 2012).

2.5.1.2 LIQUIDITY

Liquidity and risk-taking are tightly interrelated and can reinforce each other. Liquidity can be thought of as the ease of which perceptions of value can be turned into purchasing power. Diamond and Rajan (2009) capture liquidity by two notions: funding liquidity and market liquidity. Funding liquidity refers to the ability of realise cash in value in order to meet cash flow commitments, either by selling assets or accessing external funding. Market liquidity refers to the ability to trade an asset at the market at short notice with only little impact on its price. In this view of Diamond and Rajan (2009), market liquidity is an unobservable variable that denotes a key dimension of the impact from financial conditions to the real economy. Higher liquidity weakens spending constraints, ceteris paribus. Similarly, Kiyotaki and Moore (2005, 2019) capture liquidity in their model by two parameters: liquidity as an external funding constraint and as a transferability constraint. Liquidity as an external funding constraint refers to the fraction of income from assets that can be pledged against external funds. That means if for example a firm aims to invest in new capital, it issues equity claims to the future returns of that capital. Since the realisation of future return of the new capital depends on the skills of the entrepreneur, he can only credibly pledge a fraction of the future returns from capital. Unless this fraction is high enough, the firm faces an external funding constraint as it must finance a part of the investment costs from own assets. The lower the fraction of assets that can be pledged, the tighter the borrowing constraint and the lager the fraction of investment that must be financed out of own funds, ceteris paribus. Liquidity as a transferability constraint refers to the ability of transferring assets at short notice to third parties in order to generate funding liquidity for investments. The lower the fraction of short-term transferable assets, the greater the transferability constraint, ceteris paribus.

Those frameworks of Diamond and Rajan (2009) and Kiyotaki and Moore (2005, 2019) treat liquidity as an exogenous variable. That means liquidity is exclusively driven by changes in collateral values and profits, rather than fluctuations in the two notions of liquidity. In contrast, Borio and Zhu (2012) suggest that in the context of monetary transmission, liquidity should be at least partly regarded as endogenous: This endogeneity should not only apply at secular frequencies, reflecting changes in institutional arrangements, but instead should apply at cyclical frequencies, reflecting economic conditions and its link to monetary policy. Therefore, in the theoretical representation of the risk channel, liquidity is considered as endogenous: Expansionary monetary policy tends to ease liquidity conditions, while contractionary monetary policy corresponds to a tightening of liquidity, ceteris paribus.

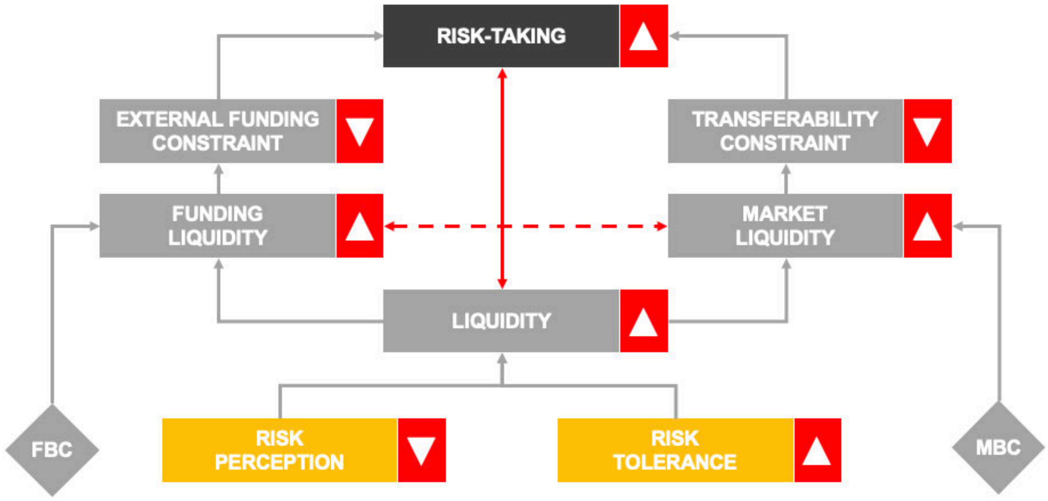


FIGURE 2.30:
LIQUIDITY AND RISK-TAKING

Source: author's illustration

Figure 2.30 visualises the tight interrelation between liquidity and risk-taking of commercial banks, which are mutually reinforcing each other in the transmission mechanism of the risk channel. Lower perceptions of risk and higher risk tolerance weaken constraints on external funding and transferability. This high degree of liquidity in turn promotes higher risk-taking. Conversely, as perceptions of risk grow and risk tolerance lessens, liquidity conditions exacerbate, with the decline in funding liquidity and market liquidity reinforcing each other. This downward spiral is typically observed in times of financial distress, as investigated by Borio (2004). Under financial distress, concerns about counterparty default risk lead to contractions in funding liquidity in form of cuts in credit lines and increases in margin requirements, as well as to declining market liquidity, both reinforcing each other and resulting in a rise in demand for central bank money (Adrian & Shin, 2009). One could also think of the tight interrelation between liquidity and risk-taking as the analogy to the idea of Post Keynesian effective demand (Lavoie, 2014): weaker constraints from liquidity increase "effective" risk tolerance because liquidity allows for investments with higher risk and higher expected returns, than would otherwise be possible.

The implication of the tight interrelation between liquidity and risk-taking for the risk channel mechanism is, that liquidity can add to the strength of the risk channel as a kind of liquidity multiplier (Borio, 2004; Borio & Zhu, 2012). The strength of this multiplier effect depends crucially on the financial background conditions (FBC) and the macroeconomic background conditions (MBC). Financial background conditions refer to the composition of the balance sheet of a commercial bank and affect the funding liquidity. Macroeconomic background conditions refer to market conditions such as interest rates, asset prices and volatilities and affect market liquidity. In particular after long periods of low interest rates along with highly leveraged positions, a small change in the monetary policy rate can have an outsized impact on liquidity and risk pricing. One example for such an extreme market response is the US bond market in the early 1994, when the Federal Reserve Bank exited such a prolonged period of monetary expansion (Bank for International Settlements, 1995). That means depending on the financial and macroeconomic background conditions, liquidity can unfold a liquidity multiplier effect that fuels the risk channel mechanism so that liquidity and risk-taking reinforce each other.

2.5.1.3 CAPITAL REGULATION

Macroprudential bank regulation aims to prevent systemic risk in the financial sector (BSBS, 2022). The regulatory framework affects the transmission mechanism of the risk channel through the requirements on risk measurement and the requirements on capital, leverage, and liquidity.

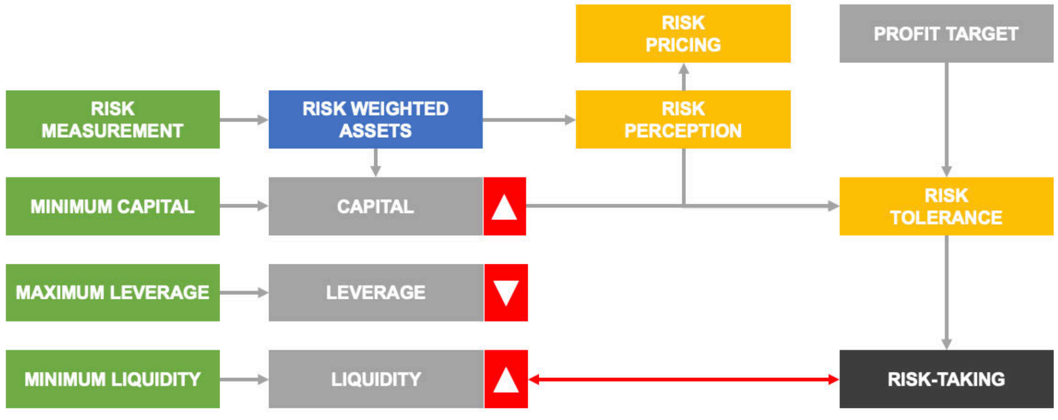


FIGURE 2.31:
MACROPRUDENTIAL BANK REGULATION AND RISK-TAKING

Source: author's illustration

Figure 2.31 shows the impact of macroprudential bank regulation (in green) on the attitude of commercial banks towards risk (in yellow). The regulatory framework imposes requirements on the measurement of risk weighted assets designed to promote risk sensitivity of commercial banks (BCBS, 2022). Thereby, for a given amount of risk in the portfolio, the regulatory standard tends to enhance the risk perception of commercial banks, which translates into the risk premia component in risk pricing. The corresponding measures of risk, such as risk weighted assets (RWA), build the basis for the calculation of the regulatory minimum capital requirement, that is the risk-based capital threshold (BCBS, 2022). The capital cushion determines the risk bearing capacity of a bank by functioning as buffer for the absorption of unexpected losses from risk (Tian, 2017). For a given amount of risk in the portfolio, changes in capital can affect the banks' risk tolerance in the same direction. This yields the assumption that the effect of changes in the policy rate on bank's risk-taking depends on the degree of capitalisation. The minimum capital requirements tend to increase the capital ratio for weakly capitalised banks and to limit risk-taking by relating the regulatory capital threshold to risk. In turn, the capital endowment relates the ability of a commercial bank to extend external debt, that is leverage in order to finance assets such as loans. With the leverage ratio requirement, the regulatory framework imposes a lower limit on capital, which implies an upper limit on leverage of the balance sheet (BCBS, 2022). Leverage represents a link towards monetary transmission: As a commercial bank borrows central bank money for funding assets like loans the leverage increases. Liquidity is necessary to fulfil payment liabilities in the leverage positions of the balance sheet. With the liquidity coverage ratio and the net stable funding ratio, the regulatory framework imposes a lower limit on liquidity (BCBS, 2022). Liquidity represents a link towards monetary transmission: With changes in the monetary policy rate of interest, the central bank affects funding liquidity of commercial banks in the opposite direction.

Borio and Zhu (2012) put forward two effects of macroprudential bank regulation on the behaviour of commercial banks. First, the capital framework effect refers to the indirect effect of the regulatory framework on bank's risk management and decisions on the composition of the balance sheet. The effect is stronger the more a bank intertwines the regulatory standards on risk measurement and risk management into its operative practice. In particular the requirements on risk measurement and management aim to promote risk sensitivity of banks, which tends to increase their risk perception (BCBS, 2022). Second, the capital threshold effect refers to the direct effect of regulatory capital requirements on the risk management of banks and decisions on the composition of the balance sheet. It operates through the costs related to breach the threshold, which are extremely high for a bank and consist in restrictive supervisory actions, reputational costs, and adverse market reactions (ECB, 2020). Due to the procyclical nature of risk measures, the risk-based capital threshold varies over the business cycle (Kashyap & Stein, 2004). The capital threshold effect is stronger the smaller the size and the greater the volatility of the capital wedge depending on the marginal costs of increasing capital in comparison to external debt funding. A stronger capital threshold effect tends to limit a bank in the extension of loans and may at the aggregate level limit the transmission of monetary policy.

2.5.2 MONETARY TRANSMISSION MECHANISM

This subchapter outlines the TMMP through the risk channel. It unveils the path of effects on risk-taking of commercial banks triggered as the central bank changes the monetary policy rate of interest. The risk channel implies, that monetary policy does not only affect real variables like output and nominal variables like prices, but also risk-taking of commercial banks. The underlying mechanism that facilitates the risk channel operates based on the attitude of commercial banks towards risk and under the influence of macroprudential bank regulation (BCBS, 2022). Under certain macroeconomic and financial conditions, even small changes in the policy rate of interest can result in an unnoticed pile up of risk in the balance sheet of commercial banks and lead to financial instability as risks materialise simultaneously. Liquidity in the notion of external funding and transferability constraints can add to the strength of the risk channel (Borio, 2004; Adrian & Shin, 2009). Macroprudential bank regulation tends to lower the sensitivity of banks towards changes in the policy rate of interest for the direction of monetary expansion due to the limitation of risk-taking.

In what follows the transmission mechanism will be explained for the direction of monetary expansion, that is a lowering of the base rate of interest by the central bank. The mechanism works equivalently for the opposite direction of monetary tightening, that is a raise of the base rate of interest by the central bank. The risk channel of monetary policy will be outlined by decomposing the transmission mechanism in three parts: the effect of the monetary policy rate of interest (MPR) on (1) risk perception, on (2) risk tolerance and on (3) risk-taking of commercial banks. Finally, the complete transmission scheme will be presented.

2.5.2.1 EFFECT OF THE MPR ON RISK PERCEPTION

The first part of monetary transmission through the risk channel operates through the effect of monetary policy on the risk perception of commercial banks. Figure 2.32 illustrates the path of effects for expansionary monetary policy on the perception of risk of commercial banks in the balance sheet.

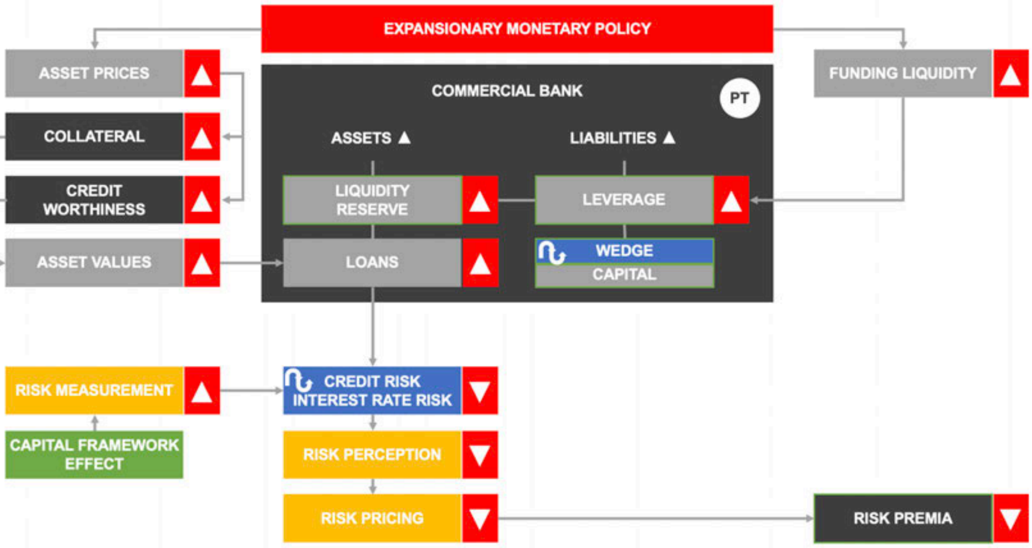


FIGURE 2.32:
MONETARY EXPANSION AND RISK PERCEPTION

Source: author's illustration

With the traditional channels of monetary policy, the economic theory offers various explanations on how a change in the base rate of interest triggers the economic expansion. The risk channel relates closely to the notion of the balance sheet channel by Bernanke and Gertler (1995), which highlights the role of external funding liquidity as trigger, but exclusively focuses on demand side effects. Accordingly, monetary easing lifts external funding constraints for commercial banks since a lower base rate of interest implies lower costs of external funding liquidity at the money market. Kashyap and Stein (2000) contribute empirical evidence of this liquidity effect of monetary policy on the volume of loans and identify the strong reliance of banks on short-term funding as main reason.

The risk channel of monetary transmission extends the traditional perspectives to the effect of monetary policy on risk-taking of commercial banks by incorporating their attitude of towards risk, endogenous liquidity and macroprudential bank regulation. The ease in liquidity conditions from monetary expansion triggers the extension of external debt finance as banks borrow funding liquidity for loan extension at the money market. The leverage of banks' balance sheets increases along with loan supply. The negative relation between the monetary policy rate and bank leverage is broadly supported by empirical studies, most notable are Dell'Ariccia, Laeven and

Marquez (2011) as well as Bruno and Shin (2015). Since leverage is associated to liquidity risk for a commercial bank and at a certain point to systemic risk at the macrolevel, macroprudential bank regulation limits leverage by imposing an upper floor with the leverage ratio (BSBS, 2022).

In line with the classical monetary theory, the empirical evidence confirms that a decrease in the policy rate of interest by the central bank affects the balance sheet of households, firms and commercial banks positively through rising net cash flows, net interest margins, earnings and asset values (Adrian & Shin, 2011). The reasons are that first, monetary expansion causes a rise in demand at the asset market, which triggers an increase in asset prices and particularly equity prices. Second, interest expenses on liabilities for borrowers decrease, which leads to an increase in net cash flows. Thus, the net worth of borrowers increases, which is reflected by higher collateral values and better creditworthiness (Bernanke & Gertler, 1995; Adrian & Shin, 2010a). Hence, in the balance sheet of banks, higher asset prices and net worth of borrowers lead to an increase in asset values of loans in the position of claims towards customers as well as asset market products like stocks, bonds and securities in the positions of proprietary investment and trade.

For a given portfolio, procyclical measures of risk decline resulting in lower risk weighted assets (RWA) in the balance sheet of commercial banks. Adrian and Shin (2014) present the empirical evidence that during an economic expansion, measures of risk naturally tend to fall due to the procyclical nature of probabilities of default (PD), loss given default (LGD), volatilities and correlations, which are input variables for the calculation of risk weighted assets in the internal ratings-based approach based on the loan exposure at default (EAD). Lower probabilities of default (PD) arise from higher net worth of borrowers and a lower loss given default (LGD) is further promoted by higher collateral values. Bernanke and Gertler (1995) have studied the demand side effect of monetary policy at the credit market with a focus on credit quality by changes in firm’s investment opportunities, net worth, and collateral in the pool of borrowers. They confirm that the process of loan extension is accompanied by a decline in measures of credit risk in the of balance sheet of commercial banks. Bernanke and Gertler (1995) argue that the magnitude in the fall of measures of risk depends on the degree of effectiveness of the monetary stimulus on overall economic expansion. The fall in measures of credit risk causes the perception of credit risk of commercial banks to vanish. The longer the central bank keeps the base rate of interest at a low level, the more the perception of interest rate risk declines, as well since interest rate volatilities and expectations adjust. In turn, Adrian and Shin (2014) as well as Drechsler, Savov and Schnabl (2018) point out that lower perceptions of risk affect risk pricing as commercial banks hand out new loans for a price that contains lower risk premia as reflected by the rate of interest at the credit market. That means monetary policy can affect market risk premia in two ways: (1) Through the effect of economic expansion and contraction, that is accompanied by a procyclical movement in risk premia. (2) Furthermore, transparency and credibility on future actions of the central bank decrease uncertainty for commercial banks. With a high degree of transparency, the central bank can reduce risk arising from uncertainty for commercial banks. This can affect their risk pricing by depressing risk premia, and vice versa.

Macroprudential bank regulation targets high risk sensitivity, in particular with the requirements on risk measurement (BCBS, 2022). Thereby, the capital framework effect tends to increase risk perception of commercial banks. The strength of this effect depends on the degree of how much a commercial bank intertwines the regulatory standards into its operating business of risk measurement (Borio and Zhu, 2012).

Altogether, monetary expansion causes the creditworthiness and collateral values of borrowers to rise and measures of risk in the balance sheet of commercial banks to fall. This is associated to a decline in the perception risk of commercial banks, which is reflected by lower risk premia in the supply of new loans.

2.5.2.2 EFFECT OF THE MPR ON RISK TOLERANCE

With the decline in risk perception, the transmission of the expansionary monetary stimulus proceeds onwards to an effect on risk tolerance of commercial banks, which operates predominantly through capital and the regulatory capital threshold effect. Figure 2.33 illustrates the corresponding path of effects in the risk channel mechanism.

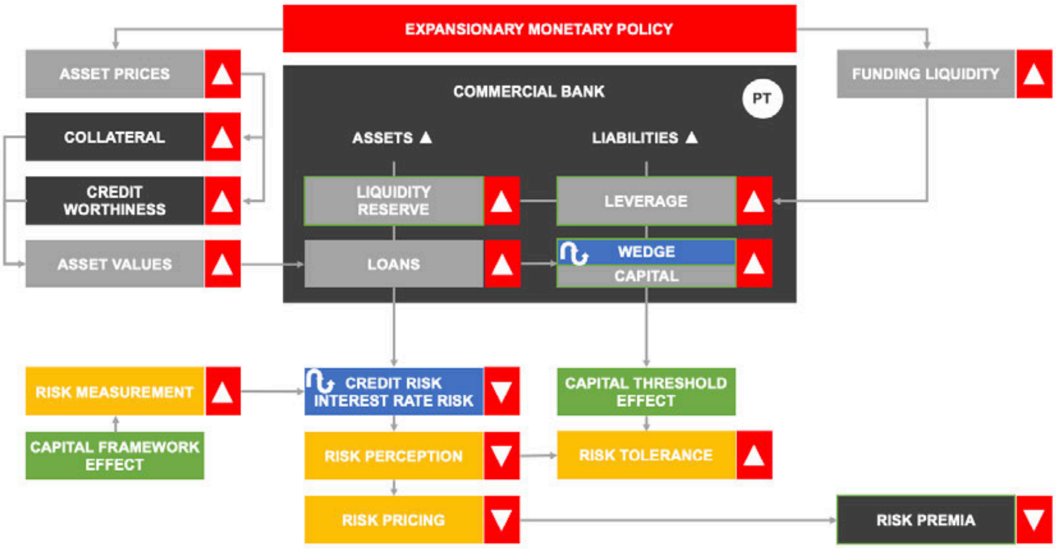


FIGURE 2.33:
MONETARY EXPANSION AND RISK TOLERANCE

Source: author's illustration

The positive effect of rising net cash flows, net interest margins, earnings and asset values strengthens the capital position in the balance sheet of commercial banks, as empirically supported by Adrian and Shin (2011) as well as Diamond and Rajan (2012). A rise in capital implies a higher risk bearing capacity, which incentivises commercial banks to increase risk-tolerance in order to boost profits depending on the profit target (PT), as investigated by Altunbas, Gambacorta and Marques-Ibanez (2014) as well as Jimenez, Ongena and Peydro (2014).

For a given portfolio, a lower perception of risk associated to the fall in risk weighted assets (RWA) tends to lower the regulatory capital threshold, which reflects the procyclical nature of regulatory capital requirements:

$$capital\ threshold \downarrow = RWA \downarrow * minimum\ capital\ ratio \tag{2.37}$$

The increase in capital in association with a lower regulatory capital threshold implies a rise in the regulatory capital wedge, that is the gap between regulatory capital and the regulatory capital threshold:

$$capital\ wedge \uparrow = capital \uparrow - capital\ threshold \downarrow \tag{2.38}$$

As Borio and Zhu (2012) point out, the increase in the regulatory capital wedge results in a weaker capital threshold effect. That means the costs for a commercial bank to avoid falling below the regulatory threshold decrease, just like the value of an option falls as the market price and the exercise price of the option move apart. The result is an incentive for commercial banks to increase in risk tolerance.

Adrian, Estrella and Shin (2019) empirically investigated the effect of monetary policy on the term spread, that is the difference between short-term and long-term interest rates. Commercial banks typically borrow central bank liquidity in order to lend. Since the loans offered by banks are typically of longer maturity than the liabilities that fund those loans, the term spread is indicative for the marginal profitability of an additional Euro of loans in the balance sheet. Adrian, Estrella and Shin (2019) outline that for any given risk premium in the market, a compression of the term spread may lead the marginal loan to become uneconomic for a bank. Against the interest rate channel theory that relies on a positive relation between short-term and long-term interest rates, their study as some others[26] present evidence that tightening monetary policy leads to a flattening of the term spread, which reduces loan supply through falling net interest margins and profitability. Furthermore, the work of Adrian and Shin (2010a, 2010b) points out that the decrease in the supply of loans exhibits an amplifying effect due to the widening of risk premia demanded by banks, which promotes the downward spiral on real activity.

2.5.2.3 EFFECT OF THE MPR ON RISK-TAKING

An increase in risk tolerance in association with a weaker capital threshold effect affects the requirements on collateral and on creditworthiness of borrowers in the supply of new loans (Altunbas, Gambacorta & Marques-Ibanez, 2014; Jimenez, Ongena & Peydro, 2014). Figure 2.35 illustrates the corresponding path of effects.

[26] Related studies confirming the negative effect of a flattening of the yield curve on the profitability of banks by compressing net interest margins include Adrian and Shin (2011), Meaning and Zhu (2011) as well as Alessandri and Nelson (2015).

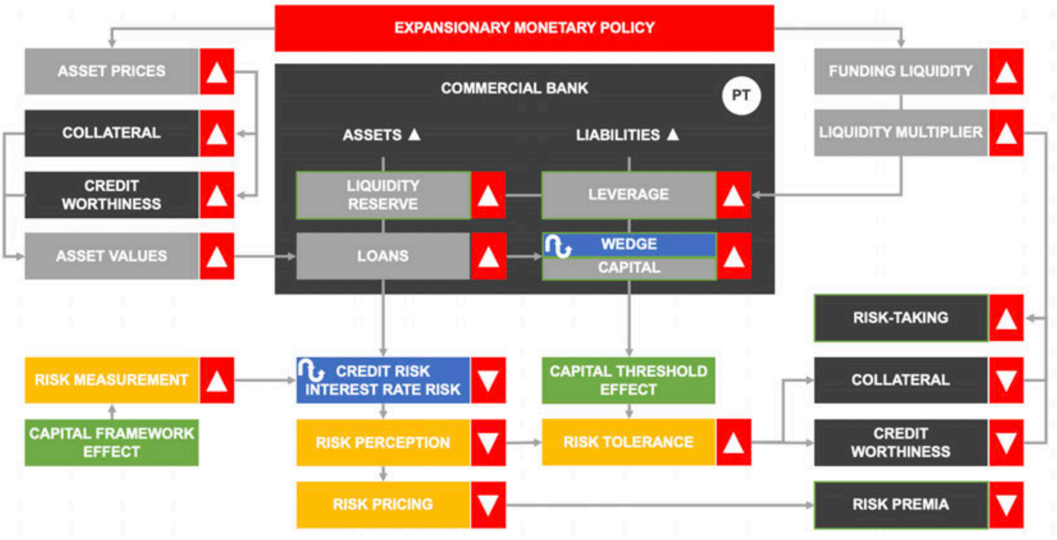


FIGURE 2.34:
MONETARY EXPANSION AND RISK-TAKING

Source: author's illustration

A rise in risk tolerance can incentivise commercial banks to lower the requirements on collateral and credit worthiness of borrowers, predominantly driven by the subordinate motive to reach a certain profit target (Delis & Kouretas, 2011; Maddaloni & Peydro, 2011; Angeloni & Faia, 2013; Abbate & Thaler 2015). In result, risk-taking increases, which is reflected in changes in the balance sheet composition of commercial banks. The self-reinforcing dynamic between liquidity and risk-taking can add to the strength of the mechanism, which corresponds to the notion of a liquidity multiplier (Borio, 2004; Adrian & Shin, 2009).

Risk-taking can manifest at both the liability and asset side of the balance sheet, as shown in Figure 2.35. On the one hand, higher risk-taking can consist of excessive leverage at the liability side of the balance sheet (Adrian & Shin, 2014; de Groot, 2014), which corresponds to a rise in liquidity risk, systemic risk and asset risks including credit risk and interest rate risk (Angeloni, Faia & Duca, 2015; Alessi & Detken, 2018) and a lower capacity for loss absorption (Dell'Ariccia, Laeven & Marquez, 2014). Macroprudential bank regulation limits the effect with the requirements on capital, leverage and liquidity (BCBS, 2022).

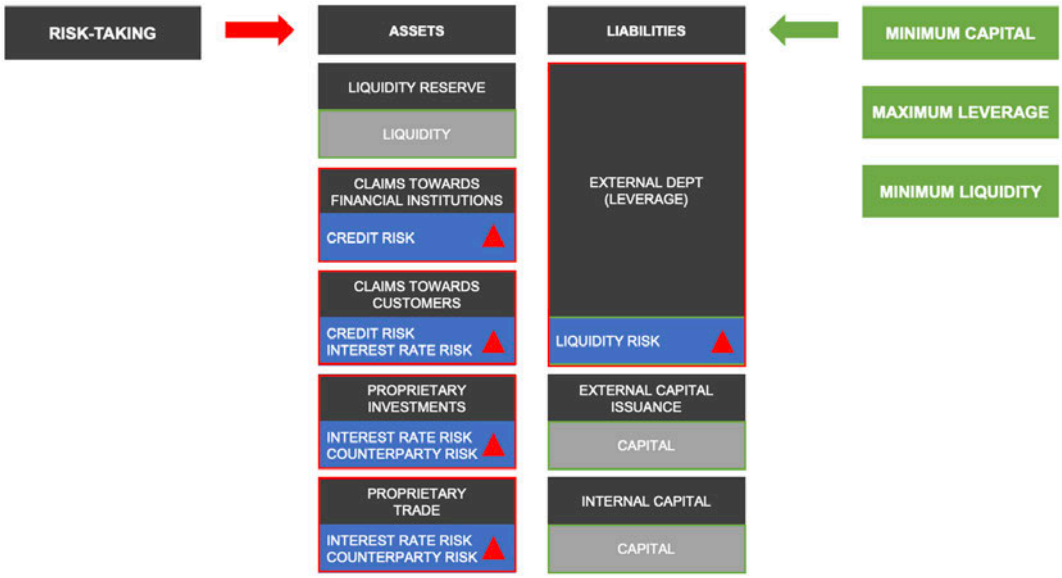


FIGURE 2.35:
MONETARY EXPANSION AND RISK-TAKING IN THE BALANCE SHEET

Source: author's illustration

On the other hand, more risk-taking can comprise lower standards on the creditworthiness and collateral of borrowers in the supply of new loans, which corresponds to higher credit risk at the asset side of the balance sheet. The numerous empirical studies[27] on micro data from Europe and the US find evidence for the negative relation between low monetary policy rates and risk-measures, that can be traced back to a deterioration in credit standards. In the special case of long periods of a very low base rate of interest, higher risk-taking can also be reflected in a rise in net asset duration (German Central Bank, 2020a). The reason is that commercial banks have an incentive to counteract falling interest margins by extending maturity transformation, that is the funding of long-term assets like loans by short term liabilities like customer deposits (Adrian, Estrella & Shin, 2019). Bank regulation limits the effect with the risk-based capital requirements, so that the extension in risk-taking requires a corresponding extension in the risk-based capital ratio (BCBS, 2022).

[27] Notable contributions come from Delis and Kouretas (2011), Maddaloni and Peydro (2011), Bekaert, Hoerova and Duca (2012), Angeloni and Faia (2013), Jimenez, Ongena, Peydro and Saurina (2014), Abbate and Thaler (2015), Dell'Ariccia, Laeven and Suarez (2017) as well as Neuenkirch and Nöckel (2018).

The strength of this risk channel mechanism can be amplified by certain effects, including the liquidity multiplier, the search for yield effect and moral hazard as outlined in what follows.

LIQUIDITY MULTIPLIER: Liquidity constitutes a crucial factor for the strength of the risk channel. Liquidity and risk-taking of commercial banks are tightly interrelated and mutually reinforcing each other in the transmission mechanism of the risk channel (Borio, 2004; Adrian & Shin, 2009). That means lower perceptions of risk in association with high risk tolerance weaken constraints on external funding and transferability (Diamond & Rajan, 2009). A high degree of liquidity in turn promotes higher risk-taking. The rise in the notions of liquidity, that is funding and market liquidity, adds to the strength of the risk channel in the sense of a liquidity multiplier, with funding liquidity and market liquidity reinforcing each other. The implication for the risk channel mechanism is that liquidity is not only an exogenous variable but should at least partly considered as endogenous variable with funding liquidity and market liquidity reacting to monetary policy measures and interrelating the attitude of banks towards risk (Borio & Zhu, 2012).

SEARCH FOR YIELD: The search for yield effect can under certain conditions operate as an accelerator that increases the risk-taking of commercial banks by promoting their risk tolerance (Manganelli & Wolswijk, 2009). Under economic conditions of long-lasting monetary expansion, very low policy rates of interest at the money market affect long-term market interest rates and reduce market volatilities, return from interest and speculation on rising prices. Low market interest rates are associated to a decline in the rate of return from assets that generate a return from interest, which includes loans as well as stocks, bonds and securities in the investment and trade positions of the balance sheet. Search for yield in this context refers to the reaction of commercial banks to lower earning opportunities with an increase in risk-taking as a means of bolstering profitability. This view follows the notion of Rajan (2005), who points out how a decreased profitability of classic lending business, as it results from a flatter yield curve, induces search for yield of commercial banks in order to counteract decreasing profits. In the context of the risk channel, the search for yield effect implies that a long-lasting monetary expansion with very low policy rates tends to increase on the gap between actual profits and the sticky profit target (Rajan, 2006; Buch, Eickmeier & Prieto; 2014). This incentivises commercial banks to increase their risk tolerance and to take on higher risk. The search for yield motive is more likely to occur for relatively low capitalised banks, as a low capital ratio indicates a profit target gap. The empirical study of Jiménez, Ongena, Peydró and Saurina (2014) contributes empirical evidence for Spain in support of the search for yield effect, finding that low policy rates over longer periods are associated to riskier borrowers.

MORAL HAZARD: Another effect that amplifies the risk channel originates from the principal-agent theory, which puts the emphasis on moral hazard (Diamond & Rajan, 2009; Acharya & Naqvi, 2012). The application of that theory in the context of the risk channel implies, that commercial banks have an incentive for excessive risk-taking, as they expect the central bank to act as lender of last resort in providing liquidity as liquidity risk materialises. While there is a lot of theoretical research on moral hazard, the empirical evidence lacks somewhat behind due to the challenges in the measurement of the moral hazard effect. However, the work of Heppke-Falk and Wolff (2007) identifies empirical evidence for moral hazard looking at the German bond market. They show that the tolerance for liquidity risk increases from the expectation of commercial banks on the ECB to act as lender of last resort. The theory on moral hazard supports the risk channel property of a mutual reinforcing interrelation between liquidity and risk-taking. Bailouts of commercial banks by the central bank can shape expectations of commercial banks. Resulting moral hazard can accelerate the transmission mechanism of the risk channel as expectations on a bail out by the central bank diminish the perception of liquidity risk and lead to excessive leverage of the balance sheet. The empirical studies of Chari and Kehoe (2009), Diamond and Rajan (2009) and Farhi and Tirole (2012) contribute evidence of moral hazard, as well, showing that commercial banks are incentivised by bailouts to take higher risk by leveraging up their balance sheet.

2.5.2.4 TRANSMISSION SCHEME

This subchapter presents a concise summary of the underlying mechanism implied by the theoretical representation of the risk channel in the TMMP. The transmission operates equally for monetary expansion and contraction, but in the opposite direction and with asymmetric effects, as explained in what follows.

The path of effects of monetary expansion through the risk channel can be expressed by the following transmission scheme:

$$\begin{aligned} & MPR_{ECB}\downarrow \\ & \Rightarrow LIQ_{CB}\uparrow \Rightarrow A\uparrow \Rightarrow CW_B \,\&\, CV_B\uparrow \Rightarrow L_D\uparrow \Rightarrow RPER_{CB}\downarrow \Rightarrow RPRM_{CB}\downarrow \\ & \Rightarrow CAP_{CB}\uparrow \Rightarrow RCW_{CB}\uparrow \Rightarrow RTOL_{CB}\uparrow \\ & \Rightarrow L_S\uparrow \Rightarrow SCW_{CB} \,\&\, CR_{CB}\downarrow \Rightarrow RTAK_{CB}\uparrow \end{aligned} \tag{2.39}$$

A decrease in the monetary policy rate of interest by the central bank (MPR_{ECB}) increases liquidity (LIQ_{CB}) by lifting constraints on funding liquidity for commercial banks and borrowers. The corresponding increase in demand at the asset market leads to a rise in asset prices. In balance sheets of firms and households this is reflected by a rise in asset values (A). Long term interest rates on loans decline as well, which implies a decrease in interest expenses, so that net cash flows rise. In result, the balance sheet of borrowers shows higher net worth. At the credit market, this is reflected by a rise in creditworthiness and collateral values of borrowers (CW_B & CV_B) and hence an increase in creditworthy demand for loans (L_D). In consequence, procyclical measures of risk fall. Along with the ease in funding liquidity, this causes the risk perception of commercial banks ($RPER_{CB}$) to diminish by a degree that depends on the applied methods of risk measurement and the regulatory capital framework effect. In risk pricing, this is reflected by lower risk premia ($RPRM_{CB}$) in the supply of new loans.

In the balance sheet of commercial banks net cash flows, net interest margins, earnings, and asset values (A) rise, as well. This strengthens the capital position (CAP_{CB}) and thus increases the risk bearing capacity. The fall in measures of risk corresponds to a decline in the procyclical regulatory capital threshold. Along with the rise in capital, this causes regulatory capital wedge (RCW_{CB}) to increase, which weakens the regulatory capital threshold effect so that the related costs decline. Depending on the profit target, higher capital incentivises commercial banks to increase their risk tolerance ($RTOL_{CB}$).

The increase in risk tolerance adds to the expansionary effect of higher funding liquidity, so that the extension of loan supply (L_S) is further promoted. Finally, risk-taking of commercial banks ($RTAK_{CB}$) tends to increase in the supply of new loans, potentially in the form of rising (1) liquidity risk and systemic risk due to the incentive to increase leverage, (2) credit risk due to the incentive to lower the standards on the creditworthiness of borrowers (SCW_{CB}) and on collateral requirements (CR_{CB}), and (3) interest rate risk due to a rise in net asset duration in association with higher maturity transformation, in particular as market interest rates remain at a very low level for a long time.

Liquidity operates as an accelerator of the transmission mechanism: Higher funding liquidity (LIQ_{CB}) reinforces market liquidity and vice versa. The rise in liquidity diminishes the perception of liquidity risk ($RPER_{CB}$) and promotes risk-taking ($RTAK_{CB}$). The corresponding rise in assets in turn increases the perception of liquidity in the balance sheet. Hence, liquidity and risk-taking are mutually reinforcing each other.

The path of effects of monetary contraction through the risk channel operates equally in the opposite direction and can be stated by the following transmission scheme:

$$\begin{aligned}&MPR_{ECB} \uparrow\\&\Longrightarrow LIQ_{CB} \downarrow\Longrightarrow A \downarrow\Longrightarrow CW_B \;\&\; CV_B \downarrow\Longrightarrow L_D \downarrow\Longrightarrow RPER_{CB} \uparrow\Longrightarrow RPRM_{CB} \uparrow\\&\Longrightarrow CAP_{CB} \downarrow\Longrightarrow RCW_{CB} \downarrow\Longrightarrow RTOL_{CB} \downarrow\\&\Longrightarrow L_S \downarrow\Longrightarrow SCW_{CB} \;\&\; CR_{CB} \uparrow\Longrightarrow RTAK_{CB} \downarrow\end{aligned} \tag{2.40}$$

The monetary effect might be asymmetric between increases and decreases of the base rate of interest depending on financial background conditions and the profit target. The reason is the option like nature of the capital threshold effect. For a weak balance sheet, monetary contraction will for certain amplify deleverage as the capital threshold is attained. In turn, monetary expansion might have little impact on the increase in leverage and risk-taking, which depends on the profit target. Bikker and Vervliet (2018) studied the effect of unusually low interest rates on profitability and risk-taking of US banks. The empirical evidence supports the asymmetry in that banks did not compensate the impairment in profits by higher risk-taking.

2.5.3 BACKGROUND CONDITIONS

The theoretical representation on the risk channel of monetary transmission is not meant to assign a prominent role to the risk channel compared to the traditional channels of monetary transmission. The identified risk channel should rather be regarded as an additional path in monetary transmission. Therefore, one could think of it as a multiplier channel, which adds to the traditional channels in result of the self-reinforcing link between liquidity and risk-taking. That means the claim is not that monetary policy transmission works primarily through the risk channel, but under certain macroeconomic and financial background conditions the risk channel would add to the conventional channels like an accelerator that is accompanied by a pile up of risk in the financial sector. Since monetary transmission generally operates through multiple channels as pointed out by Kuttner and Mosser (2002), the risk channel should not be regarded as an isolated or parallel channel, but rather as an additional, risk-related path of monetary transmission.

The strength of the risk channel depends crucially on macroeconomic and financial background conditions. While financial background conditions refer to liquidity and capital in the balance sheet of commercial banks, macroeconomic background conditions capture the broader dynamics at the aggregate level such as interest rates and asset values. This subchapter outlines the background conditions that promote monetary transmission through the risk channel.

2.5.3.1 FINANCIAL BACKGROUND CONDITIONS

Liquidity is the key dimension for the impact of financial conditions on the real economy and reflects the link between the risk-taking of commercial banks towards macroeconomic conditions and monetary policy. In the transmission mechanism of the risk channel, liquidity functions as a multiplier. Borio (2004) emphasises that liquidity and risk-taking are closely interrelated and can potentially reinforce each other, as visualised in Figure 2.36. Lower perceptions of risk and higher risk tolerance weaken external funding constraints (higher funding liquidity) and transferability constraints (higher market liquidity). In tun, higher liquidity promotes risk-taking. Conversely, as perceptions of risk increase and the risk tolerance of commercial banks fades, overall liquidity conditions tighten with the aggravation of funding liquidity and market liquidity mutually reinforcing each other.

FIGURE 2.36:
SELF-REINFORCING DYNAMIC OF LIQUIDITY AND RISK-TAKING

Source: author's illustration

The example of the world financial crisis that emerged in the USA in 2007 has demonstrated, how a prolonged period of abundant liquidity and risk-taking along with extraordinary low measures of risk turned over in a crisis. Under increased concerns about default risk, the vanishing of market liquidity reinforces and is reinforced by the tightening in funding liquidity due to the deleveraging process of reductions in loan supply along with increases in requirements on creditworthiness and collateral of borrowers by commercial banks (Baily, Litan & Johnson, 2008). The bank sector experienced the downward spiral of the leverage cycle triggered by tail-events in the materialisation of risk. The result was contagion effects among commercial banks at an international scale as well as skyrocketing demand of commercial banks for central bank liquidity, as empirically investigated in the work of Cornett, McNutt, Strahan and Tehranian (2011). The consequence of this financial instability for the real economy was the downturn in a boom-bust cycle with adverse effects on output and employment.

Hence, liquidity operates as an accelerator for the transmission mechanism of the risk channel. The risk channel of monetary policy should be stronger under extreme liquidity conditions, that is either abundant liquidity or extraordinary tight liquidity conditions (Borio & Zhu, 2012). For example, after a long period of abundant liquidity, a small change in the monetary policy stance by monetary contraction can have an outsized impact on the financial system, as liquidity accelerates the deleverage cycle with the deconstruction of risk through the risk channel mechanism (Alessi & Detken, 2018).

Another financial background condition relates to the balance sheet composition with respect to the capitalisation of commercial banks. Due to the option like nature of the capital threshold effect, the sensitivity of commercial banks to changes in the monetary policy rate of interest should vary with the size of capital (Borio & Zhu, 2012). For example, a balance sheet with low capital and a high amount of risk-weighted assets implies a close to zero regulatory capital wedge. The commercial bank is exposed to a strong capital threshold effect. A small monetary contraction would exhibit a great impact on its behaviour. Empirical evidence of Chmielewski, Lyziak and Stanislawska (2020) supports the relevance of the balance sheet composition, in that the magnitudes of changes in risk-taking of commercial banks depend on the size of total assets, the deposits-to-liabilities ratio and the degree of liquidity.

To sum up, the risk channel of monetary policy should be stronger under either extreme financial conditions with respect to liquidity or weak financial conditions with respect to capital.

2.5.3.2 MACROECONOMIC BACKGROUND CONDITIONS

The strength of the risk channel also depends on macroeconomic background conditions. One reason for that is that the regulatory capital threshold is sensitive to macroeconomic conditions.

Interest rates are crucial for the strength of the risk channel due to their impact on valuations, incomes and cashflows in the balance sheet of commercial banks (German Central Bank, 2020a). For example, a prolonged period of extraordinary low interest rates along with inflated prices in particular asset classes and extraordinary low measures of risk, possibly even underestimated risk, provide perfect conditions for the risk channel to operate. Another reason is the close relation between market rates and target rates of return. Reductions in interest rates interact with sticky rates of return, the search for yield effect incentivises commercial banks to increase risk tolerance in order to reach the profit target. Since very low nominal rates have a negative impact on profits, a prolonged period of close to zero nominal rates can amplify the impact of the risk channel on risk-taking (Bikker & Vervliet, 2018). The risk channel is stronger under extreme macroeconomic conditions such as very low nominal interest rates over a long period of time.

Another potential factor in terms of macroeconomic background conditions is central bank behaviour. A repetitive bail out of commercial banks by the central bank can give rise to expectations of commercial banks that diminish the perception of liquidity risk due to the moral hazard effect. The risk channel is stronger under widespread expectations of commercial banks on a bailout by the central bank.

2.6 CHAPTER CONCLUSION

This chapter 2 “Literature Review” identifies a gap of research on the risk channel in the TMMP. The investigation of economic monetary theory indicates that risk is at best considered in terms of uncertainty and not in the focus of attention in research on monetary transmission. The effect of changes in the monetary policy rate of interest on risk-taking of commercial banks is not incorporated in the classical, Keynesian or Post Keynesian models. However, the classical and Keynesian theories both highlight the close link between money and assets. The Post-Keynesian theory adds the perspective on mark-up pricing and credit rationing of commercial banks at the credit market as well as the role of institutions and contracts. However, the endogenous money approach of the Post Keynesian school for example does not allow for funding constraints to the balance sheet of commercial banks arising from capital and liquidity or from macroprudential bank regulation. Finance theory contributes insights on how commercial banks manage, measure and price the risk in their balance sheet. This leads to the conceptual affiliation of risk perception and risk tolerance. The institutional framework of macroprudential bank regulation for the EMU exhibits an impact through the requirements on the measurement of risk and on capital, leverage and liquidity, which is incorporated in the risk channel mechanism through the capital framework effect and the capital threshold effect.

The result of the literature review consists of a theoretical representation of the risk channel in the TMMP, derived by the synthesis of economic and financial theory and the incorporation of macroprudential bank regulation for the EMU. The risk channel highlights the effect of monetary policy on the risk-taking of commercial banks, which is facilitated by endogenous changes of liquidity and the attitude of commercial banks towards risk as well as the impact of macroprudential bank regulation. The theoretical representation of the risk channel explains the single stages of the mechanism complemented by visualisations and a summary based on a transmission scheme.

3 METHODOLOGY

3.1 CHAPTER INTRODUCTION

This chapter introduces the empirical part of the research, which consists of chapters 3 “Methodology” and 4 “Empirical Analysis” that follow the theoretical part in chapter 2 “Literature Review”. It outlines the methodological foundations of this research. Grix (2004) describes methodology as a “branch of science dedicated to methods and techniques of scientific enquiry” (p. 169). The term methodology refers to the science of methods and assumptions about the way in which knowledge is produced. The research methodology is underpinned by and reflects specific ontological and epistemological assumptions. These assumptions determine the choice of approach and methods adopted in this research by emphasising particular ways of knowing and finding out about the world. This chapter outlines the research paradigm, the research approach, the economic model and hypotheses, the collection of data, the research method and ethical considerations.

3.2 RESEARCH PARADIGM

This subchapter highlights the underlying research paradigm that leads this research study. The research on the risk channel in the TMMP is conducted under the research paradigm of Post-Positivism. Accordingly, the researcher is objective and takes a neutral, outside standing position throughout the whole research process.

The paradigm of research indicates the intellectual foundations of core perspectives and helps to place them through structure, language, terms and methods in the context of assumptions and limitations of the research. Landman (2000) outlines that the choice of the paradigm depends on the ontological, epistemological and methodological position of the researcher. In the notion of Tuli (2010), ontology refers to the “nature of reality”, that means the understanding of the researcher of what one can know about something. Epistemology refers to the “nature of knowledge”, that is the theory of knowledge that informs the research. Methodology is how that knowledge may be gained in terms of the structural framework of specific methods applied by the researcher. While the rage of different paradigms of research is wide with blurred boarders between related paradigms, the categorization reaches from Positivism to Interpretivism as the two opposing edges of the broad spectrum of research paradigms.

The Post-Positivist view of this research has its roots in the Positivist paradigm. Grix (2004) outlines that the Positivist position represents a “very broad church” building up on the ontological view, that there is one truth in an external given reality, which can be fully explained through the collection of data and the application of quantitative methods (pp. 80-82). Main characteristics with respect to epistemology include an objective, value-free approach with no prejudices conducted by a researcher from a neutral, outside standing position (Krauss, 2005). Knowledge is generated by the reduction of complexity in a deductive approach with a clear structured, controlled and highly front-loaded process of programmatic steps that ends with the generalisation from findings. The methodology builds up on a quantitative method, which is applied in chapter 4 “Empirical Analysis” of the research. Quantitative research is characterised by three basic phases: finding variables for concepts, operationalising them in the study, and measuring them. In the words of Grix (2004), this type of research approach tends, in general, “to abstract from particular instances to seek general descriptions or to test causal hypotheses” (p. 117). The analysis of data plays a crucial role in the Positivist approach and is characterised by manipulating variables, control and making choices in a general process of “hypothesis - proof - theory - falsification”. Rubinstein (1981) noticed that Positivists lay great emphasis on explanation in social research, as opposed to understanding, and many believe that the “real purpose of explanation is prediction” (p. 11).

Following Baronov (2021), the Post-Positivist paradigm or Critical Realism, is closely related to the Positivist view, but it opens up space to some of the Interpretivist elements. The researcher attempts to combine the ontological positions of explanation of one reality (“Why?”), which relates to the Positivist position, and that of understanding multiple realities (“How?”), which relates to the Interpretivist position. The reason for approaching the risk channel under the Post-Positivist paradigm is that the Positivist ontological starting point of “one truth” is very limited and the researcher accepts that the reality of monetary transmission is of high complexity and the truth is expected to be not always fully visible. This requires to some extent interpretation in order to give a more comprehensive explanation on the risk channel mechanism.

The researcher recognises that it is not possible to explain the reality of the risk channel of monetary transmission completely. An element drawn from the Interpretivist position is the consideration of context, in particular the role of structures and actors. Grix (2004) points out that causality can come from both: actors initiate action while structures constrain or facilitate action, that means structures affect actors and are affected by actors. This assumption is reflected in the consideration of the role of institutions, contracts and transaction costs, which are necessary for the understanding of monetary transmission. The emphasis on causality in the Post-Positivist paradigm underlines the characteristics of the research question on explaining the mechanism of the risk channel. As typical for the Post-Positivist approach, the aim of the research is to explain reality. Because limitations exist in terms of visibility, the goal of the study is to get as close as possible. It is acknowledged that an interpretive understanding is a necessary and important feature in social science, which can bridge the gap from the invisible parts in causal relations.

With respect to methodology, it is accepted in Post-Positivism that social and natural sciences can use the same methods, which are typically of quantitative nature in the Positivist approach and predominantly of qualitative nature in the Interpretivist approach (Grix, 2004). In this quantitative analysis, the limitations to the view of one truth are considered for instance by confidence intervals. Furthermore, it is accepted that it can be necessary to incorporate an interpretive understanding in order to make the picture more comprehensive. This Post-Positivist research exclusively draws on quantitative methods in the empirical analysis part.

The researcher takes the view, that the versatile nature of the risk channel requires research under the Post-Positivist paradigm. The thesis on the risk channel comes from the ontological position of one reality. The epistemological position is that limitations in the explanation of reality exist, so that the incorporation of Interpretivist elements can contribute to a more comprehensive understanding. This opens up space in the theoretical part of the study for the integration of elements from different disciplines and theories. The highly frontloaded process of this research starts with theory in order to develop the theoretical representation of the risk channel. Subsequently, a quantitative method is applied in the empirical analysis in order to test the hypotheses on the risk channel of monetary transmission on data of German commercial banks in order to draw conclusions on the causal relationships.

3.3 RESEARCH APPROACH

The research approach refers to a particular method of generating knowledge, the way of setting about a problem including the employed sources. In the notion of Grix (2004), approaches “are informed by the paradigmatic assumptions upon which they are based” (p. 161). In other words, the research paradigm drives how the research questions are approached. The general distinction of research approaches is on inductive and deductive research.

Landman (2000) describes induction as “the process by which conclusions are drawn from direct evidence of empirical observation” (p. 226). These conclusions are then fed into the development of theory. Therefore, inductive research is not hypothesis driven. Theory is generated through the analysis of empirical data, where the researcher looks for patterns in the data and in particular for relationships between variables. Generalisations are made from specific to other, wider contexts. The inductive approach rather relates to qualitative research methods and hence to the interpretivist research paradigm. In the deductive approach, theory constitutes the starting point and hypotheses dictate the evidence the researcher is looking for (Saunders, Lewis & Thornhill, 2007). Then data is collected to confirm or falsify the hypotheses. Grix (2004) defines a hypothesis is a “proposition or assumption put forward for empirical testing” (p. 168). It consists in a testable proposition about the relationship of two or more concepts. According to Landman (2000), deductive theories, in contrast to inductive theories “arrive at their conclusions by applying reason to a given set of premisses” (p. 15). The deductive approach is traditionally associated to the Positivist paradigm and quantitative research strategies. The distinction between deductive and inductive approaches is useful for identifying the underlying logic of research. Limitations in the distinction exist from a certain point, as Grix (2004) pointed out: “In reality, most research uses both induction and deduction, as there is a necessary interplay between ideas and evidence in each research process” (p. 114).

This research study follows a deductive approach, which is guided by the Post-Positivist research paradigm. In chapter 2 “Literature Review”, theory informs research at the outset, representing the highly frontloaded process of empirical research that leads to the theoretical representation of the risk channel in the TMMP. The literature review follows the objective to derive a theoretical representation of the risk channel in monetary transmission that explains the underlying mechanism by incorporating the role of macroprudential bank regulation in the EMU and furthermore to formulate hypotheses based on the economic model implied as basis for the empirical analysis.

The theoretical representation on the risk channel of monetary transmission unveils the mechanism behind the effect of a change in the base rate of interest controlled by the central bank on risk-taking of commercial banks. To explore that mechanism, the focus of the study is on the effect of changes in the base rate of interest set by the ECB on the amount of risk in the balance sheet of German commercial banks as well as the price and non-price conditions of credit extension. The concept is derived from the intersections of financial and economic theory as well as the investigation of the institutional setting of macroprudential bank regulation in the European Monetary Union. The theoretical representation includes an economic model that builds the basis for the formulation of hypotheses and the design of the research approach including the requirements on data collection and data analysis.

Regarding the empirical analysis on the risk channel different eligible quantitative methods come into question. The choice is driven by (1) the aim of the research, (2) the findings on the mechanism in the theoretical representation and (3) the availability of data. The researcher considered in particular the regression analysis and the Structural Equation Model (SEM). The primary goal of a regression analysis is to estimate the direct causal effect of an independent variable x on a dependent variable y by fitting a regression plane into a multidimensional scatter of observations on y. The result is a conditional expected mean $E(y|x)$ where x is a vector of weighted predictors. In a regression model, each independent variable has a direct effect on the dependent variable. The inclusion of further predictors is possible as long as non-multicollinearity is given. This is a weakness for the investigation of complex mechanisms and as the question is on the indirect effects of variables along the path, that is multicollinear predictors. In contrast, SEM is a series of regressions applied sequentially to data. In such a path analysis model, there is, additionally to the direct effect, an indirect effect of an independent variable via a mediating variable on the dependent variable.

The choice of the researcher is on the regression analysis as method for the empirical analysis based on the following consideration: The research aim is to explain the risk channel in monetary transmission, which is defined as the effect of the monetary policy rate of interest on risk-taking of banks. Under this aspect both methods can be justified. The theoretical representation of the risk channel mechanism points to a mechanism of high complexity that involves many indirect effects as well as multicollinear predictors. While the regression analysis is suitable to estimate the direct effect of the monetary policy rate on risk-taking, the SEM would bring additional insights on the indirect effects within the mechanism. The decisive factor is finally the availability of data. Since the relevant bank data is highly sensitive and protected by law, in particular the data on indirect effects such as asset values, loan volume, liquidity, capital and leverage of each commercial bank is not available. Therefore, a regression analysis is applied to estimate the effect of the monetary policy rate of interest as independent variable on risk-taking of banks as dependent variable.

The regression analysis serves the objective to empirically test the hypotheses. The quantitative procedure is characterised by clear rules and follows a sequence of programmatic steps. The orderly procedure of the regression analysis applied in this research is oriented on the empirical approach of Hill, Griffiths and Lim (2008):

(1) Research questions
(2) Literature review
(3) Economic model and hypothesis
(4) Econometric model
(5) Data description
(6) Methodology of estimation and inference procedures
(7) Regression model diagnostics
(8) Empirical results
(9) Regression evaluation
(10) Discussion of economic conclusions and implications

The statistical software R is used to conduct the regression analysis. In contrast to other commonly used software such as SPSS, the RStudio has a script-based environment with the advantage that it offers a very wide range of functions which can be implemented through method-specific packages. Since this research requires specific statistical functions for the estimation and highly individualised plots, the R software is the appropriate choice. The table below lists the applied R packages that facilitate the descriptive statistics, model specification, regression, model diagnostics, hypothesis tests and regression results:

Table 3.1:
R packages

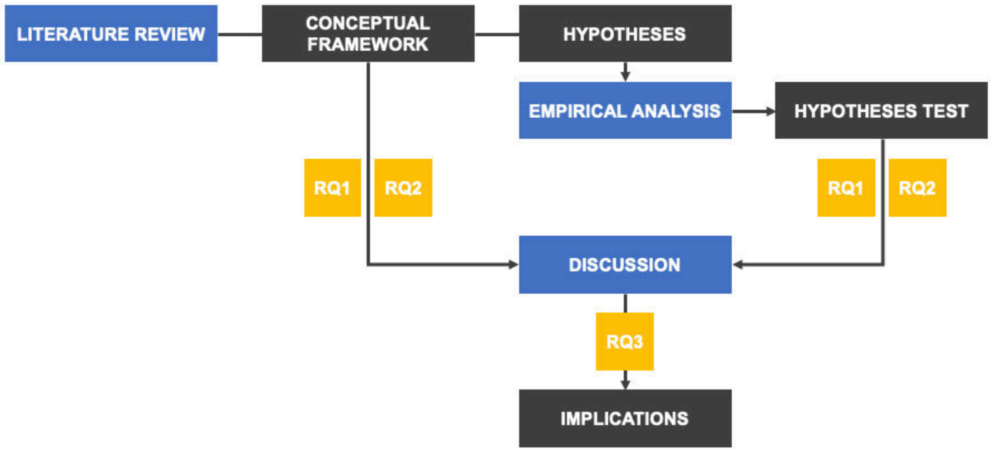
R Package	Description
AICcmodavg	Model Selection and Multimodel Inference Based on (Q)AIC(c)
base	The R base package
car	Companion of applied regression
dplyr	A Grammar of Data Manipulation
dynlm	Dynamic Linear Regression
forecast	Forecasting functions for Time Series and Linear Models
formattable	Create 'Formattable' Data Structures
fUnitRoots	Rmetrics - Modelling Trends and Unit Roots
ggfortify	Data Visualization Tools for Statistical Analysis Results
ggplot2	Create Elegant Data Visualizations Using the Grammar of Graphics
ggpubr	ggplot 2 Based Publication Ready Plots
ggrepel	Automatically Position Non-Overlapping Text Labels with 'ggplot2'
gplots	Various R Programming Tools for Plotting Data
gridExtra	Miscellaneous Functions for "Grid" Graphics
gtools	Various R Programming Tools
interp	Interpolation Methods
lfe	Linear Group Fixed Effects

R Package	Description
lmtest	Testing Linear Regression Models
lubridate	Make Dealing with Dates a Little Easier
margins	Marginal Effects for Model Objects
MASS	Support Functions and Datasets for Venables and Ripley's MASS
modelr	Modelling Functions that Work with the Pipe
modelsummary	Summary Tables and Plots for Statistical Models and Data: Beautiful, Customizable, and Publication-Ready
moments	Moments, Cumulants, Skewness, Kurtosis and Related Tests
nhstplot	Plot Null Hypothesis Significance Tests
olsrr	Tools for Building OLS Regression Models
rstatix	Pipe-Friendly Framework for Basic Statistical Tests
sandwich	Robust Covariance Matrix Estimators
stargazer	Well-Formatted Regression and Summary Statistics Tables
tidyr	Tidy Messy Data
tseries	Time Series Analysis and Computational Finance
vars	VAR Modelling

The research approach is shown in Figure 3.1 in the context of the research aim and relates the research procedure to the three research questions reflecting how the research aim will be achieved under the Post-Positivist paradigm.

RESEARCH AIM

To explain the risk channel of monetary policy in the EMU by identifying the operating transmission mechanism.



RESEARCH QUESTIONS

RQ1: What is the underlying mechanism of the risk channel in the transmission of monetary policy within the EMU?
RQ2: What is the role of macroprudential bank regulation in the risk channel in the transmission of monetary policy within the EMU?
RQ3: What are the implications of the risk channel for the decision makers of monetary policy for the EMU?

FIGURE 3.1:
RESEARCH APPROACH

Source: author's illustration

3.4 ECONOMIC MODEL AND HYPOTHESES

In this subchapter, the conceptual findings of the risk channel of the TMMP are formulated as an economic model of the risk channel in a functional form. The economic model builds the basis for the derivation of the hypotheses for the empirical analysis based on data of German commercial banks.

3.4.1 ECONOMIC MODEL

An economic theory can be expressed by a formal economic model that consists of mathematical equations or less formally in terms of a function. As Wooldridge (2008) points out, for the purpose of empirical analysis it is more common to use economic theory less formally in terms of a function. In general, a positive relationship between variables y and x can be expressed as the function

$$y = f(+x) \tag{3.1}$$

which states that outcome y is some positive function $f(\cdot)$ of x. The theoretical representation unveils that the underlying mechanism of the risk channel follows a complex path driven by a variety of macroeconomic, financial and regulatory determinants. Figure 3.2 visualises the respective economic model by extracting the determinants[28] that facilitate the risk channel from the theoretical representation. The economic model of the risk channel in monetary transmission represents the relationship between the monetary policy rate of interest and risk-taking of commercial banks. The findings on the risk channel mechanism indicate, that risk-taking of commercial banks ($RTAK$) depends on three key determinants: funding constraints to the balance sheet of commercial banks ($FCON$), risk perception of commercial banks ($RPER$) and risk tolerance of commercial banks ($RTOL$). The corresponding function of the relationship can be expressed as:

[28] Red frames indicate effects from monetary policy, green frames indicate effects from macroprudential bank regulation.

$$RTAK = f(-FCON, -RPER, +RTOL) \tag{3.2}$$

with

$RTAK$ = risk taking of commercial banks

$FCON$ = funding constraints to the balance sheet of commercial banks

$RPER$ = risk perception of commercial banks

$RTOL$ = risk tolerance of commercial banks

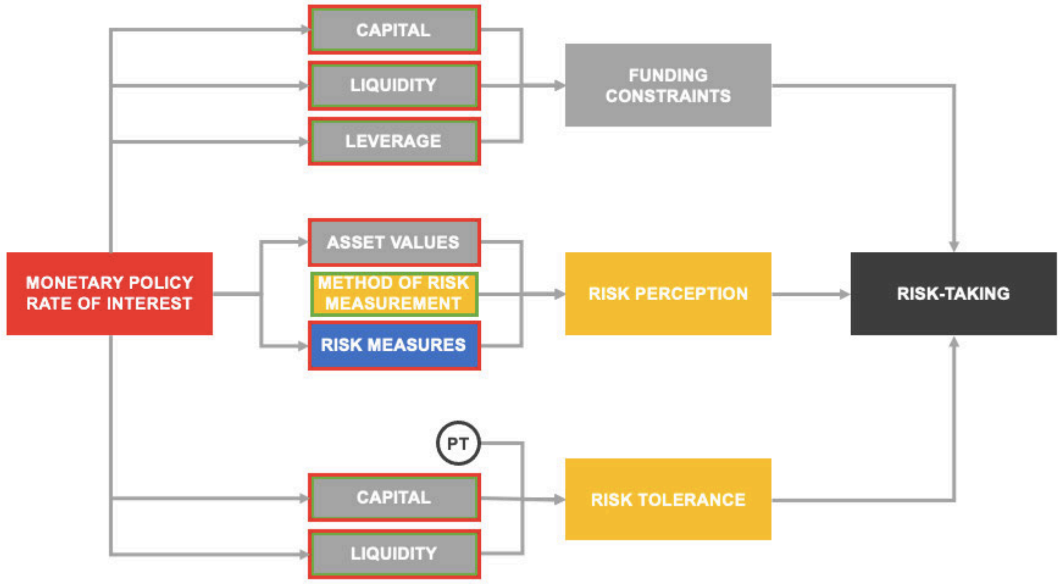


FIGURE 3.2:
ECONOMIC MODEL

Source: author's illustration

Funding constraints to the balance sheet of commercial banks ($FCON$) refer to the financial conditions for refinancing assets, including especially the supply of loans. Capital (CAP), liquid assets (LIQ) that can be pledged for borrowing central bank money, and the leverage ratio (LEV) in the balance sheet of commercial banks affect funding constraints. Monetary policy affects funding constraints, as well because the monetary policy rate of interest (MPR) represents the price of funding liquidity at the money market but also due to the cyclical effects on capital. The requirements of macroprudential bank regulation (MBR) on capital, liquidity and leverage impose additional constraints on funding.

$$FCON = f(+MPR, -CAP[MBR], -LIQ[MBR], +LEV[MBR]) \tag{3.3}$$

with

$FCON$ = funding constraints to the balance sheet of commercial banks

MPR = monetary policy rate of interest

CAP = capital in the balance sheet of commercial banks

LIQ = liquidity in the balance sheet of commercial banks

LEV = leverage of the balance sheet of commercial banks

MBR = macroprudential bank regulation on capital, liquidity and leverage

Risk perception of commercial banks ($RPER$) is affected by the monetary policy rate (MPR) due to its cyclical effect on asset values ($ASSV$) and risk measures ($RMEA$) in the balance sheet of commercial banks. The methods of risk measurement (MRM), which are subject to macroprudential bank regulation (MBR), affect risk perception, as well: The more sophisticated the method the more risk banks perceive in their balance sheet.

$$RPER = f(+MPR, -ASSV, +MRM[MBR], +RMEA) \tag{3.4}$$

with

$RPER$ = risk perception of commercial banks

MPR = monetary policy rate of interest

$ASSV$ = asset values in the balance sheet of commercial banks

MRM = method of risk measurement

$RMEA$ = risk measures in the balance sheet of commercial banks

MBR = macroprudential bank regulation on methods of risk measurement

Excluding the determinants that are themselves affected by monetary policy, risk perception of commercial banks ($RPER$) depends positively on the monetary policy rate (MPR) and the methods of risk measurement (MRM). Macroprudential bank regulation tends to enhance risk perception through the requirements on the methods of risk measurement through the capital framework effect.

$$RPER = f(+MPR, +MRM) \tag{3.5}$$

Risk tolerance of a commercial banks ($RTOL$) depends on its profit target ($PTAR$) as well as the amount of capital (CAP) and liquidity (LIQ) in its balance sheet. The monetary policy rate of interest (MPR) affects the latter two factors. Macroprudential bank regulation (MBR) tends to limit risk tolerance through the requirements on capital and liquidity.

$$RTOL = f(-MPR, +PTAR, +CAP[MBR], +LIQ[MBR]) \tag{3.6}$$

with

$RTOL$	=	risk tolerance of commercial banks
MPR	=	monetary policy rate of interest
$PTAR$	=	profit target of commercial banks
CAP	=	capital in the balance sheet of commercial banks
LIQ	=	liquidity in the balance sheet of commercial banks
MBR	=	macroprudential bank regulation on capital and liquidity

Excluding the determinants that are themselves affected by monetary policy, these functional relationships on funding constraints, risk perception and risk tolerance yield the conclusion that the monetary policy rate of interest (MPR) negatively affects risk-taking of commercial banks ($RTAK$) through its influence on all of the 3 factors. In addition, risk-taking depends negatively on the method of risk measurement (MRM) and positively on the profit target ($PTAR$).

$$RTAK = f(-MPR, -MRM, +PTAR) \tag{3.7}$$

Hence, the risk channel mechanism implies that a fall in the monetary policy rate of interest causes risk-taking of commercial banks to increase. Macroprudential bank regulation tends to limit risk-taking through the requirements on the methods of risk measurement as well as on capital, liquidity and leverage that affect funding constraints, risk perception and risk tolerance. The capital wedge effect promotes the risk channel mechanism with a rising impact as the regulatory capital wedge approaches the threshold.

3.4.2 HYPOTHESES

This subchapter presents the hypotheses, which are driven by the research aim to explain the risk channel in the TMMP for the EMU by identifying the operating mechanism. The hypotheses relate directly (RQ1 and RQ2) or indirectly (RQ3) to the three research questions that guide this research study:

RQ1: What is the underlying mechanism of the risk channel in the transmission of monetary policy within the EMU?

RQ2: What is the role of macroprudential bank regulation in the risk channel in the transmission of monetary policy within the EMU?

RQ3: What are the implications of the risk channel for the decision makers of monetary policy for the EMU?

The hypotheses refer to the core of the risk channel mechanism: the causal relationship between the central bank's base rate of interest as monetary instrument and the attitude of commercial banks towards risk in terms of risk perception and risk-taking.

RISK PERCEPTION: Credit risk is the main type of risk in lending business. The economic model implies that the perception of credit risk ($RPER$) depends positively on the monetary policy rate of interest (MPR) and on the method of risk measurement (MRM): $RPER = f(+MPR, +MRM)$. First, monetary expansion (contraction), that is a fall (rise) in the base rate of interest, brings asset values to rise (fall), while measures of credit risk, such as risk weighted assets, simultaneously fall (rise) due to their procyclical character. The resulting effect is a decline (increase) in the perception of credit risk in the balance sheet of commercial banks. Second, the more sophisticated the applied method of credit risk measurement, the greater the effect of monetary policy on credit risk perception of commercial banks. The relationship between the monetary policy rate of interest and credit risk perception in the balance sheet of commercial banks is subject of Hypothesis 1:

H1: There is a positive relationship between the central bank's monetary policy rate of interest and the perception of credit risk in the balance sheet of commercial banks (ceteris paribus). $RPER_{CRR} = f(+MPR)$

RISK-TAKING: Risk-taking refers to the outcome variable of the risk channel mechanism in terms of risk in the balance sheet of commercial banks. Hence, it is the variable of main interest in this context. The economic model implies that risk-taking of commercial banks ($RTAK$) depends negatively on the monetary policy rate of interest (MPR) and the method of risk measurement (MRM) and positively on the profit target ($PTAR$): $RTAK = f(-MPR, -MRM, +PTAR)$. In loan business, the predominant distinction of risk-taking by classes of risk is on credit risk and interest rate risk. Credit risk (CRR) relates to unexpected losses from default and deterioration of the credit standing of borrowers. Hypothesis 2 addresses the relationship between the monetary policy rate of interest and credit risk-taking of commercial banks:

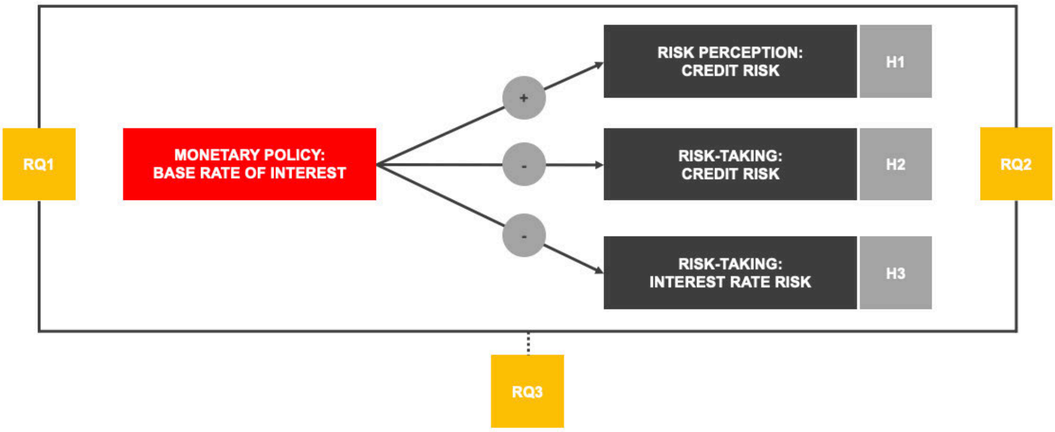
H2: There is a negative relationship between the central bank's monetary policy rate of interest and risk-taking in terms of credit risk in the balance sheet of commercial banks (ceteris paribus). $RTAK_{CRR} = f(-MPR)$

Interest rate risk (IRR) relates to unexpected losses from changes in market interest rates. The relationship between the monetary policy rate of interest and risk-taking in terms of interest rate risk is covered by hypothesis 3:

H3: There is a negative relationship between the central bank's monetary policy rate of interest and risk-taking in terms of interest rate risk in the balance sheet of commercial banks (ceteris paribus). $RTAK_{IRR} = f(-MPR)$

The three hypotheses represent the underlying mechanism indicated by the theoretical representation of the risk channel of monetary transmission. The test of these hypotheses is the objective of the empirical analysis of this research study. Figure 3.3 presents the research hypotheses and their relation to the research questions. Hypotheses H1, H2 and H3 target the effect of monetary policy on risk perception and risk-taking of commercial banks facilitated through the risk channel of monetary transmission.

RESEARCH AIM
To explain the risk channel of monetary policy in the EMU by identifying the operating transmission mechanism.



RESEARCH QUESTIONS
RQ1: What is the underlying mechanism of the risk channel in the transmission of monetary policy within the EMU?
RQ2: What is the role of macroprudential bank regulation in the risk channel in the transmission of monetary policy within the EMU?
RQ3: What are the implications of the risk channel for the decision makers of monetary policy for the EMU?

FIGURE 3.3:
HYPOTHESES AND RESEARCH QUESTIONS

Source: author's illustration

The hypotheses directly relate to research question RQ1 on the underlying mechanism of the risk channel within the EMU and RQ2 on the role of macroprudential bank regulation in monetary transmission through the risk channel within the EMU.

3.4.3 IDENTIFICATION STRATEGY

For the empirical test of the hypotheses, an operationalisation of the abstract variables of the economic model on risk perception and risk taking is necessary. To recap, the relationships indicated by the economic model for risk perception and risk-taking are:

$$\begin{aligned} RPER &= f(+MPR, +MRM) \\ RTAK &= f(-MPR, -MRM, +PTAR) \end{aligned} \tag{3.8}$$

Practically, risk perception ($RPER$) and risk-taking ($RTAK$) of commercial banks are closely related, if not in a certain sense equal, as both rely on measures of risk. The fine distinction applied in the empirical analysis is as follows: Risk perception refers to the fraction of risk in the balance sheet of commercial banks that is visible at a certain point in time, which depends heavily on the method of risk measurement. Hence, risk perception is indicated by measures of risk that rely on market inputs and thus are sensitive to business cycle movements so that they reflect the effects of monetary policy measures on the creditworthiness of borrowers. In contrast, risk-taking is associated to ex-ante measures of risk that commercial banks consider in their loan decision.

TABLE 3.2:
IDENTIFICATION STRATEGY

Economic Model	Empirical Analysis
Risk perception ($RPER$)	Credit risk perception: RWA density (IRBA)
Risk-taking ($RTAK$)	Credit risk-taking: share of risky loans
Risk-taking ($RTAK$)	Interest rate risk-taking: duration of net assets
Base rate of interest (MPR)	ECB interest rate on main refinancing operations
Method of risk measurement (MRM)	Business area: retail loans (less sophisticated) loans to enterprises (more sophisticated)
Profit target ($PTAR$)	Profit target of the banks' strategy

Table 3.2 presents the operationalisation of the economic model of the risk channel in regard to the economic model. The first column shows the abstract variable of the economic model of the risk cannel in monetary transmission, the second column presents the translation into an operational variable for the empirical analysis. The reasoning for the choice of these indicators is outlined below. Commercial banks are the main providers of credit in most economies. Credit risk is their most important risk (Kuritzkes & Schuermann, 2010) and any compositional changes in their credit supply directly impact future financial stability and economic growth (Allen & Gale 2007; Matsuyama 2007).

RISK PERCEPTION – CREDIT RISK: Risk perception is empirically examined for credit risk as the main class of risk in lending (Bessis & Bessis, 2015). In this study, credit risk perception proxied by the regulatory measure of RWA density of the loan portfolio of German IRBA banks. RWA density refers to the ratio of risk-weighted assets (RWA) to the respective gross exposure (German Central Bank, 2020a). A higher RWA density is associated to higher credit risk perception, and vice versa. The regression analysis will examine the risk measure calculated by the internal ratings-based approach (IRBA), because the measure is a “point-in-time” estimate and hence more sensible to changes in asset values and creditworthiness of borrowers as compared to the external ratings as “through-the-cycle” estimate applied in the regulatory standard approach (Borio & Zhu, 2012).

RISK-TAKING – CREDIT RISK: Risk-taking is empirically examined for credit risk as the main class of risk in lending (Bessis & Bessis, 2015). In this study, credit risk-taking proxied by the regulatory measure of share of relatively risky loans to enterprises based on their interest coverage ratio. The risky loan share refers to the lending to relatively risky non-financial corporations as a percentage of total credit claims based on firm’s interest coverage ratio, that is the ratio of earnings before interest, taxation, depreciation and amortisation (EBITDA) to interest expenditure. Enterprises above the median are considered as “relatively risky” (German Central Bank, 2020a). A greater share of risky loans in the balance sheet of a commercial bank corresponds to higher credit risk-taking, and vice versa.

RISK-TAKING – INTEREST RATE RISK: Another relevant class of risk in lending business is interest rate risk, especially for fixed rate loans (Kuritzkes & Schuermann, 2010; Bessis & Bessis, 2015). In this study, interest rate risk-taking is proxied by the regulatory measure of duration of net assets. It is based on commercial bank's reports for the Basel interest rate coefficient and refers to positions in the banking book exposed to interest rate risk, hence the interest book. The so-called Macaulay duration is a measure of the sensitivity of the present value of the interest book to the Basel interest rate shock, that is an abrupt interest rate rise of 200 basis points across all maturities (German Central Bank, 2020a). A higher duration of net assets corresponds to higher interest rate risk-taking, and vice versa.

BASE RATE OF INTERREST: The ECB interest rate on main refinancing operations is used as indicator for the monetary base rate of interest because it is the rate of interest that applies for the bulk of liquidity borrowed by commercial banks from the ECB (ECB, 2021).

METHOD OF RISK MEASUREMENT: With respect to the risk measures under consideration, that is RWA density, share of risky loans and duration of net assets, the method of risk measurement is relevant only for RWA density as indicator for credit risk perception, since this risk measure relies on the calculation of risk weights. In contrast, the share of risky loans and the duration of net assets are not subject to the variety in the methods of calculating these risk measures. The variety in methods of credit risk measurement causes challenges in observing this variable. One approximation is to distinguish method of measurement for RWA density by the regulatory approach on credit risk measurement: RWA density calculated based on the regulatory internal ratings-based approach (IRBA) relies on market inputs and is therefore sensitive to changes in economic conditions. In contrast the regulatory standardised approach (SA) relies on external ratings and standard risk weights, which corresponds to a low sensitivity. Therefore, to capture credit risk perception the empirical analysis will rely on RWA density of banks that apply the IRBA approach, because this method is capable of reflecting market driven changes from monetary policy. An approximation to capture the variance in the sophistication of methods for calculating the RWA density measure is to distinguish by the business area of loans: Risk of loans to enterprises is commonly measured by more sophisticated methods, while risk of retail loans is measured by less sophisticated methods (Bessis & Bessis, 2015). Hence, the indicator for credit risk perception will be RWA density based on the IRBA approach and the indicator for variation in its method of risk measurement will be the business area.

PROFIT TARGET: The profit target that each commercial bank defines in its strategy will be excluded from the regression analysis due to a lack of data. The variable is not included in the regulatory data that is collected on a regular basis for the relevant population.

In consideration of this identification strategy, the collection of data and the specification of the regression models targets the following economic relationships that reflect the risk channel of monetary transmission:

$$\begin{aligned} RPER &= f(+MPR, +MRM) \\ RTAK &= f(-MPR) \end{aligned} \tag{3.9}$$

The specification process of the econometric models on credit risk perception, credit risk-taking and interest rate risk-taking will include both linear and nonlinear versions in order to capture possible nonlinearities of the risk channel. The version that shows the best fit will be used for the regression analysis and in particular the hypothesis tests.

3.5 DATA COLLECTION

This subchapter is dedicated to methodological aspects of the data collection for this research, which covers data source, data descriptions and the data preparation of the data samples used in the empirical analysis.

3.5.1 DATA SOURCE

The source of data has implications on the control of the researcher over the data collected. Primary data refers to new information directly collected by the researcher from the original source through interviews, surveys, and observations. In contrast, secondary data has already been collected through primary sources and made readily available for researchers. The use of secondary data implies that the researcher has no control on the characteristics of the data and hence on methodological consequences. However, the use of secondary data supports the objectivity of a study in the sense that subjective influences of the researcher in the process of primary data collection are excluded. The basis for the empirical analysis of this research is secondary data collected by the German Central Bank from German commercial banks in the context of the regulatory reporting required from the legal framework of macroprudential bank supervision. The data samples are publicly available in the statistical data warehouse of the German Central Bank (2021), which is partially updated on a regular basis.

The 4 variables that arise from the 3 hypotheses, that is (1) the base rate of interest, (2) credit risk perception, (3) credit risk-taking and (4) interest rate risk-taking are collected by the German Central Bank (2021) by 8 time series, because some time series apply for a certain category, as presented in Table 3.3. Time series (1) ECB interest rate on main refinancing operations indicates the base rate of interest set by the central bank, time series (2) and (3) RWA density by business area indicate risk perception, time series (4) credit allocation risk indicates credit risk-taking and time series (5), (6), (7) and (8) duration of net assets by bank group indicate interest rate risk-taking.

TABLE 3.3:
TIME SERIES

Economic Model	Time Series
Base rate of interest (MPR)	(1) ECB interest rate on main refinancing operations
Risk perception - credit risk ($RPER$) Method of risk measurement (MRM)	(2) RWA densities of German banks - IRBA - loans to enterprises - aggregate (3) RWA densities of German banks - IRBA - loans to retail business - aggregate
Risk-taking - credit risk ($RTAK$)	(4) Allocation risk in the domestic loan portfolio of German banks
Risk-taking - interest rate risk ($RTAK$)	(5) Duration of net assets (banking book) - Credit Cooperatives (6) Duration of net assets (banking book) - large, systemically important banks (7) Duration of net assets (banking book) - Savings banks (8) Duration of net assets (banking book) - small and medium-sized commercial banks

3.5.2 DATA DESCRIPTIONS

The choice of the data samples that builds the empirical basis for the regression analysis is driven by the hypotheses derived from the theoretical representation of the risk channel. Wooldridge (2008) outlines that data may be distinguished by source, structure, type, and level of aggregation. The form of the data sample and the nature of its variables have an impact on the appropriate choice of the econometric model and regression method.

With respect to quantitative analysis, Brooks (2019) distinguishes between three data structures: time-series data, cross-sectional data and panel data. This research study covers the time period between 2002 to 2019, whereby the starting point corresponds to the introduction of the Euro as cash money in the member states of the European Monetary Union. Hence, the data collected by the German Central Bank is of time-series nature, as Wooldridge (2008) suggests the time-series structure refers to data on "one economic unit collected over discrete intervals of time" (p. 5). The structure of the data affects methodological issues. As Hill, Griffiths and Lim (2008) outline, time-series observations are likely to be correlated over time. Economic actions at time t may affect the economy at time t but also at times $t+1$, $t+2$ and so on. Therefore, the effects of a change in the explanatory variable x on the dependent variable y may be distributed over future time periods. Depending on the purpose, data can be collected at several levels of aggregation (Wooldridge, 2008). Microlevel data is collected on individual economic decision-making agents such as individuals, households and firms. Macrolevel data results from pooling or aggregating over individuals, households or firms at local, state or national level. The 8 time series differ partly in their characteristics. The following tables present the key characteristics of each data sample, where related time series that reflect one measure for different categories are combined in one table.

3.5.2.1 BASE RATE OF INTEREST

Time series (1) ECB interest rate for main refinancing operations contributes the explanatory variable for the empirical analysis, which corresponds to the base rate of interest or monetary policy rate in the theoretical representation. The characteristics of the data sample are summarised in Table 3.4.

TABLE 3.4:
TIME SERIES 1 ECB INTEREST RATE

Name	ECB interest rates for main refinancing operations
Sample population	European Monetary Union
Structure	Time series
Type	Quantitative
Level	Macro
Unit	% p.a.
Frequency	End of month
Time period	2002-01 to 2019-04
Pooling	-
Methodology	-
Source	German Central Bank (secondary data)
Source code	BBK01.SU0202 (German Central Bank, 2021)
Updated	31.01.2021
Regression: name	ECB.MRO
Regression: role	Independent variable

3.5.2.2 CREDIT RISK PERCEPTION

Time series (2) and (3) include the RWA density for German banks with pooling to the business areas of loans to enterprises and loans to retail business, respectively. The measure RWA density ($RWAD$) corresponds to the regulatory measure “banks assets riskiness” and is calculated by commercial banks as ratio of risk-weighted assets (RWA) to the original gross exposures for the respective loans (EAD) (BCBS, 2022):

$$RWAD = \frac{RWA}{EAD} \tag{3.10}$$

where

$RWAD$ = RWA density

RWA = risk weighted assets

EAD = exposure at default

The measure RWA density corresponds to the element of "risk perception" in the theoretical representation and takes the role of the response variable in the first regression model "Credit Risk Perception" of the empirical analysis. Table 3.5 summarises the characteristics of time series 2 and 3.

TABLE 3.5:
TIME SERIES 2 AND 3 RWA DENSITY

Name (long)	RWA densities of German IRBA banks
Sample population	German commercial banks (IRBA)
Structure	Time series
Type	Quantitative (stock)
Level	Micro at unit of commercial bank
Unit	%
Frequency	Quarter
Time period	2008-01 - 2019-04
Pooling	Business area: Loans to enterprises (BA.ETP) Loans to retail business (BA.RTL)
Methodology	RWAD = RWA / EAD
Source	German Central Bank (secondary data)
Source code	BBQFS.Q.DE.BANK.RWADE_IRBA_CO._X.0000 BBQFS.Q.DE.BANK.RWADE_IRBA_RE._X.0000 (German Central Bank, 2021)
Updated	24.11.2021
Regression: name	RWAD – BA.ETP, BA.RTL
Regression: role	Dependent variable

3.5.2.3 CREDIT RISK-TAKING

Time series (4) captures credit allocation risk in the portfolio of German banks. The indicating measure is the share of relatively risky loans (RLS) based on enterprises whose interest coverage ratio (ICR) is in the worst 30th percentile. The interest coverage ratio is calculated from the enterprise's ratio of $EBITDA$ to interest expenditure (German Central Bank, 2021):

$$ICR = \frac{EBITDA}{interest\ expenditure} \tag{3.11}$$

where

ICR = interest coverage ratio

$EBITDA$ = earnings before interest, taxation, depreciation and amortisation

The corresponding element from the theoretical representation is “risk-taking” in terms of credit risk as outcome variable of the risk channel mechanism. In the empirical analysis, credit allocation risk takes the role of the response variable in the second regression model “Credit Allocation Risk-Taking”. Table 3.6 summarises the characteristics of time series (4) on credit allocation risk of German commercial banks.

TABLE 3.6:
TIME SERIES 4 CREDIT ALLOCATION RISK

Name (long)	Credit allocation risk of German banks
Sample population	German commercial banks
Structure	Time series
Type	Quantitative (stock)
Level	Micro at unit of commercial bank
Unit	%
Frequency	Quarter
Time period	2002-01 - 2018-10
Pooling	-
Methodology	Relatively risky enterprises whose interest coverage ratio (ICR) in the worst 30th percentile, ICR = EBITDA / interest expenditure
Source	German Central Bank (secondary data)
Source code	BBQFS.Q.DE.BANK.ALM_SH_INTCOV_RAT.DE. CONF (German Central Bank, 2021)
Updated	10.02.2021
Regression: name	RLS
Regression: role	Dependent variable

3.5.2.4 INTEREST RATE RISK-TAKING

Time series (5), (6), (7) and (8) capture interest rate risk through the indicating measure net asset duration (NAD) in the banking book of German banks. The regulatory measure is calculated in the context of the Basel interest rate coefficient, which is the change in the economic value of the banking book resulting from different interest rate scenarios (German Central Bank, 2021).

The German Central Bank pools the measure by bank group: Credit Cooperatives (5), large, systemically important banks (6), Savings banks (7) and small and medium sized commercial banks (8). Interest rate risk indicated by the measure net asset duration corresponds to the element of “risk-taking” in terms of interest rate risk in the theoretical representation and takes the role of the response variable in the third regression model “Interest Rate Risk-Taking” of the empirical analysis. Table 3.7 summarises the characteristics of the time series in question.

TABLE 3.7:
TIME SERIES 5, 6, 7, 8 DURATION OF NET ASSETS

Name (long)	Duration of net assets of German banks
Sample population	German commercial banks
Structure	Time series
Type	Quantitative (stock)
Level	Micro at unit of commercial bank
Unit	Years
Frequency	Quarter
Time period	2012-01 - 2019-04
Pooling	Bank group: Credit cooperatives (BG.CC), Savings banks (BG.SB), Large, systemically important banks (BG.LSI), Small and medium sized commercial banks (BG.SMCB)
Methodology	Weighted means
Source	German Central Bank (secondary data)
Source code	BBQFS.Q.DE.CCBA.DUR_NETASS_BANK._X.0000 BBQFS.Q.DE.OSII.DUR_NETASS_BANK._X.0000 BBQFS.Q.DE.SABA.DUR_NETASS_BANK._X.0000 BBQFS.Q.DE.X1BA.DUR_NETASS_BANK._X.0000 (German Central Bank, 2021)
Updated	01.11.2021
Regression: name	NAD
Regression: role	Dependent variable

Each sample of the response variables is collected by the German Central Bank in the regulatory context of macroprudential bank supervision. Since the regulatory standards were developed over time, the time periods of the samples on RWA density, allocation risk and duration of net assets do not cover the whole research time period from 2002 to 2019. The choice of the data period would be ideally the same for all variables in order to capture a consistent picture.

3.6 RESEARCH METHOD

In this study, the choice of quantitative methods for the empirical analysis is driven by the explanatory objective of the Post-Positivist research and in line with the relevant research questions (RQ1 and RQ2). The methodological underpinnings of this subchapter correspond to the standard approach in economic research on econometrics and follow the methodological underpinnings of Hill, Griffiths and Lim (2008) as well as Wooldridge (2008). The following subchapters outline the regression model specification, the regression method and statistical inference in a general form, while the specific application for each of the 3 regression models is detailed in chapter 4 “Empirical Analysis”.

3.6.1 REGRESSION MODEL SPECIFICATION

Economic theory is used to construct an economic model that reflects causal relationships between economic variables. This economic model leads to an econometric regression model, which is based on assumptions and used to answer quantitative questions of an “how much” type, such as direction and strength on these relationships. The econometric model builds the basis for the quantitative analysis, which is used for estimating the unknown parameters, making predictions and testing the hypotheses of the theoretical representation of the risk channel.

3.6.1.1 ECONOMIC MODEL

An economic model describes the relationship between variables, like that of two variables y and x.

$$y = f(x) \tag{3.12}$$

As outlined in Hill, Griffiths and Lim (2008), the mathematical representation of an economic model with a simple linear relationship between the dependent variable y and the independent or explanatory variable x is

$$E(y|x) = \mu_{y|x} = \beta_1 + \beta_2 x \tag{3.13}$$

The conditional mean $E(y|x)$ is called a simple regression function because there is only one explanatory variable on the right-hand side of the equation. The unknown regression parameters β_1 and β_2 are the intercept and slope of the regression function, respectively. Hill, Griffiths and Lim (2008) note that the economic interpretation of that slope β_2 is the marginal effect of a change in x on y.

$$\Delta y = \beta_2 \Delta x \tag{3.14}$$

If x changes by one unit, $\Delta x = 1$, the $\Delta y = \beta_2$. The marginal effect β_2 is always the same for a linear relationship because the slope is a constant. From the perspective of calculus, the derivative d of a function is its slope

$$\frac{dy}{dx} = \beta_2 \tag{3.15}$$

The derivate yields the change in y for an infinitesimal change in x. For a linear relationship it is constant and equal to $\beta_2 = \Delta y / \Delta x$, whereby the "infinitesimal" does not matter for linear relationships. The economic model of equation (3.13) summarises what theory tells on the relationship between the dependent variable y and the independent variable x. The parameters of the model, β_1 and β_2, indicate the quantities in terms of the direction and strength of the relationship. If the linear relationship is extended to a number of explanatory variables, it is referred to as multiple linear relationship in the general form of

$$y = \beta_1 + \beta_2 x_2 + \beta_K x_{iK} \tag{3.16}$$

with y-intercept β_1 and K unknown parameters. The multiple linear relationship

$$y = \beta_1 + \beta_2 x_2 + \beta_3 x_3 \tag{3.17}$$

is that of a plane with y-intercept β_1. The value of y is now affected by both variables x_2 and x_3. In order to deduce the marginal effect of either variable on y, the other variable is held constant. This corresponds to the economic assumption of "ceteris paribus", that is "holding all other factors constant". Following Hill, Griffiths and Lim (2008). The slope parameters are:

$$\beta_2 = \frac{\Delta y}{\Delta x_2}\bigg| given\ constant\ x_3$$
$$\beta_3 = \frac{\Delta y}{\Delta x_3}\bigg| given\ constant\ x_2 \tag{3.18}$$

In this multivariate context the calculus requires a partial derivative ∂ instead of the simple derivative d.

$$\frac{\partial y}{\partial x_2} = \beta_2, \qquad \frac{\partial y}{\partial x_3} = \beta_3 \tag{3.19}$$

The partial derivative ∂ is the derivative with the additional assumption that all other variables are held constant. In contrast to a linear relationship, the slope of a nonlinear relationship is not a constant, implying the marginal effect changes at any point of the curve. Since the slope is different at any point, only statements on the effect of small changes of x on y are possible. Therefore, the Δ indication of a "change in" is replaced by d as means of an "infinitesimal change in". The slope of a simple nonlinear relationship at a single point is given by the simple derivative

$$dy = \beta_2 dx$$
$$\frac{dy}{dx} = \beta_2 \tag{3.20}$$

Geometrically, the slope of this nonlinear curve at point A is given by the slope of the tangent line β_2. For a simple quadratic relationship of the from $y = \beta_1 + \beta_2 x + \beta_3 x^2$, which is geometrically a parabola, the slope of the tangent line depends on the value of x and is given by the derivative:

$$\frac{dy}{dx} = \beta_2 + 2\beta_3 x \tag{3.21}$$

The vertex reflects the minimum or maximum of the parabolic relationship and is the point where the slope of the tangent line is zero.

$$\frac{dy}{dx} = \beta_2 + 2\beta_3 x = 0$$
$$x_{vertex} = -\beta_2/2\beta_3 \tag{3.22}$$

The shape of the curve is determined by β_3. If $\beta_3 > 0$ then the curve is U-shaped and reflects increasing marginal effects. If $\beta_3 < 0$ then the curve is an inverted U-shape and represents diminishing marginal effects. It is expected that both the linear and non-linear functional form will be used for the regression models in this thesis.

3.6.1.2 ECONOMETRIC MODEL

The analysis of empirical data requires the specification of an econometric model, which allows to investigate the relationship between variables. Hill, Griffiths and Lim (2008) point out, that the econometric model consists of a regression function and assumptions on the empirical data, with the regression function corresponding to the economic model. The essence of regression analysis is that any observation on the dependent variable y_t can be decomposed in a systematic component and a random component. The systemic component of y_t is its mean $E(y_t|x_t) = \beta_1 + \beta_2 x_t$ that describes the average or systematic behaviour of many economic agents. The random component of y_t is the random, unobservable error term e_t that reflects the difference between y_t and its conditional mean value $E(y_t|x_t)$.

$$e_t = y_t - E(y_t|x_t) = y_t - \beta_1 + \beta_2 x_t \tag{3.23}$$

The error term captures (1) any other factors than the explanatory variable x_t, (2) any approximation error that arises because the assumed functional form of the regression function may be only an approximation to reality and (3) any elements of random, unpredictable human behaviour. Rearranging equation (3.23) yields the simple linear regression model in general form:

$$y_t = \beta_1 + \beta_2 x_t + e_t \tag{3.24}$$

The dependent variable y_t is explained by a component that varies systematically with the independent variable x_t and by the random error term e_t. The regression function is already the basis of an econometric model. Hill, Griffiths and Lim (2008) outline that the extension to a general multiple regression model is done by relating the dependent variable to a number of explanatory variables $x_{t2}, \ldots, x_{tK}$ to a linear equation:

$$y_t = \beta_1 + \beta_2 x_{t2} + \beta_K x_{tK} + e_t \tag{3.25}$$

The coefficient β_1 denotes the intercept term. The coefficients $\beta_2, \dots, \beta_K$ are unknown coefficients that correspond to the explanatory variables $x_{t2}, \dots, x_{tK}$. The K denotes the number of unknown parameters with $k = (1, \dots, K)$. A single parameter β_K measures the effect of a change in the variable x_K upon the expected value of y, all other variables held constant. In terms of partial derivatives:

$$\beta_K = \frac{\Delta E(y)}{\Delta x_K}\bigg| other\ x's\ constant = \frac{\partial E(y)}{\partial \Delta x_K} \tag{3.26}$$

The linear regression model can be used for nonlinear relationships between variables, by including transformations of the basic economic variables y and x such as logarithms, squares, cubes or reciprocals. The term “linear” in the name of the model refers to the parameters β_K, which are not transformed in any way. An econometric model with a quadradic relationship can take the general form:

$$y_t = \beta_1 + \beta_2 x_t + \beta_3 x_t^2 + e_t \tag{3.27}$$

To complete the econometric model, further assumptions on the data need to be made. As Hill, Griffiths and Lim (2008) state: “part of the challenge in econometric analysis is making realistic assumptions and then checking if they hold.” (pp. 110-111). The assumptions (A) of a multiple linear time series regression model are listed below (Wooldridge, 2008). For the purpose of better interpretation, variable x_t is considered fix and hence non-random, henceforth the conditioning notation $y_t|x_t$ is not used.

TABLE 3.8:
ASSUMPTIONS

A1	Cointegration: The time series y_t and x_t are either stationary or cointegrated.
A2	Linearity of coefficients: The value of y_t, for each value of x_t is given by a linear regression function $y_t = \beta_1 + \beta_2 x_{t2} + \beta_K x_{tK} + e_t,\ t = 1, \dots, n.$

A3	Zero mean of residuals (exogeneity): The expected value of the random error e_t is zero or the random error e_t is not correlated with any regressors $E(y_t) = \beta_1 + \beta_2 x_{t2} + \beta_K x_{tK} \leftrightarrow E(e_t) = 0$.
A4	Homoscedasticity: The variance of the random error e_t is $var(y_t) = var(e_t) = \sigma^2$.
A5	No autocorrelation: The covariance between any pair of random errors e_t and e_s is $cov(y_t, y_s) = cov(e_t, e_s) = 0$ for all $t \neq s$.
A6	No multicollinearity: The values of each x_{tK} are not random and are not exact linear functions of the other explanatory variables.
A7	Normality: The values of e_t are normally distributed about their mean if the values of y_t are normally distributed $y_t \sim N(\beta_1 + \beta_2 x_{t2} + \beta_K x_{tK}, \sigma^2) \leftrightarrow e_t \sim N(0, \sigma^2)$.
A8	No outliers: No extreme outliers exist.

The choice of the econometric model depends crucially on the assumptions on the economic relationship, which relates to the type of data. Since the regression is based on time series data, specific characteristics of time series models need to be considered.

TIME SERIES MODELS: Dynamic models are typically used for time-series data in order to capture dynamic relationships from lag effects, referred to as autocorrelation. Dynamic means that the effects of changes in the explanatory variable x_t on the dependent variable y_t are distributed over future time periods.

$$y_t = \beta_1 + \beta_2 x_t + e_t \tag{3.28}$$

According to Hill, Griffiths and Lim (2008) in dynamic regression models, stationarity of variables is a general assumption. A time series is stationary, if its mean and variance are constant over time and if the covariance between two values of the time series depends only on the length of time separating the two values and not on the actual times at which the variables are observed. A non-stationary time series has a unit root.

TABLE 3.9:
STATIONARITY OF TIME SERIES

Mean	Constant mean: $E(y_t) = \mu$
Variance	Constant variance: $var(y_t) = \sigma^2$
Covariance	Covariance depends on s not t: $cov(y_t, y_{t+s}) = cov(y_t, y_{t-s}) = \gamma_s.$

The order of integration is a deeper assessment of the stationarity property. Series, which can be made stationary by taking first difference are said to be integrated of order 1 and denoted as I(1). Stationary series are said to be stationary at order zero and denoted as I(0). As a rule, non-stationary time series should not be used in regression to avoid the problem of spurious regression. Hill, Griffiths and Lim (2008) explain spurious regression as the "danger of obtaining apparently significant regression results from unrelated data when nonstationary series are used in regression analysis" (p. 333).

However, there is an exception of this rule. If series y_t and x_t are nonstationary I(1) variables, then we expect their difference or any linear combination of them such as $e_t = y_t - \beta_1 - \beta_2 x_t$ to be nonstationary I(1), as well. However, there is an important case when $e_t = y_t - \beta_1 - \beta_2 x_t$ is a stationary process. In this case, y_t and x_t are cointegrated. Following Hill, Griffiths and Lim (2008), cointegration implies that y_t and x_t share similar stochastic trends and, since the difference e_t is stationary, they never diverge too far from each other. If residuals are stationary, meaning they have no unit root, a fundamental relationship exists between the variables and the relationship is not spurious.

3.6.2 REGRESSION METHOD

The ordinary least squares (OLS) regression is a standard method to estimate the unknown parameters β of the regression model. Hill, Griffiths and Lim (2008) outline that the ordinary least squares regression fits a regression line to the data values by minimising the sum of squared differences between the observed values of y_t and its expected value $E(y_t) = \beta_1 + \beta_2 x_{t2} + \beta_K x_{tK}$. The resulting intercept and slope of the regression line that best fits the data using the least squares principle are the least squares estimates b. The fitted regression line is generally represented by

$$\hat{y}_t = b_1 + b_2 x_{t2} + b_K x_{tK} \tag{3.29}$$

with b representing the least squares estimates of the K unknown parameters β Hill, Griffiths and Lim (2008).

3.6.2.1 SAMPLING PROPERTIES

The estimators b_k have properties referred to as sampling properties that relate to their expected values, variances, covariance and probability distributions. They are summarised in Table 3.10 following Hill, Griffiths and Lim (2008). Sampling properties provide a basis for assessing the reliability of the estimates. The probability of an estimator to produce estimates that are close to the unknown parameters depends critically on whether the assumptions of the regression model hold. Table 3.10 provides an overview on the sampling properties (SP) of the least squares estimator.

The Gauss-Markov Theorem states that the ordinary least squares estimator b is the best linear unbiased estimator (BLUE) of β (Hill, Griffiths & Lim, 2008). Under the assumptions A2 to A6 of the multiple linear regression model, the estimator b has the smallest variance of all linear and unbiased estimators of β.

TABLE 3.10:
SAMPLING PROPERTIES OF LEAST SQUARES ESTIMATOR

SP1	Random variables: The least squares estimator b is a general formula that can be used to estimate unknown parameters β and hence random variables. $S(\beta) = \sum_{t=1}^{N}(y_t - x_t'\beta)^2 = (y - X\beta)'(y - X\beta) \rightarrow \min_{\beta}$ $b = (X'X)^{-1}X'y$
SP2	Linear estimators: The least squares estimators b are linear estimators, which can be written as weighted averages of the y_t values.
SP3	Unbiased expected value: The least squares estimator b is unbiased if the assumptions A2 to A6 hold. An estimator is unbiased (reliable) when the expected value of any estimator of a parameter equals the true parameter: $E(b\|X) = \beta$.
SP4	Variance and covariance: The least squares estimators b have a variance and covariance: $V(b\|X) = \hat{\sigma}^2(X'X)^{-1}$ with $\widehat{\sigma^2} = \frac{\hat{e}\prime\hat{e}}{N-K}$ The variance of an estimator measures the spread of its probability distribution given by its probability density function $f(b)$. The sampling precision of an estimator is higher the smaller variance of its probability density function is. A smaller variance implies that the probability of the estimator is more concentrated around the true parameter value, so that the probability of getting an estimate close to the true parameter is higher. The square roots of the estimated variances are the standard errors of b and used in hypothesis testing and confidence interval estimation.
SP5	Probability distributions: If the normality assumption A7 holds than the random errors e_t are normally distributed around mean 0 and variance σ^2, then the probability distributions of the least squares estimators are also normal: $b\|X \sim N[\beta, V(b\|X)]$ The probability distributions are important for the construction of interval estimates and hypothesis tests. Under normality assumption, the t and F statistics have exact t and F distributions.

The Central Limit Theorem states that the ordinary least squares estimators have a distribution that approximates the normal distributions, if assumptions A2 to A6 hold and if the sample size N is sufficiently large. Hill, Griffiths and Lim (2008) point out that the meaning of “sufficiently large” varies with the problem, but as a rule of thumb a number of $N-K$ between 30 and 50 is widely considered large enough.

3.6.2.2 ROBUST STANDARD ERRORS

For valid statistical inference, standard F and t tests rely on the assumptions that errors are homoscedastic and uncorrelated (A4, A5). Economic data typically exhibits some form of heteroscedasticity and/or autocorrelation. If the covariance structure were known, it could be considered in a parametric model. Zeileis (2004) notes that, despite the form of heteroscedasticity and/or autocorrelation is frequently unknown, regression coefficients can still be consistently estimated using ordinary least squares given the functional form is correctly specified. But for valid statistical inference a consistent matrix estimate is essential. Over the past 35 years, several procedures for heteroscedasticity and autocorrelation consistent (HAC) matrix estimation have been suggested in the econometrics literature. Kleiber and Zeileis (2008) point out, that these procedures are today "routinely applied in econometric practice" (p. 105).

In the regression analysis of this study, a HAC matrix is estimated based on the general framework proposed by Zeileis (2004). Various specific HAC estimators have been suggested in econometrics literature differing in the choices for the vector of weights ω, most notably by authors like White and Domowitz (1984), Newey and West (1987), Andrews (1991), Andrews and Monahan (1992) as well as Lumley and Haegerty (1999). This study uses the approach of Newey and West (1987, 1994) by applying so called Bartlett kernel weights, that is linearly declining weights[29]. This approach on estimating the covariance matrix relies on a non-parametric bandwidth selection. Zeileis (2004) points out, that for many data structures it is a reasonable assumption to assume that autocorrelations decrease with increasing lag $l=|i-j|$.

[29] Without specifying the maximum lag L through the 'lag' argument in the NeweyWest() function of the sandwich package in R, the non-parametric selection procedure of Newey and West (1994) is applied.

Otherwise β can typically not be estimated consistently by OLS, so that it is intuitive that weights ω_l should also decrease.

3.6.3 STATISTICAL INFERENCE

Based on the method of least squares regression, the estimator b_k leads to point estimates for the parameters β_k in the multiple linear regression model. These estimates represent an inference about the regression function that describes a relationship between economic variables. The tools for statistical inference applied in this study include interval estimation and testing.

3.6.3.1 INTERVAL ESTIMATION

Interval estimation is a procedure for creating ranges of values also referred to as confidence intervals, in which the unknown parameters are likely to be located. Hill, Griffiths and Lim (2008) point out, that the procedure depends heavily on normality assumption (A7) of the regression model and the resulting normality of the of the least squares estimators. If the normality assumption does not hold, the sample size N must be sufficiently large so that the distributions of the least squares estimators are approximately normal, and the central limit theorem applies. By providing a range of values, interval estimation gives a sense of what the parameter value might be and of the precision of estimation. The probability statement outlined in Hill, Griffiths and Lim (2008)

$$P[b_k - t_c se(b_k) \leq \beta_k \leq b_k + t_c se(b_k)] = 1 - \alpha \tag{3.30}$$

implies that the interval $b_k \pm t_c se(b_k)$ has a probability $1 - \alpha$ of containing the true but unknown parameter β_k. The interval endpoints $b_k - t_c se(b_k)$ and $b_k + t_c se(b_k)$ define the interval estimator of β_k. The estimated values of $b_k \pm t_c se(b_k)$ for a given sample of data are called the $100(1 - \alpha)\%$ interval estimate of β_k or equivalently a $100(1 - \alpha)\%$ confidence interval. The properties of the interval estimation procedure are based on the notion of repeated sampling. That means for many random samples of size N then $100(1 - \alpha)\%$ of all the intervals constructed would contain the true parameter β_k. Hence, the confidence refers to the procedure used to construct the interval estimate rather than any one interval estimate from a sample data. Hill, Griffiths and Lim (2008) note that the point estimates b_k alone give no sense of reliability. In contrast, the interval estimates incorporate the point estimation with a measure of sampling variability to provide a range of values in which the unknown parameter might fall. A narrow interval estimate implies a low standard error due to a low sampling variability of the least squares estimator. This implies the least squares estimates are “reliable”. In contrast, if the least squares estimators suffer from large sampling variability, then the interval estimates will be wide, implying that the least squares estimates are “unreliable”.

3.6.3.2 TESTING

Another tool for statistical inference refers to hypothesis testing. Hill, Griffiths and Lim (2008) define hypothesis testing as a procedure for “comparing conjectures about the regression parameters to the parameter estimates obtained from the sample data”. Hypothesis tests use information about a parameter that is contained in a sample data, its least squares estimate, and its standard error, to draw a conclusion about the hypothesis. A hypothesis test involves 6 components:

(1) Regression model (test equation)
(2) Null hypothesis H_0
(3) Alternative hypothesis H_1
(4) Test statistic
(5) Rejection union
(6) Conclusion

As for interval estimation, the procedure depends heavily on the normality assumption (A7) of the regression model and the resulting normality of the of the ordinary least squares estimators. If the normality assumption does not hold, the sample size N must be sufficiently large so that the distributions of the least squares estimators are approximately normal following the central limit theorem. In what follows, the relevant test procedures will be outlined including (1) single hypothesis tests, (2) joint hypothesis tests and (3) specific tests for regression model diagnostics.

(1) SINGLE HYPOTHESIS TEST

For the general regression model of the form $y_t = \beta_1 + \beta_2 x_{t2} + \beta_K x_{tK} + e_t$ with $k = 1, \ldots, K$, the single null hypothesis H_0 specifies a value for a regression parameter β_k in the form

$$H_0: \beta_k = c \tag{3.31}$$

where c is a constant that reflects an important value in the context of the specific regression model. Paired with every null hypothesis is a logical alternative hypothesis H_1 which is accepted if the null hypothesis is rejected. The alternative hypothesis is flexible and depends to some extent on economic theory. One possible alternative hypothesis to H_0 is

$$H_1: \beta_k \neq c \tag{3.32}$$

A special characteristic of a test statistic is, that its probability distribution is completely known when the null hypothesis is true and has some other distribution if the null hypothesis is not true. Hill, Griffiths and Lim (2008) show that if the null hypothesis $H_0: \beta_k = c$ is true, then β_k can be substituted by c and it follows that t-statistic has a t-distribution with $N - K$ degrees of freedom:

$$t = \frac{b_k - c}{se(b_k)} \sim t_{(N-K)} \tag{3.33}$$

The rejection region depends on the form of the alternative hypothesis. It is the range of values of the test statistic that leads to a rejection of the null hypothesis. According to Hill, Griffiths and Lim (2008), the construction of a rejection union requires a test statistic whose distribution is known when the null hypothesis is true, an alternative hypothesis and a level of significance. The rejection union consists of values that are unlikely and have low probability of occurring when the null hypothesis is true. The choice of the probability α is called the level of significance of the test and provides a meaning for an unlikely event. Depending on the formulation of the hypothesis, it is distinguished between two-tail tests and one-tails tests for the right or left tail of the t-distribution. An alternative hypothesis of “smaller than” nature is tested with a left-tail test, while a “greater than” nature is tested with a right-tail test.

The rejection union depends on the tails that are tested and refers to a critical value t_c. A test statistic value greater than the critical value t_c leads to reject the null hypothesis and to accept the alternative hypothesis. A statistical hypothesis test also includes the report of the probability value p. A value $p = 0$ states a probability of 0%, a value $p = 1$ states a probability of 100% that the random sample is drawn from a population for which the null hypothesis is true. The comparison of the p value of a test with the chosen level of significance α allows for conclusions on the outcome of the test without referring of critical values. A null hypothesis is rejected, when the p value is less than or equal to the level of significance α. That means if $p \leq \alpha$, H_0 is rejected and if $p > \alpha$, H_0 is not rejected. The computation of the p value depends on the alternative hypothesis. If t is the calculated value of the t-statistic, then if $H_1: \beta_k > c$, value p is the probability to the right of t, if $H_1: \beta_k < c$, value p is the probability to the left of t, and if $H_1: \beta_k \neq c$, value p is the sum of probabilities to the right of t and to the left of $-t$. Table 3.11 summarises the components of the t-test as single hypothesis test in the one tail and two tail option following Hill, Griffiths and Lim (2008).

TABLE 3.11:
SINGLE HYPOTHESIS TEST PROCEDURE

	Right-tail test	Two-tail test
Regression model	$y_t = \beta_1 + \beta_2 x_{t2} + \beta_K x_{tK} + e_t, k = 1, \dots, K$	
Null hypothesis	$H_0: \beta_k = 0$	$H_0: \beta_k = 0$
Alternative hypothesis	$H_1: \beta_k > 0$	$H_1: \beta_k \neq 0$
Test statistic	$t = \frac{b_k - \beta_k}{se(b_k)} \sim t_{(N-K)}$	$t = \frac{b_k - \beta_k}{se(b_k)} \sim t_{(N-K)}$
Rejection union	t-value: $t \geq t_{(1-\alpha, N-K)}$ p-value: $p \leq \alpha$	t-value: $t \leq t_{(\alpha/2, N-K)}$ or $t \geq t_{(1-\alpha/2, N-K)}$ p-value: $p \leq \alpha$
Conclusion	H_0 is rejected: if $\beta_k > 0$ H_0 is not rejected: if $\beta_k = 0$	H_0 is rejected: if $\beta_k \neq 0$ H_0 is not rejected: if $\beta_k = 0$

The p value in the regression output corresponds to a two-tail test of significance for each coefficient with H_0: $\beta_k = 0$ against H_1: $\beta_k \neq 0$. An estimate is statistically different from zero at a level of significance α if $p \leq \alpha$.

(2) JOINT HYPOTHESIS TEST

There are many instances where tests involve more than one parameter, such as the test of the significance of a regression model. According to Hill, Griffiths and Lim (2008) a joint null hypothesis requires an F-test. Considering the general multiple regression model of the form $y_t = \beta_1 + \beta_2 x_{t2} + \beta_K x_{tK} + e_t$ with $k = 1, \ldots, K$, the overall significance of a regression model can be tested applying the hypotheses

$$\begin{aligned} &H_0\colon \beta_2 = 0, \ldots, \beta_K = 0 \\ &H_1\colon at\ least\ one\ of\ the\ \beta_k \neq 0\ for\ k = 2, \ldots, K \end{aligned} \tag{3.34}$$

The null hypothesis is joint because it has $J = K - 1$ restrictions and states the conjecture that every one of the parameters β_k other than the intercept parameter β_1 is zero. If the alternative hypothesis is true then at least one of the parameters β_k is not zero and should be included in the model. If the null hypothesis is true, then the statistic F has a F-distribution with J numerator degrees of freedom (m_1) and $N - K$ denominator degrees of freedom (m_2).

TABLE 3.12:
JOINT HYPOTHESIS TEST PROCEDURE

	Right-tail test
Regression model	$y_t = \beta_1 + \beta_2 x_{t2} + \beta_K x_{tK} + e_i, k = 1, \ldots, K$
Null hypothesis	$H_0\colon \beta_2 = 0, \ldots, \beta_K = 0$
Alternative hypothesis	$H_1\colon at\ least\ one\ of\ the\ \beta_k \neq 0\ for\ k = 2, \ldots, K$
Test statistic	$F = \dfrac{(SSE_R - SSE_U)/J}{SSE_U/(N-K)} \sim F_{(J,N-K)}$
Rejection union	F-value: $F \geq F_{(1-\alpha,J,N-K)}$ p-value: $p \leq \alpha$
Conclusion	H_0 is rejected: if $F \geq F_{(1-\alpha,J,N-K)}$ or $p \leq \alpha$ H_0 is not rejected: if $F < F_{(1-\alpha,J,N-K)}$ or $p > \alpha$

Asymmetrical distributions like the F distribution have only one right tail, hence there is no two-tail option for the F-test. Table 3.12 summarises the components of the F-test as joint hypothesis test procedure as outlined by Hill, Griffiths and Lim (2008, 135-140).

(3) TESTS FOR REGRESSION MODEL DIAGNOSTICS

Regression model diagnostics cover specific tests in order to check whether model assumptions on the relationship between independent and dependent variables hold. The choice of the appropriate test depends on the assumption that is to be tested as well as partly on the assumptions the tests itself relies on. Table 3.13 presents the tests for regression model diagnostics applied in this study along with their specific purpose as recommended by Hill, Griffiths and Lim (2008). The details on these test procedures are explained below.

TABLE 3.13:
TESTS FOR MODEL DIAGNOSTICS

ID	Name	Purpose
(3.1)	Augmented Dickey-Fuller test	Stationarity
(3.2)	Engle-Granger test	Cointegration
(3.3)	Breusch-Pagan / LM test	Homoscedasticity
(3.4)	Durbin-Watson test	Autocorrelation
(3.5)	Residual correlogram	Autocorrelation
(3.6)	Shapiro-Wilk test	Normality
(3.7)	Wald test	Quasi t-test and quasi F-test based on robust covariance matrix

(3.1) AUGMENTED DICKEY-FULLER TEST: The Dickey-Fuller test is a unit root test on stationarity (Dickey & Fuller, 1979). To perform this test, we assume an AR(1) process: $y_t = \rho y_{t-1} + v_t$ and want to determine whether $|\rho| = 1$ (unit root) against die alternative $|\rho| < 1$. An important extension of the Dickey-Fuller test is the augmented Dickey-Fuller test that allows for autocorrelated errors. In this version as many first difference terms $\sum_{s=1}^{m} \delta_s \Delta y_{t-s}$ where $\Delta y_{t-1} = (y_{t-1} - y_{t-2})$ are added as needed in order to ensure that residuals are not correlated. There are three options of this test that account for stochastic processes that reflect (1) a pure random walk (unit root), (2) a random walk (unit root) with drift by including a constant term and

(3) a random walk (unit root) with drift and linear time trend by including a trend term as shown in Table 3.14. For a more convenient form, the equations include the transformations $\gamma = \rho - 1$ and $\Delta y_t = y_t - y_{t-1}$ of the basic AR(1) model.

TABLE 3.14:
REGRESSION MODELS FOR STATIONARITY TEST

ID	Stochastic Process	Model
(1)	Random walk	$\Delta y_t = \gamma y_{t-1} + \sum_{s=1}^{m} \delta_s \Delta y_{t-s} + \nu_t$
(2)	Random walk with drift	$\Delta y_t = \alpha + \gamma y_{t-1} + \sum_{s=1}^{m} \delta_s \Delta y_{t-s} + \nu_t$
(3)	Random walk with drift and linear time trend	$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \sum_{s=1}^{m} \delta_s \Delta y_{t-s} + \nu_t$

The choice of the appropriate regression model is based on a visual inspection of the time series as well as a general-to-specific approach by first using a test equation (3) with a drift and time trend, then (2) with a drift and finally (1) the pure random walk. The inclusion of lags of the dependent variable can be used to eliminate autocorrelation in the error. The number of lagged terms is determined based on a residual correlogram of the estimated residuals $\hat{\nu}_t$.

The unit root is tested by a t-test on the left tail. When the null hypothesis $H_0: \gamma = 0$ is true, then the first-order autoregressive process $y_t = \rho y_{t-1} + \nu_t$ has a coefficient of unity $\rho = 1$, which implies a random walk that is nonstationary. It is to note that if we are unable to reject the null hypothesis of a unit root, it would imply that the series y_t is integrated of order 1, such that $y_t \sim I(1)$ (Kotzé, 2022). In this case, the variance increases with the sample size, which alters the distribution of the regular t-statistic. Therefore, the statistic is often called tau (τ) statistic and its value must be compared to specially generated critical values (Hill, Griffiths & Lim, 2008). The alternative hypothesis takes the form $H_1: \gamma < 0$ and implies that y_t is stationary, such that $y_t \sim I(0)$. The critical values τ_c are taken from Davidson and MacKinnon (1993, p. 708) and depend on the regression model, sample size (N) as well as the confidence level (α).

The procedure involves several steps that are iteratively carried out for the stochastic processes in the general-to-specific approach:

(1) Visual inspection of series y_t

(2) Estimation of test equation of the Dickey-Fuller test (non-augmented)

(3) Residual correlogram to test for autocorrelation of residuals v_t

(4) If autocorrelation is present: augmented Dickey-Fuller test by including the appropriate number of first difference terms, otherwise Dickey-Fuller test

(5) Comparison of test statistic DF_τ to model specific critical value

Table 3.15 presents the components of the augmented Dickey-Fuller test on stationary with the three options following Hill, Griffiths and Lim (2008).

TABLE 3.15:
AUGMENTED DICKEY-FULLER TEST ON STATIONARITY

	Left-tail test
Regression model	(1) $\Delta y_t = \gamma y_{t-1} + \sum_{s=1}^{m} \delta_s \, \Delta y_{t-s} + v_t$ (2) $\Delta y_t = \alpha + \gamma y_{t-1} + \sum_{s=1}^{m} \delta_s \, \Delta y_{t-s} + v_t$ (3) $\Delta y_t = \alpha + \gamma y_{t-1} + \lambda t + \sum_{s=1}^{m} \delta_s \, \Delta y_{t-s} + v_t$
Null hypothesis	$H_0: \gamma = 0$ $(unit\ root \rightarrow no\ stationarity)$
Alternative hypothesis	$H_1: \gamma < 0$ $(no\ unit\ root \rightarrow stationarity)$
Test statistic	$DF_\tau = \dfrac{\hat{\tau}}{se(\hat{\tau})}$
Rejection union	tau-value: $\tau \leq \tau_c$ p-value: $p \leq \alpha$
Conclusion	H_0 is rejected: stationarity H_0 is not rejected: no stationarity

(3.2) ENGLE-GRANGER TEST: The Engle-Granger test is a two-step test procedure on the cointegration of time series (Engle & Granger, 1987). Hill, Griffiths and Lim (2008) note that “the test for cointegration is effectively a test of the stationarity of the residuals” (p. 339). The way to check whether y_t and x_t are cointegrated is (1) to estimate the regression $y_t = \beta_1 + \beta_2 x_t + e_t$ and (2) to test whether the estimated least squares residuals $\hat{e}_t = y_t - b_1 - b_2 x_t$ are stationary. The test regression has no constant because the regression residual mean is zero. The inclusion of lags of the dependent variable can be used to eliminate autocorrelation in the error. The number of lagged terms is determined based on a residual correlogram of the estimated residuals $\hat{v}_t$.

Since this one-sided test is based on estimated values of the residuals $\hat{e}_t$, specific critical values apply depending on the functional from of the original regression model, from which the estimated residuals $\hat{e}_t$ were derived from. It is distinguished between regression equations with (1) no constant term, (2) constant term and (3) constant term and time trend as presented in Table 3.16.

TABLE 3.16:
REGRESSION MODELS FOR COINTEGRATION TEST

ID	Components	Regression model
(1)	No constant term	$y_t = \beta x_t + e_t$
(2)	Constant term	$y_t = \beta_1 + \beta_2 x_t + e_t$
(3)	Constant term and time trend	$y_t = \beta_1 + \delta t + \beta_2 x_t + e_t$

The critical values τ_c for the cointegration test are taken from Hamilton (1994, p. 766) and depend on the original regression model, sample size (N) as well as the confidence level (α). A rejection of the null hypothesis that the series are not cointegrated leads to the conclusion that the residuals are stationary and hence the series are cointegrated. In this case, a fundamental relationship exists between the variables and the relationship is not spurious. Table 3.17 presents the procedure of the Engle-Granger test on cointegration as outlined in Hill, Griffiths and Lim (2008).

TABLE 3.17:
ENGLE-GRANGER TEST ON COINTEGRATION

Test	Engle-Granger test on cointegration (left tail)
Regression model	$\Delta\hat{e}_t = \gamma\hat{e}_{t-1} + \sum_{s=1}^{m} \delta_s \Delta\hat{e}_{t-s} + v_t$
Null hypothesis	$H_0: \gamma = 0$ $(unit\ root \rightarrow no\ cointegration)$
Alternative hypothesis	$H_1: \gamma < 0$ $(no\ unit\ root \rightarrow cointegration)$
Test statistic	$EG_\tau = \frac{\hat{t}}{se(\hat{t})}$
Rejection union	tau-value: $\tau \leq \tau_c$ p-value: $p \leq \alpha$
Conclusion	H_0 is rejected: cointegration H_0 is not rejected: no cointegration

(3.3) BREUSCH-PAGAN TEST: The Breusch-Pagan test is used for detecting heteroscedasticity in the errors (Breusch & Pagan, 1997). Like an F random variable, a χ^2 random variable has an asymmetric distribution that takes only positive values. The Breusch-Pagan test is also called Lagrange multiplier (LM) test and valid for large samples. The Breusch-Pagan test procedure is summarised in Table 3.18 following Hill, Griffiths and Lim (2008).

TABLE 3.18:
BREUSCH-PAGAN TEST FOR HETEROSCEDASTICITY

	Right-tail test
Regression model	$\hat{e}_t^2 = \alpha_1 + \alpha_2 z_{t2} + \cdots + \alpha_S z_{tS} + v_t$
Null hypothesis	$H_0: \alpha_2 = \alpha_3 = \cdots = \alpha_S = 0$ $(homoscedasticity)$
Alternative hypothesis	$H_1: not\ all\ the\ \alpha_S\ in\ H_0\ are\ zero$ $(heteroscedasticity)$
Test statistic	$\chi^2 = N \times R^2 \sim \chi^2_{S-1}$
Rejection union	χ^2-value: $\chi^2 \geq \chi^2_{(1-\alpha,S-1)}$ p-value: $p \leq \alpha$
Conclusion	H_0 is rejected: heteroscedasticity H_0 is not rejected: homoscedasticity

(3.4) DURBIN-WATSON TEST: The Durbin-Watson test is a traditional test for autocorrelation of errors (Durbin & Watson, 1959). The d-statistic can take a value between 0 and 4. A d-value close to 2 is an indication that the model residuals are not autocorrelated. The probability distribution $f(d)$ depends on the explanatory variables of the regression model. Therefore, the critical value d_c depends on the explanatory variables as well. In contrast, critical values of other test statistics such as t, F and χ^2 are relevant for all models. To overcome that problem, the R software computes the p-value for the explanatory variables of the regression model under consideration. The Durbin-Watson test does not rely on large sample approximation. The test procedure is summarised in Table 3.19 in line with Hill, Griffiths and Lim (2008).

TABLE 3.19:
DURBIN-WATSON TEST FOR AUTOCORRELATION

	Left-tail test
Regression model	$e_t = \rho e_{t-1} + v_t$
Null hypothesis	$H_0: \rho = 0$ $(no\ autocorrelation, \quad d \approx 2)$
Alternative hypothesis	$H_1: \rho > 0$ $(positive\ autocorrelation, \quad d \approx 0)$
Test statistic	$d = \frac{\sum_{t=2}^{T} (\hat{e}_t - \hat{e}_{t-1})^2}{\sum_{t=2}^{T} \hat{e}_t{}^2}$
Rejection union	d-value: $d \leq d_c$ p-value: $p \leq \alpha$
Conclusion	H_0 is rejected: positive autocorrelation H_0 is not rejected: no autocorrelation

(3.5) RESIDUAL CORRELOGRAM: Hill, Griffiths and Lim (2008) point out, that the residual correlogram as another testing procedure for the autocorrelation of residuals has a broader applicability compared to the traditional Durbin-Watson test. The correlogram of residuals shows the correlations r_k between the residuals $\hat{e}_t$ and $\hat{e}_{t-k}$, that are k periods apart. The test procedure of the residual correlogram is presented in Table 3.20 following Hill, Griffiths and Lim (2008).

TABLE 3.20:
RESIDUAL CORRELOGRAM ON AUTOCORRELATION

	Two-tail test
Regression model	$e_t = \rho e_{t-1} + v_t$
Null hypothesis	$H_0: \rho = 0$ $(no\ autocorrelation)$
Alternative hypothesis	$H_1: \rho \neq 0$ $(autocorrelation)$
Test statistic	$Z = \sqrt{T} r_k \sim N(0,1)$
Rejection union	r_k-value: $-\frac{1.96}{\sqrt{T}} \leq r_k \geq \frac{1.96}{\sqrt{T}}$ for $\alpha = 0.05$ p-value: $p \leq \alpha$
Conclusion	H_0 is rejected: autocorrelation H_0 is not rejected: no autocorrelation

(3.6) SHAPIRO-WILK TEST: The Shapiro-Wilk test is a procedure to test if a random sample X is drawn from a Gaussian normal probability distribution with true mean μ and variance σ^2 (Shapiro & Wilk, 1965). The W-statistic can take a value between 0 and 1. The closer the W-value is to 1, the less deviation is shown by the true sample variance from the hypothetical variance of a normal distribution. As is generally true for test procedures, the Shapiro-Wilk test has the advantage that it offers an objective measure to evaluate the hypotheses in contrast to the more subjective visual inspection of the distribution of errors, such as a QQ-plot. The Shapiro-Wilk test has high testing power for small samples with $n < 50$. However, there are also disadvantages. Since the test objective of detecting a normal distribution is placed in the null hypothesis, almost each distribution can be tested as normal distribution, if the level of significance is chosen small enough. That means, the test design carries a high probability of a type 2 error by erroneous concluding the presence of a normal distribution. Furthermore, the test is sensitive to outliers and ties, that is the presence of many identical values. Table 3.21 summarises the test procedure as outlined in Royston (1992).

TABLE 3.21:
SHAPIRO-WILK TEST ON NORMALITY

	Left-tail test
Regression model	$\hat{e}_t = y_t - \beta_1 - \beta_2 x_{t2} - \beta_K x_{tK}$
Null hypothesis	$H_0: \hat{e}_t \sim N(\mu, \sigma^2)$ $(normal\ distribution)$
Alternative hypothesis	$H_1: \hat{e}_t\ does\ not\ follow\ N(\mu, \sigma^2)$ $(no\ normal\ distribution)$
Test statistic	$W = \frac{\sum_{t=1}^{n}(\alpha_t \hat{e}_{(t)})^2}{\sum_{t=1}^{n}(\hat{e}_t - \bar{e})^2} \sim N_{(\mu,\sigma^2)}$
Rejection union	W-value: $W \leq W_{c_{(\alpha,\mu,\sigma^2)}}$ p-value: $p \leq \alpha$
Conclusion	H_0 is rejected: no normal distribution H_0 is not rejected: normal distribution

(3.7) WALD TEST: Wooldridge (2008) recommends the asymptotic Wald test procedure as quasi t-test and quasi F-test if a heteroscedasticity and autocorrelation robust variance-covariance matrix is applied. The Wald test procedure for testing a single or joint hypothesis on the parameters β is equivalent to that of the t-test or F-test, respectively. A Wald-statistic that is robust to heteroscedasticity and autocorrelation is obtained by using an estimated HAC matrix as outlined in chapter 3.6.2.2 "Robust Standard Errors" (Wald, 1943). Table 3.22 shows the Wald test procedure for a joint hypothesis following Wooldridge (2008).

TABLE 3.22:
ROBUST WALD TEST FOR JOINT HYPOTHESIS

	Right-tail test
Regression model	$y_t = \beta_1 + \beta_2 x_{t2} + \beta_K x_{tK} + e_t, \qquad k = 1, \ldots, K$
Null hypothesis	$H_0: \beta_2 = 0, \ldots, \beta_K = 0$
Alternative hypothesis	$H_1: at\ least\ one\ of\ the\ \beta_k \neq 0\ for\ k = 2, \ldots, K)$
Test statistic	$W \sim F_{(K-1, N-K)}$
Rejection union	W-value: $W \geq F_{(1-\alpha, K-1, N-K)}$ p-value: $p \leq \alpha$
Conclusion	H_0 is rejected: at least one parameter is statistically significant H_0 is not rejected: all parameters β_k are statistically insignificant

3.7 ETHICAL CONSIDERATIONS

All research procedures in this study comply with the University of Gloucestershire's research ethics, specified in "Research Ethics: A Handbook of Principles and Procedures" (2022).

According to these research ethics, the "primary responsibility for the conduct of ethical research lies with the researcher". This research is conducted under consideration of the responsibilities of the researcher, which comprise the responsibility (1) towards research participants with respect to their physical, social and psychological well-being, (2) towards other researchers with respect to adverse consequences and reputation of their discipline and (3) towards the environment with respect to sustainability of natural resources and general environmental protection.

The empirical part of this research builds up on a regression analysis based on secondary data collected and published by the German Central Bank (2021). In compliance with the applicable regulation on data protection in Germany, the German Central Bank ensures anonymity through the process of pooling before the data gets published. Hence, the empirical analysis of this study complies to the principles of data protection as the results apply to the pool of German commercial banks and do not allow for conclusions on a single bank or even its customers. The researcher avoids any deception and respects that the German Central Bank protects the anonymity and privacy of the entities whose data were collected.

3.8 CHAPTER CONCLUSION

This chapter focuses on the methodology of this research, which is conducted under the Post-Positivist paradigm of research. In a deductive approach, theories and concepts constitute the starting point of the research and lead to a theoretical representation on the risk channel of monetary transmission. That theory is the basis for the derivation of the hypotheses, which are tested on secondary data of German commercial banks in the empirical analysis of this study. The hypotheses reflect propositions on the relationship between the explanatory variable ECB interest rate on main refinancing operations and the dependent variables credit risk perception, credit allocation risk-taking and interest rate risk-taking.

The research design is driven by the Post-Positivist objective to explain the real-world phenomenon “risk channel in the TMMP” by identifying the operating mechanism behind. The empirical analysis comprises a regression analysis on data of German commercial banks that is performed in the statistical software package R. The frontloaded procedure follows clear programmatic steps and has the objective to test the hypotheses on the relationship between monetary policy and the risk perception or risk-taking of commercial banks. It may be noted that the objective is not to specify a regression model for the purpose of making predictions, but to examine the causal relationship between monetary policy and risk in the German bank sector.

The entire research is conducted in compliance with the University of Gloucestershire’s research ethics, specified in “Research Ethics: A Handbook of Principles and Procedures” (2022).

4 EMPIRICAL ANALYSIS

4.1 CHAPTER INTRODUCTION

This chapter follows the objective to empirically test the hypotheses derived chapter 3.4.2 from the theoretical representation of the risk channel in the TMMP. The corresponding regression analysis is structured in the presentation of the data sample, descriptive statistics, specification of the econometric model, time series diagnostics, regression model diagnostics, hypothesis test, regression results and finally a regression evaluation.

To recap the relevant key results of chapter 2 "Literature Review" and chapter 3 "Methodology", the foundations for the regression analysis are summarised in what follows. First, this concerns the economic model derived of the theoretical representation of the risk channel of monetary transmission. The functional relationships indicate that risk perception of commercial banks ($RPER$) may relate positively with the monetary policy rate of interest (MPR) and the method of risk measurement (MRM). Risk-taking of commercial banks ($RTAK$) may relate negatively with the monetary policy rate of interest (MPR) and the method of risk measurement (MRM) and positively on the profit target (MPR). The corresponding economic model can be expressed in the following functional form:

$$\begin{aligned} RPER &= f(+MPR, +MRM) \\ RTAK &= f(-MPR, -MRM, +PTAR) \end{aligned} \tag{4.1}$$

Derived from this economic model, the hypotheses for the empirical test based on a regression analysis are visualised in Figure 4.1. The 3 research hypotheses refer to the causal relationship between the base rate of interest as the monetary policy instrument of the central bank and credit risk perception, credit risk-taking and interest rate risk-taking representing the risk channel mechanism of monetary transmission.

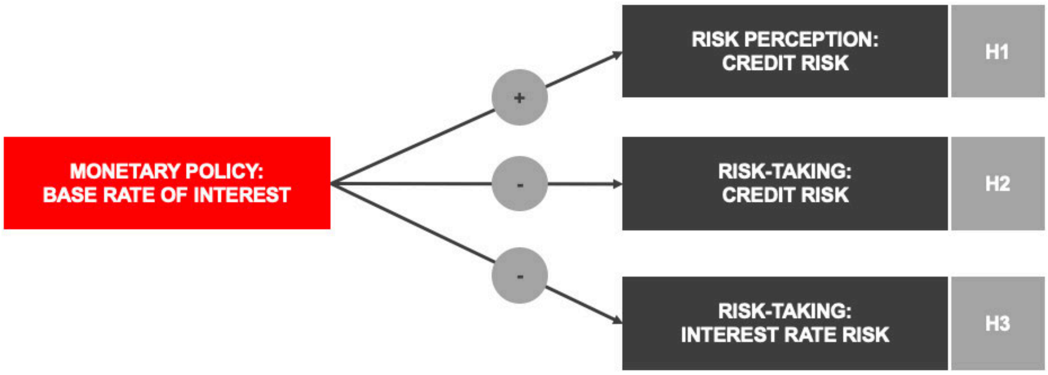


FIGURE 4.1:
HYPOTHESES

Source: author's illustration

The corresponding hypotheses statements are listed below.

H1: There is a positive relationship between the central bank's monetary policy rate of interest and the perception of credit risk in the balance sheet of commercial banks (ceteris paribus). $RPER_{CRR} = f(+MPR)$

H2: There is a negative relationship between the central bank's monetary policy rate of interest and risk-taking in terms of credit risk in the balance sheet of commercial banks (ceteris paribus). $RTAK_{CRR} = f(-MPR)$

H3: There is a negative relationship between the central bank's monetary policy rate of interest and risk-taking in terms of interest rate risk in the balance sheet of commercial banks (ceteris paribus). $RTAK_{IRR} = f(-MPR)$

For each hypotheses test, a specific regression model will be specified as shown in Table 4.1.

TABLE 4.1:
HYPOTHESES AND REGRESSION MODEL

Hypothesis	Regression Model	Dependent Variable
H1: $RPER_{CRR} = f(+MPR)$	M1 CRP: 1 Credit risk perception	RWAD: RWA Density
H2: $RTAK_{CRR} = f(-MPR)$	M2 CART: 2 Credit risk-taking	RLS: Risky Loan Share
H3: $RTAK_{IRR} = f(-MPR)$	M3 IRRT: 3 Interest rate risk-taking	NAD: Net Asset Duration

4.2 DATA SAMPLE

To test the hypotheses stated in chapter 3.4.2 "Hypotheses" the time-series data collected by the German Central Bank as introduced in chapter 3.5 "Data Collection" is applied in a regression analysis. To recall, Table 4.2 summarises the variables in the 3 data sets by contrasting the economic model variables and the empirical variables in the econometric model that are used as proxy.

TABLE 4.2:
VARIABLES FOR REGRESSION ANALYSIS

Economic Model	Econometric Model
Time	TIME
Commercial bank	BANK.GROUP
Method of risk measurement	BUSINESS.AREA
Base rate of interest	ECB.MRO
Risk perception - credit risk	RWAD
Risk-taking - credit risk	RLS
Risk-taking - interest rate risk	NAD

The data set includes the dimension time (TIME) and dummy variables reflecting the bank group (BANK.GROUP) or business area (BUSINESS AREA) respectively. The categorial variable bank group allows to distinguish between credit cooperatives (BG.CC), Savings Banks (BG.SB), large, significant institutions (BG.LSI) as well as small and medium sized commercial banks (BG.SMCB). The categorial variable business area includes retails loans (BA.RTL) and loans to enterprises (BA.ETP) and approximates differences in the method of risk measurement which is more sophisticated in the business area of loans to enterprises. The ECB interest rate on main refinancing operations (ECB.MRO) takes the role of the explanatory variable in the regression analysis and operationalises the monetary policy rate of interest of the central bank in the economic model. RWA density (RWAD), Risky Loan Share (RLS) and Net Asset Duration (NAD) take the role of the response variable in the respective econometric model and operationalise "risk perception" and "risk-taking", respectively.

4.2.1 DATA SAMPLE POPULATION

The aim of this research study is to explain the underlying mechanism of the risk channel in monetary transmission of monetary policy of the ECB for the EMU by investigating data of German commercial banks covering the time period 2002 to 2019. The population of this research in general are commercial banks in the countries that belong to the European Monetary Union.

In this research the term “commercial banks” refers to monetary financial institutions that engage in the commercial bank business including deposits, lending business and transactions. Those banks are particularly subject to the TMMP conducted by the ECB to the EMU due to their high reliance on central bank liquidity (Borio & Zhu, 2012). For the purpose of bank statistics, the German Central Bank (2020b) divides German (commercial) banks into the following groups: Credit cooperatives (CC), Savings banks (SB), Commercial banks[30] (CB), Building and loan associations (BLA), Banks with special, development and other central support tasks (BCST), Mortgage banks (MB) and Regional banks (RB). As of December 2019, Figure 4.2 presents the number and balance sheet total of commercial banks in Germany by bank group based on the bank statistics of the German Central Bank. (2020b). Commercial bank means monetary financial institution (MFI) excluding foreign branches, money market funds and the German Central Bank. Balance sheet total refers to the total amount of assets and liabilities in the balance sheet of a bank.

[30] The group of commercial banks in the categorisation of the balance sheet statistics of the German Central Bank can be imagined as a subgroup of “credit banks” in Germany that exists besides other subgroups that represent commercial banks, as well, but exercise a specific role. It does not imply that the banks in other subgroups are no “commercial banks” as in the notion of this study.

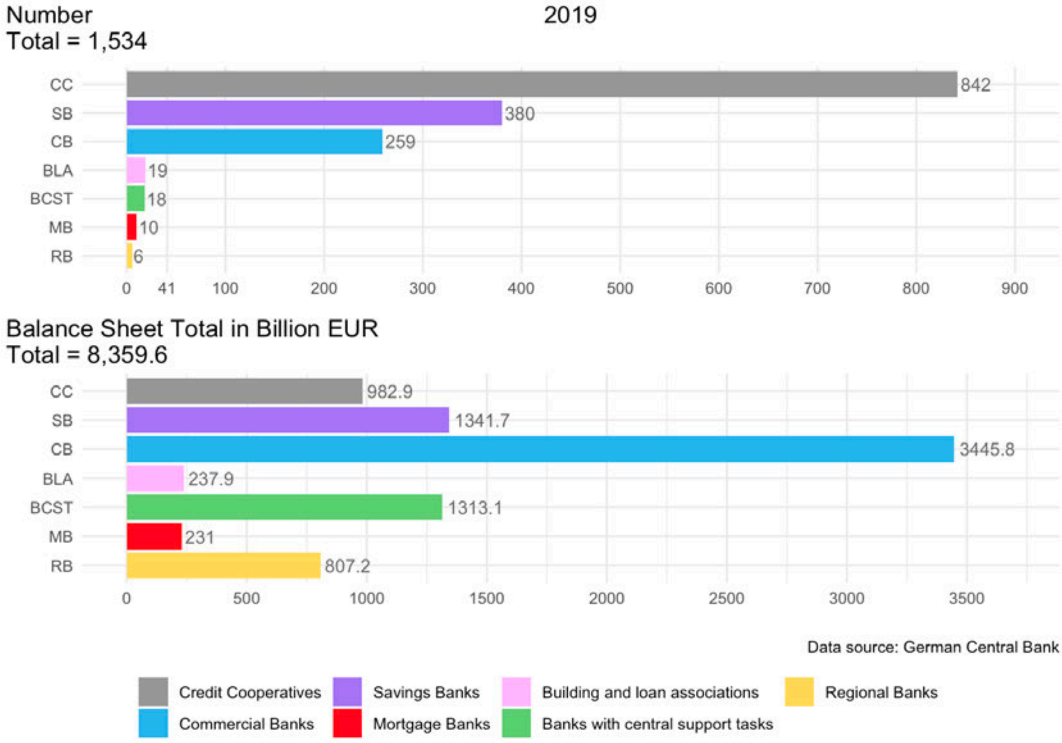


FIGURE 4.2:
COMMERCIAL BANKS IN GERMANY

Source: author's R output

The 1,534 German banks together generated a balance sheet total of 8,359.6 billion EUR at the reporting date end of December 2019. While the group of credit cooperatives shows the highest number of banks with 842, the group of commercial banks had the highest balance sheet total with 3,445.8 billion EUR (German Central Bank, 2020b).

Other categorisations of bank groups do exist that are applied by authorities in the context of macroprudential bank regulation, such as LSI and IRBA banks, among others. The group of LSI banks refers to large, systemically important banks in the statistics of the German Central Bank, which comprises in 2019 for Germany the 13 other systemically important institutions (O-SII) of the regulatory view of the ECB (German Central Bank, 2020a). According to the German Federal Financial Supervisory Authority (2020) the group of IRBA banks includes the 41 banks that apply the regulatory Internal Ratings Based Approach (IRBA) for the calculation of risk weighted assets as opposed to the other banks that use the regulatory standardised approach (SA). Although the number of 41 IRBA banks seems small in relation to the total number of 1,534 banks in Germany, the German Central Bank (2020a) reports that these IRBA banks are the ones with the largest portfolios that account in terms of lending for around one-third of the German banking system.

The data samples on the Risky Loan Share (RLS) and Net Asset Duration (NAD) comprises all of the 1,534 German banks. The size of the data sample on RWA density (RWAD) is restricted to German IRBA banks by the German Central Bank. The reason for collecting the RWA density data only from IRBA banks is that measures on changes in risk perception over time such as risk weighted assets (RWA) are better visible for IRBA banks that apply their own internal models for calculating credit risk, while risk weights in the standardised approach tend to be rather stable over time since they depend heavily on factors that barely vary with the business cycle, such as the exposure class. Therefore, the use of a subsample for risk perception indicated by RWA density can be justified by methodological reasons. To sum up, the data samples applied in this study for each of the 3 dependent variables collected by the German Central Bank cover German banks as follows:

- RWA density (RWAD): 41 German IRBA banks
- Risky Loan Share (RLS): 1,534 German commercial banks
- Net Asset Duration (NAD): 1,534 German commercial banks

4.2.2 DATA SAMPLE PREPARATION

The preparation of the 8 times series collected by the German Central Bank as introduced in chapter 3.5 covers the following steps:

(1) Merging the time series
(2) Calculations
(3) Coding dummy variables
(4) Specification and labelling
(5) Quality checks
(6) Slicing into 3 data samples for the 3 econometric models

4.2.2.1 MERGING

The merge of the 8 time series to one data set is done with reference to the common variable TIME, which is called the foreign key in data science. That means the quantitative variables ECB.MRO, RWAD, RLS and NAD are combined as columns of one table based on the foreign key column TIME. Additionally, new variables result from the pooling category, that is the BUSINESS.AREA and the BANK.GROUP which take the role of categorical control variables in the empirical analysis.

4.2.2.2 CALCULATIONS

A calculation is necessary for time series (1) on the ECB interest rate on main refinancing operations ($ECB.MRO$), because is collected in monthly frequency as opposed to the other time series which are collected in a quarterly frequency. The quarterly average of the ECB MRO is calculated as the sum of the 3 months of each quarter divided by 3:

$$ECB.MRO_q = \frac{ECB.MRO_{mq} + ECB.MRO_{mq} + ECB.MRO_{mq}}{3} \tag{4.2}$$

where

$ECB.MRO_q$ = ECB MRO quarterly average

$ECB.MRO_{mq}$ = ECB MRO at the end of month m with $m = (1, 2, 3)$ of the respective quarter q with $q = (1, 2, 3, 4)$

The resulting data set contains quarterly data that consists of quantitative and qualitative variables. Table 4.3 presents the structure of the data set describing each column in terms of the reference to the economic model, the variable name in the econometric model, the specification and role in regression analysis.

TABLE 4.3:
DATA SET AFTER STEP 2

Economic Model	Econometric Model
Time	TIME
Commercial bank	BANK.GROUP
Method of risk measurement	BUSINESS.AREA
Base rate of interest	ECB.MRO
Risk perception (credit risk)	RWAD
Risk-taking (credit risk)	RLS
Risk-taking (interest rate risk)	NAD

4.2.2.3 CODING DUMMY VARIABLES

Dummy variables are coded with the values 0 and 1 depending on the categorial variable. A dichotomous dummy variable is created for the business area of loans to enterprises ($BA.ETP$), which is coded 0 for retail loans (RTL) and 1 for loans to enterprises (ETP):

$$BA.ETP = \begin{cases} 0 \; for \; RTL \\ 1 \; for \; ETP \end{cases} \tag{4.3}$$

A polytomous dummy variable for the 4 bank groups is coded with credit cooperatives (CC) building the baseline group. Hence, 3 dummy variables are included for Savings banks (SB), large, systemically important institutions (LSI) and small and medium sized commercial banks (SMCB). The dummies are coded 1 for the respective bank group and 0 otherwise:

$$BG.SB = \begin{cases} 1 \; for \; SB \\ 0 \; otherwise \end{cases} \tag{4.4}$$

$$BG.LSI = \begin{cases} 1 \; for \; LSI \\ 0 \; otherwise \end{cases} \tag{4.5}$$

$$BG.SMCB = \begin{cases} 1 \; for \; SMCB \\ 0 \; otherwise \end{cases} \tag{4.6}$$

4.2.2.4 SPECIFICATION AND LABELLING

Each column is specified in terms of the data type. Furthermore, the technical names of the econometric model are supplemented with labels that can be used in the output. The resulting data set takes the following form:

TABLE 4.4:
DATA SET AFTER STEP 4

Econometric Model	Specification	Label
TIME	date (YYYY-MM-DD)	Time
BANK.GROUP	character (CC, SB, LSI, SMCB)	Bank Group
BG.SB	dummy (0, 1) with 1 for SB	Savings Banks
BG.LSI	dummy (0, 1) with 1 for LSI	Large, Systemically Important Institutions
BG.SMCB	dummy (0, 1) with 1 for SMCB	Small and Medium Sized Commercial Banks
BUSINESS.AREA	character (RTL, ETP)	Business Area
BA.ETP	dummy (0, 1) with 1 for ETP	Loans to enterprises
ECB.MRO	Numeric	ECB MRO (%)
RWAD	Numeric	RWA Density (%)
RLS	Numeric	Risky Loan Share (%)
NAD	Numeric	Net Asset Duration (years)

4.2.2.5 QUALITY CHECKS

The quality of the data set in Table 4.4 is ensured based on the following checks:

(1) Successful import of the 8 time series

(2) Unique technical name of each column

(3) Correct assignment of data type of each column

(4) Unique and correct label of each column

(5) Correct coding of categorial dummy variables

(6) No missing values

(7) Successful storing of the prepared data set that passed all quality checks

The quality measures were successfully conducted with no need for treatment of missing values. This stage of data preparation does not include data transformations such as logs or first differences of quantitative variables or the construction of interaction variables, because this conducted in the specification of the econometric model as needed.

4.2.2.6 SLICING

Finally, the prepared data set is sliced into 3 data sets (D1, D2 and D3), each corresponding to 1 of the 3 regression models:

- Regression model 1 "Credit Risk Perception" (M1 CRP),
- Regression model 2 "Credit Allocation Risk-Taking" (M2 CART)
- Regression model 3 "Interest Rate Risk-Taking" (M3 IRRT)

The 3 resulting data sets differ in the dependent variable and category variables. Table 4.5 presents the final data sets after preparation that are applied in the regression analysis.

TABLE 4.5:
DATA SETS FOR REGRESSION MODELS

Data Set	D1	D2	D3
Regression Model	M1 CRP	M2 CART	M3 IRRT
Time	TIME	TIME	TIME
Independent	**ECB.MRO**	**ECB.MRO**	**ECB.MRO**
Dependent	**RWAD**	**RLS**	**NAD**
Category	BA		BG
Category (Dummy)	BA.ETP		BG.SB
Category (Dummy)			BG.LSI
Category (Dummy)			BG.SMCB

4.3 DESCRIPTIVE STATISTICS

The descriptive statistics summarise the characteristics of the data set used in the respective regression model. Descriptive statistics refer to two basic categories of measures: measures of central tendency and measures of variability (Hill, Griffiths and Lim, 2008). Measures of central tendency describe the centre of a data sample, such as mean, median and mode. Measures of variability or spread describe the dispersion of data within the sample, such as standard deviation, variance, minimum, maximum, percentiles, kurtosis and skewness.

The following subchapters introduce the regression analysis with a descriptive statistic of the relevant data set for each of the 3 regression models. The corresponding measures comprise the number of categories (n), the number of time observations (N), mean, standard deviation (SD), minimum (Min), 25th percentile (P25), 75th percentile (P75) and maximum (Max). The 25th percentile means that 25% of the values fall below that 1st quartile, analogously the 75th percentile means that 75% of the values fall below that 3rd quartile.

4.3.1 MODEL 1: CREDIT RISK PERCEPTION

In preview of the following chapter, the series under consideration will be used in an econometric model that takes the following form:

$$\begin{aligned} RWAD_t = \alpha + \beta\, ECB.MRO_t + \gamma\, BA.ETP_t \\ + \delta_1\,(BA.ETP_t \times ECB.MRO_t) \\ + \delta_2\,(BA.ETP_t \times ECB.MRO_t^2) + e_t, \\ t = 1, \dots, N \end{aligned} \tag{4.7}$$

The descriptive statistics of the time series for regression model 1 on credit risk perception (M1 CRP) is summarised in Table 4.6 including the dimensions as well as the descriptive measures.

TABLE 4.6:
M1 CRP - DESCRIPTIVE STATISTICS

Dimensions		
Category	BUSINESS.AREA	n = 2
Time	TIME	N = 46

Descriptive Measures							
Statistic	N	Mean	SD	Min	P25	P75	Max
$RWAD_{RTL}$	46	23.77	3.02	20.41	22.04	24.35	33.40
$RWAD_{ETP}$	46	40.64	8.48	29.11	33.56	45.88	57.79
ECB.MRO	46	0.84	1.15	0.00	0.01	1.00	4.08

The dimensions refer to the indices of the quantitative variables and state that the observations cover 46 time observations in quarterly frequency from 2008-Q1 to 2019-Q2 as well as 2 categories for the business area including retail loans and loans to enterprises. This implies a data sample of 92 tuples in total.

4.3.2 MODEL 2: CREDIT ALLOCATION RISK-TAKING

In preview of the following chapter, the series under consideration will be used in an econometric model that takes the following form:

$$RLS_t = \beta_0 + \beta_1 ECB.MRO_t + \beta_2 ECB\_MRO_t^2 + e_t, \quad t = 1, \dots, N \tag{4.8}$$

The descriptive statistics of the time series for regression model 2 on credit allocation risk taking (M2 CART) is summarised in Table 4.7 including the dimensions as well as the descriptive measures.

TABLE 4.7:
M2 CART - DESCRIPTIVE STATISTICS

Dimensions		
Category	-	-
Time	TIME	N = 68

Descriptive Statistics							
Statistic	N	Mean	SD	Min	P25	P75	Max
RLS	68	39.06	3.92	28.15	35.99	42.07	45.84
ECB.MRO	68	1.51	1.33	0.00	0.16	2.46	4.08

The dimensions refer to the indices of the quantitative variables and state that the observations cover 68 time observations in quarterly frequency from 2002-Q1 to 2018-Q4 and no categories.

4.3.3 MODEL 3: INTEREST RATE RISK-TAKING

In preview of the following chapter, the series under consideration will be used in an econometric model that takes the following form:

$$\begin{aligned} NAD_t &= \alpha + \delta_1\, BG.SB_t + \delta_2\, BG.LSI_t + \delta_3\, BG.SMCB_t \\ &\quad + \beta\, ECB.MRO_t + e_t, \\ &\qquad t = 1, \dots, N \end{aligned} \tag{4.9}$$

The descriptive statistics of the time series for regression model 3 on interest rate risk-taking (M3 IRRT) is summarised in Table 4.8 including the dimensions as well as the descriptive measures.

TABLE 4.8:
M3 IRRT - DESCRIPTIVE STATISTICS

Dimensions		
Category	BANK.GROUP	N = 4
Time	TIME	N = 30

Descriptive Statistics							
Statistic	N	Mean	SD	Min	P25	P75	Max
NAD_{CC}	30	7.93	0.99	6.23	7.21	8.77	9.41
NAD_{SB}	30	7.11	0.54	6.10	6.78	7.51	8.02
NAD_{LSI}	30	1.87	0.80	0.11	1.45	2.43	3.49
NAD_{SMCB}	30	1.24	0.27	0.76	1.04	1.42	1.89
ECB.MRO	30	0.26	0.37	0.00	0.00	0.46	1.25

The dimensions refer to the indices of the quantitative variables and state that the observations cover 30 time observations in quarterly frequency from 2012-Q1 to 2019-Q2 as well as 4 categories for the bank group. This implies a data sample of 120 tuples in total.

4.4 ECONOMETRIC MODEL

This subchapter presents the results of the specification process of the econometric models. For the regression of the independent variable ECB MRO on each of the 3 dependent variables, one econometric model is specified as presented in Table 4.9.

TABLE 4.9:
ECONOMETRIC MODELS

Econometric Model Name	Model ID	Dependent Variable
Credit risk perception	M1 CRP	RWA Density (RWAD)
Credit allocation risk-taking	M2 CART	Risky Loan Share (RLS)
Interest rate risk-taking	M3 IRRT	Net Asset Duration (NAD)

The specification process of the econometric models is based on the comparison of model variations, which differ in the inclusion of categorial dummy variables and non-linear terms of the independent variable. The applied specification method is a backward selection following the sequential selection method of Marill and Green (1963). In this stepwise regression procedure, single parameters are removed from the econometric model based on their significance. The econometric model with the best fit is selected based on the p-values of the parameters and the adjusted R-squared.

Driven by the research aim and hypothesis to be tested, all 3 of the regression models are specified as non-dynamic models. That means according to the aim of explaining the mechanism behind the risk channel in monetary transmission, they allow for conclusions on the relationship between the monetary policy rate and risk-perception or risk-taking of commercial banks, respectively, with a focus on heterogeneity across business areas and bank groups rather than the distribution of effects over time. For the purpose of making predictions, which is not the aim of this research study, a dynamic model that captures the distribution of the effect over time would be more suitable.

In the following subchapters, each of the 3 specified econometric models is presented including the explanatory data analysis, the econometric model, the regression summary, and the fitted regression line plot. To recap, the methodology subchapter 3.4.3 Identification Strategy outlines the choice of variables and subchapter 3.5.2 Data Descriptions explains the calculations of the variables.

4.4.1 MODEL 1: CREDIT RISK PERCEPTION

The first regression model "M1 CRP" is focused on the investigation of the relationship between the dependent variable RWA density indicating credit risk perception of German IRBA banks and the independent variable ECB interest rate on main refinancing operations representing the monetary policy rate of interest. The business area serves as categorial variable to account for heterogeneity across methods of risk measurement. Less sophisticated methods are applied for retail loans and more sophisticated methods are applied for loans to enterprises. An overview on the variables with the abbreviation of the name and the role in the regression model is presented in Table 4.10.

TABLE 4.10:
M1 CRP - VARIABLES

Name	Abbreviation	Regression Model
RWA density	RWAD	Dependent
ECB interest rate on main refinancing operations	ECB.MRO	Independent
Business area: retail loans, Business area: loans to enterprises	BA.RTL, BA.ETP	Category

The explanatory data analysis aims to detect heterogeneity across business areas to determine the functional form of the regression model. Figure 4.3 plots heterogeneity in the development of the dependent variable RWA density between the 2 business areas of commercial banks over time.

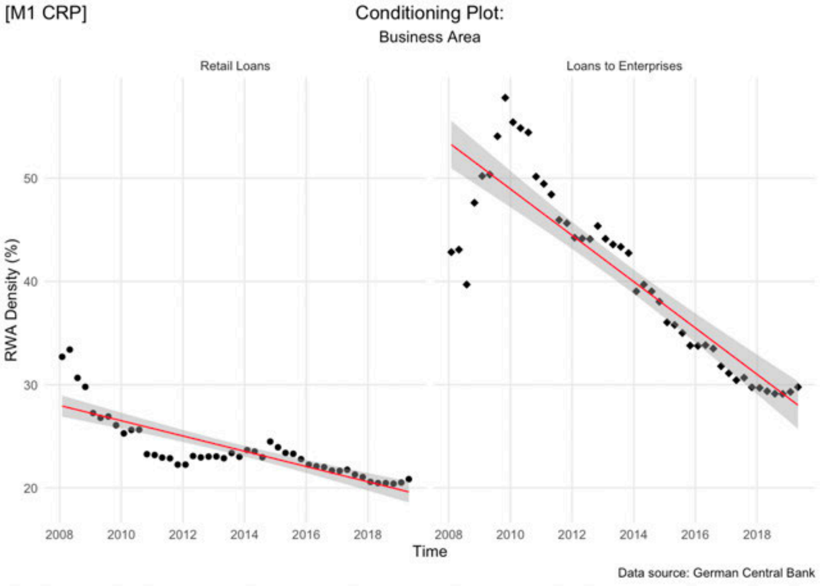


FIGURE 4.3:
M1 CRP - CONDITIONING PLOT

Source: author's R output

The mean plot in Figure 4.4 indicates the existence of heterogeneity in RWA density between business areas. Therefore, categorial dummy variables will be included in the regression model through a categorial variable business area.

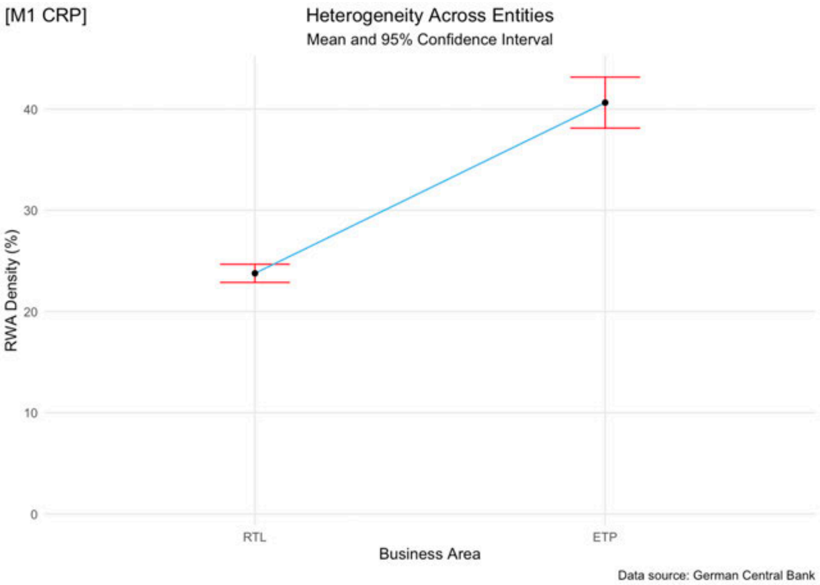


FIGURE 4.4:
M1 CRP - HETEROGENEITY ACROSS BUSINESS AREAS

Source: author's R output

In the specified econometric model, the categorial variable to capture heterogeneity in the business areas is a dichotomous dummy variable. For the business area of loans to enterprises ($BA.ETP$) it is coded 0 for retail loans (RTL) and 1 for loans to enterprises (ETP).

$$BA.ETP = \begin{cases} 0 \; for \; RTL \\ 1 \; for \; ETP \end{cases} \tag{4.10}$$

The specified econometric model is a dummy variable model, which captures a simple relationship between the dependent variable $RWAD$ and the independent variable $ECB.MRO$ allowing for heterogeneity in business areas to capture variety in the method of risk measurement through individual intercepts with parameters α and γ, as wells as individual slopes with parameters β, δ_1 and δ_2:

$$\begin{aligned} RWAD_t = \alpha + \beta \; ECB.MRO_t + \gamma \; BA.ETP_t \\ + \delta_1 \; (BA.ETP_t \times ECB.MRO_t) \\ + \delta_2 \; (BA.ETP_t \times ECB.MRO_t^2) + e_t, \\ t = 1, \ldots, N \end{aligned} \tag{4.11}$$

with e_t being the normally distributed errors, with zero mean and constant variance $e_t \sim N(0, \sigma^2)$. Depending on the value of the categorial dummy variable $BA.ETP_t$, the regression model can be solved for each of the business areas as follows:

$$\begin{aligned} &Retail\ loans: \\ &RWAD_{t|BA.RTL} = \alpha + \beta \; ECB.MRO_t + \gamma \; (0) + \delta_1 \; (0 \times ECB.MRO_t) \\ &\qquad + \delta_2 \; (0 \times ECB.MRO_t^2) + e_t \\ &RWAD_{t|BA.RTL} = \alpha + \beta \; ECB.MRO_t + e_t \end{aligned} \tag{4.12}$$

$$\begin{aligned} &Loans\ to\ enterprises: \\ &RWAD_{t|BA.ETP} = \alpha + \beta \; ECB.MRO_t + \gamma \; (1) + \delta_1 \; (1 \times ECB.MRO_t) \\ &\qquad + \delta_2 \; (1 \times ECB.MRO_t^2) + e_t \\ &RWAD_{t|BA.ETP} = (\alpha + \gamma) + (\beta + \delta_1) \; ECB.MRO_t + \delta_2 \; ECB.MRO_t^2 + e_t \end{aligned} \tag{4.13}$$

The OLS results of the specified econometric model for credit risk perception in equation (4.11) are summarised in Table 4.11. The regression output includes the parameter estimates, their significance levels of the t-test as stars and their standard error in brackets. The t-test of each parameter and the F-test of the econometric model show high significance with $p < 0.001$, indicating an appropriately specified regression model with respect to the included parameters and functional form of the econometric model.

TABLE 4.11:
M1 CRP – OLS SUMMARY

	Dependent variable:
	RWA Density (%)
Intercept	21.81***
	(0.51)
ECB.MRO (%)	2.34***
	(0.36)
BA.ETP	10.62***
	(0.80)
BA.ETP x ECB.MRO (%)	17.98***
	(1.21)
BA.ETP x ECB.MRO^2 (%)	-4.41***
	(0.29)
Observations	92
R^2	0.93
Adjusted R^2	0.93
Residual Standard Error	2.81 (df = 87)
F Statistic	300.20*** (df = 4; 87)
Significance codes	*p<0.05; **p<0.01; ***p<0.001

The corresponding plot of the fitted regression line is shown in Figure 4.5. The visual inspection of the regression fit substantiates the specified regression model.

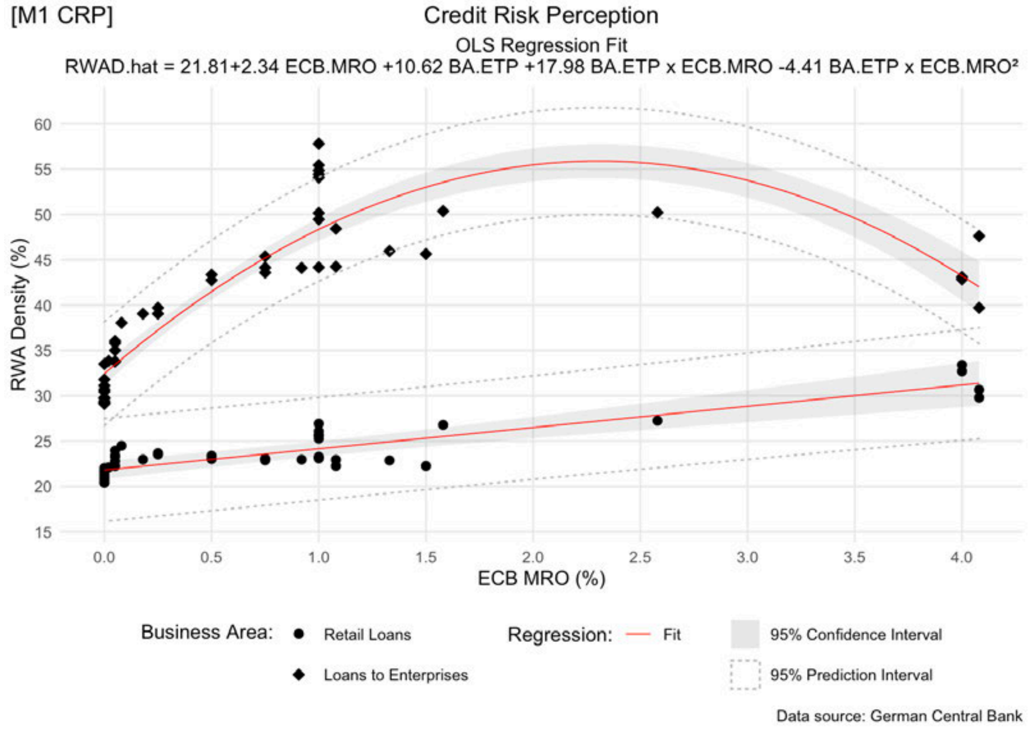


FIGURE 4.5:
M1 CRP - REGRESSION FIT

Source: author's R output

Therefore, both the categorial dummy variable for business area approximating the method of risk measurement and the quadratic term of the independent variable ECB.MRO for the business area of loans to enterprises will be retained in the econometric model.

4.4.2 MODEL 2: CREDIT ALLOCATION RISK-TAKING

The second regression model "M2 CART" is focused on the investigation of the relationship between the dependent variable risky loan share indicating credit allocation risk-taking of German commercial banks and the independent variable ECB interest rate on main refinancing operations representing the monetary policy rate of interest. An overview on the variables with the abbreviation of the name and the role in the regression model is presented in Table 4.12.

TABLE 4.12:
M2 CART - VARIABLES

Name	Abbreviation	Regression Model
Risky loan share	RLS	Dependent
ECB interest rate on main refinancing operations	ECB.MRO	Independent

The specified econometric model for credit allocation risk-taking is a simple nonlinear regression model capturing the relationship between the independent variable $ECB.MRO$ and the dependent variable RLS allowing for an intercept with coefficient β_0 and a quadratic slope with coefficients β_1 and β_2:

$$RLS_t = \beta_0 + \beta_1 ECB.MRO_t + \beta_2 ECB.MRO_t^2 + e_t, \quad t = 1, \ldots, N \tag{4.14}$$

with e_t being the normally distributed errors, with zero mean and constant variance $e_t \sim N(0, \sigma^2)$.

The OLS results of the specified econometric model for credit allocation risk-taking in equation (4.14) are summarised in Table 4.13 with the parameter estimates, their significance level of a t-test as stars and their standard error in brackets. The t-test of each parameter and the F-test of the econometric model show high significance with $p < 0.001$, indicating an appropriately specified regression model with respect to the included parameters and functional form of the econometric model.

TABLE 4.13:
M2 CART – OLS SUMMARY

	Dependent variable:
	Risky Loan Share (%)
Intercept	44.03***
	(0.47)
ECB.MRO (%)	-7.06***
	(0.65)
ECB.MRO^2 (%)	1.41***
	(0.17)
Observations	68
R^2	0.72
Adjusted R^2	0.71
Residual Standard Error	2.12 (df = 65)
F Statistic	81.76*** (df = 2; 65)
Significance codes	*p<0.05; **p<0.01; ***p<0.001

The corresponding plot of the fitted regression line is shown in Figure 4.6. The visual inspection of the regression fit substantiates the specified non-linear econometric model.

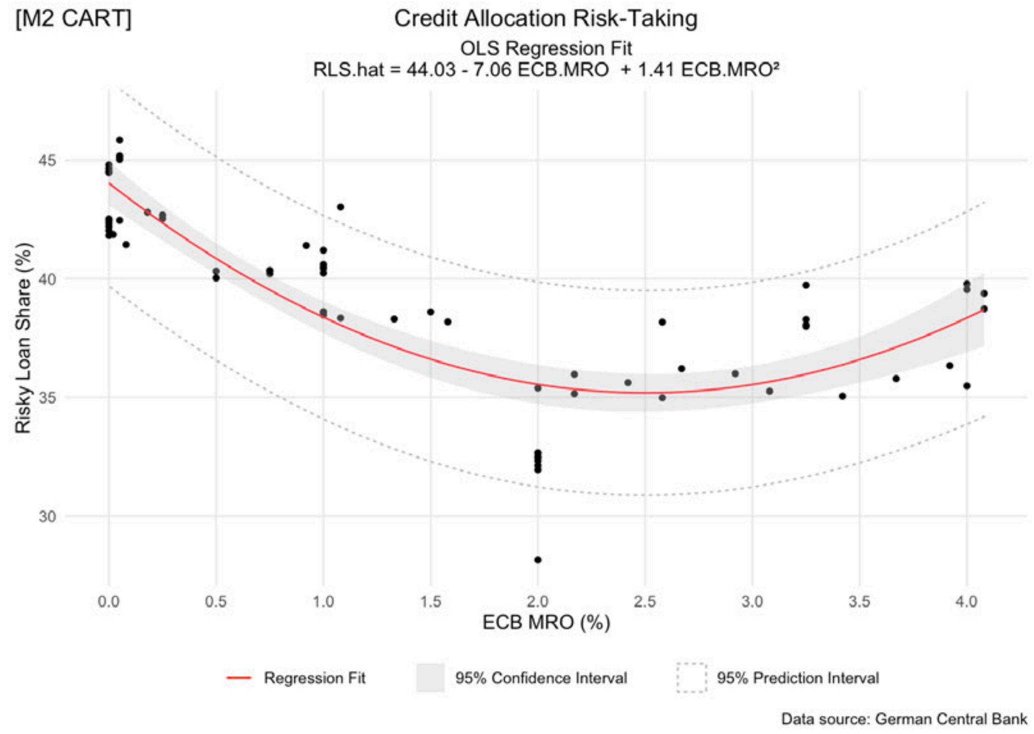


FIGURE 4.6:
M2 CART - REGRESSION FIT

Source: author's R output

Therefore, the quadratic term of the independent variable ECB.MRO will be retained in the econometric model.

4.4.3 MODEL 3: INTEREST RATE RISK-TAKING

The third regression model "M3 IRRT" is focused on the investigation of the relationship between the dependent variable net asset duration indicating interest rate risk-taking of German commercial banks and the independent variable ECB interest rate on main refinancing operations representing the monetary policy rate of interest. The bank group serves as categorial variable to account for heterogeneity across bank groups. This distinction unveils differences between the groups, which may relate to variations in unobserved factors that affect risk-taking such as the profit target, the method of risk measurement and the balance sheet composition (capital, liquidity, and leverage). An overview on the variables with the abbreviation of the name and the role in the regression model is presented in Table 4.14.

TABLE 4.14:
M3 IRRT - VARIABLES

Name	Abbreviation	Regression Model
Net asset duration	NAD	Dependent
ECB interest rate on main refinancing operations	ECB.MRO	Independent
Bank group: credit cooperatives (CC), Bank group: Savings banks (SB), Bank group: large, significant institutions (LSI), Bank group: small and medium sized commercial banks (SMCB)	BG.CC, BG.SB, BG.LSI, BG.SMCB	Category

The explanatory data analysis aims to detect heterogeneity across bank groups to determine the functional form of the regression model. The conditioning plot in Figure 4.7 shows level heterogeneity in the development of the dependent variable net asset duration between the 4 groups of commercial banks over time.

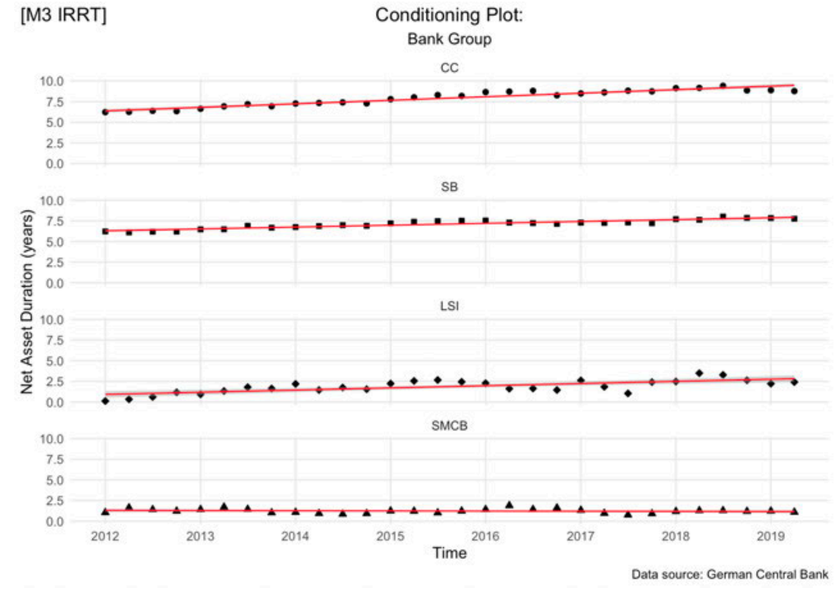


FIGURE 4.7:
M3 IRRT - CONDITIONING PLOT

Source: author's R output

The mean plot in Figure 4.8 indicates the existence of heterogeneity in net asset duration between business areas. Therefore, categorial dummy variables for the bank group will be included in the regression model.

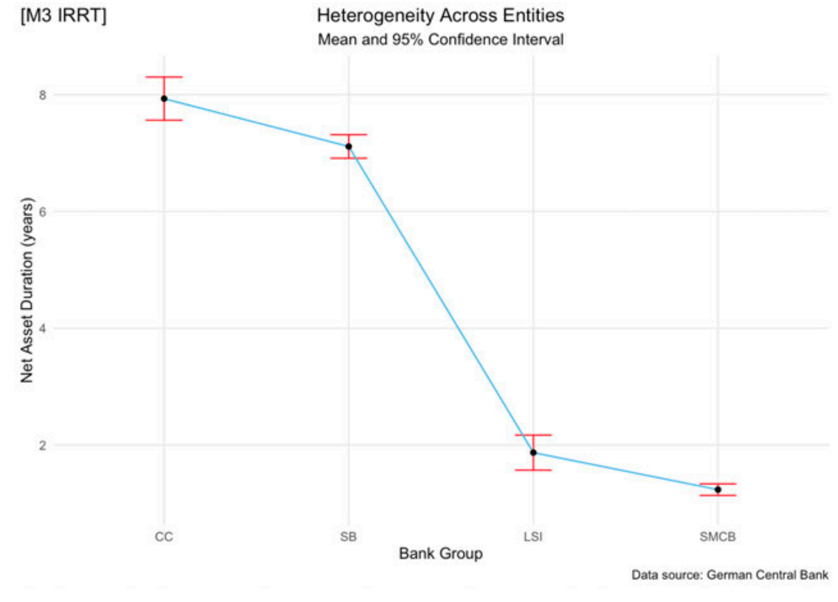


FIGURE 4.8:
M3 IRRT - HETEROGENEITY ACROSS BANK GROUPS

Source: author's R output

In the specified econometric model, the categorial variable to capture heterogeneity between bank groups is a polytomous dummy variable for the 4 bank groups where credit cooperatives (CC) build the baseline group, and 3 other dummy variables are included for Savings banks (SB), large, systemically important institutions (LSI) and small and medium sized commercial banks (SMCB). The dummies are coded 1 for the respective bank group and 0 otherwise:

$$BG.SB = \begin{cases} 1\ for\ SB \\ 0\ otherwise \end{cases} \tag{4.15}$$

$$BG.LSI = \begin{cases} 1\ for\ LSI \\ 0\ otherwise \end{cases} \tag{4.16}$$

$$BG.SMCB = \begin{cases} 1\ for\ SMCB \\ 0\ otherwise \end{cases} \tag{4.17}$$

The resulting econometric model is a dummy variable model, which captures a simple relationship between the independent variable $ECB.MRO$ and dependent variable NAD allowing for heterogeneity in bank groups through individual intercepts with parameters α, δ_1, δ_2 and δ_3 as well as a common slope parameter β. The specified regression model takes the following form:

$$\begin{aligned} NAD_t = \alpha + \delta_1\ BG.SB_t + \delta_2\ BG.LSI_t + \delta_3\ BG.SMCB_t \\ +\beta\ ECB.MRO_t + e_t, \\ t = 1, \dots, N \end{aligned} \tag{4.18}$$

with e_t being the normally distributed errors, with zero mean and constant variance $e_t \sim N(0, \sigma^2)$. Depending on the value of the categorial dummy variables $BG.SB_t$, $BG.LSI_t$ and $BG.SMCB_t$, the regression model can be solved for each of the bank groups as follows:

$$\begin{aligned} &Credit\ cooperatives: \\ &NAD_t = \alpha + \delta_1\ (0) + \delta_2\ (0) + \delta_3\ (0) + \beta\ ECB.MRO_t + e_t \\ &NAD_t = \alpha + \beta\ ECB.MRO_t + e_t \end{aligned} \tag{4.19}$$

$$\begin{aligned} &Savings\ banks: \\ &NAD_t = \alpha + \delta_1\ (1) + \delta_2\ (0) + \delta_3\ (0) + \beta\ ECB.MRO_t + e_t \\ &NAD_t = (\alpha + \delta_1) + \beta\ ECB.MRO_t + e_t \end{aligned} \tag{4.20}$$

$$\begin{aligned} &Large, systemically\ important\ banks: \\ &NAD_t = \alpha + \delta_1\ (0) + \delta_2\ (1) + \delta_3\ (0) + \beta\ ECB.MRO_t + e_t \\ &NAD_t = (\alpha + \delta_2) + \beta\ ECB.MRO_t + e_t \end{aligned} \tag{4.21}$$

$$\begin{aligned} &Small\ and\ medium\ sized\ commercial\ banks: \\ &NAD_t = \alpha + \delta_1\ (0) + \delta_2\ (0) + \delta_3\ (1) + \beta\ ECB.MRO_t + e_t \\ &NAD_t = (\alpha + \delta_3) + \beta\ ECB.MRO_t + e_t \end{aligned} \tag{4.22}$$

The OLS results of the specified econometric model for interest rate risk-taking in Equation (4.18) are summarised in Table 4.15 with the parameter estimates, their significance level of a t-test as stars and their standard error in brackets. The t-test of each parameter and the F-test of the econometric model show high significance with $p < 0.001$, indicating an appropriately specified regression model with respect to the included parameters and functional form of the econometric model.

TABLE 4.15:
M3 IRRT – OLS SUMMARY

	Dependent variable:
	NAD (years)
Intercept	8.26***
	(0.10)
ECB.MRO (%)	-1.29***
	(0.13)
BG.SB	-0.82***
	(0.13)
BG.LSI	-6.06***
	(0.13)
BG.SMCB	-6.69***
	(0.13)
Observations	120
R^2	0.97
Adjusted R^2	0.97
Residual Standard Error	0.52 (df = 115)
F Statistic	1,043.00*** (df = 4; 115)
Significance codes	*p<0.05; **p<0.01; ***p<0.001

The corresponding plot of the fitted regression line is shown in Figure 4.9. The visual inspection of the regression fit substantiates the specified econometric model.

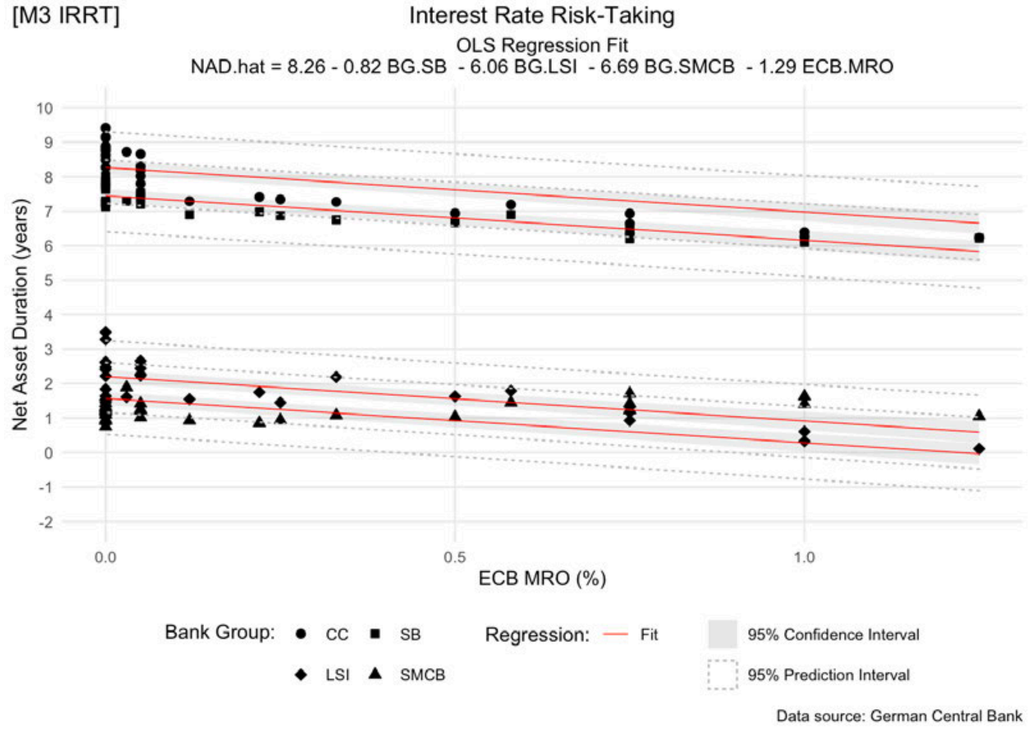


FIGURE 4.9:
M3 IRRT - REGRESSION FIT

Source: author's R output

Therefore, both the categorial dummy variable for the bank group will be retained in the econometric model.

4.5 TIME SERIES DIAGNOSTICS

To avoid spurious regression, the time series need to be either stationary or cointegrated (Hill, Griffiths & Lim, 2008).

TABLE 4.16:
TIME SERIES ASSUMPTIONS

TS1	Stationarity
TS2	Cointegration

That means nonstationary time series in their untransformed levels can only be used in the econometric model if the series are cointegrated. Otherwise, the difference-transformation of the series appropriate to the order of integration is required. Therefore, specific time series tests on stationarity and cointegration are conducted as listed in Table 4.17.

TABLE 4.17:
TIME SERIES DIAGNOSTICS

Assumption	Diagnostic Instrument
Stationarity	Test: Augmented Dickey-Fuller
Cointegration	Test: Engle-Granger

The following subchapters present the results of the time series diagnostics to examine the stochastic process of the time series with respect to stationarity and cointegration. For all the tests on statistical inference in this regression analysis, a confidence level of 95% is applied as conventional in economic analysis.

4.5.1 MODEL 1: CREDIT RISK PERCEPTION

The regression model builds up on time series data, which requires stationarity of each variable or cointegration between the variables, that is stationarity of residuals, to avoid a spurious regression. In what follows, the assumptions (TS1) stationarity of each series and (TS2) cointegration between series will be evaluated based on methods of statistical inference.

TS1 - STATIONARITY: The stationarity of the time series is assessed based on an augmented Dickey-Fuller test. The procedure involves (1) a visual inspection of the series against time for detecting drifts and trends and (2) a residual correlogram to examine autocorrelation as well as (3) the test itself by an assessment of the test statistic against a model specific critical value, which is taken from Davidson and MacKinnon (1993).

Figure 4.10 shows the plot of the series RWA density (RWAD) for the business areas retail loans and loans to enterprises, respectively, as well as the ECB interest rate on main refinancing operations (ECB MRO) against time. All 3 series exhibit some time trend, so that a test equation of a random walk model with drift and trend will be considered and then step by step reduced to a pure random walk model.

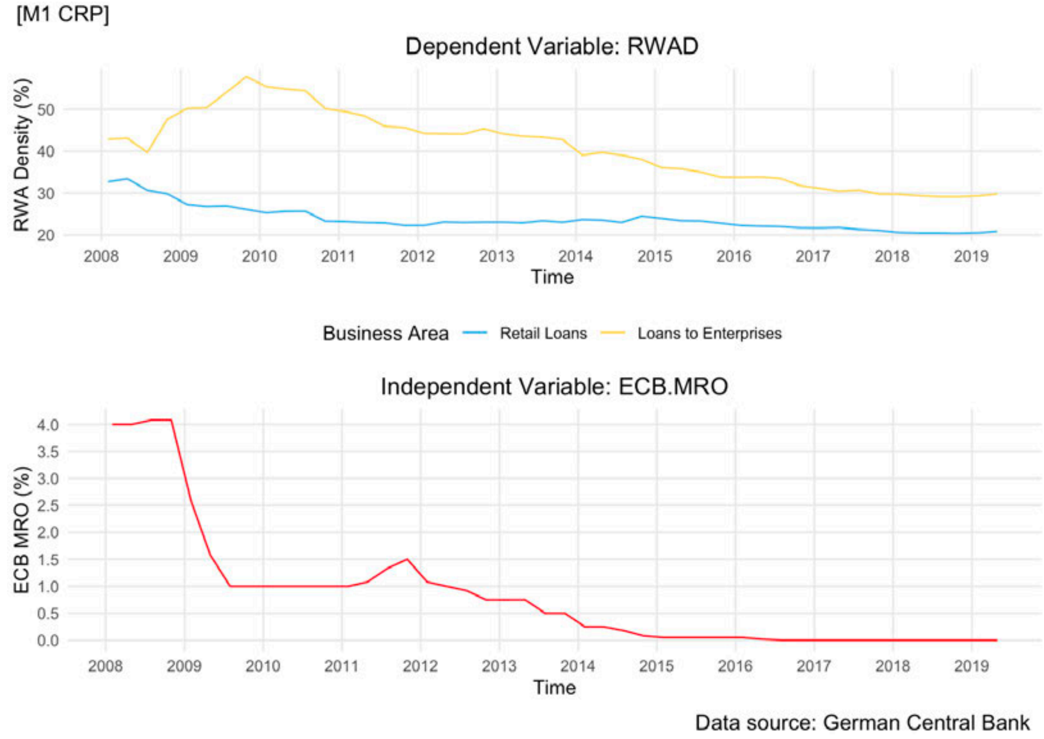


FIGURE 4.10:
M1 CRP - OBSERVATIONS AGAINST TIME

Source: author's R output

The stationary test is a Dickey-Fuller test in the augmented or non-augmented version depending on the existence of autocorrelated errors in the test equation. Hence, prior to the stationarity test, a residual correlogram of the estimated residuals $\hat{v}_t$ from the respective test equation for the Dickey-Fuller test is inspected to determine the number of lagged difference terms that need to be included in the test equation to account for autocorrelation. The residual correlogram in Figure 4.11 shows that the number of lagged difference terms needed to eliminate autocorrelation is none for series RWA density in the business area of retail loans (nonaugmented Dickey-Fuller test with $m = 0$), 5 in the business area of loans to enterprises ($m = 5$) and 3 for series ECB MRO ($m = 3$).

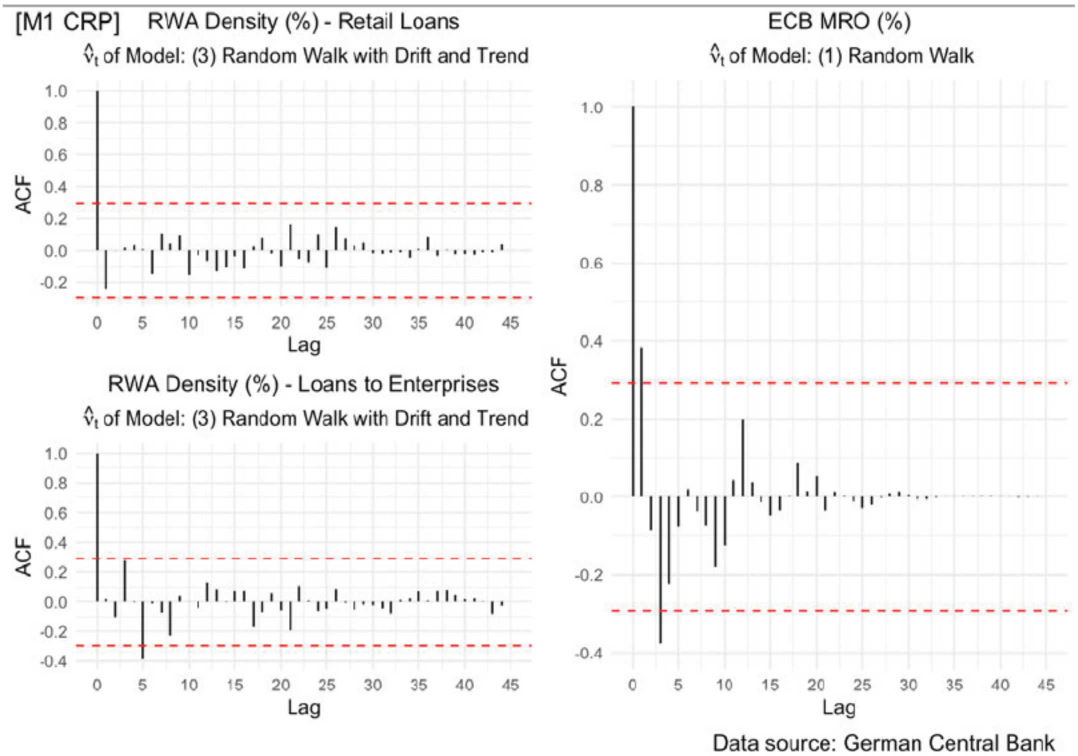


FIGURE 4.11:
M1 CRP - ACF OF RESIDUALS

Source: author's R output

Table 4.18 summarises the results of the augmented Dickey-Fuller test on stationarity for series RWA density by business area based on the specified test equations.

TABLE 4.18:
M1 CRP - AUGMENTED DICKEY-FULLER TEST (RWAD)

Test	Augmented Dickey-Fuller test on unit root of series RWAD by business area (left tail)
Regression model	(3) $\Delta RWAD_{t\|RTL} = \alpha + \gamma RWAD_{t-1} + \lambda t + v_t$ (3) $\Delta RWAD_{t\|ETP} = \alpha + \gamma RWAD_{t-1} + \lambda t + \sum_{s=1}^{5} \delta_s \Delta RWAD_{t-s} + v_t$
Null hypothesis	$H_0: \gamma = 0$ $(unit\ root \rightarrow nonstationarity)$
Alternative hypothesis	$H_1: \gamma < 0$ $(no\ unit\ root \rightarrow stationarity)$
Rejection union	$DF_{\tau\|RTL} \leq -3.50$ $DF_{\tau\|ETP} \leq -3.50$ $p \leq 0.05$
Test statistic	$DF_{\tau\|RTL} = -2.98$ $DF_{\tau\|ETP} = -3.20$

Probability	$p_{RTL} = 0.19$ $p_{RTL} = 0.10$
Conclusion	$H_{0\|RTL}$ is not rejected: unit root (nonstationarity) $H_{0\|ETP}$ is not rejected: unit root (nonstationarity)

For the series of ECB MRO, the test on stationarity was conducted for all three variations of test equations with (1) random walk, (2) random walk with drift and (3) random walk with drift and trend. Table 4.19 summarises the results of the augmented Dickey-Fuller tests.

TABLE 4.19:
M1 CRP - AUGMENTED DICKEY-FULLER TEST (ECB MRO)

Test	Augmented Dickey-Fuller test on unit root of series ECB MRO (left tail)
Regression model	(1) $\Delta ECB.MRO_t = \gamma ECB.MRO_{t-1} + \sum_{s=1}^{3} \delta_s \Delta ECB.MRO_{t-s} + v_t$ (2) $\Delta ECB.MRO_t = \alpha + \gamma ECB.MRO_{t-1} + \sum_{s=1}^{3} \delta_s \Delta ECB.MRO_{t-s} + v_t$ (3) $\Delta ECB.MRO_t = \alpha + \gamma ECB.MRO_{t-1} + \lambda t + \sum_{s=1}^{3} \delta_s \Delta ECB.MRO_{t-s} + v_t$
Null hypothesis	$H_0: \gamma = 0$ $(unit\ root \rightarrow nonstationarity)$
Alternative hypothesis	$H_1: \gamma < 0$ $(no\ unit\ root \rightarrow stationarity)$
Rejection union	$DF_{\tau(1)} \leq -1.95$ $DF_{\tau(2)} \leq -2.93$ $DF_{\tau(3)} \leq -3.50$ $p \leq 0.05$
Test statistic	$DF_{\tau(1)} = -6.88$ $DF_{\tau(2)} = -7.13$ $DF_{\tau(3)} = -10.05$
Probability	$p_{(1)} < 0.01$ $p_{(2)} < 0.01$ $p_{(3)} < 0.01$
Conclusion	H_0 is rejected: no unit root (stationarity)

Since time series variables are used in the regression analysis, evaluating the stationarity is important to avoid spurious regression. For series ECB MRO, the null hypothesis of a unit root is rejected at a confidence level of 95% in the augmented Dickey-Fuller test as the test statistic falls in the rejection union for all 3 versions of the stochastic process. Hence, it is concluded that the series $ECB.MRO_t$ is a stationary process, hence integrated at order zero. For the series RWA density in the business area of loans to enterprises and of retail loans, respectively, the null hypothesis of a unit root is not rejected at a confidence level of 95% in the augmented Dickey-Fuller test as the respective test statistic does not fall in the rejection union. Hence, it is concluded that series $RWAD_{t|RTL}$ and $RWAD_{t|ETP}$ are nonstationary and integrated of order 1. In consequence, the two series on RWA density require either a first difference transformation for stationarity or cointegration of the series in the econometric model to avoid spurious regression. Table 4.20 summarises the results on the examination of the stochastic process of the time series designated to the first regression model on credit risk perception (M1 CRP) based on the augmented Dickey-Fuller test on stationarity.

TABLE 4.20:
M1 CRP – ORDER OF INTEGRATION

Variable	Order of Integration
$RWAD_{RTL}$	I(1)
$RWAD_{ETP}$	I(1)
ECB.MRO	I(0)

TS2 - COINTEGRATION: The cointegration test of the series is an Engle-Granger test, which is effectively a test on stationarity of the estimated residuals $\hat{e}_t$. The residual plot of the regression model for credit allocation risk-taking (M1 CRP) in Figure 4.12 indicates approximately constant mean and variance so that stationarity of residuals is suspected.

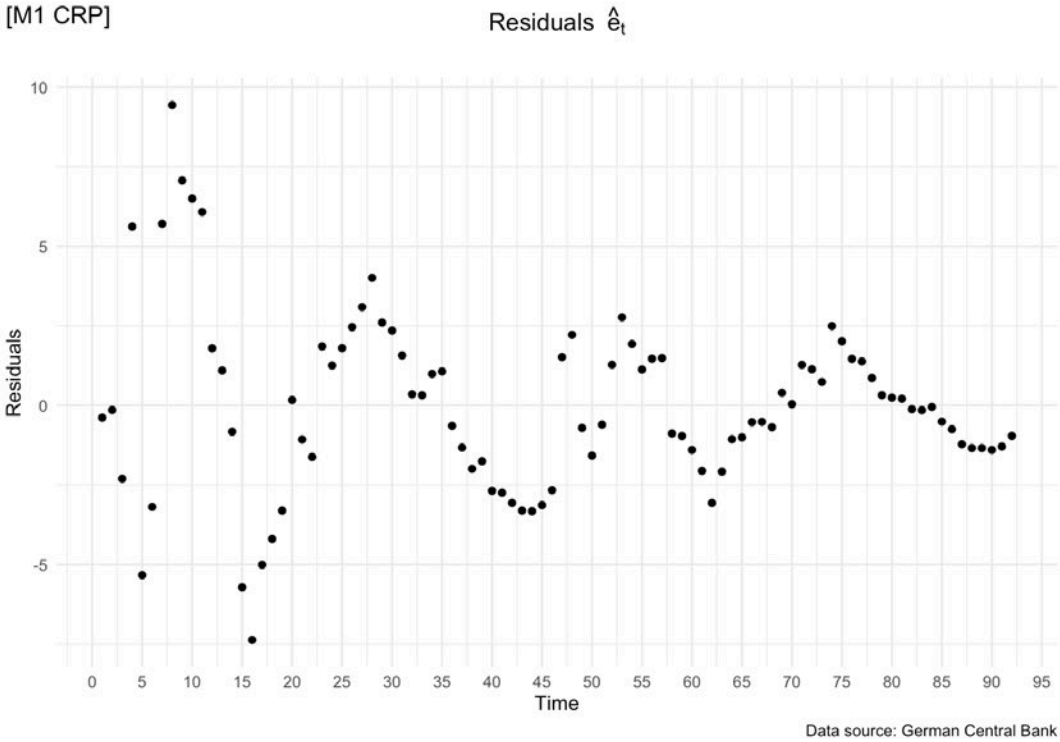


FIGURE 4.12:
M1 CRP - STATIONARITY SIGNAL OF RESIDUALS

Source: author's R output

Based on the regression model for the Engle-Granger test $\Delta\hat{e}_t = \gamma\hat{e}_{t-1} + v_t$, the autocorrelation of the estimated residuals $\hat{v}_t$ is assessed with the following ACF plot. Since autocorrelation is present in lag 8, the same number of lagged difference terms ($m = 8$) are included in the right side of the equation for the Engle-Granger test.

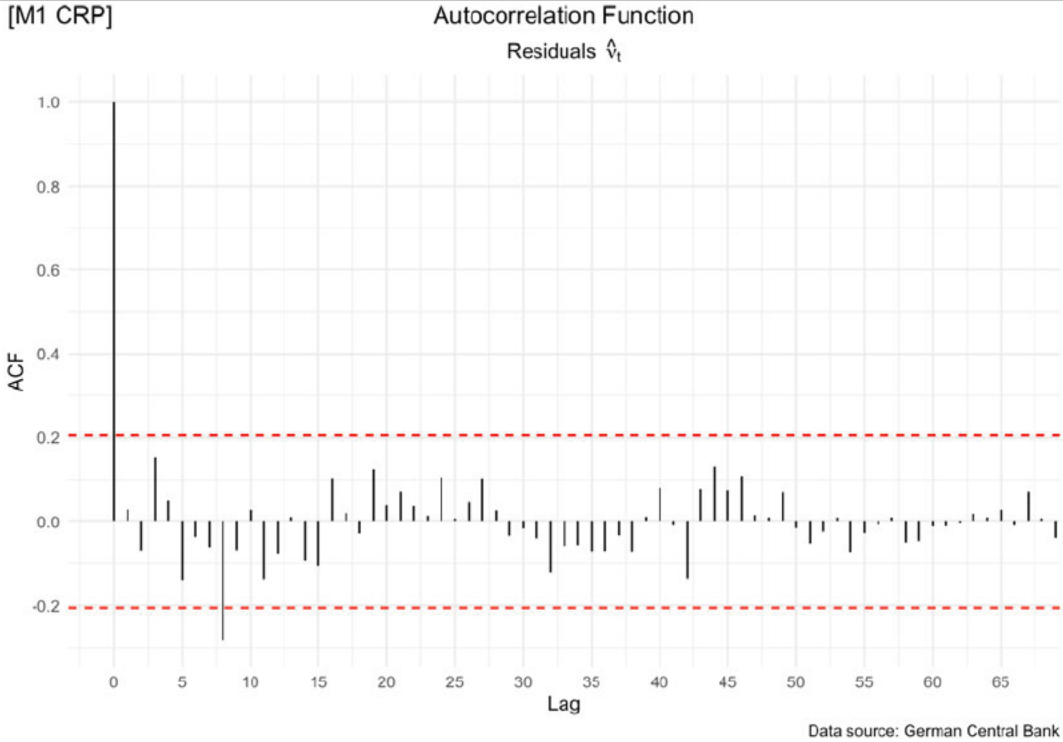


FIGURE 4.13:
M1 CRP – ACF OF RESIDUALS

Source: author's R output

The choice of the critical value depends on the functional form of the regression model of which the residuals $\hat{e}_t$ are derived from, in this case a model with a constant term and no time trend:

$$\begin{aligned} \hat{e}_t = RWAD_t - \hat{\alpha} - \hat{\beta}\, ECB.MRO_t - \hat{\gamma}\, BA.ETP_t \\ -\hat{\delta}_1\,(BA.ETP_t \times ECB.MRO_t) \\ -\hat{\delta}_2\,(BA.ETP_t \times ECB.MRO_t^2) \end{aligned} \tag{4.23}$$

Table 4.21 presents the results of the Engle-Granger test on cointegration of the series $RWAD_t$ and $ECB.MRO_t$ based on the estimated residuals $\hat{e}_t$ of the specified regression model.

TABLE 4.21:
M1 CRP – ENGLE-GRANGER TEST

Test	Engle-Granger test on cointegration (left tail)
Regression model	$\Delta\hat{e}_t = \gamma\hat{e}_{t-1} + \sum_{s=1}^{8}\alpha_s\,\Delta\hat{e}_{t-s} + v_t$
Null hypothesis	$H_0\!:\gamma = 0$ $(unit\ root \rightarrow no\ cointegration)$
Alternative hypothesis	$H_1\!:\gamma < 0$ $(no\ unit\ root \rightarrow cointegration)$

Rejection union	$\tau \leq -3.37$ $p \leq 0.05$
Test statistic	$EG_\tau = -3.96$
Conclusion	H_0 is rejected: cointegration

To avoid spurious regression, the cointegration of the dependent and independent variables is examined with an Engle-Granger test on cointegration of the time series. The null hypothesis of no cointegration is rejected at a confidence level of 95% because the test statistic falls inside the rejection union. It is concluded that there is statistical evidence of cointegration of series RWA density and ECB MRO. In consequence, the causal relationship indicated based on the applied regression model that builds up on the untransformed, nonstationary variables is not spurious. Hence, the level variables will be retained in the econometric model instead of their first difference transformations.

4.5.2 MODEL 2: CREDIT ALLOCATION RISK-TAKING

The regression model builds up on time series data, which requires stationarity of each variable or cointegration between the variables, that is stationarity of residuals, to avoid a spurious regression. In what follows, the assumptions (TS1) stationarity of each series and (TS2) cointegration between series will be evaluated based on methods of statistical inference.

TS1 - STATIONARITY: The stationarity of the time series is assessed based on an augmented Dickey-Fuller test. The procedure involves (1) a visual inspection of the series against time for detecting drifts and trends and (2) a residual correlogram to examine autocorrelation as well as (3) the test itself by an assessment of the test statistic against a model specific critical value, which is taken from Davidson and MacKinnon (1993).

Figure 4.14 shows the plot of the series risky loan share (RLS) and ECB interest rate on main refinancing operations (ECB MRO), respectively, against time. Both series exhibit some time trend, the risky loan share also shows wandering behaviour. Therefore, a test equation of a random walk model with drift and trend will be considered and then step by step reduced to a pure random walk model.

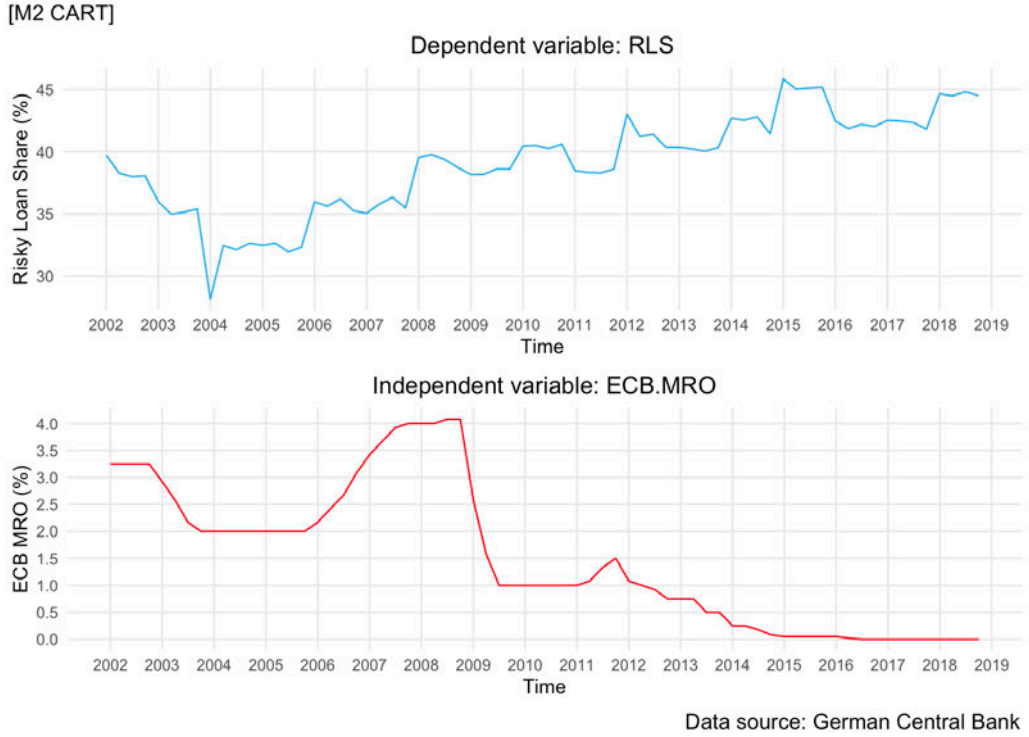


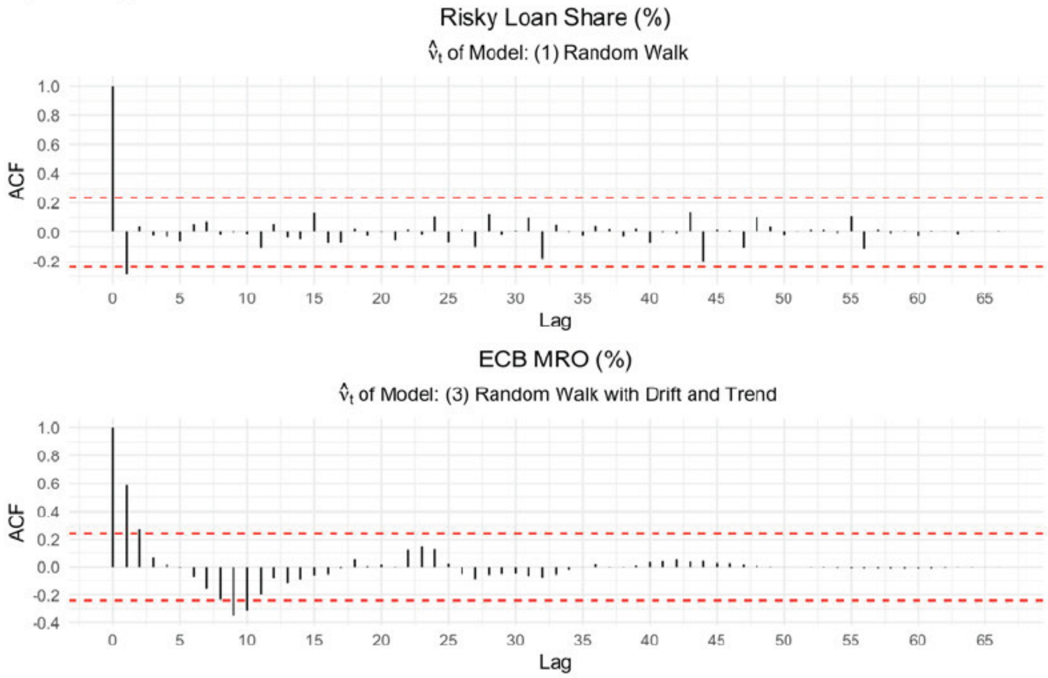
FIGURE 4.14:
M2 CART – OBSERVATIONS AGAINST TIME

Source: author's R output

The stationary test is a Dickey-Fuller test in the augmented or non-augmented version depending on the existence of autocorrelated errors in the test equation. Hence, prior to the stationarity test, a residual correlogram of the estimated residuals $\hat{v}_t$ from the respective test equation for the Dickey-Fuller test is inspected to determine the number of lagged difference terms that need to be included in the test equation to account for autocorrelation. The residual correlogram in Figure 4.15 shows for the respective test equation that the number of lagged difference terms needed to eliminate autocorrelation is 1 for series risky loan share ($m = 1$) and 2 for series ECB MRO[31] ($m = 2$).

[31] For series ECB MRO, the residual correlogram indicates autocorrelation in lags 1, 2, 9 and 10. Another residual correlogram based on the model that includes 2 lag terms indicates that 2 lags are sufficient to remove autocorrelation in the residuals.

[M2 CART]



Data source: German Central Bank

FIGURE 4.15:
M2 CART - ACF OF RESIDUALS

Source: author's R output

For series risky loan share, the test on stationarity was conducted for all three variations of test equations with (1) random walk, (2) random walk with drift and (3) random walk with drift and trend. Table 4.22 summarises the results of the augmented Dickey-Fuller test.

TABLE 4.22:
M2 CART - AUGMENTED DICKEY-FULLER TEST (RLS)

Test	Augmented Dickey-Fuller test on unit root of series RLS (left tail)
Regression model	(3) $\Delta RLS_t = \alpha + \gamma \Delta RLS_{t-1} + \lambda t + v_t$ (2) $\Delta RLS_t = \alpha + \gamma \Delta RLS_{t-1} + v_t$ (1) $\Delta RLS_t = \gamma RLS_{t-1} + \delta_1 \Delta RLS_{t-1} + v_t$
Null hypothesis	$H_0: \gamma = 0$ $(unit\ root \rightarrow nonstationarity)$
Alternative hypothesis	$H_1: \gamma < 0$ $(no\ unit\ root \rightarrow stationarity)$
Rejection union	$DF_{\tau(3)} \leq -3.45$ $DF_{\tau(2)} \leq -2.89$ $DF_{\tau(1)} \leq -1.95$ $p \leq 0.05$

Test statistic	$DF_{\tau(3)} = -4.27$ $DF_{\tau(2)} = -1.51$ $DF_{\tau(1)} = 0.48$
Probability	$p_{(3)} < 0.01$ $p_{(2)} = 0.50$ $p_{(1)} = 0.77$
Conclusion	$H_{0(3)}$ is rejected: no unit root (stationarity) $H_{0(2)}$ is rejected: no unit root (stationarity) $H_{0(1)}$ is not rejected: unit root (nonstationarity)

Table 4.23 summarises the results of the augmented Dickey-Fuller test on stationarity for the series ECB MRO based on the specified test equation.

TABLE 4.23:
M2 CART - AUGMENTED DICKEY-FULLER TEST (ECB MRO)

Test	Augmented Dickey-Fuller test on unit root of series ECB MRO (left tail)
Regression model	(3) $\Delta ECB.MRO_t = \alpha + \gamma ECB.MRO_{t-1} + \lambda t + \sum_{s=1}^{2} \delta_s \, \Delta ECB.MRO_{t-s} + \nu_t$
Null hypothesis	$H_0\!: \gamma = 0$ $(unit\ root \rightarrow nonstationarity)$
Alternative hypothesis	$H_1\!: \gamma < 0$ $(no\ unit\ root \rightarrow stationarity)$
Rejection union	$DF_\tau \leq -3.45$ $p \leq 0.05$
Test statistic	$DF_\tau = -2.64$
Probability	$p = 0.32$
Conclusion	H_0 is not rejected: unit root (nonstationarity)

Since time series variables are used in the regression analysis, evaluating the stationarity is important to avoid spurious regression. For both series, the null hypothesis of a unit root is not rejected at a confidence level of 95% in the augmented Dickey-Fuller test as the respective test statistic does not fall in the rejection union. Hence, it is concluded that the series risky loan share and ECB MRO are nonstationary and integrated of order 1. In consequence, the variables require either a first difference transformation for stationarity or cointegration of the dependent and independent variables to avoid spurious regression. Table 4.24 summarises the results on the examination of the stochastic process of the time series designated to the second regression model on credit allocation risk-taking (M2 CART) based on the augmented Dickey-Fuller test on stationarity.

TABLE 4.24:
M2 CART – ORDER OF INTEGRATION

Variable	Order of Integration
RLS	I(1)
ECB.MRO	I(1)

TS2 - COINTEGRATION: The cointegration test is an Engle-Granger test, which is effectively a test on stationarity of the estimated residuals $\hat{e}_t$. The residual plot of the regression model for credit allocation risk-taking (M1 CART) in Figure 4.16 indicates approximately constant mean and variance so that stationarity of residuals is suspected.

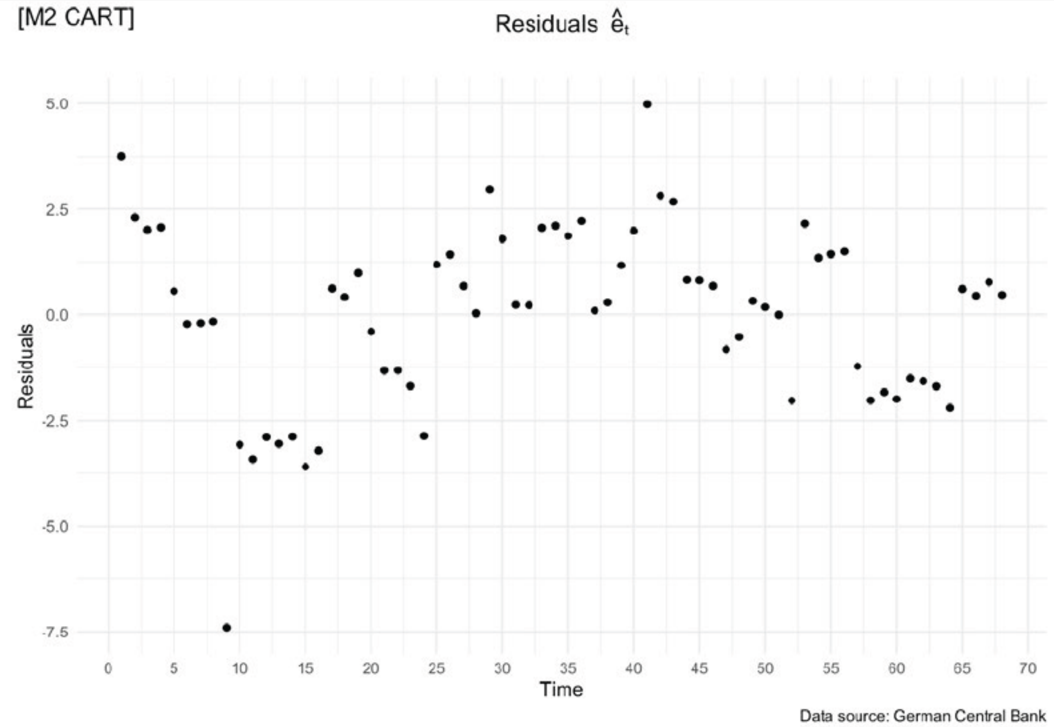


FIGURE 4.16:
M2 CART - STATIONARITY SIGNAL OF RESIDUALS

Source: author's R output

Based on the regression model for the Engle-Granger test $\Delta\hat{e}_t = \gamma\hat{e}_{t-1} + v_t$, the autocorrelation of residuals v_t is assessed with the following ACF plot. Since no autocorrelation is present, no lagged difference term ($m = 0$) needs to be included on the right side of the equation for the Engle-Granger test.

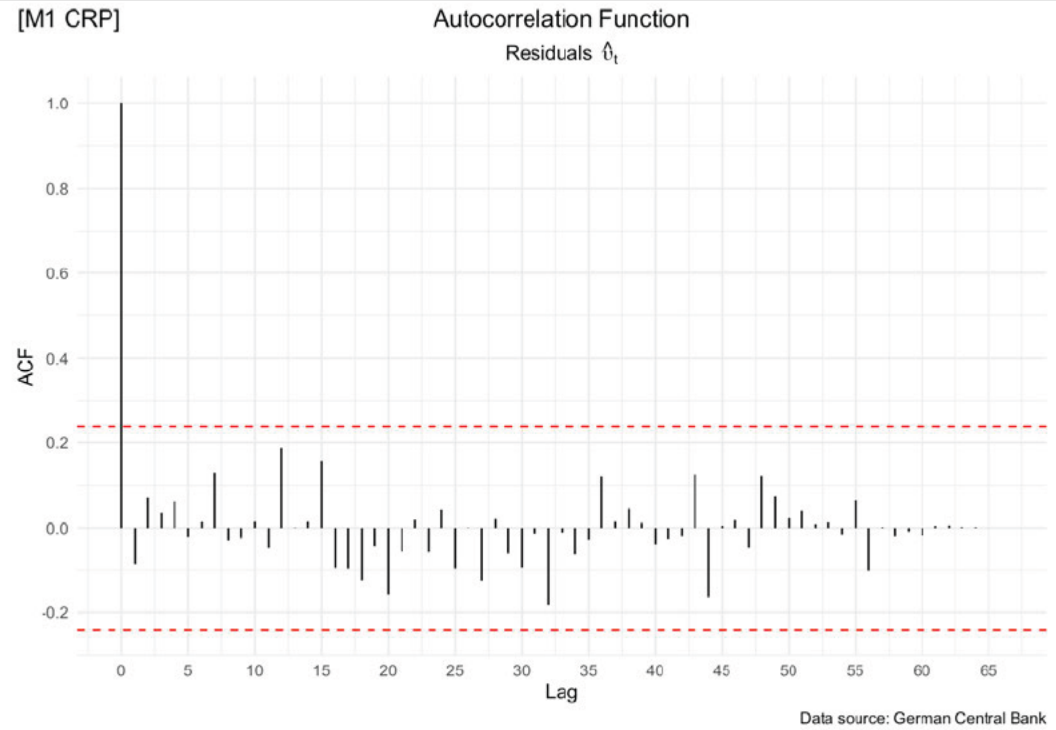


FIGURE 4.17:
M2 CART – ACF OF RESIDUALS

Source: author's R output

The choice of the critical value depends on the functional form of the regression model of which the residuals $\hat{e}_t$ are derived from, in this case a model with a constant term and no time trend.

$$\hat{e}_t = RLS_t - \hat{\beta}_0 - \hat{\beta}_1 ECB.MRO_t - \hat{\beta}_2 ECB\_MRO_t^2 \tag{4.24}$$

Table 4.25 presents the results of the Engle-Granger test on cointegration of the series RLS_t and $ECB.MRO_t$ based on the estimated residuals $\hat{e}_t$ of the specified regression model.

TABLE 4.25:
M2 CART – ENGLE-GRANGER TEST

Test	Engle-Granger test on cointegration (left tail)
Regression model	$\Delta\hat{e}_t = \gamma\hat{e}_{t-1} + v_t$

Null hypothesis	$H_0: \gamma = 0$ $(unit\ root \rightarrow no\ cointegration)$
Alternative hypothesis	$H_1: \gamma < 0$ $(no\ unit\ root \rightarrow cointegration)$
Rejection union	$\tau \leq -3.37$ $p \leq 0.05$
Test statistic	$EG_\tau = -3.96$
Conclusion	H_0 is rejected: cointegration

To avoid spurious regression, the cointegration of the dependent and independent variables is examined with an Engle-Granger test on cointegration of the time series. The null hypothesis of no cointegration is rejected at a confidence level of 95% because the test statistic falls inside the rejection union. It is concluded that there is statistical evidence of cointegration of the series of risky loan share (RLS) and ECB MRO. In consequence, the causal relationship indicated based on the applied regression model that builds up on the untransformed, nonstationary variables is not spurious. Hence, the level variables will be retained in the econometric model instead of their first difference transformations.

4.5.3 MODEL 3: INTEREST RATE RISK-TAKING

The regression model builds up on time series data, which requires stationarity of each variable or cointegration between the variables, that is stationarity of residuals, to avoid a spurious regression. In what follows, the assumptions (TS1) stationarity of each series and (TS2) cointegration between series will be evaluated based on methods of statistical inference.

TS1 - STATIONARITY: The stationarity of the time series is assessed based on an augmented Dickey-Fuller test. The procedure involves (1) a visual inspection of the series against time for detecting drifts and trends and (2) a residual correlogram to examine autocorrelation as well as (3) the test itself by an assessment of the test statistic against a model specific critical value, which is taken from Davidson and MacKinnon (1993).

Figure 4.18 shows the charts of the series net asset duration (NAD) by bank group and ECB interest rate on main refinancing operations (ECB MRO), respectively, against time. All 5 series indicate no cyclical pattern but some time trend, so that a test equation of a random walk model with drift and trend will be considered and then step by step reduced to a pure random walk model.

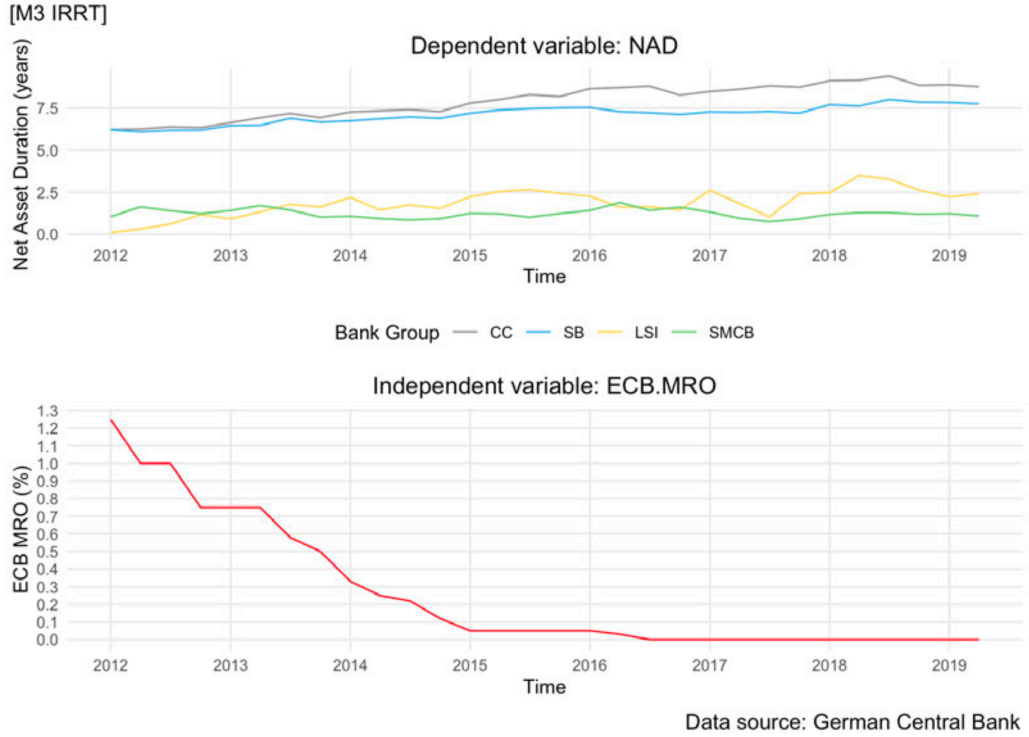


FIGURE 4.18:
M3 IRRT - OBSERVATIONS AGAINST TIME

Source: author's R output

The stationary test is a Dickey-Fuller test in the augmented or non-augmented version depending on the existence of autocorrelated errors in the test equation. Hence, prior to the stationarity test, a residual correlogram of the estimated residuals $\hat{v}_t$ from the respective test equation for the Dickey-Fuller test is inspected to determine the number of lagged difference terms that need to be included in the test equation to account for autocorrelation. The residual correlogram in Figure 4.19 shows that the number of lagged difference terms needed to eliminate autocorrelation are lags of $m_{CC} = 3$, $m_{SB} = 2$, $m_{LSI} = 0$, $m_{SMCB} = 0$ for net asset duration[32] by bank group and lags of $m = 0$ for the ECB MRO.

[32] For series NAD, the residual correlogram indicates autocorrelation in lags 3, 4, 5 and 8 for group CC and in lags 2 and 5 for group SB. Another residual correlogram based on the model that includes 3 (CC) and 2 (SB) lagged difference terms indicates that this number of lags is sufficient to remove autocorrelation in the residuals.

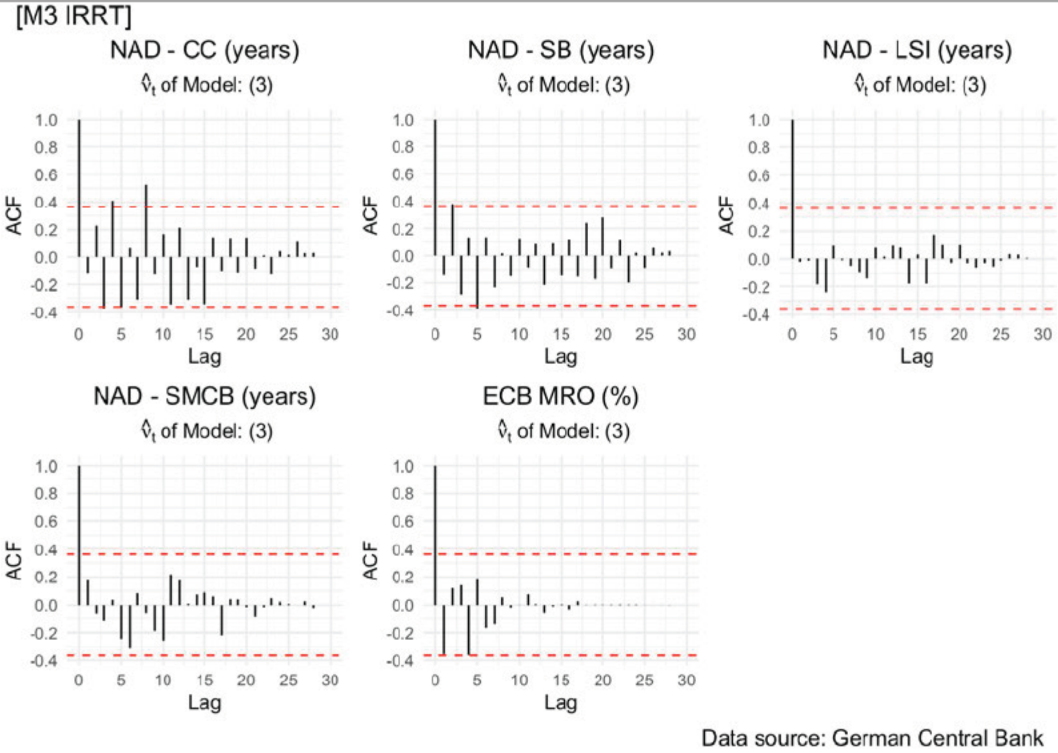


FIGURE 4.19:
M3 IRRT - ACF OF RESIDUALS

Source: author's R output

Table 4.26 summarises the results of the augmented Dickey-Fuller test on stationarity for variable net asset duration by bank group based on the specified test equations.

TABLE 4.26:
M3 IRRT - AUGMENTED DICKEY-FULLER TEST (NAD)

Test	Augmented Dickey-Fuller test on unit root of series NAD by bank group (left tail)
Regression model	(3) $\Delta NAD_{t\|CC} = \alpha + \gamma NAD_{t-1} + \lambda t + \sum_{s=1}^{3} \delta_s \Delta NAD_{t-s} + \nu_t$ (3) $\Delta NAD_{t\|SB} = \alpha + \gamma NAD_{t-1} + \lambda t + \sum_{s=1}^{2} \delta_s \Delta NAD_{t-s} + \nu_t$ (3) $\Delta NAD_{t\|LSI} = \alpha + \gamma NAD_{t-1} + \lambda t + \nu_t$ (3) $\Delta NAD_{t\|SMCB} = \alpha + \gamma NAD_{t-1} + \lambda t + \nu_t$
Null hypothesis	$H_0: \gamma = 0$ $(unit\ root \rightarrow nonstationarity)$
Alternative hypothesis	$H_1: \gamma < 0$ $(no\ unit\ root \rightarrow stationarity)$
Rejection union	$DF_\tau \leq -3.50$ $p \leq 0.05$

Test statistic	$DF_{\tau\|CC} = -0.52$ $DF_{\tau\|SB} = -2.72$ $DF_{\tau\|LSI} = -3.21$ $DF_{\tau\|SMCB} = -2.99$
Probability	$p_{CC} = 0.97$ $p_{SB} = 0.30$ $p_{LSI} = 0.11$ $p_{SMCB} = 0.19$
Conclusion	H_0 is not rejected: unit root (nonstationarity)

Table 4.27 summarises the results of the Dickey-Fuller test on stationarity for variable ECB MRO based on the specified test equation.

TABLE 4.27:
M3 IRRT - DICKEY-FULLER TEST (ECB MRO)

Test	Dickey-Fuller test on unit root of series ECB MRO (left tail)
Regression model	(3) $\Delta ECB.MRO_t = \alpha + \gamma ECB.MRO_{t-1} + \lambda t + \nu_t$
Null hypothesis	$H_0: \gamma = 0$ $(unit\ root \rightarrow nonstationarity)$
Alternative hypothesis	$H_1: \gamma < 0$ $(no\ unit\ root \rightarrow stationarity)$
Rejection union	$DF_\tau \leq -3.50$ $p \leq 0.05$
Test statistic	$DF_\tau = -2.33$
Probability	$p = 0.45$
Conclusion	H_0 is not rejected: unit root (nonstationarity)

Since time series variables are used in the regression analysis, evaluating the stationarity is important to avoid spurious regression. For all of the 5 series on net asset duration by bank group and ECB MRO, the null hypothesis of a unit root is not rejected at a confidence level of 95% in the augmented Dickey-Fuller test as the test statistics does not fall in the rejection union. Hence, it is concluded that the series are nonstationary and integrated of order 1. In consequence, the series require either a first difference transformation or cointegration to avoid spurious regression. Table 4.28 summarises the results on the examination of the stochastic process of the time series designated to the third regression model on interest rate risk-taking (M3 IRRT) based on the augmented Dickey-Fuller test on stationarity.

TABLE 4.28:
M3 IRRT – ORDER OF INTEGRATION

Variable	Order of Integration
NAD_{CC}	I(1)
NAD_{SB}	I(1)
NAD_{LSI}	I(1)
NAD_{SMCB}	I(1)
ECB.MRO	I(1)

The inspection of variables in the descriptive statistics has led to the insight that the series net asset duration by bank group are I(1) stationary and series ECB.MRO is I(0) stationary:

TABLE 4.29:
M3 IRRT – ORDER OF INTEGRATION

Variable	Order of Integration
NAD_{CC}	I(1)
NAD_{SB}	I(1)
NAD_{LSI}	I(1)
NAD_{SMCB}	I(1)
ECB.MRO	I(0)

TS2 - COINTEGRATION: The cointegration test is an Engle-Granger test, which is effectively a test on stationarity of the estimated residuals $\hat{e}_t$. The residual plot of the regression model for interest rate risk-taking (M3 IRRT) in Figure 4.20 indicates approximately constant mean and variance so that stationarity of residuals is suspected.

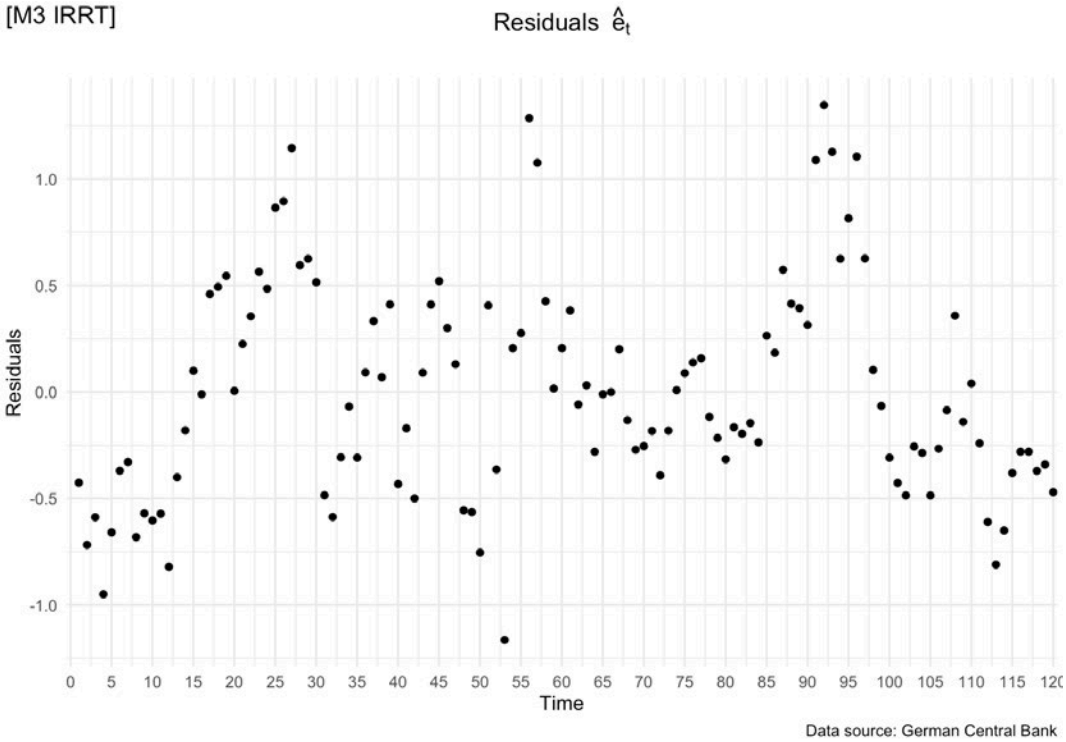


FIGURE 4.20:
M3 IRRT - STATIONARITY SIGNAL OF RESIDUALS

Source: author's R output

Based on the regression model for the Engle-Granger test $\Delta\hat{e}_t = \gamma\hat{e}_{t-1} + v_t$, the autocorrelation of the corresponding estimated residuals $\hat{e}_{it}$ is assessed with the following ACF plot. Some autocorrelation is present in lags 24 and 25, since the lag numbers are high with a small value of the correlation coefficient, no lagged difference terms ($m = 0$) are included in the right side of the equation for the Engle-Granger test.

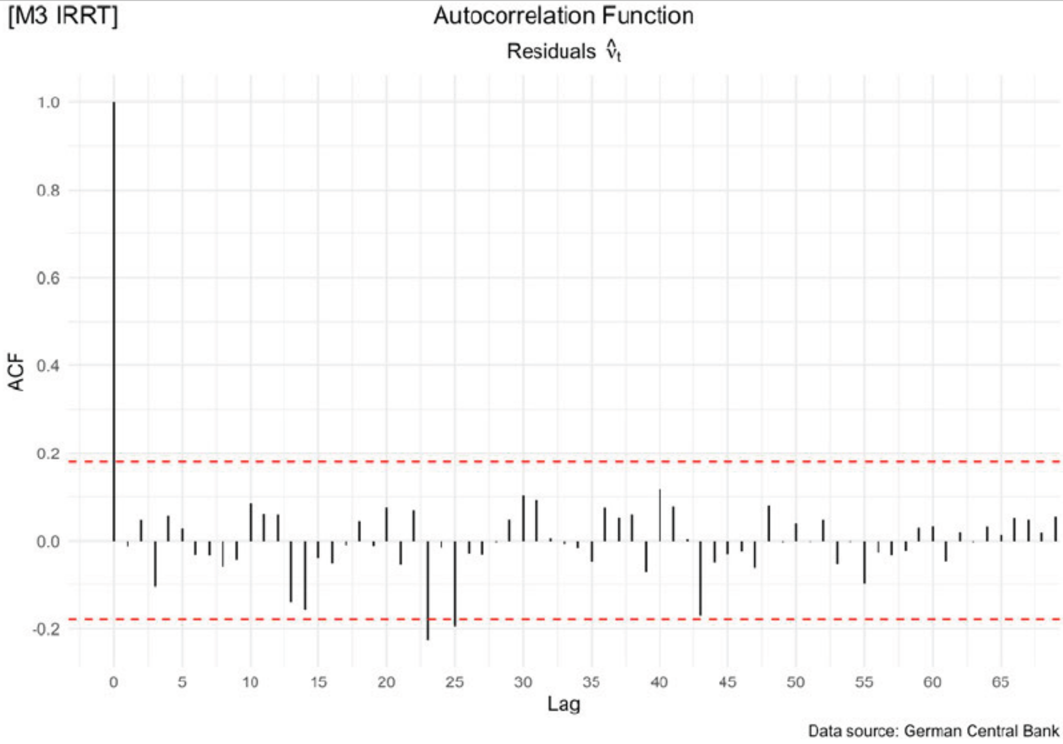


FIGURE 4.21:
M3 IRRT - ACF OF RESIDUALS

Source: author's R output

The choice of the critical value depends on the functional form of the regression model of which the residuals $\hat{e}_t$ are derived from, in this case a model with a constant term and no time trend:

$$\hat{e}_t = NAD_t - \hat{\alpha} - \hat{\delta}_1\, BG.SB_t + \hat{\delta}_2\, BG.LSI_t + \hat{\delta}_3\, BG.SMCB_t + \hat{\beta}\, ECB.MRO_t + \tag{4.25}$$

Table 4.30 presents the Engle-Granger test on cointegration series NAD_t and $ECB.MRO_t$.

TABLE 4.30:
M3 IRRT - ENGLE-GRANGER TEST

Test	Engle-Granger test on cointegration (left tail)
Regression model	$\Delta\hat{e}_t = \gamma\hat{e}_{t-1} + v_t$
Null hypothesis	$H_0: \gamma = 0$ $(unit\ root \rightarrow no\ cointegration)$
Alternative hypothesis	$H_1: \gamma < 0$ $(no\ unit\ root \rightarrow cointegration)$
Rejection union	$\tau \leq -3.37$ $p \leq 0.05$

Test statistic	$EG_{\tau} = -4.18$
Conclusion	H_0 is rejected: cointegration

To avoid spurious regression, the cointegration of the dependent and independent variables is examined based on an Engle-Granger test on cointegration of the time series. The null hypothesis of no cointegration is rejected at a confidence level of 95% because the test statistic falls inside the rejection union. It is concluded that there is statistical evidence for cointegration of the series of net asset duration (NAD) and ECB MRO. In consequence, the causal relationship indicated based on the applied regression model that builds up on the untransformed, nonstationary variables is not spurious. Hence, the level variables will be retained in the econometric model instead of their first difference transformations.

4.6 REGRESSION MODEL DIAGNOSTICS

Before the hypothesis can be tested based on the specified economic model, diagnostics are conducted in order to evaluate whether the regression model assumptions hold and the results on parameter estimates and statistical inference are reliable. The assumptions that apply to all 3 of the specified econometric models are listed in Table 4.31

TABLE 4.31:
REGRESSION MODEL ASSUMPTIONS

A1	Linearity of coefficients
A2	Zero mean of residuals
A3	Homoscedasticity of residuals
A4	No autocorrelation of residuals
A5	Normality of residuals
A6	No extreme outliers
A7	Random sample

The quality of an estimation method is evaluated by unbiasedness, efficiency and consistency of the estimated parameters. The applied ordinary least squares method has certain estimation properties, provided that the standard assumptions of the multiple regression model are met. As Hill, Griffiths and Lim (2008) outline: If the disturbance variable on average is equal to 0 and its variance is constant, then the OLS estimators for the regression coefficients are best linear unbiased estimators (BLUE) in the absence of autocorrelation, with appeal to the Gauss-Markov theorem. Unbiasedness implies that the mean values of the OLS-estimated regression coefficients are conform with the unknown population regression coefficients. Best estimator refers to the accuracy of the estimation and means efficiency. Under the standard assumptions, the OLS estimator in the linear regression model is thus unbiased and efficient. That means no other linear and unbiased estimator of the regression coefficients exists which leads to a smaller variance. In addition, the OLS method is consistent. Consistency means that with increasing sample size the estimated regression coefficients better and better approach the unknown population regression coefficients.

An overview on the applied key instruments in the diagnostics of the econometric model is presented in Table 4.32.

TABLE 4.32:
ECONOMETRIC MODEL DIAGNOSTICS

Assumption	Diagnostic Instrument
(A1) Linearity of coefficients	Plot: Residuals vs. Fitted
(A2) Zero mean of residuals	Plot: Residuals vs. Fitted
(A3) Homoscedasticity of residuals	Plot: Scale-Location Test: Breusch-Pagan
(A4) Non-Autocorrelation of residuals	Plot: Autocorrelation Function Test: Durbin-Watson
(A5) Normality of residuals	Plot: Normal Q-Q Test: Shapiro-Wilk
(A6) No extreme outliers	Plot: Residuals vs. Leverage, Cook's D, Cook's D vs. Leverage

The following subchapters present the results of the regression model diagnostics to evaluate whether the assumptions hold, and the OLS properties unbiasedness, efficiency and consistency apply. The model diagnostics is crucial for the validity of empirical results and incorporates the calculation of measures, visual inspections of diagnostic plots and statistical tests.

4.6.1 MODEL 1: CREDIT RISK PERCEPTION

The regression model diagnostics is based on the specified econometric model on credit risk perception of German commercial IRBA banks (M1 CRP):

$$\begin{aligned} RWAD_t = \alpha + \beta\, ECB.MRO_t + \gamma\, BA.ETP_t \\ + \delta_1\,(BA.ETP_t \times ECB.MRO_t) \\ + \delta_2\,(BA.ETP_t \times ECB.MRO_t^2) + e_t, \\ t = 1, \dots, N \end{aligned} \tag{4.26}$$

A1 - LINEARITY OF COEFFICIENTS: A plot of residuals versus fitted values is applied to investigate the assumption of linearity of coefficients in the regression model. Figure 4.22 shows no fitted pattern in the estimated values for the business areas of retail loans and loans to enterprises. It is concluded that the assumption of linearity of coefficients holds.

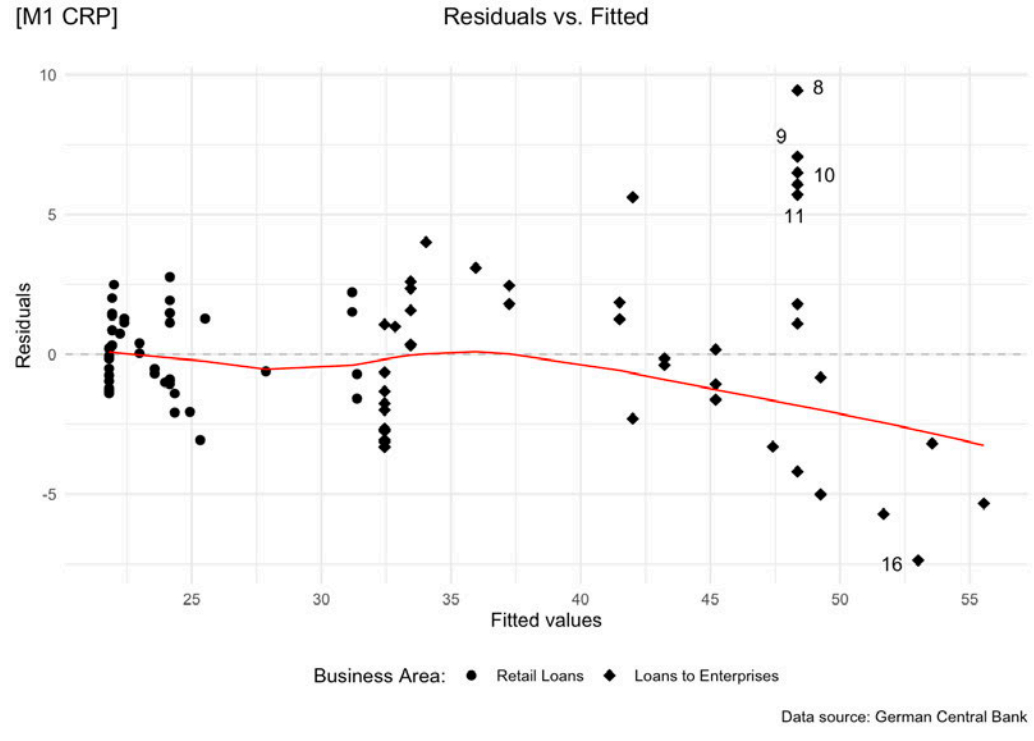


FIGURE 4.22:
M1 CRP - RESIDUALS VS. FITTED

Source: author's R output

A2 - ZERO MEAN OF RESIDUALS: The plot of residuals versus fitted values is also applied to investigate the assumption of a zero mean of residuals in the regression model. The red LOWESS curve (locally weighted scatterplot smoothing) in Figure 4.22 is approximately horizontal. It is concluded that the assumption of residuals with zero mean holds.

A3 - HOMOSCEDASTICITY OF RESIDUALS: The assumption on homoscedastic errors is investigated by visual inspection of a scale-location plot, which is complemented by a Breusch-Pagan test on heteroscedasticity. The scale-location plot in Figure 4.23 shows an upward trending red LOWESS curve, which indicates increasing variance of residuals, that is heteroscedasticity.

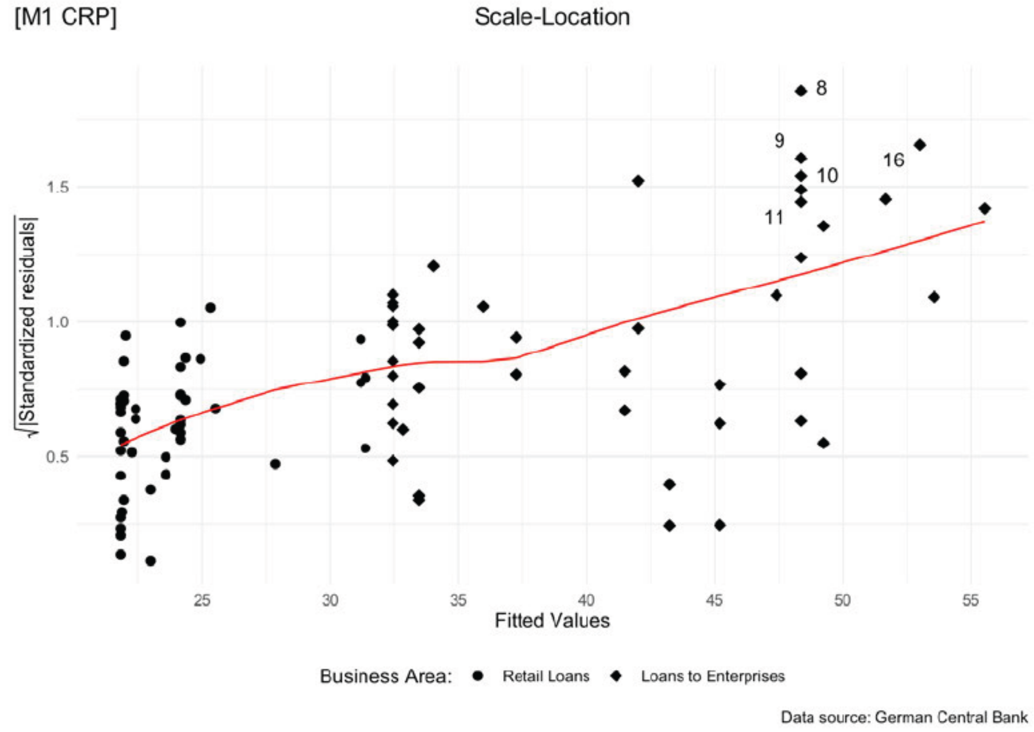


FIGURE 4.23:
M1 CRP - SCALE-LOCATION

Source: author's R output

The results of the Breusch-Pagan test on heteroscedasticity are summarised in Table 4.33.

TABLE 4.33:
M1 CRP - BREUSCH-PAGAN TEST

Test	Breusch-Pagan on heteroscedasticity (right tail)
Regression model	$\hat{e}_t^2 = \alpha_1 + \alpha_2 z_{t2} + \cdots + \alpha_S z_{tS} + v_t$
Null hypothesis	$H_0: \alpha_2 = \alpha_3 = \alpha_S = 0$ $(homoscedasticity)$
Alternative hypothesis	$H_1: not\ all\ the\ \alpha_S\ in\ H_0\ are\ zero$

	$(heteroscedasticity)$
Rejection union	$BP \geq 9.49$ $p \leq 0.05$
Test statistic	$BP = 61.75$
Degrees of freedom	$df = 4$
Probability	$p < 0.001$
Conclusion	H_0 is rejected: heteroscedasticity

This test result is visualised in Figure 4.24, which shows that the calculated test statistic falls inside the rejection union of the chi-square distribution with a probability of the null hypothesis of $p < 0.001$.

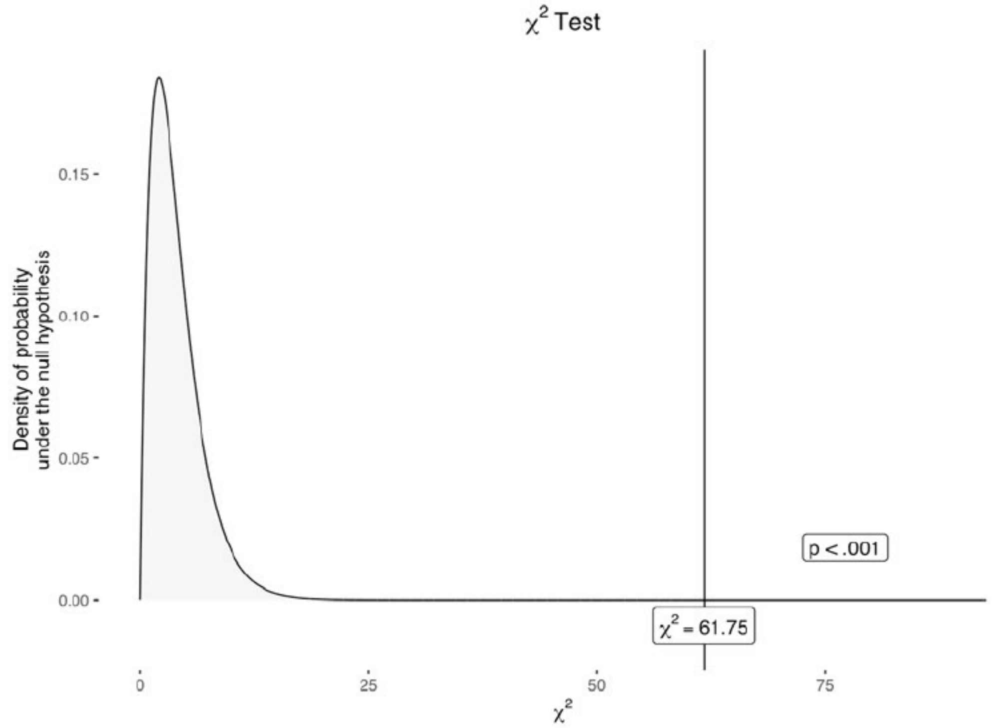


FIGURE 4.24:
M1 CRP - BREUSCH-PAGAN TEST

Source: author's R output

Homoscedasticity of residuals is an assumption of the regression model for credit risk perception. The presence of heteroscedasticity has been analysed using a scale-location plot along with a Breusch-Pagan test on heteroscedasticity. The null hypothesis of homoscedasticity of residuals is rejected at a confidence level of above 95%. It is concluded that there is statistical evidence of heteroscedasticity and therefore the assumption of homoscedastic residuals does not hold. This violation implies, that the estimators are still consistent, but their statistical inference including standard errors, t value, F value and p value are biased since the covariance matrix estimate is inconsistent. A transformation of the variables did not improve this result. In consequence, the standard errors of the estimates will be corrected by estimating a heteroscedasticity robust covariance matrix so that a consistent statistical inference is achieved through heteroscedasticity robust standard errors and with heteroscedasticity robust Wald tests in the form of a quasi t-test and quasi F-test, respectively.

A4 - NO AUTOCORRELATION OF RESIDUALS: The assumption of no autocorrelation in errors is assessed through a visual inspection of a residual correlogram or autocorrelation function (ACF) plot, which is complemented by a Durbin-Watson test on autocorrelation. At a confidence level of 95%, the ACF plot in Figure 4.25 indicates positive autocorrelation with a coefficient $\rho > 0$ in lags 1 to 3 as well as negative autocorrelation with a coefficient $\rho < 0$ in lags 7 to 13 and so on for some higher lags.

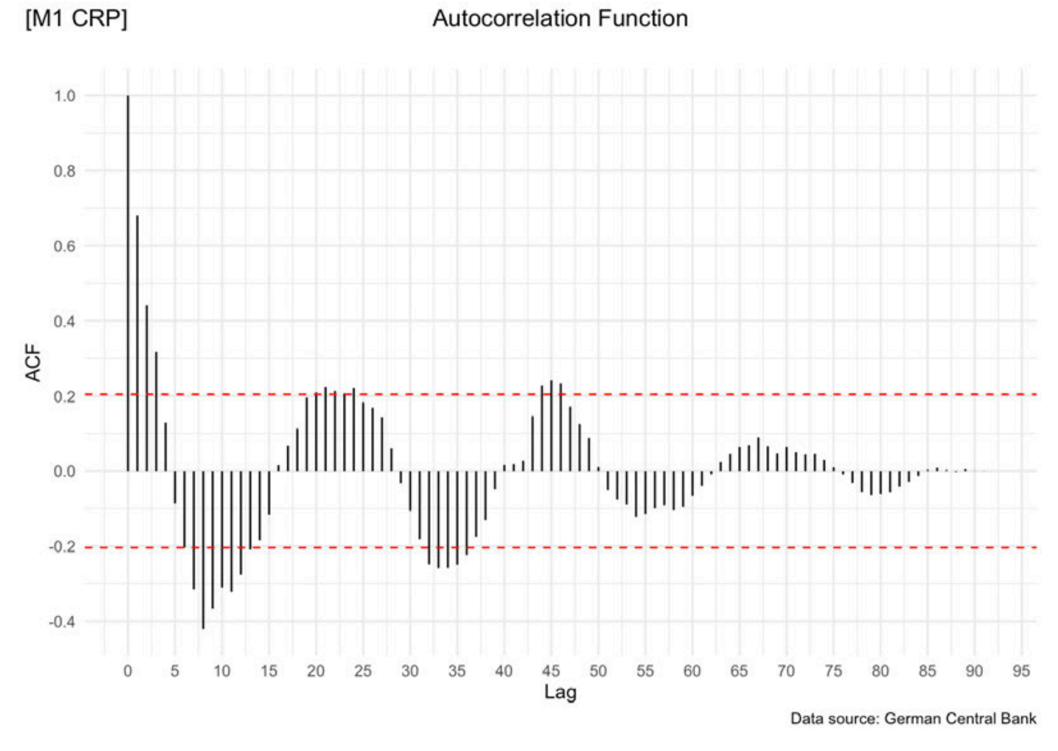


FIGURE 4.25:
M1 CRP - ACF

Source: author's R output

The results of the corresponding Durbin-Watson test on positive first-order autocorrelation based on an AR(1) error regression model are summarised in Table 4.34. Non-autocorrelation of residuals is an assumption of the regression model for credit risk perception. The presence of autocorrelation has been analysed using an ACF plot along with a Durbin-Watson test on positive first-order autocorrelation. The null hypothesis of no autocorrelation in residuals is rejected at a confidence level of above 95% since the test statistic falls inside the rejection union of the left tail. It is concluded that there is statistical evidence of autocorrelation and therefore the assumption of non-autocorrelated residuals does not hold.

TABLE 4.34:
M1 CRP - DURBIN-WATSON TEST

Test	Durbin-Watson on autocorrelation (left tail)
Regression model	$\hat{e}_t = \rho\hat{e}_{t-1} + v_t$
Null hypothesis	$H_0: \rho = 0$ $(no\ first - order\ autocorrelation, d \approx 2)$
Alternative hypothesis	$H_1: \rho > 0$ $(positive\ first - order\ autocorrelation, d \approx 0)$
Rejection union	$p \leq 0.05$
Test statistic	$d = 0.64$
Probability	$p < 0.001$
Conclusion	H_0 is rejected: positive first-order autocorrelation

This violation implies, that the estimators are still consistent, but their statistical inference including standard errors, t value, F value and p value are biased since the covariance matrix estimate is inconsistent. In consequence, the standard errors of the estimates will be corrected by estimating an autocorrelation robust covariance matrix so that a consistent statistical inference is achieved through autocorrelation robust standard errors and with autocorrelation robust Wald tests in the form of a quasi t-test and quasi F-test, respectively.

A5 - NORLMALITY OF RESIDUALS: The assumption of normally distributed errors is assessed through a visual inspection of a normal quantity-quantity (QQ) plot, which is complemented by a Shapiro-Wilk test on normal distribution of residuals for small samples. The normal QQ plot in Figure 4.26 allows to compare the quantiles of the standardised residuals of the regression model against a normal distribution indicated by the red line. The raw residual is the mathematical difference between an observed data point and a calculated predicted value for that point. The standardised residual takes that raw residual and divides it by the standard deviation of the total set of residuals. The QQ plot indicates an approximately normal distribution, whereby the standardised residuals for loans to enterprises reflect expectedly some more deviation due to outliers visible in the fitted regression line plot (Figure 4.5).

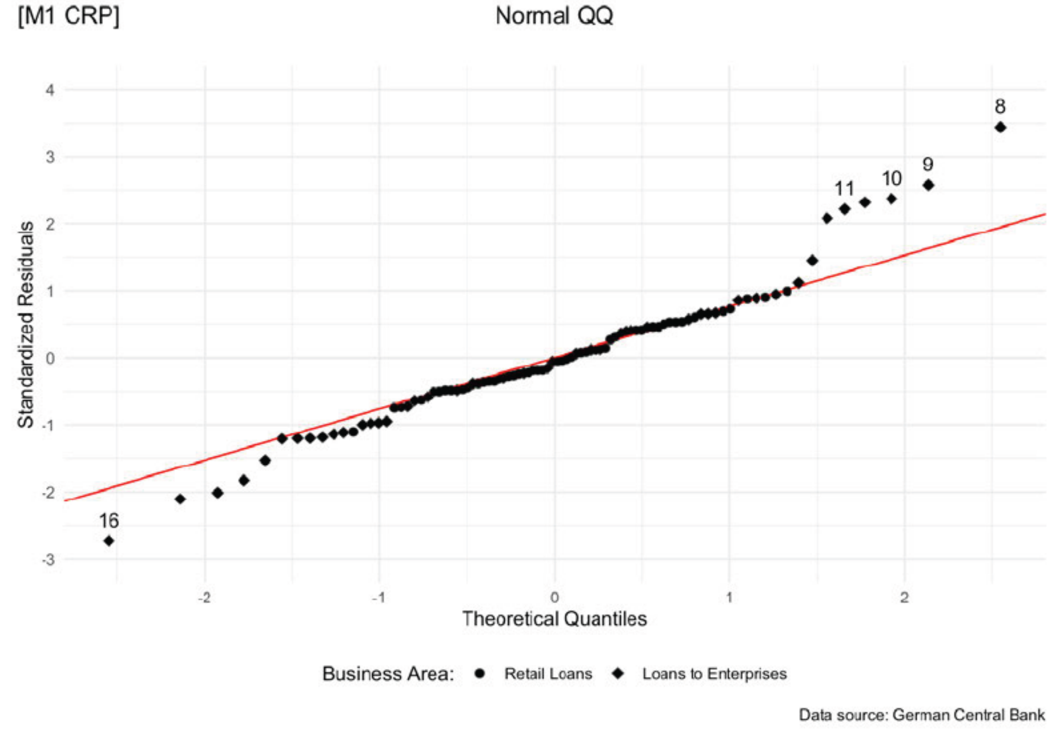


FIGURE 4.26:
M1 CRP - NORMAL QQ

Source: author's R output

The results of the Shapiro-Wilk test on normal distribution of residuals are summarised in Table 4.35. The test has the weakness that the probability p falls with increasing sample size N and small deviances from a normal distribution. To account for this sensitivity, the normal distribution is tested separately for each business area based on the respective small subsamples.

TABLE 4.35:
M1 CRP - SHAPIRO-WILK TEST

Test	Shapiro-Wilk on normal distribution (left tail)

Regression model	$\hat{e}_{t\|RTL} = RWAD_t - \hat{\alpha} - \hat{\beta}\ ECB.MRO_t$ $\hat{e}_{t\|ETP} = RWAD_t - (\hat{\alpha} + \hat{\gamma}) - (\hat{\beta} + \hat{\delta}_1)ECB.MRO_t - \hat{\delta}_2\ ECB.MRO_t^2$
Null hypothesis	$H_0: \hat{e}_t \sim N(\mu, \sigma^2)$ $(normal\ distribution)$
Alternative hypothesis	$H_1: no\ normal\ distribution$
Rejection union	$p \leq 0.05$
Test statistic	$W_{RTL} = 0.97$ $W_{ETP} = 0.98$
Probability	$p_{RTL} = 0.32$ $p_{ETP} = 0.48$
Conclusion	H_0 is not rejected: normal distribution

Normality of residuals is an assumption of the regression model for credit risk perception because the values of the dependent variable RWA density follow an approximately normal distribution. The distribution has been analysed using a normal QQ plot along with a Shapiro-Wilk test on normal distribution of residuals. The null hypothesis of a normal distribution of residuals is not rejected at a confidence level of above 95%. It is concluded that there is statistical evidence of a normal distribution and therefore the assumption of normally distributed residuals holds.

A6 - NO EXTREME OUTLIERS: The assumption of the absence of extreme outliers that are influential on the regression fit is assessed based on the measures standardised residual r, the hat value indicating leverage and Cook's Distance D indicating high influence. The visual inspection builds up on these measures and is carried out through the residuals versus leverage plot, the Cook's Distance plot and the Cook's Distance versus leverage plot. Table 4.36 presents the observations, that exceeded the common rule of thumb thresholds for the measures absolute standardised residual ($|r| > 2$), leverage ($hat > 2\frac{(p+1)}{n}$) and influence ($D > \frac{4}{(n-p-1)}$) with number of parameters p and number of observations n.

TABLE 4.36:
M1 CRP - POTENTIALLY INFLUENTIAL OBSERVATIONS

Observation	lrl
8	3.44
16	2.74
9	2.58
10	2.37
4	2.32
11	2.22
15	2.11
7	2.08
5	2.01

Observation	Hat
3	0.26
4	0.26
1	0.23
2	0.23
49	0.20
50	0.20
47	0.19
48	0.19

Observation	D
4	0.37
16	0.14
8	0.12
5	0.10
9	0.07
15	0.07
3	0.06
10	0.06
11	0.05

There are some potentially influential observations identified based on the 3 measures and their thresholds. However, the Cook's Distance values indicate that there is no highly influential observation with $D > 0.5$ which would require further inspection or even with $D > 1$ which indicates extreme influence. Figure 4.27 visualises the influence of observations based on Cook's Distance where those that exceed the Cook's Distance threshold are labelled.

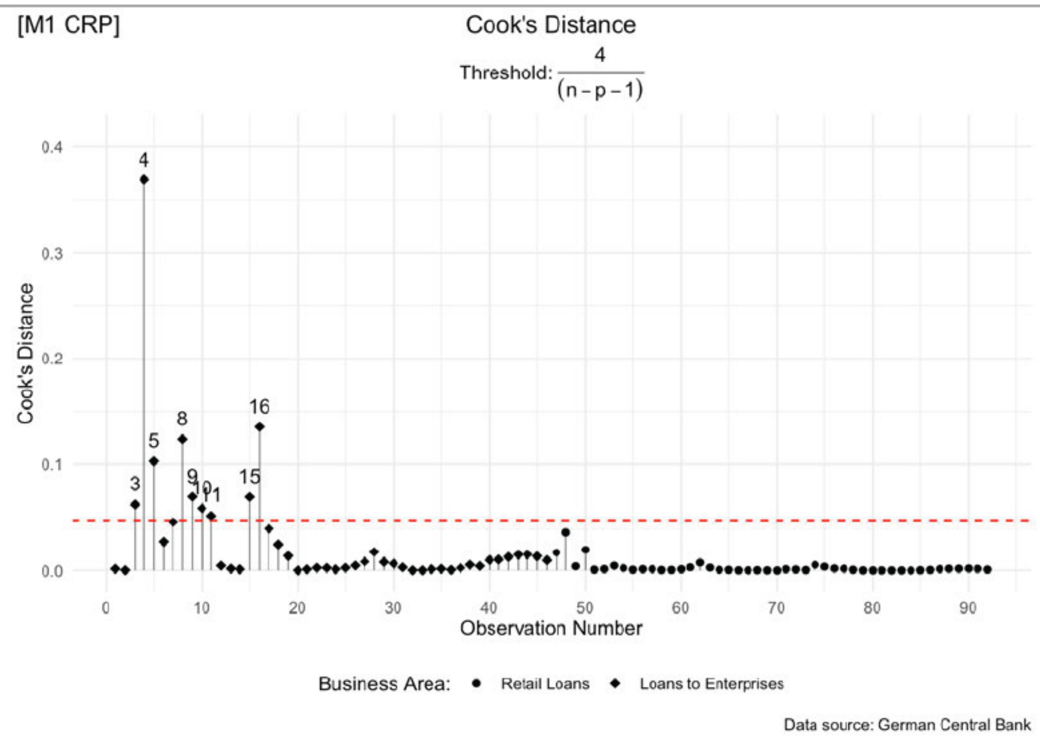


FIGURE 4.27:
M1 CRP - COOK'S DISTANCE

Source: author's R output

Figure 4.28 shows the residuals versus leverage plot in which potentially influential observations based on their leverage and Cook's Distance are labelled.

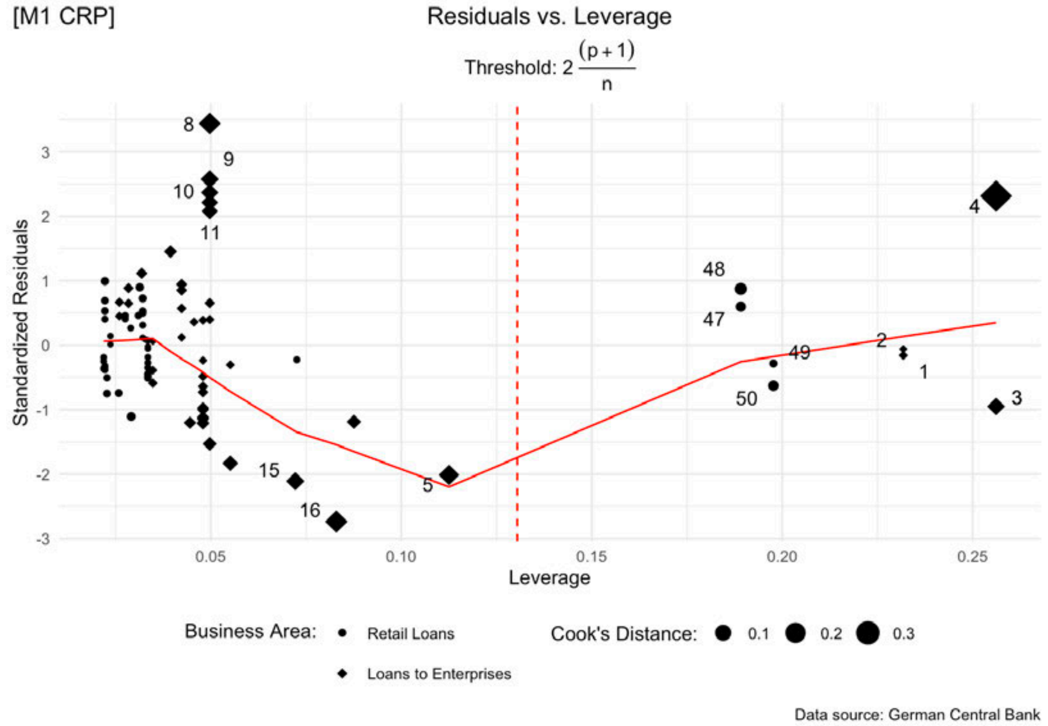


FIGURE 4.28:
M1 CRP - RESIDUALS VS. LEVERAGE

Source: author’s R output

Figure 4.29 shows the Cook's Distance versus leverage plot in which again potentially influential observations based on the Cook's Distance and leverage thresholds are labelled. Observation number 4 displays the greatest Cook's Distance and leverage but remains below the critical value of $D = 0.5$.

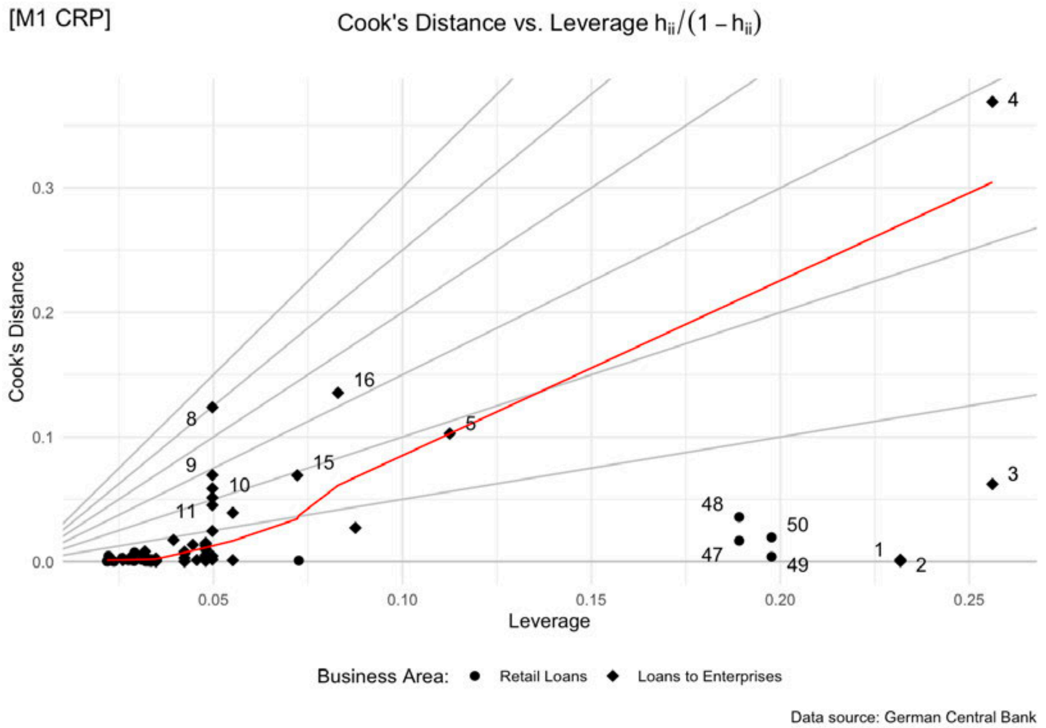


FIGURE 4.29:
M1 CRP - COOK'S DISTANCE VS. LEVERAGE

Source: author's R output

The influence of the top five potentially influential observations (PIO) based on the influence measure Cook's Distance on the regression fit is visually inspected by comparing the regression fit based on the unrestricted sample including potentially influential observations against that based on the restricted sample excluding the top 5 potentially influential observations. Figure 4.30 shows the outlier influence based on the identical regression model of Equation (4.11) and samples that differ in the top 5 outliers based on Cook's Distance.

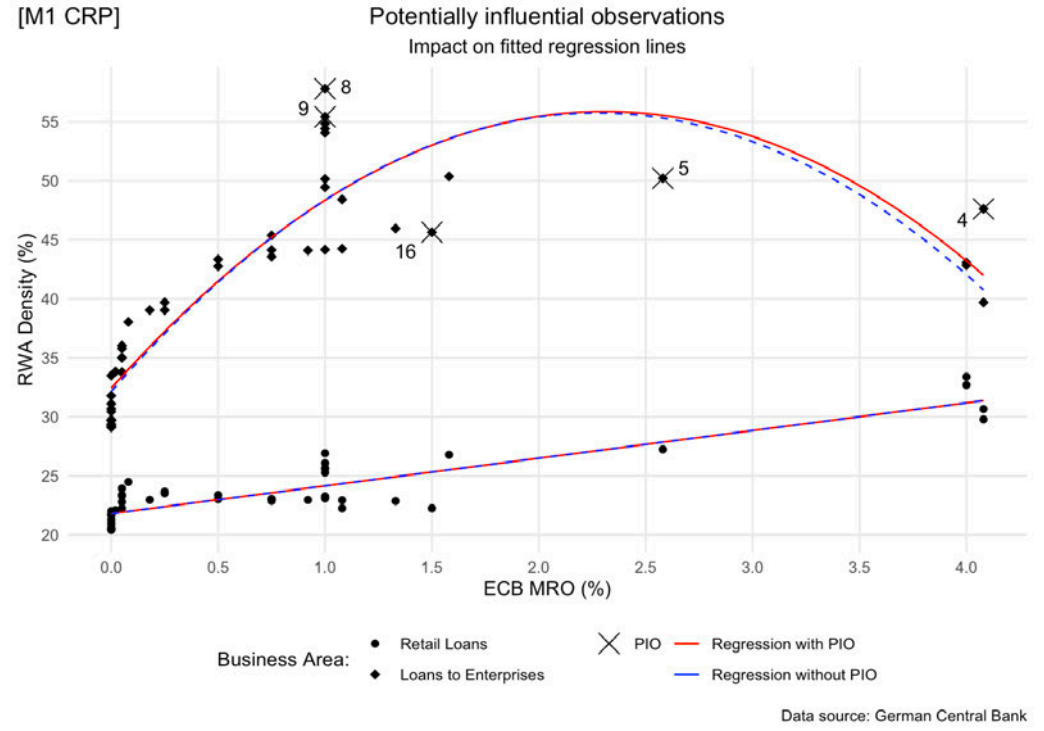


FIGURE 4.30:
M1 CRP - IMPACT OF PIO ON REGRESSION FIT

Source: author's R output

The plot supports the indication of the magnitudes of the measures. No observation exhibits an extreme influence which distorts the regression fit. It is concluded that the assumption of no extreme outliers holds.

A7 - RANDOM SAMPLE: The assumption of random sampling requires that the sample is drawn randomly from the population. A non-random sample causes the risk of introducing an unknown factor into the analysis that the OLS regression will not account for. The sample collected by the German Central Bank comprises all German commercial banks that apply the regulatory IRBA approach, which constitutes a methodically driven sample of commercial banks in Germany. This implies the random sampling assumption holds, but the aspect needs to be considered in the generalisation of the empirical results. Furthermore, OLS is a statistical method to investigate the causal relationship of the independent variable towards the dependent variable, in contrast to a correlation analysis. For the credit risk perception model, the independent variable ECB MRO is theorised to cause the dependent variable RWA density. Finally, the number of observations taken in the sample are required to exceed the number of parameters in the regression model, which is true for model 1 credit risk perception. It is concluded that the assumption of random sampling holds.

An overview of the outcomes of the regression model diagnostics is presented in Table 4.37. The violation of the assumptions on A4 homoscedasticity and A5 non-autocorrelation in the residuals causes statistical inference to be invalid. Therefore, the OLS standard errors are corrected by estimating heteroscedasticity and autocorrelation consistent (HAC) standard errors.

TABLE 4.37:
M1 CRP – DIAGNOSTIC RESULTS

A1	Linearity of coefficients	✓
A2	Zero mean of residuals	✓
A3	Homoscedasticity of residuals	X
A4	No autocorrelation of residuals	X
A5	Normality of residuals	✓
A6	No extreme outliers	✓
A7	Random sample	✓

HAC ROBUST STANDARD ERRORS: The choice is on Newey West HAC standard errors as one type of the HAC robust standard errors, because the method relies on linearly declining weights in estimating the covariance matrix, which seems appropriate with respect to the evaluation of the autocorrelation function that indicates a decrease in autocorrelations with increasing lag. Table 4.38 compares for each coefficient the original standard errors (SE) to the heteroscedasticity and autocorrelation robust standard errors derived from the Newey West HAC covariance matrix (robust SE).

TABLE 4.38:
M1 CRP - HAC ROBUST STANDARD ERRORS

	SE	Robust SE
Intercept	0.51	0.35
ECB.MRO (%)	0.36	0.22
BA.ETP	0.8	0.94
BA.ETP x ECB.MRO (%)	1.21	2.64
BA.ETP x ECB.MRO^2 (%)	0.29	0.65

The HAC covariance matrix leads to an increase in the robust standard errors for the estimated coefficients on BA.ETP, (BA.ETP x ECB.MRO) and (BA.ETP x ECB.MRO^2). The corresponding adjustment in the 95% confidence intervals of the coefficient estimates is visualised by a forest plot in Figure 4.31.

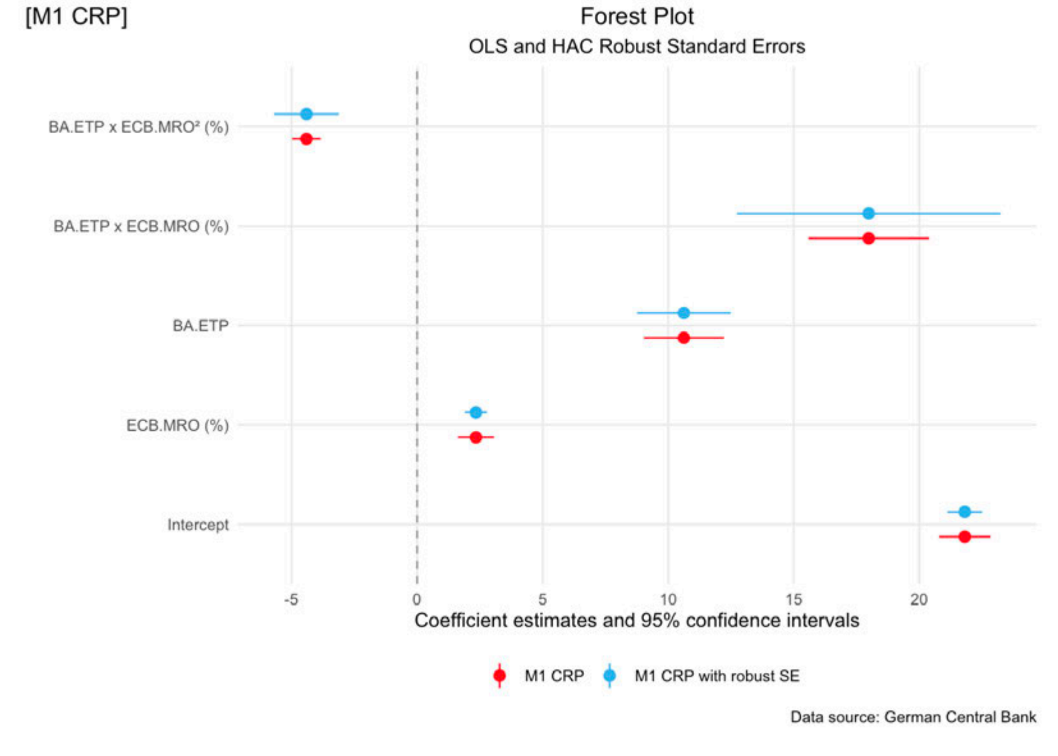


FIGURE 4.31:
M1 CRP - FOREST PLOT

Source: author's R output

In the further process of the regression analysis of credit risk perception, all statistical inference will be based on this HAC covariance matrix.

4.6.2 MODEL 2: CREDIT ALLOCATION RISK-TAKING

The regression model diagnostics is based on the specified econometric model on credit allocation risk-taking of German commercial banks (M2 CART):

$$RLS_t = \beta_0 + \beta_1 ECB.MRO_t + \beta_2 ECB.MRO_t^2 + e_t, \quad t = 1, \dots, N \tag{4.27}$$

A1 - LINEARITY OF COEFFICIENTS: A plot of residuals versus fitted values is applied to investigate the assumption of linearity of coefficients in the regression model. Figure 4.32 shows no fitted pattern in the estimated values for risky loan share (RLS). It is concluded that the assumption of linearity of coefficients holds.

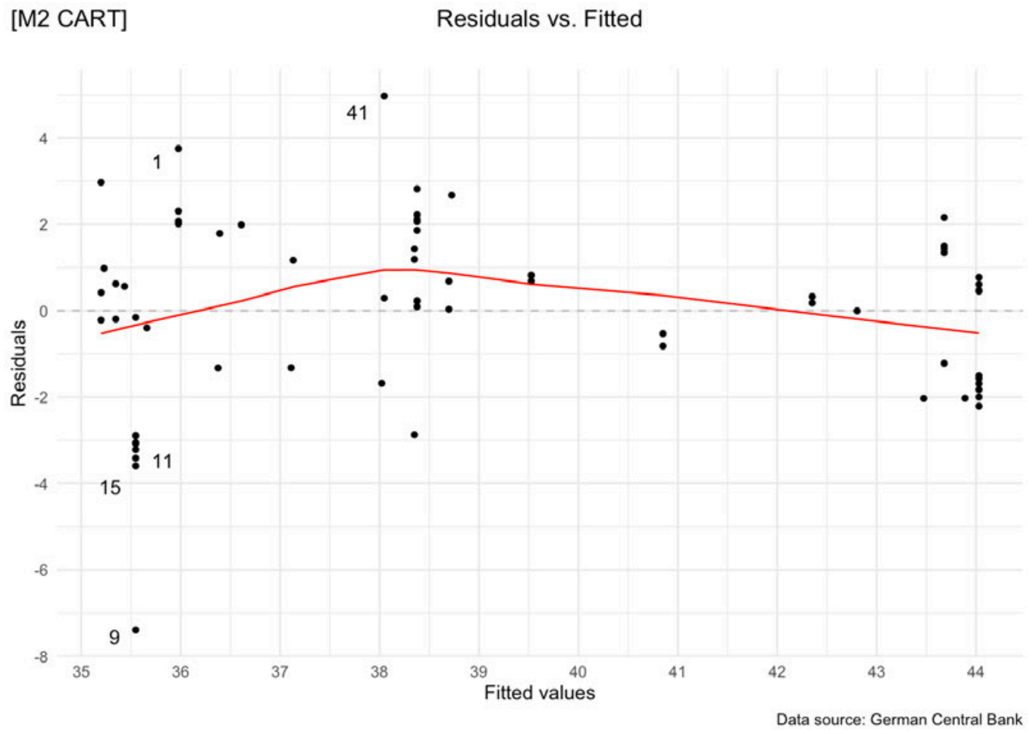


FIGURE 4.32:
M2 CART - RESIDUALS VS. FITTED

Source: author's R output

A2 - ZERO MEAN OF RESIDUALS: The plot of residuals versus fitted values is also applied to investigate the assumption of a zero mean of residuals in the regression model. The red LOWESS curve (locally weighted scatterplot smoothing) in Figure 4.32 is approximately horizontal. It is concluded that the assumption of residuals with zero mean holds.

A3 - HOMOSCEDASTICITY OF RESIDUALS: The assumption on homoscedastic errors is investigated through a visual inspection of a scale-location plot, which is complemented by a Breusch-Pagan test on heteroscedasticity. The scale-location plot in Figure 4.33 shows an approximately horizontal red LOWESS curve with a step. The outliers introduce some increased variance for lower fitted values, so that heteroscedasticity might be present.

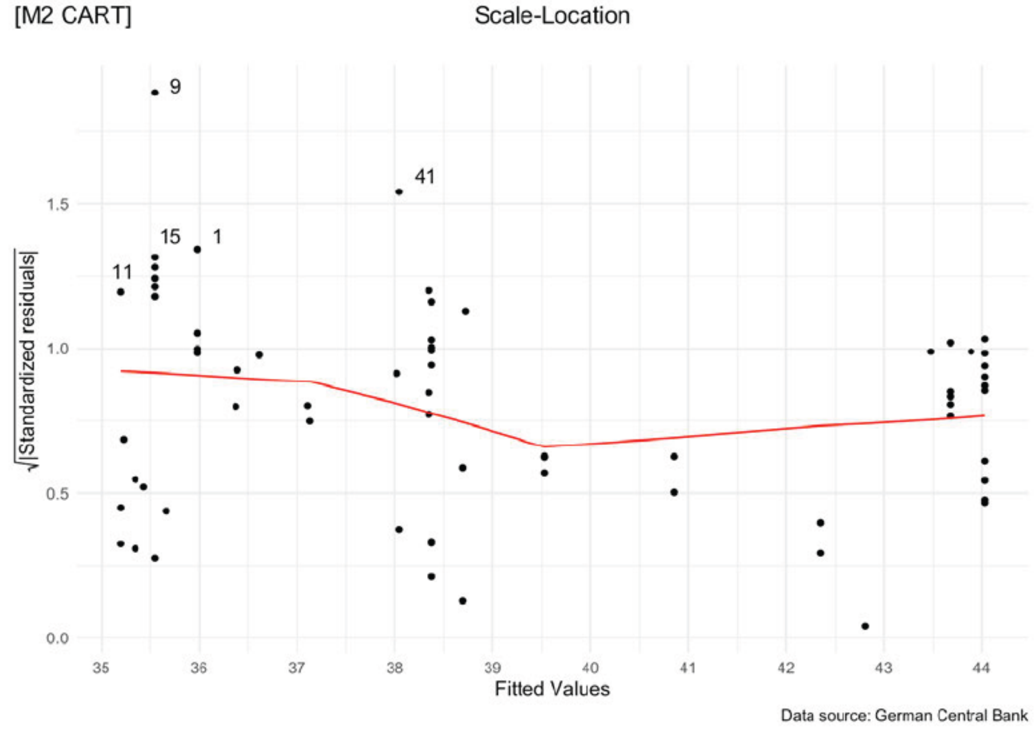


FIGURE 4.33:
M2 CART - SCALE-LOCATION

Source: author's R output

The results of the Breusch-Pagan test on heteroscedasticity are summarised in Table 4.39.

TABLE 4.39:
M2 CART - BREUSCH-PAGAN TEST

Test	Breusch-Pagan on heteroscedasticity (right tail)
Regression model	$\hat{e}_t^2 = \alpha_1 + \alpha_2 z_{t2} + \cdots + \alpha_S z_{tS} + v_t$
Null hypothesis	$H_0: \alpha_2 = \alpha_3 = \cdots = \alpha_S = 0$ $(homoscedasticity)$
Alternative hypothesis	$H_1: not\ all\ the\ \alpha_S\ in\ H_0\ are\ zero$ $(heteroscedasticity)$

Rejection union	$BP \geq 5.99$ $p \leq 0.05$
Test statistic	$BP = 9.47$
Degrees of freedom	$df = 2$
Probability	$p = 0.009$
Conclusion	H_0 is rejected: heteroscedasticity

This test result is visualised in Figure 4.34, which shows that the calculated test statistic falls inside the rejection union of the chi-square distribution with a probability of the null hypothesis of $p = 0.009$.

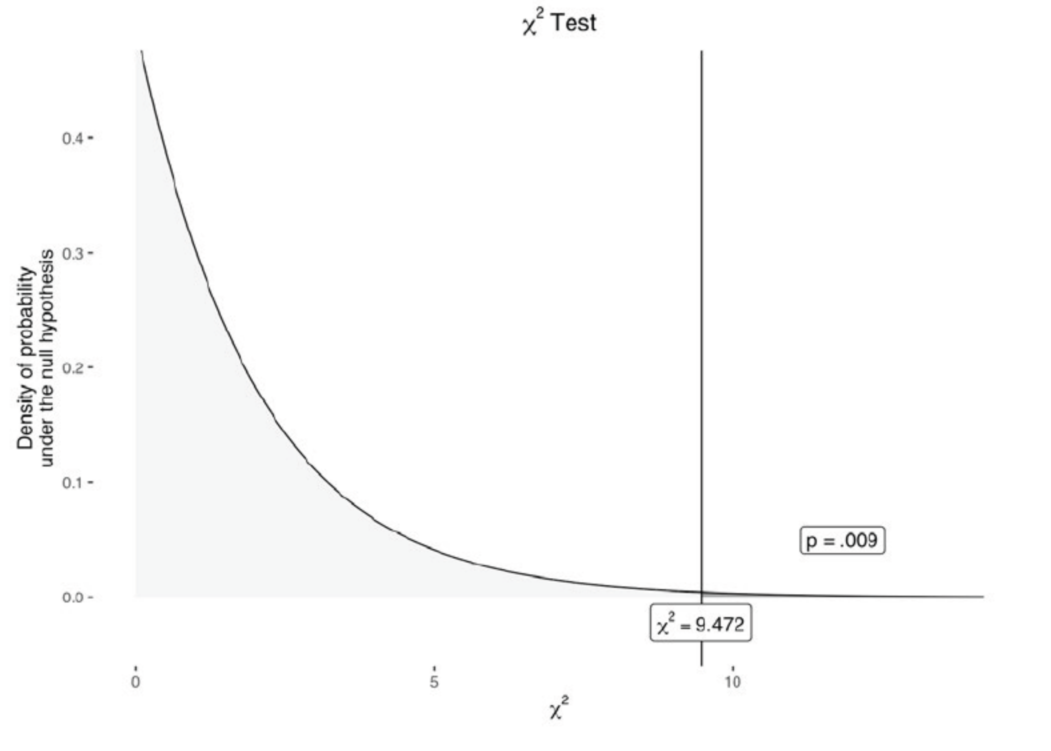


FIGURE 4.34:
M2 CART - BREUSCH-PAGAN TEST

Source: author's R output

Homoscedasticity of residuals is an assumption of the regression model for credit allocation risk-taking. The presence of heteroscedasticity has been analysed using a scale-location plot along with a Breusch-Pagan test on heteroscedasticity. The null hypothesis of homoscedasticity of residuals is rejected at a confidence level of above 95%. It is concluded that there is statistical evidence of heteroscedasticity and therefore the assumption of homoscedastic residuals does not hold. This violation implies, that the estimators are still consistent, but their statistical inference including standard errors, t value, F value and p value are biased since the covariance matrix estimate is inconsistent. A transformation of the variables did not improve this result. In consequence, the standard errors of the estimates will be corrected by estimating a heteroscedasticity robust covariance matrix so that a consistent statistical inference is achieved through heteroscedasticity robust standard errors and with heteroscedasticity robust Wald tests in the form of a quasi t-test and quasi F-test, respectively.

A4 - NO AUTOCORRELATION OF RESIDUALS: The assumption of no autocorrelation in errors is assessed through a visual inspection of a residual correlogram or autocorrelation function (ACF) plot, which is complemented by a Durbin-Watson test on autocorrelation. At a confidence level of 95%, the ACF plot in Figure 4.35 indicates positive autocorrelation with a coefficient $\rho > 0$ in lags 1 to 4 as well as negative autocorrelation with a coefficient $\rho < 0$ in lags 18 to 21.

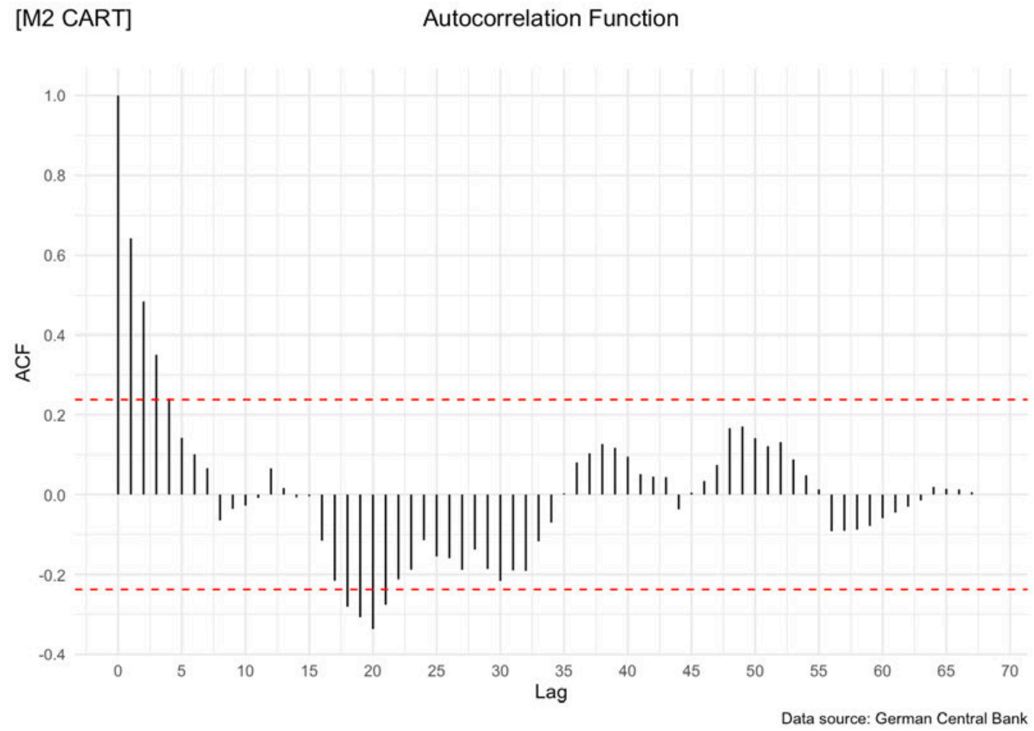


FIGURE 4.35:
M2 CART - ACF

Source: author’s R output

The results of the corresponding Durbin-Watson test on positive first-order autocorrelation based on an AR(1) error regression model are summarised in Table 4.40. Non-autocorrelation of residuals is an assumption of the regression model for credit allocation risk-taking. The presence of autocorrelation has been analysed using an ACF plot along with a Durbin-Watson test on positive first-order autocorrelation. The null hypothesis of no autocorrelation in residuals is rejected at a confidence level of above 95% since the test statistic falls inside the rejection union of the left tail. It is concluded that there is statistical evidence of autocorrelation and therefore the assumption of non-autocorrelated residuals does not hold.

TABLE 4.40:
M2 CART - DURBIN-WATSON TEST

Test	Durbin-Watson on autocorrelation (left tail)
Regression model	$\hat{e}_t = \rho \hat{e}_{t-1} + v_t$
Null hypothesis	$H_0: \rho = 0$ $(no\ autocorrelation, d \approx 2)$
Alternative hypothesis	$H_1: \rho > 0$ $(positive\ autocorrelation, d \approx 0)$
Rejection union	$p \leq 0.05$
Test statistic	$d = 0.67$
Probability	$p < 0.001$
Conclusion	H_0 is rejected: positive autocorrelation

This violation implies, that the estimators are still consistent, but their statistical inference including standard errors, t value, F value and p value are biased since the covariance matrix estimate is inconsistent. In consequence, the standard errors of the estimates will be corrected by estimating an autocorrelation robust covariance matrix so that a consistent statistical inference is achieved through autocorrelation robust standard errors and with autocorrelation robust Wald tests in the form of a quasi t-test and quasi F-test, respectively.

A5 - NORLMALITY OF RESIDUALS: The assumption of normally distributed errors is assessed through a visual inspection of a normal quantity-quantity (QQ) plot, which is complemented by a Shapiro-Wilk test on normal distribution of residuals for small samples. The normal QQ plot in Figure 4.36 allows to compare the quantiles of the standardised residuals of the regression model against a normal distribution indicated by the red line. The raw residual is the mathematical difference between an observed data point and a calculated predicted value for that point. The standardised residual takes that raw residual and divides it by the standard deviation of the total set of residuals. The QQ plot indicates an approximately normal distribution of the standardised residuals.

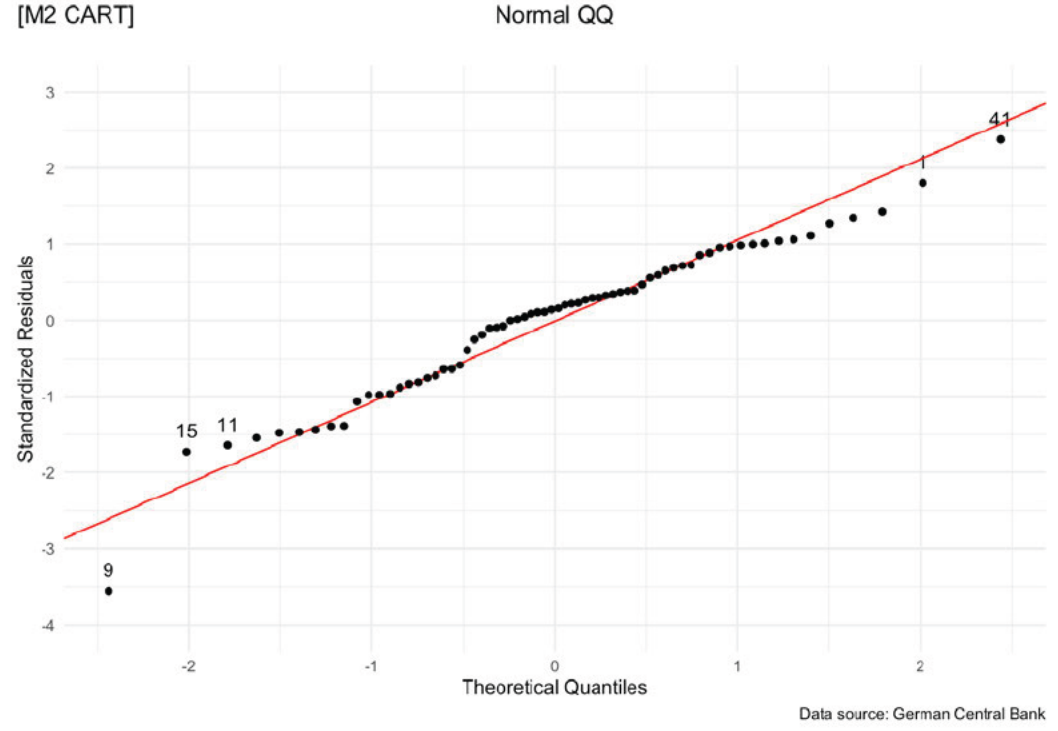


FIGURE 4.36:
M2 CART - NORMAL QQ

Source: author's R output

The results of the Shapiro-Wilk test on normal distribution of residuals are summarised in Table 4.41. The test has the weakness that the probability p falls with increasing sample size N and small deviances from a normal distribution.

TABLE 4.41:
M2 CART - SHAPIRO-WILK TEST

Test	Shapiro-Wilk on normal distribution (left tail)
Regression model	$\hat{e}_t = RLS_t - \hat{\beta}_0 - \hat{\beta}_1 ECB.MRO_t - \hat{\beta}_2 ECB.MRO_t^2$
Null hypothesis	$H_0\colon \hat{e}_t \sim N(\mu, \sigma^2)$ $(normal\ distribution)$

Alternative hypothesis	H_1: *no normal distribution*
Rejection union	$p \leq 0.05$
Test statistic	$W = 0.97$
Probability	$p = 0.06$
Conclusion	H_0 is not rejected: normal distribution

Normality of residuals is an assumption of the regression model for credit allocation risk-taking because the values of the dependent variable risky loan share follow an approximately normal distribution. The distribution has been analysed using a normal QQ plot along with a Shapiro-Wilk test on normal distribution of residuals. The null hypothesis of a normal distribution of residuals is not rejected at a confidence level of 95%. It is concluded that there is statistical evidence of a normal distribution and therefore the assumption of normally distributed residuals holds.

A6 - NO EXTREME OUTLIERS: The assumption of the absence of extreme outliers that are influential on the regression fit is assessed based on the measures standardised residual r, the hat value indicating leverage and Cook's Distance D indicating influential observations. The visual inspection builds up on these measures and is carried out through the residuals versus leverage plot, the Cook's Distance plot and the Cook's Distance versus leverage plot. Table 4.42 presents the observations, that exceeded the common rule of thumb thresholds for the measures absolute standardised residual ($|r| > 2$), leverage ($hat > 2\frac{(p+1)}{n}$) and influence ($D > \frac{4}{(n-p-1)}$) with number of parameters p and number of observations n.

TABLE 4.42:
M2 CART - POTENTIALLY INFLUENTIAL OBSERVATIONS

Observation	|r|
9	3.55
41	2.38

Observation	Hat
27	0.13
28	0.13

Observation	D
9	0.17
24	0.09

There are 5 potentially influential observations identified based on the 3 measures and their thresholds. However, the Cook's Distance values indicate that there is no highly influential observation with $D > 0.5$ which would require further inspection or even with $D > 1$ which indicates extreme influence. Figure

4.37 visualises the influence of observations based on Cook's Distance, where those that exceed the Cook's Distance threshold are labelled.

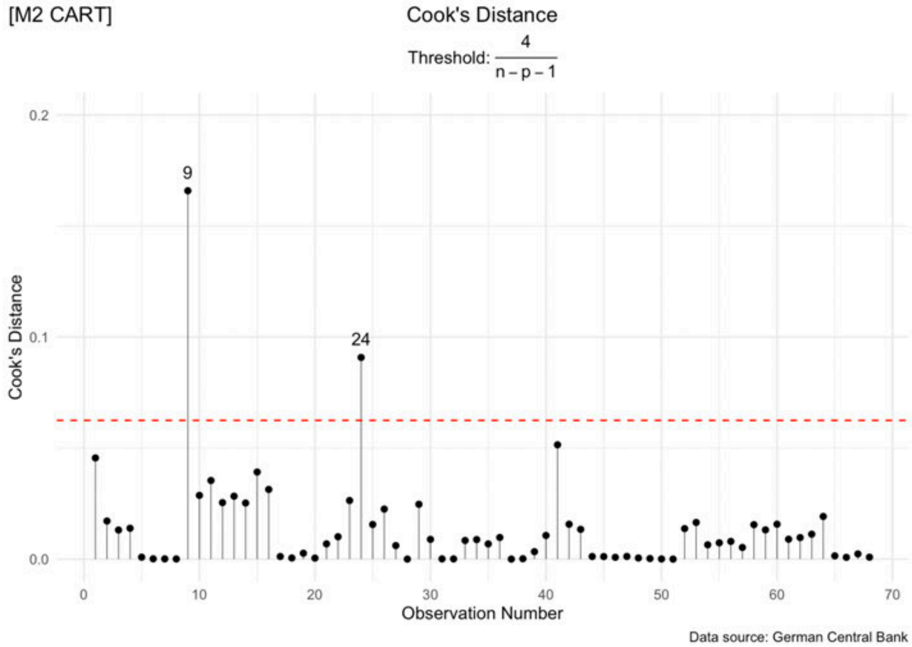


FIGURE 4.37:
M2 CART - COOK'S DISTANCE

Source: author's R output

Figure 4.38 shows the residuals versus leverage plot in which the 5 potentially influential observations based on their absolute standardised residual, leverage and Cook's Distance are labelled.

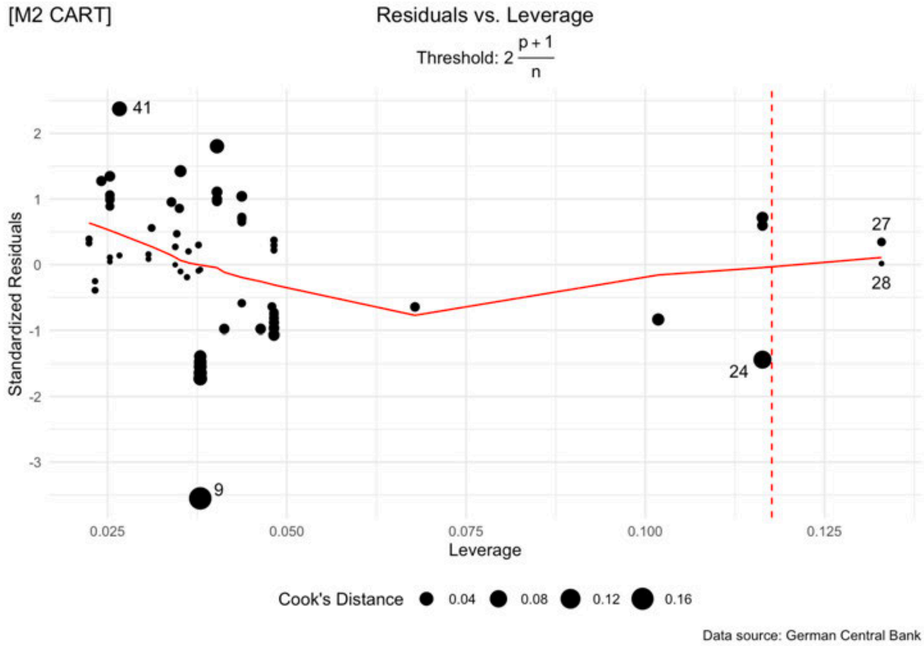


FIGURE 4.38:
M2 CART - RESIDUALS VS. LEVERAGE

Source: author's R output

Figure 4.39 presents the Cook's Distance versus leverage plot in which again the 5 potentially influential observations are labelled. Observations number 9, 24, 27 and 28 display the greatest Cook's Distance and leverage but remain well below the critical value of $D = 0.5$.

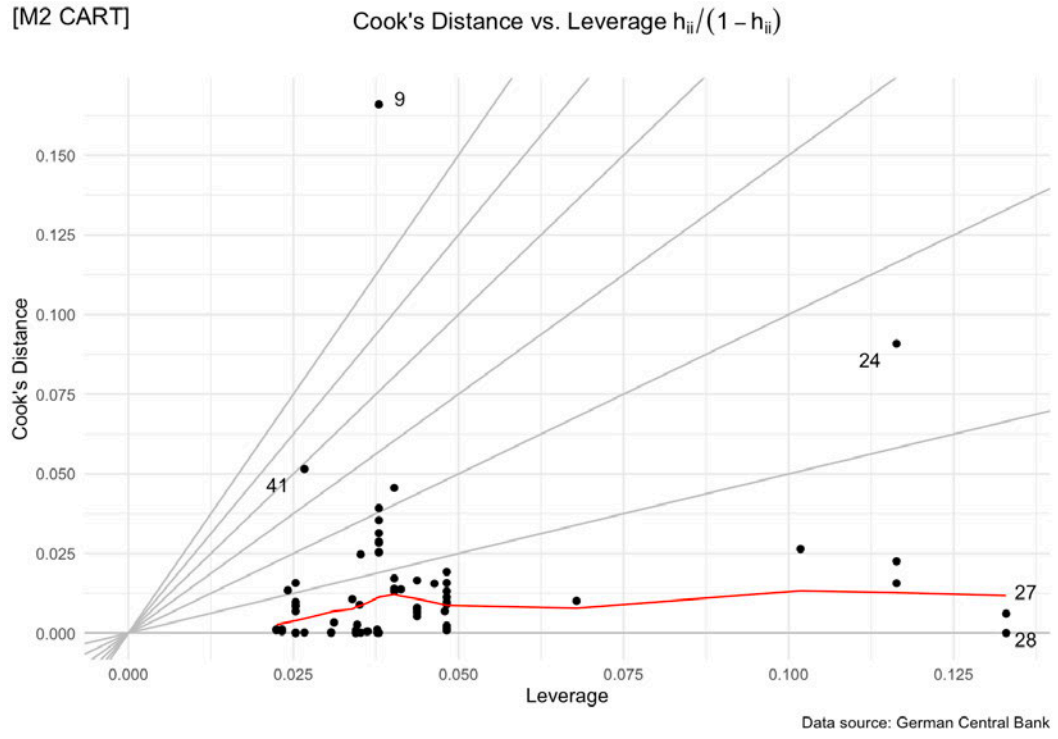


FIGURE 4.39:
M2 CART - COOK'S DISTANCE VS. LEVERAGE

Source: author's R output

The influence of all the 5 potentially influential observations (PIO) based on the 3 measures on the regression fit is visually inspected by comparing the regression fit based on the unrestricted sample including potentially influential observations against that based on the restricted sample excluding potentially influential observations. Figure 4.40 visualises the outlier influence based on the identical regression model of equation (4.14) and samples that differ in the potentially influential observations.

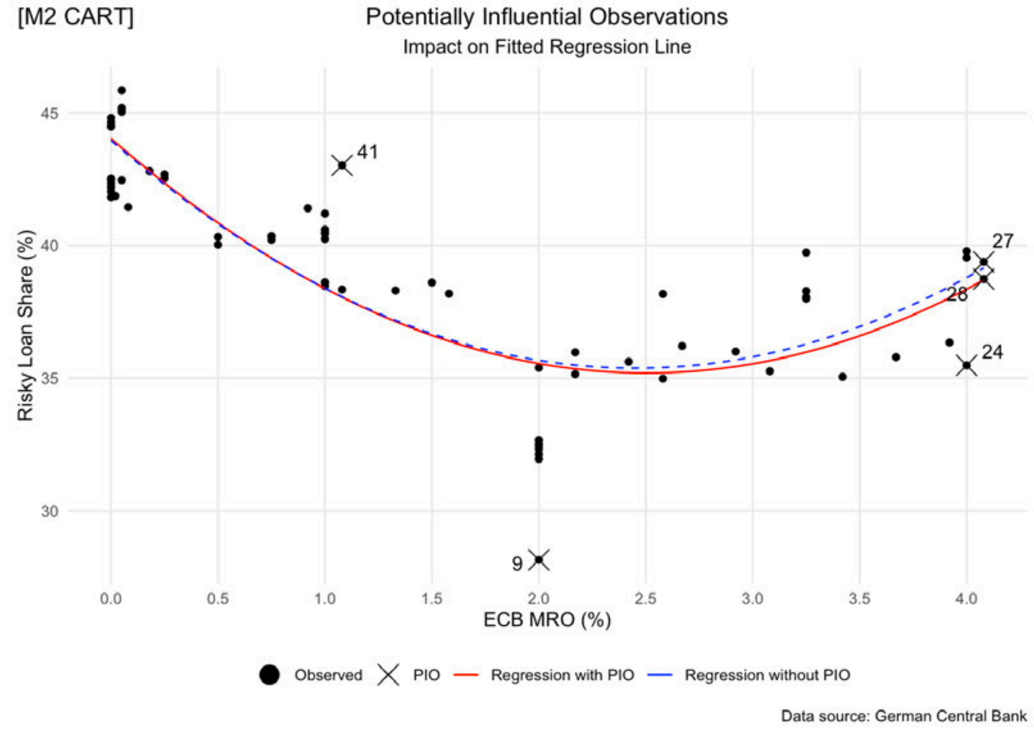


FIGURE 4.40:
M2 CART - IMPACT OF PIO ON REGRESSION FIT

Source: author's R output

The plot supports the indication of the magnitudes of the measures. No observation exhibits an extreme influence which distorts the regression fit. It is concluded that the assumption of no extreme outliers holds.

A7 - RANDOM SAMPLE: The assumption of random sampling requires that the sample is drawn randomly from the population. A non-random sample causes the risk of introducing an unknown factor into the analysis that the OLS regression will not account for. The sample collected by the German Central Bank comprises all German commercial banks and hence the total population of interest for Germany, which implies the random sampling holds. Furthermore, OLS is a statistical method to investigate the causal relationship of the independent variable towards the dependent variable, in contrast to a correlation analysis. For the credit allocation risk-taking model, the independent variable ECB MRO is theorised to cause the dependent variable risky loan share. Finally, the number of observations taken in the sample are required to exceed the number of parameters in the regression model, which is true for model 2 CART. It is concluded that the assumption of random sampling holds.

An overview of the outcomes of the regression model diagnostics are summarised in Table 4.43.

TABLE 4.43:
M2 CART – DIAGNOSTIC RESULTS

A1	Linearity of coefficients	✓
A2	Zero mean of residuals	✓
A3	Homoscedasticity of residuals	X
A4	No autocorrelation of residuals	X
A5	Normality of residuals	✓
A6	No extreme outliers	✓
A7	Random sample	✓

The violation of the assumptions of homoscedasticity and non-autocorrelation in the residuals causes statistical inference to be invalid. Therefore, the OLS standard errors are corrected by estimating heteroscedasticity and autocorrelation consistent (HAC) standard errors.

HAC ROBUST STANDARD ERRORS: The choice is on Newey West HAC standard errors as one type of the HAC robust standard errors, because the method relies on linearly declining weights in estimating the covariance matrix, which seems appropriate with respect to the evaluation of the autocorrelation function that indicates a decrease in autocorrelations with increasing lag. Table 4.44 compares for each coefficient the original standard errors (SE) to the heteroscedasticity and autocorrelation robust standard errors derived from the Newey West HAC covariance matrix (robust SE).

TABLE 4.44:
M2 CART - HAC ROBUST STANDARD ERRORS

	SE	Robust SE
Intercept	0.47	0.53
ECB.MRO (%)	0.65	1.20
$ECB.MRO^2$ (%)	0.17	0.30

The HAC covariance matrix leads to an increase in the robust standard errors for all estimated coefficients. The corresponding adjustment in the 95% confidence intervals of the coefficient estimates is visualised by a forest plot in Figure 4.41.

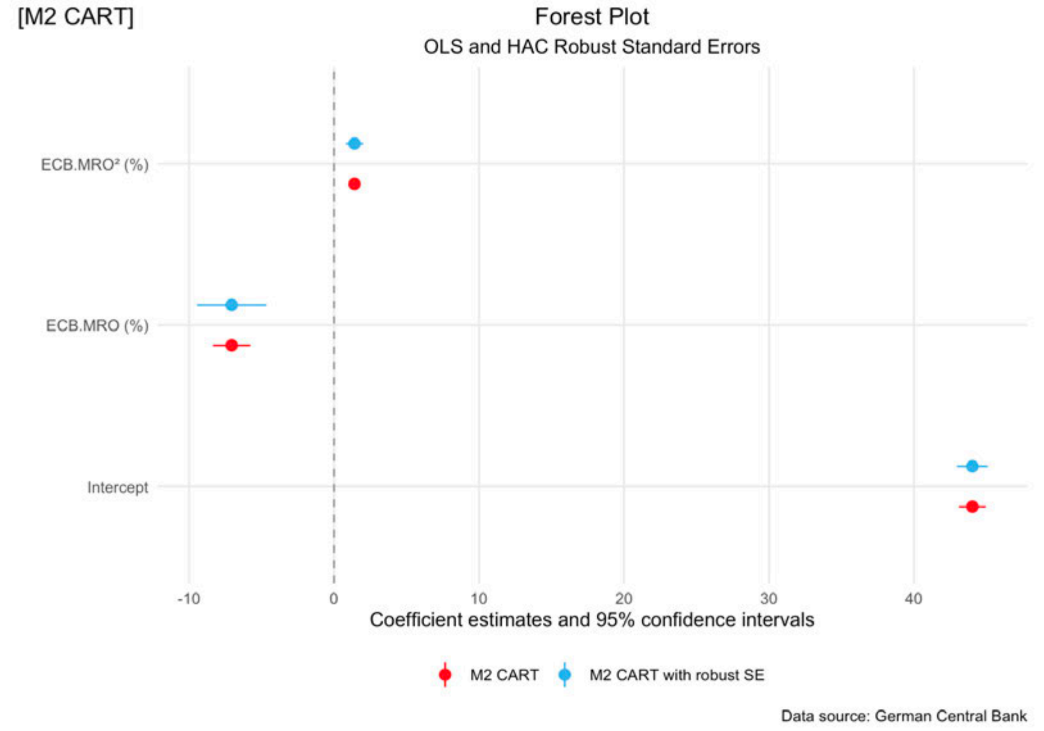


FIGURE 4.41:
M2 CART - FOREST PLOT

Source: author's R output

In the further process of the regression analysis of credit allocation risk-taking, all statistical inference will be based on this HAC covariance matrix.

4.6.3 MODEL 3: INTEREST RATE RISK-TAKING

The regression model diagnostics is based on the specified econometric model on interest rate risk-taking of German commercial banks (M3 IRRT):

$$NAD_t = \alpha + \delta_1 \, BG.SB_t + \delta_2 \, BG.LSI_t + \delta_3 \, BG.SMCB_t + \beta \, ECB.MRO_t + e_t, \quad t = 1, \dots, N \tag{4.28}$$

A1 - LINEARITY OF COEFFICIENTS: A plot of residuals versus fitted values is applied to investigate the assumption of linearity of coefficients in the regression model. Figure 4.42 shows no fitted pattern in the estimated values for the bank groups. It is concluded that the assumption of linearity of coefficients holds.

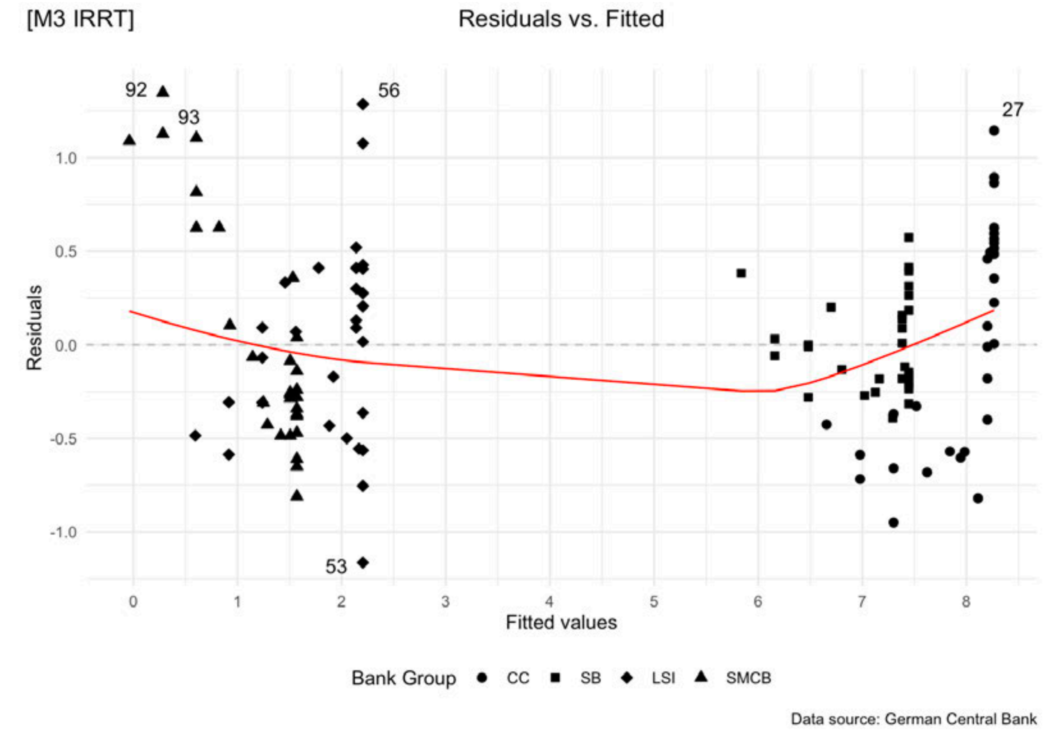


FIGURE 4.42:
M3 IRRT - RESIDUALS VS. FITTED

Source: author's R output

A2 - ZERO MEAN OF RESIDUALS: The plot of residuals versus fitted values is also applied to investigate the assumption of a zero mean of residuals in the regression model. The red LOWESS curve (locally weighted scatterplot smoothing) in Figure 4.42 is approximately horizontal. It is concluded that the assumption of residuals with zero mean holds.

A3: HOMOSCEDASTICITY OF RESIDUALS: The assumption on homoscedastic errors is investigated through a visual inspection of a scale-location plot, which is complemented by a Breusch-Pagan test on heteroscedasticity. The scale-location plot in Figure 4.43 exhibits variation in the LOWESS curve, which indicates changing variance of residuals, that is heteroscedasticity.

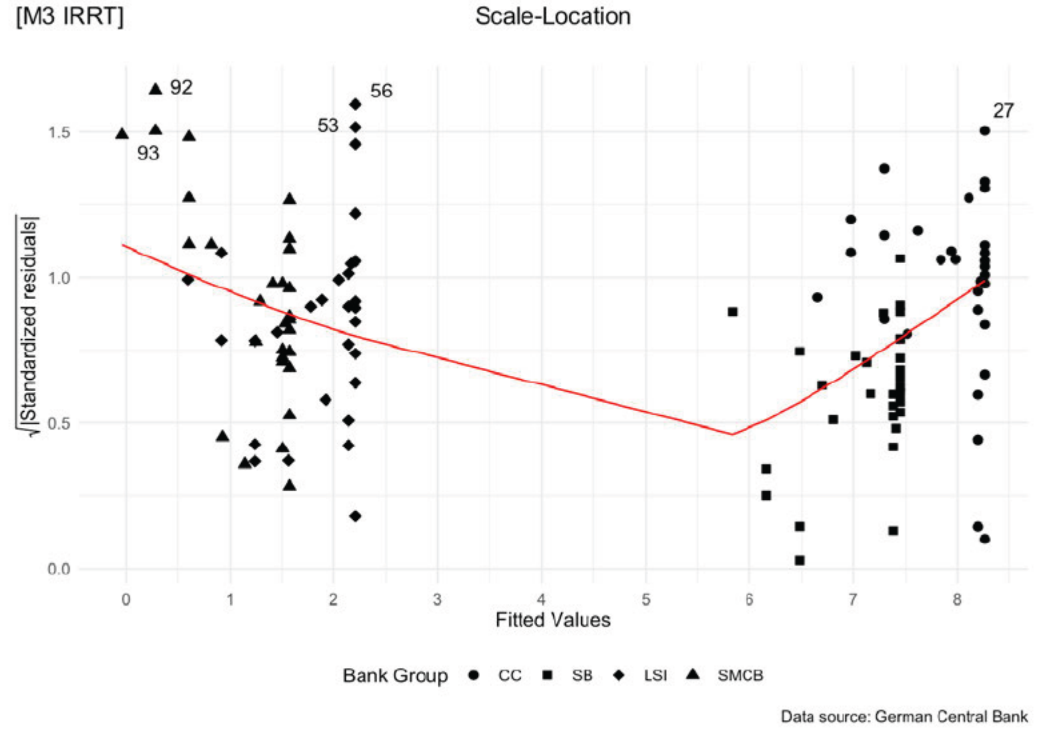


FIGURE 4.43:
M3 IRRT - SCALE-LOCATION

Source: author's R output

The results of the Breusch-Pagan test on heteroscedasticity are summarised in Table 4.45.

TABLE 4.45:
M3 IRRT - BREUSCH-PAGAN TEST

Test	Breusch-Pagan on heteroscedasticity (right tail)
Regression model	$\hat{e}_t^2 = \alpha_1 + \alpha_2 z_{t2} + \cdots + \alpha_S z_{tS} + v_t$
Null hypothesis	$H_0: \alpha_2 = \alpha_3 = \cdots = \alpha_S = 0$ $(homoscedasticity)$
Alternative hypothesis	$H_1: not\ all\ the\ \alpha_S\ in\ H_0\ are\ zero$ $(heteroscedasticity)$
Rejection union	$BP \geq 9.49$ $p \leq 0.05$

Test statistic	$BP = 16.45$
Degrees of freedom	$df = 4$
Probability	$p = 0.002$
Conclusion	H_0 is rejected: heteroscedasticity

This test result is visualised in Figure 4.44, which shows that the calculated test statistic falls inside the rejection union of the chi-square distribution with a probability of the null hypothesis of $p = 0.002$.

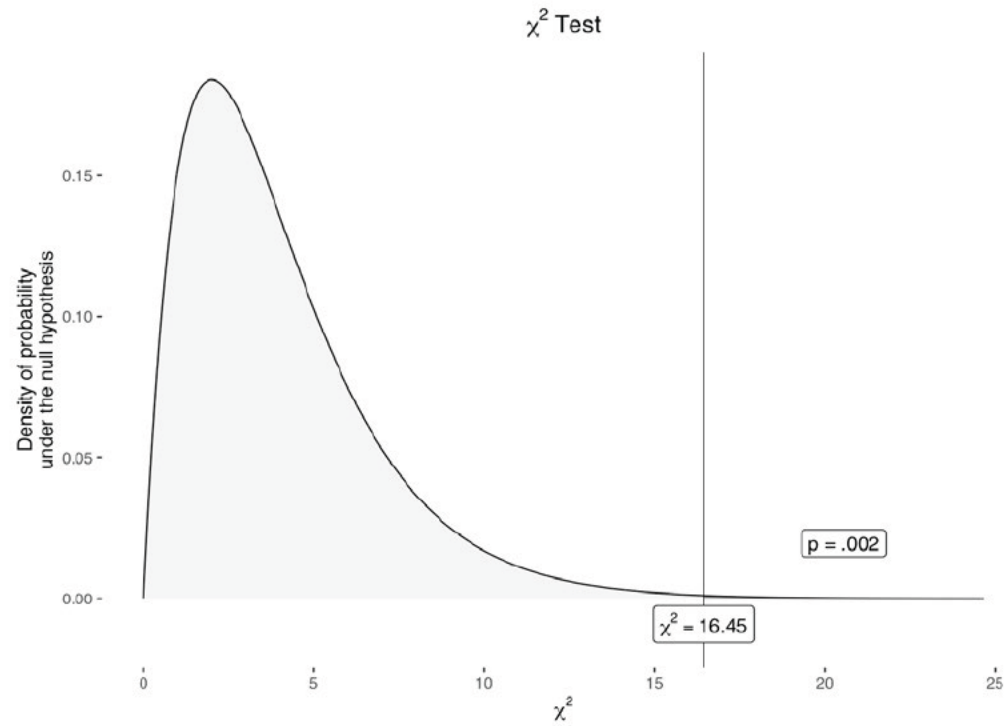


FIGURE 4.44:
M3 IRRT - BREUSCH-PAGAN TEST

Source: author's R output

Homoscedasticity of residuals is an assumption of the regression model for interest rate risk-taking. The presence of heteroscedasticity has been analysed using a scale-location plot along with a Breusch-Pagan test on heteroscedasticity. The null hypothesis of homoscedasticity of residuals is rejected at a confidence level of above 95%. It is concluded that there is statistical evidence of heteroscedasticity and therefore the assumption of homoscedastic residuals does not hold. This violation implies, that the estimators are still consistent, but their statistical inference including standard errors, t value, F value and p value are biased since the covariance matrix estimate is inconsistent. A transformation of the variables did not improve this result. In consequence, the standard errors of the estimates will be corrected by estimating a heteroscedasticity robust covariance matrix so that a consistent statistical inference is achieved through heteroscedasticity robust standard errors and with heteroscedasticity robust Wald tests in the form of a quasi t-test and quasi F-test, respectively.

A4 - NO AUTOCORRELATION OF RESIDUALS: The assumption of no autocorrelation in errors is assessed through a visual inspection of a residual correlogram or autocorrelation function (ACF) plot, which is complemented by a Durbin-Watson test on autocorrelation. At a confidence level of 95%, the ACF plot in Figure 4.45 indicates positive autocorrelation with a coefficient $\rho > 0$ in lags 1 to 5 as well as negative autocorrelation with a coefficient $\rho < 0$ in lags 13 to 15 and so on for some higher lags.

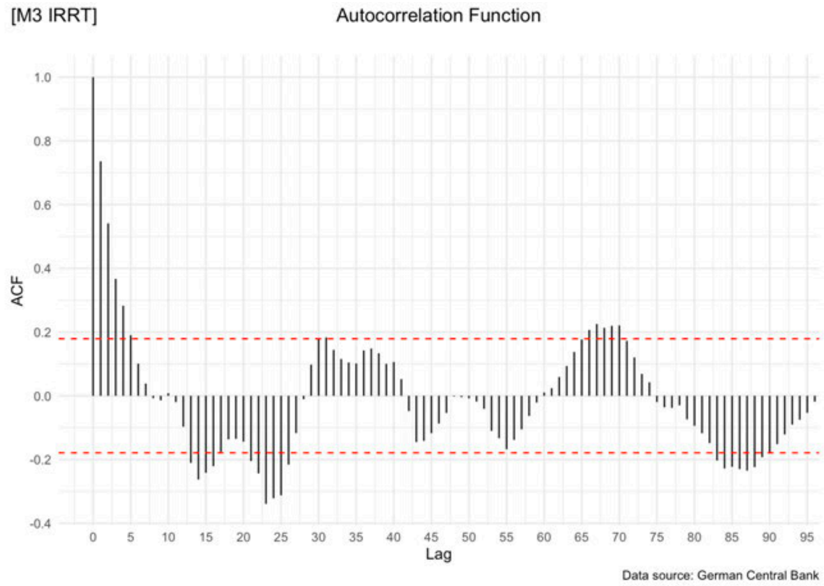


FIGURE 4.45:
M3 IRRT - ACF

Source: author's R output

The results of the corresponding Durbin-Watson test on positive first-order autocorrelation based on an AR(1) error regression model are summarised in Table 4.46.

TABLE 4.46:
M3 IRRT - DURBIN-WATSON TEST

Test	Durbin-Watson on autocorrelation (left tail)
Regression model	$\hat{e}_t = \rho\hat{e}_{t-1} + v_t$
Null hypothesis	$H_0: \rho = 0$ $(no\ autocorrelation, d \approx 2)$
Alternative hypothesis	$H_1: \rho > 0$ $(positive\ autocorrelation, d \approx 0)$
Rejection union	$p \leq 0.05$
Test statistic	$d = 0.52$
Probability	$p < 0.001$
Conclusion	H_0 is rejected: positive autocorrelation

Non-autocorrelation of residuals is an assumption of the regression model for interest rate risk-taking. The presence of autocorrelation has been analysed using an ACF plot along with a Durbin-Watson test on positive first-order autocorrelation. The null hypothesis of no autocorrelation in residuals is rejected at a confidence level of above 95% since the test statistic falls inside the rejection union of the left tail. It is concluded that there is statistical evidence of autocorrelation and therefore the assumption of non-autocorrelated residuals does not hold. This violation implies, that the estimators are still consistent, but their statistical inference including standard errors, t value, F value and p value are biased since the covariance matrix estimate is inconsistent. In consequence, the standard errors of the estimates will be corrected by estimating an autocorrelation robust covariance matrix so that a consistent statistical inference is achieved through autocorrelation robust standard errors and with autocorrelation robust Wald tests in the form of a quasi t-test and quasi F-test, respectively.

A5 - NORLMALITY OF RESIDUALS: The assumption of normally distributed errors is assessed through a visual inspection of a normal quantity-quantity (QQ) plot, which is complemented by a Shapiro-Wilk test on normal distribution of residuals for small samples. The normal QQ plot in Figure 4.46 allows to compare the quantiles of the standardised residuals of the regression model against a normal distribution indicated by the red line. The raw residual is the mathematical difference between an observed data point and a calculated predicted value for that point. The standardised residual takes that raw residual and divides it by the standard deviation of the total set of residuals. The QQ plot indicates an approximately normal distribution for all of the bank groups.

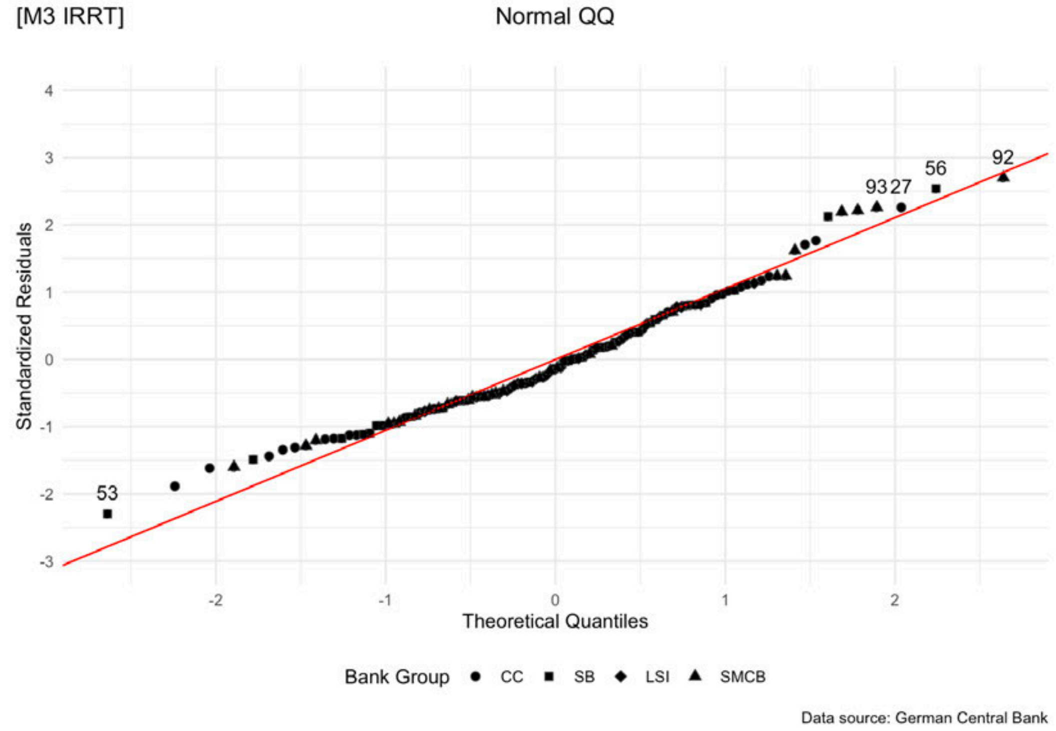


FIGURE 4.46:
M3 IRRT - NORMAL QQ

Source: author’s R output

The results of the Shapiro-Wilk test on normal distribution of residuals are summarised in Table 4.47. The test has the weakness that the probability p falls with increasing sample size N and small deviances from a normal distribution. To account for this sensitivity, the normal distribution is tested separately for each business area based on the respective small subsamples.

Normality of residuals is an assumption of the regression model for interest rate risk-taking because the values of the dependent variable net asset duration follow an approximately normal distribution. The distribution has been analysed using a normal QQ plot along with a Shapiro-Wilk test on normal distribution of residuals. For the bank groups CC, SB and LSI, the null hypothesis of a normal distribution of residuals is not rejected at a confidence level of 95%. For the bank group SMCB, the null hypothesis of a normal distribution of residuals is rejected at a confidence level of 95% and not rejected at a confidence level of 99.9%. The Shapiro-Wilk test does not provide clear statistical evidence for normally distributed residuals at the 95% confidence level.

TABLE 4.47:
M3 IRRT - SHAPIRO-WILK TEST

Test	Shapiro-Wilk on normal distribution (left tail)
Regression model	$\hat{e}_t = NAD_t - \hat{\alpha} - \hat{\delta}_1\, BG.SB_t - \hat{\delta}_2\, BG.LSI_t - \hat{\delta}_3\, BG.SMCB_t - \hat{\beta}\, ECB.MRO_t$
Null hypothesis	$H_0\colon \hat{e}_t \sim N(\mu, \sigma^2)$ $(normal\ distribution)$
Alternative hypothesis	$H_1\colon \hat{e}_t \neq N(\mu, \sigma^2)$ $(no\ normal\ distribution)$
Rejection union	$p \leq 0.05$
Test statistic	$W_{CC} = 0.94$ $W_{SB} = 0.95$ $W_{LSI} = 0.97$ $W_{SMCB} = 0.86$
Probability	$p_{CC} = 0.07$ $p_{SB} = 0.14$ $p_{LSI} = 0.55$ $p_{SMCB} = 0.001$
Conclusion	H_0 for CC, SB, LSI is not rejected: normal distribution H_0 for SMCB is rejected: no normal distribution

In consideration of the high sensitivity to small deviances for high N of the small sample test and supported by the Normal QQ plot, it is concluded that the residuals follow an approximately normal distribution and therefore the assumption of normality holds.

A6 - NO EXTREME OUTLIERS: The assumption of the absence of extreme outliers that are influential on the regression fit is assessed based on the measures standardised residual r, the hat value indicating leverage and Cook's Distance D indicating high influence. The visual inspection builds up on these measures and is carried out through the residuals versus leverage plot, the Cook's Distance plot and the Cook's Distance versus leverage plot. Table 4.48 presents the observations, that exceeded the common rule of thumb thresholds for the measures absolute standardised residual ($|r| > 2$), leverage

($hat > 2\frac{(p+1)}{n}$) and influence ($D > \frac{4}{(n-p-1)}$) with number of parameters p and number of observations n. In this case no observation exceeded the leverage threshold.

TABLE 4.48:
M3 IRRT - POTENTIALLY INFLUENTIAL OBSERVATIONS

Observation	lrl	Observation	D
92	2.70	92	0.10
56	2.54	91	0.10
53	2.30	93	0.07
27	2.26	56	0.05
93	2.26	96	0.05
91	2.22	53	0.04
96	2.19	27	0.04
57	2.13	4	0.04
		57	0.04

There are some potentially influential observations identified based on the 3 measures and their thresholds. However, the Cook's Distance values indicate that there is no highly influential observation with $D > 0.5$, which would require further inspection or even with $D > 1$ which indicates extreme influence. Figure 4.47 visualises the influence of observations based on Cook's Distance where those that exceed the Cook's Distance threshold are labelled.

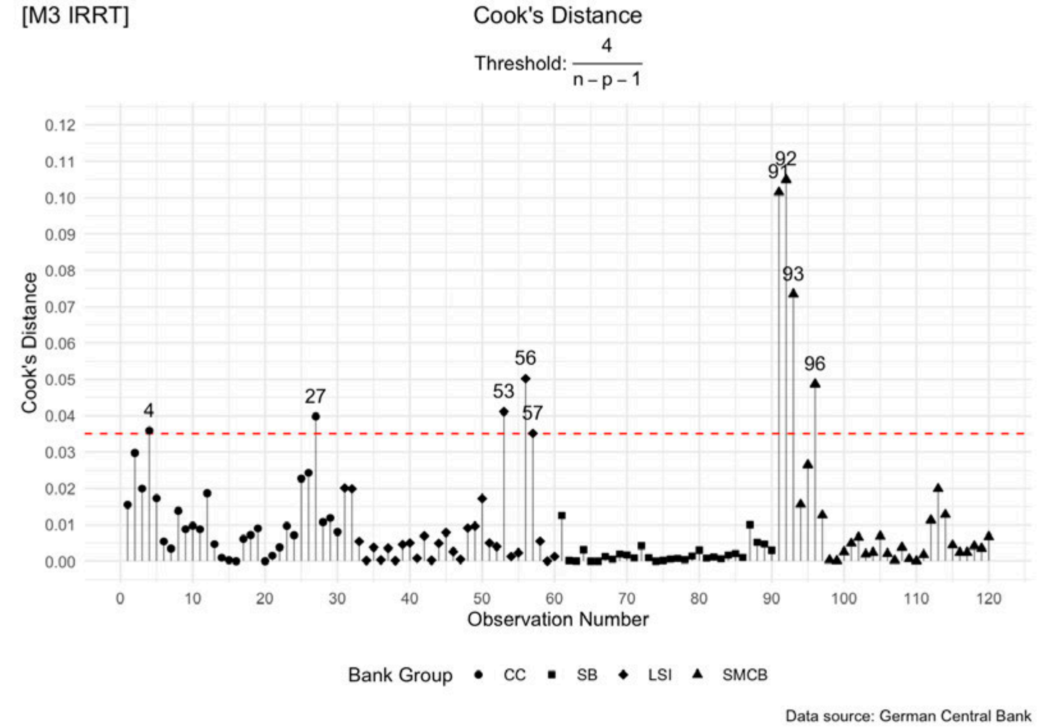


FIGURE 4.47:
M3 IRRT - COOK'S DISTANCE

Figure 4.48 shows the residuals versus leverage plot in which potentially influential observations based on their absolute standardised residual, leverage and Cook's Distance are labelled.

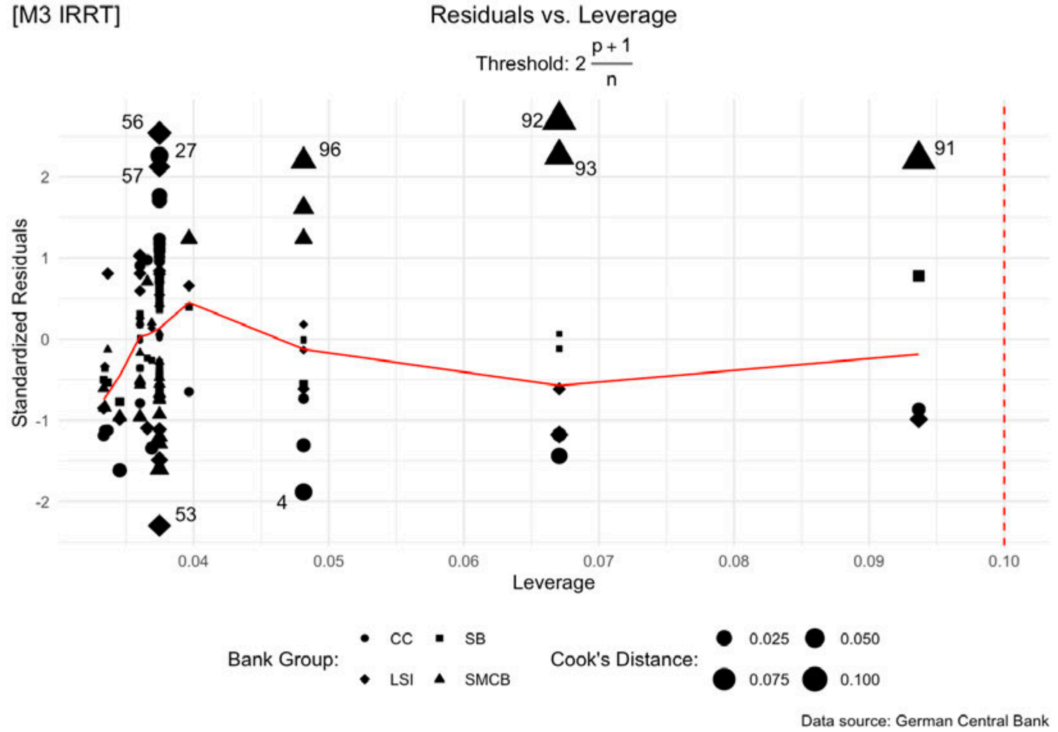


FIGURE 4.48:
M3 IRRT - RESIDUALS VS. LEVERAGE

Source: author's R output

Figure 4.49 shows the Cook's Distance versus leverage plot in which again potentially influential observations based on the absolute standardised residual, leverage and Cook's Distance labelled. Observation number 91 displays the greatest Cook's Distance and leverage but remains well below the critical value of $D = 0.5$.

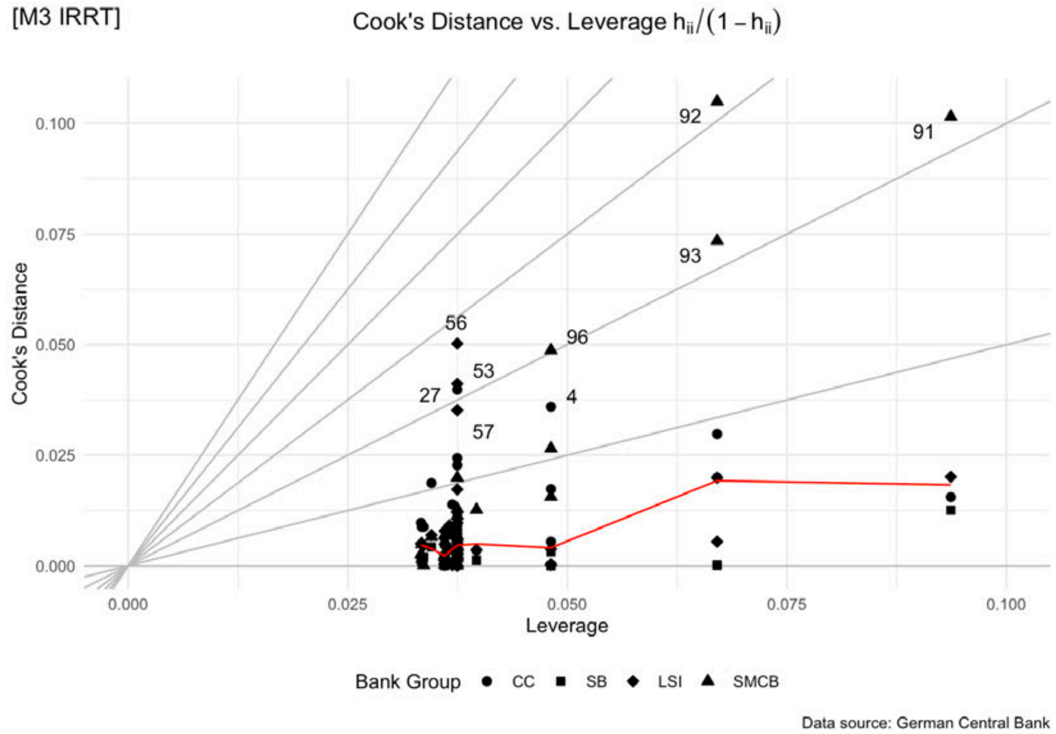


FIGURE 4.49:
M3 IRRT - COOK'S DISTANCE VS. LEVERAGE

Source: author's R output

The influence of the potentially influential observations (PIO) based on the influence measure Cook's Distance on the regression fit is visually inspected by comparing the regression fit based on the unrestricted sample including potentially influential observations against that based on the restricted sample excluding potentially influential observations. Figure 4.50 shows the outlier influence based on the identical regression model of equation (4.18) and samples that differ in the outliers based on Cook's Distance.

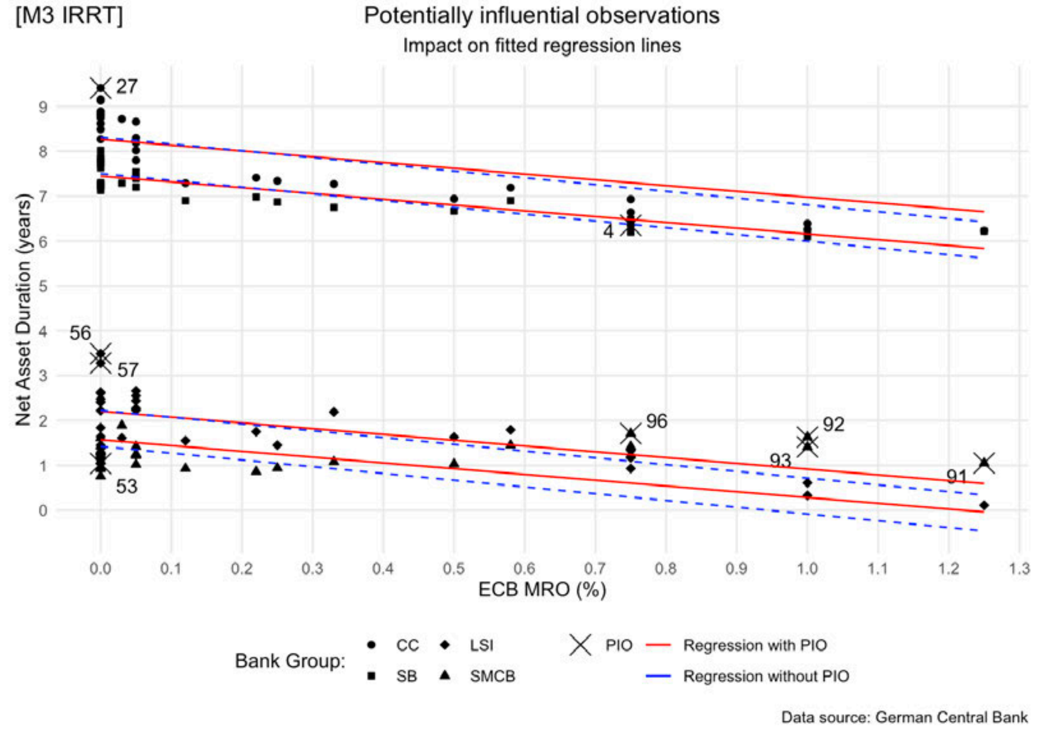


FIGURE 4.50:
M3 IRRT - IMPACT OF PIO ON REGRESSION FIT

Source: author's R output

The plot supports the indication of the magnitudes of the measures. No observation exhibits an extreme influence which distorts the regression fit. It is visual that the residuals with the highest Cook's Distance are associated to the bank group of small and medium sized banks. It is concluded that the assumption of no extreme outliers holds.

A7 - RANDOM SAMPLE: The assumption of random sampling requires that the sample is drawn randomly from the population. A non-random sample causes the risk of introducing an unknown factor into the analysis that the OLS regression will not account for. The sample collected by the German Central Bank comprises all German commercial banks and hence the whole population of interest for Germany, which implies the random sampling assumption holds. Furthermore, OLS is a statistical method to investigate the causal relationship of the independent variable towards the dependent variable, in contrast to a correlation analysis. For the interest rate risk-taking model, the independent variable ECB MRO is theorised to cause the dependent variable net asset duration. Finally, the number of observations taken in the sample are required to exceed the number of parameters in the regression model, which is true for model 3. It is concluded that the assumption of random sampling holds.

An overview of the outcomes of the regression model diagnostics are summarised in Table 4.49. The violation of the assumptions of homoscedasticity and autocorrelation in the residuals causes statistical inference to be invalid. Therefore, the OLS standard errors are corrected by estimating heteroscedasticity and autocorrelation consistent (HAC) standard errors.

TABLE 4.49:
M3 IRRT – DIAGNOSTIC RESULTS

A1	Linearity of coefficients	✓
A2	Zero mean of residuals	✓
A3	Homoscedasticity of residuals	X
A4	No autocorrelation of residuals	X
A5	Normality of residuals	✓
A6	No extreme outliers	✓
A7	Random sample	✓

HAC ROBUST STANDARD ERRORS: The choice is on Newey West HAC standard errors as one type of the HAC robust standard errors, because the method relies on linearly declining weights in estimating the covariance matrix, which seems appropriate with respect to the evaluation of the autocorrelation function that indicates a decrease in autocorrelations with increasing lag. Table 4.50 compares for each coefficient the original standard errors (SE) to the heteroscedasticity and autocorrelation robust standard errors derived from the Newey West HAC covariance matrix (robust SE).

TABLE 4.50:
M3 IRRT - HAC ROBUST STANDARD ERRORS

	SE	Robust SE
Intercept	0.10	0.28
ECB.MRO (%)	0.13	0.30
BG.SB	0.13	0.27
BG.LSI	0.13	0.30
BG.SMCB	0.13	0.35

The HAC covariance matrix leads to an increase in the robust standard errors for all of the estimated coefficients. The corresponding adjustment in the 95% confidence intervals of the coefficient estimates is visualised by a forest plot in Figure 4.51.

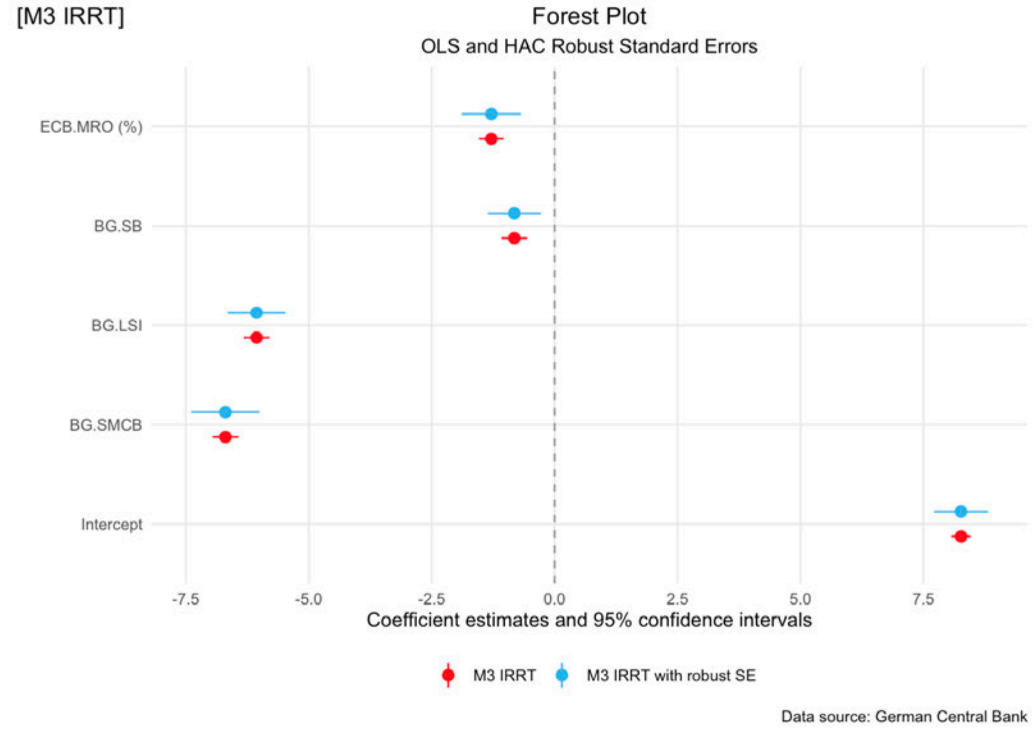


FIGURE 4.51:
M3 IRRT - FOREST PLOT

Source: author's R output

In the further process of the regression analysis of interest rate risk-taking, all statistical inference will be based on this HAC covariance matrix.

4.7 HYPOTHESIS TEST

This subchapter is dedicated to the testing with the objective to empirically test the hypotheses derived in chapter 3.4.2 “Hypotheses” that correspond to the theoretical representation on the risk channel in the TMMP. To recap, the 3 hypotheses refer to the causal relationship between the monetary policy rate indicated by the ECB interest rate on main refinancing operations (ECB MRO) and credit risk perception, credit risk-taking or interest rate risk-taking of German commercial banks (Figure 4.52). Each of the 3 regression models corresponds to one of these 3 dependent variables that reflect the risk channel of monetary transmission.

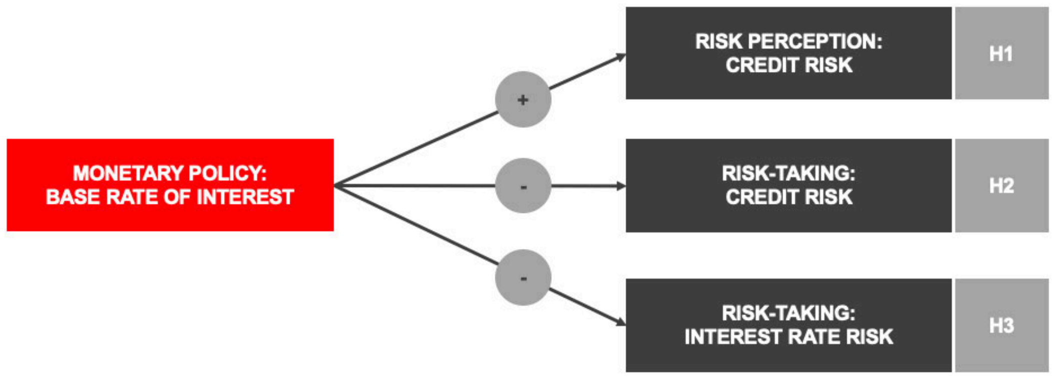


FIGURE 4.52:
HYPOTHESES

Source: author’s illustration

The hypothesis tests are based on the estimated parameters of the specified regression models for credit risk perception (M1 CRP), credit allocation risk-taking (M2 CART) and interest rate risk-taking (M3 IRRT) of German commercial banks along with the HAC robust standard errors of these parameters for valid statistical inference. Therefore, quasi t Wald tests and quasi F Wald tests are applied in order to incorporate the estimated covariance matrix of each regression model.

4.7.1 MODEL 1: CREDIT RISK PERCEPTION

Regression model 1 is applied to test the first hypothesis H1 on credit risk perception of the theoretical representation on the risk channel:

H1: There is a positive relationship between the central bank's monetary policy rate of interest and the perception of credit risk in the balance sheet of commercial banks (ceteris paribus). $RPER_{CRR} = f(+MPR)$

The specified regression model for the causal relationship between the ECB interest rate on main refinancing operations and credit risk perception of German IRBA banks takes the following form:

$$\begin{aligned} RWAD_t = \alpha + \beta\, ECB.MRO_t + \gamma\, BA.ETP_t \\ + \delta_1\, (BA.ETP_t \times ECB.MRO_t) \\ + \delta_2\, (BA.ETP_t \times ECB.MRO_t^2) + e_t, \\ t = 1, \dots, N \end{aligned} \tag{4.29}$$

Before the significance of the single model parameters is investigated, the overall significance of the regression model is tested. The results of the right tail quasi F Wald test are summarised in Table 4.51.

TABLE 4.51:
M1 CRP - QUASI F WALD TEST OF MODEL

Test	Wald on significance of model (right tail)
Regression model	$RWAD_t = \alpha + \beta\, ECB.MRO_t + \gamma\, BA.ETP_t + \delta_1\, (BA.ETP_t \times ECB.MRO_t) + \delta_2\, (BA.ETP_t \times ECB.MRO_t^2) + e_t$
Null hypothesis	$H_0: \beta = \gamma = \delta_1 = \delta_2 = 0$ $(parameters\ are\ zero\ \rightarrow$ $estimated\ model\ is\ statistically\ insignificant)$
Alternative hypothesis	$H_1: at\ least\ one\ of\ the\ parameters\ in\ H_0 \neq 0$ $(at\ least\ one\ estimate\ is\ statistically$ $significant)$
Degrees of freedom	$df1 = 4$ $df2 = 87$
Rejection union	$F \geq 2.48$ $p \leq 0.05$
Test statistic	$F = 222.12$
Probability	$p < 0.001$
Conclusion	H_0 is rejected: at least one estimate is significant

The test results are visualised in Figure 4.53, which shows that the calculated test statistic falls inside the rejection union of the F distribution with a distributional probability of $p < 0.001$.

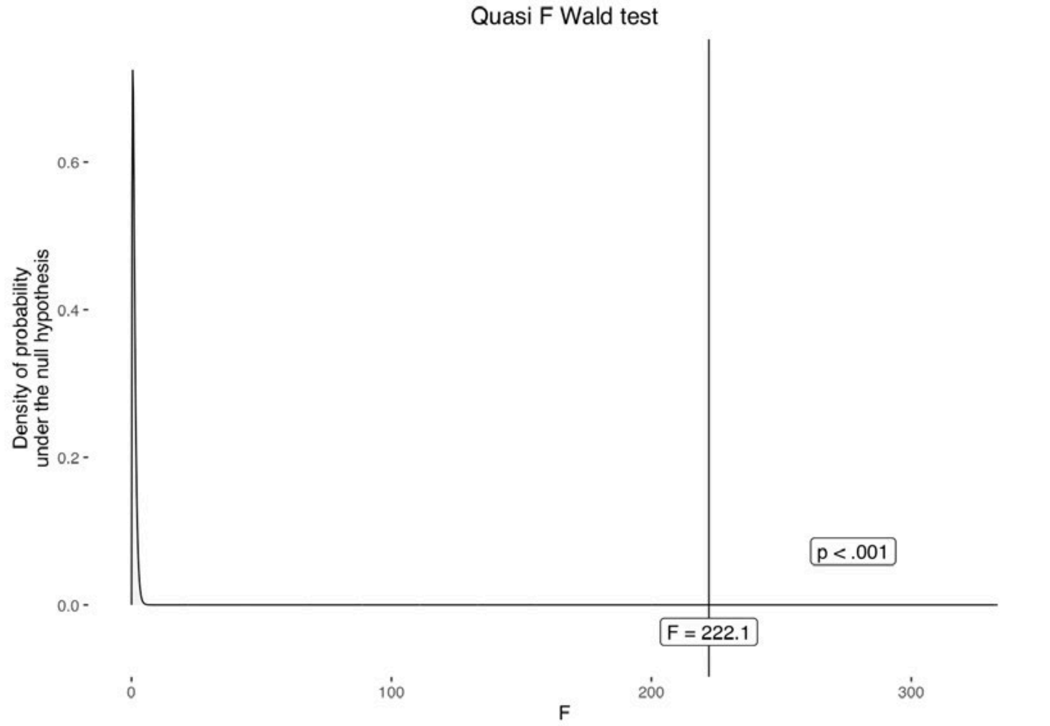


FIGURE 4.53:
M1 CRP - QUASI F WALD TEST OF MODEL

Source: author's R output

A quasi F Wald test based on the estimated HAC covariance matrix is used to test the statistical significance of the regression model. If the null hypothesis is true, then the test statistic has an F-distribution, and its values fall in the nonrejection union with probability $p = 1 - \alpha$. The test statistic falls inside the rejection union, the distributional probability $p < 0.001$ is below the 95% confidence level with $\alpha = 0.05$ applied in this research. Therefore, at a confidence level of even 99.9%, the null hypothesis of all the parameters being zero is rejected and the alternative hypothesis of at least one parameter being nonzero is accepted. This statistical evidence leads to the conclusion, that the regression model for credit risk perception is statistically significant.

In that statistically significant regression model, the coefficients of particular interest with respect to hypothesis H1 are the ones that relate to the

explanatory variable ECB MRO, that is the slope parameters β, δ_1 and δ_2. The results of the two-sided quasi t Wald test are summarised in Table 4.52.

TABLE 4.52:
M1 CRP - QUASI T WALD TEST OF COEFFICIENTS

Test	Wald on significance of coefficients (two tail)
Regression model	$RWAD_t = \alpha + \beta\, ECB.MRO_t + \gamma\, BA.ETP_t + \delta_1\,(BA.ETP_t \times ECB.MRO_t) + \delta_2\,(BA.ETP_t \times ECB.MRO_t^2) + e_t$
Null hypothesis	$H_0: \beta = 0$ $H_0: \delta_1 = 0$ $H_0: \delta_2 = 0$ $(parameter\ is\ zero$ $\rightarrow estimate\ is\ statistically\ insignificant)$
Alternative hypothesis	$H_1: \beta \neq 0$ $H_1: \delta_1 \neq 0$ $H_1: \delta_2 \neq 0$ $(parameter\ is\ different\ from\ zero$ $\rightarrow estimate\ is\ statistically\ significant)$
Degrees of freedom	$df = 87$
Rejection union	$t \leq -1.99\ or\ t \geq 1.99$ $p \leq 0.05$
Test statistic	$t_{\hat{\beta}} = 10.49$ $t_{\hat{\delta}_1} = 6.81$ $t_{\hat{\delta}_2} = -6.81$
Probability	$p_{\hat{\beta}} < 0.001$ $p_{\hat{\delta}_1} < 0.001$ $p_{\hat{\delta}_2} < 0.001$
Conclusion	H_0 is rejected: estimates are statistically significant

The test results are visualised in Figure 4.54, which shows that the calculated test statistic for each of the parameters falls inside the rejection union of the t distribution and a distributional probability of $p < 0.001$.

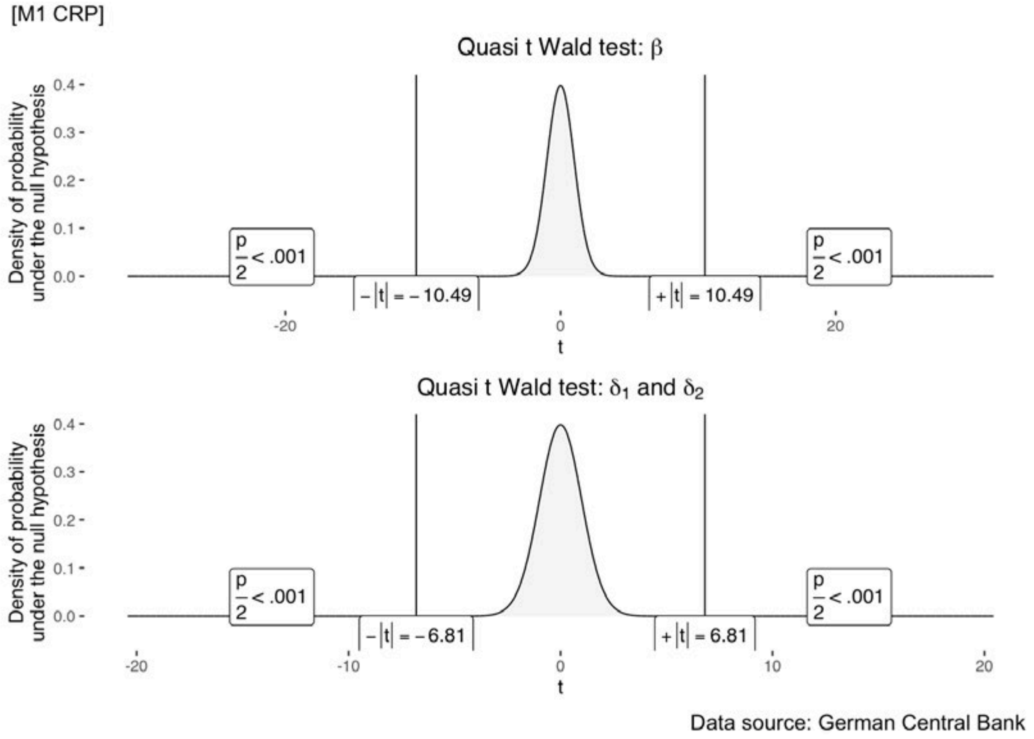


FIGURE 4.54:
M1 CRP - QUASI T WALD TEST OF COEFFICIENTS

Source: author's R output

A quasi-t Wald test based on the estimated HAC covariance matrix is used to test the statistical significance of the coefficients that correspond to hypothesis H1. If the null hypothesis is true, then the test statistic has a t-distribution, and its values fall in the nonrejection union with probability $p = 1 - \alpha$. For all three parameters β, δ_1 and δ_2 the respective test statistic falls inside the rejection union, the distributional probability $p < 0.001$ is below the 95% confidence level with $\alpha = 0.05$ applied in this research. Therefore, at a confidence level of even 99.9% the null hypothesis of the respective parameter being zero is rejected and the alternative hypothesis of the respective parameter being nonzero is accepted. This statistical evidence leads to the conclusion, that there is a statistically significant causal relationship between the independent variable ECB MRO and the dependent variable RWA density for each of the business areas.

The quasi t Wald test on the significance of coefficients was applied for all coefficients of regression model 1 CRP, that means also for the business area specific intercept coefficients. Table 4.53 presents the t-statistic and p-value for each of the coefficients.

TABLE 4.53:
M1 CRP - QUASI T WALD TEST OF ALL COEFFICIENTS

Dependent variable: RWA Density (%)

	Estimate	Robust SE	t statistic	p value
Intercept	21.81	0.35	62.51	0.00***
ECB.MRO (%)	2.34	0.22	10.49	0.00***
BA.ETP	10.62	0.94	11.30	0.00***
BA.ETP x ECB.MRO (%)	17.98	2.64	6.81	0.00***
BA.ETP x ECB.MRO^2 (%)	-4.41	0.65	-6.81	0.00***

Significance codes: *p<0.05; **p<0.01; ***p<0.001

For all parameters of the regression model, the null hypothesis of the respective parameter being zero is rejected at a confidence level of 99.9% and the alternative hypothesis of the respective parameter being statistically significant is accepted.

4.7.2 MODEL 2: CREDIT ALLOCATION RISK-TAKING

Regression model 2 is applied to test the second hypothesis H2 on credit allocation risk-taking of the theoretical representation on the risk channel:

H2:	There is a negative relationship between the central bank's monetary policy rate of interest and risk-taking in terms of credit risk in the balance sheet of commercial banks (ceteris paribus). $RTAK_{CRR} = f(-MPR)$

The specified regression model for the causal relationship between the ECB interest rate on main refinancing operations and credit allocation risk-taking of German commercial banks takes the following form:

$$RLS_t = \beta_0 + \beta_1 ECB.MRO_t + \beta_2 ECB.MRO_t^2 + e_t, \quad t = 1, \dots, T \tag{4.30}$$

Before the significance of the single model parameters is investigated, the overall significance of the regression model is tested. The results of the right tail quasi F Wald test are summarised in Table 4.54.

TABLE 4.54:
M2 CART - QUASI F WALD TEST OF MODEL

Test	Wald on significance of model (right tail)
Regression model	$RLS_t = \beta_0 + \beta_1 ECB.MRO_t + \beta_2 ECB.MRO_t^2 + e_t$
Null hypothesis	$H_0: \beta_0 = \beta_1 = \beta_2 = 0$ $(parameter\ are\ zero\ \rightarrow$ $estimated\ model\ is\ statistically\ insignificant)$
Alternative hypothesis	$H_1: at\ least\ one\ of\ the\ parameters\ in\ H_0 \neq 0$ $(at\ least\ one\ estimate\ is\ statistically$ $significant)$
Degrees of freedom	$df1 = 2$ $df2 = 65$
Rejection union	$F \geq 3.14$ $p \leq 0.05$
Test statistic	$F = 34.89$
Probability	$p < 0.001$
Conclusion	H_0 is rejected: at least one estimate is significant

This test results are visualised in Figure 4.55, which shows that the calculated test statistic falls inside the rejection union of the F distribution and a distributional probability of $p < 0.001$.

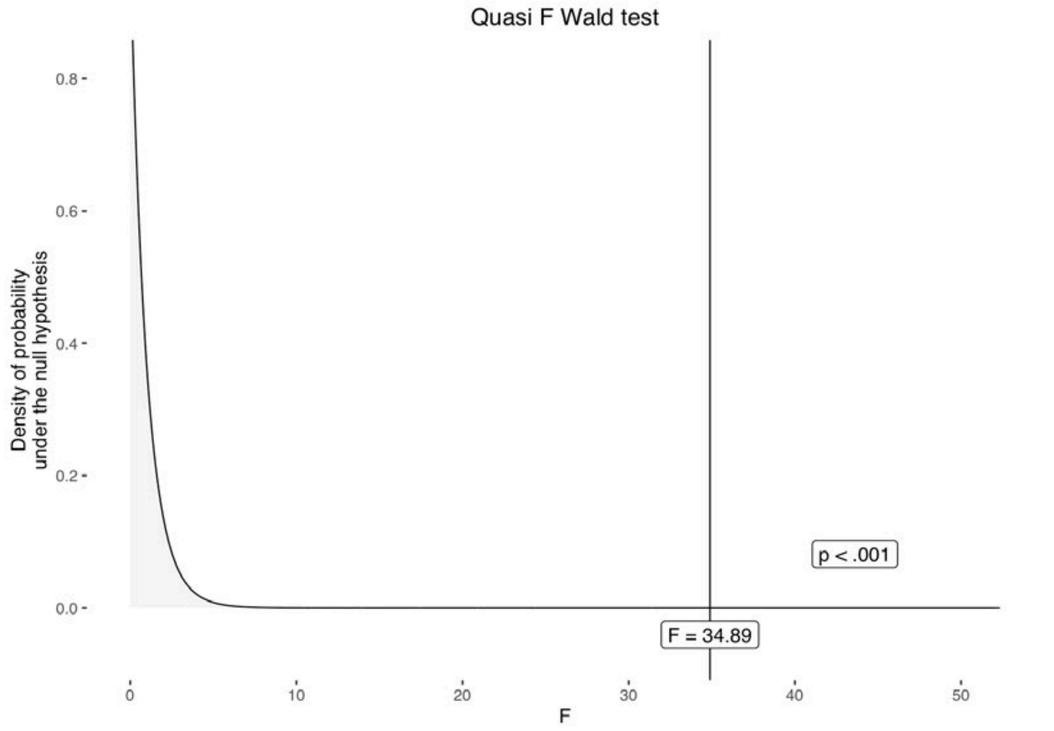


FIGURE 4.55:
M2 CART - QUASI F WALD TEST OF MODEL

Source: author's R output

A quasi F Wald test based on the estimated HAC covariance matrix is used to test the statistical significance of the regression model. If the null hypothesis is true, then the test statistic has an F-distribution, and its values fall in the nonrejection union with probability $p = 1 - \alpha$. The test statistic falls inside the rejection union, the distributional probability $p < 0.001$ is below the 95% confidence level with $\alpha = 0.05$ applied in this research. Therefore, at a confidence level of even 99.9%, the null hypothesis of all the parameters being zero is rejected and the alternative hypothesis of at least one parameter being nonzero is accepted. This statistical evidence leads to the conclusion, that the regression model for credit allocation risk-taking is statistically significant.

In that statistically significant regression model, the coefficients of particular interest with respect to hypothesis H2 are the ones that relate to the

independent variable ECB MRO, that is the slope parameters β_1 and β_2. The results of the two-sided quasi t Wald test are summarised in Table 4.55.

TABLE 4.55:
M2 CART - QUASI T WALD TEST OF COEFFICIENTS

Test	Wald on significance of coefficients (two tail)
Regression model	$RLS_t = \beta_0 + \beta_1 ECB.MRO_t + \beta_2 ECB.MRO_t^2 + e_t$
Null hypothesis	$H_0: \beta_1 = 0$ $H_0: \beta_2 = 0$ $(parameter\ is\ zero$ $\rightarrow estimate\ is\ statistically\ insignificant)$
Alternative hypothesis	$H_1: \beta_1 \neq 0$ $H_1: \beta_2 \neq 0$ $(parameter\ is\ different\ from\ zero$ $\rightarrow estimate\ is\ statistically\ significant)$
Degrees of freedom	$df = 65$
Rejection union	$t \leq -1.99\ or\ t \geq 1.99$ $p \leq 0.05$
Test statistic	$t_{\hat{\beta}_1} = -5.90$ $t_{\hat{\beta}_2} = 4.67$
Probability	$p_{\hat{\beta}_1} < 0.001$ $p_{\hat{\beta}_2} < 0.001$
Conclusion	H_0 is rejected: estimates are statistically significant

The test results are visualised in Figure 4.56, which shows that the calculated test statistic for each of the parameters falls inside the rejection union of the t distribution and a distributional probability of $p < 0.001$.

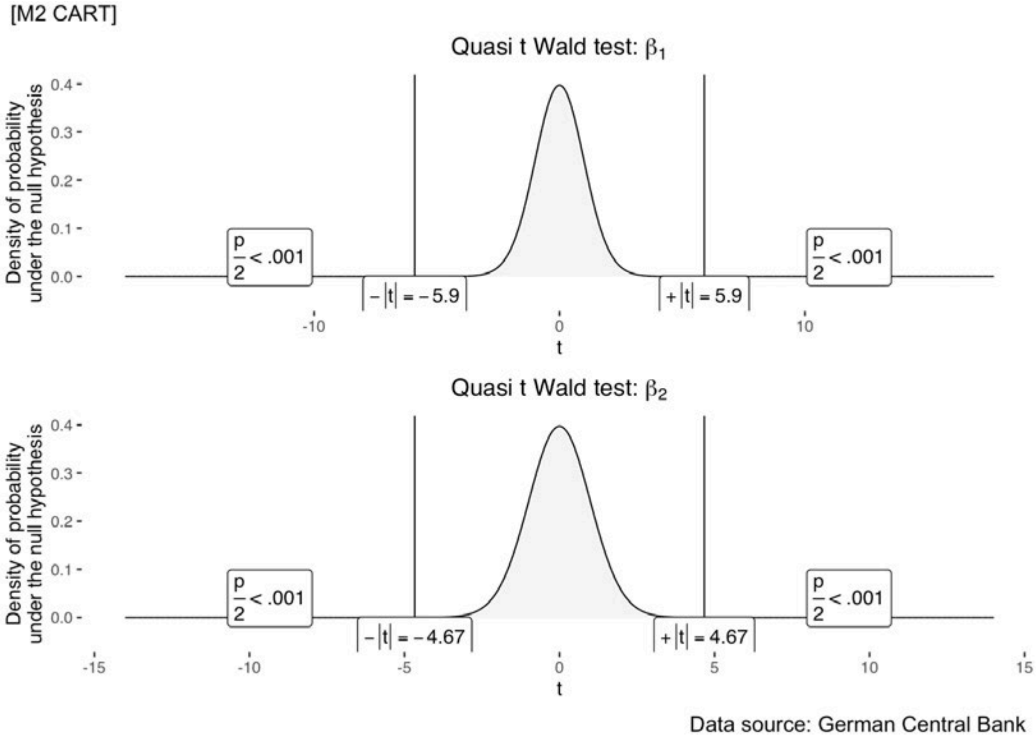


FIGURE 4.56:
M2 CART - QUASI T WALD TEST OF COEFFICIENTS

Source: author's R output

A quasi-t Wald test based on the estimated HAC covariance matrix is used to test the statistical significance of the coefficients that correspond to hypothesis H2. If the null hypothesis is true, then the test statistic has a t-distribution, and its values fall in the nonrejection union with probability $p = 1 - \alpha$. For both parameters β_1 and β_2 the respective test statistic falls inside the rejection union, the distributional probability $p < 0.001$ is below the 95% confidence level with $\alpha = 0.95$ applied in this research. Therefore, at a confidence level of even 99.9%, the null hypothesis of the respective parameter being zero is rejected and the alternative hypothesis of the respective parameter being nonzero is accepted. This statistical evidence leads to the conclusion, that there is a statistically significant causal relationship between the independent variable ECB MRO and the dependent variable risky loans share.

The quasi t Wald test on the significance of coefficients was applied for all coefficients of regression model 2 CART, that means also for the intercept coefficient β_0. Table 4.56 presents the t-statistic and p-value for each of the coefficients.

TABLE 4.56:
M2 CART - QUASI T WALD TEST OF ALL COEFFICIENTS

Dependent variable: Risky Loan Share (%)

	Estimate	Robust SE	t statistic	p value
Intercept	44.03	0.53	82.51	0.00***
ECB.MRO (%)	-7.06	1.20	-5.90	0.00***
$ECB.MRO^2$ (%)	1.41	0.30	4.67	0.00***

Significance codes: *p<0.05; **p<0.01; ***p<0.001

For all parameters of the regression model, the null hypothesis of the respective parameter being zero is rejected at a confidence level of 99.9% and the alternative hypothesis of the respective parameter being statistically significant is accepted.

4.7.3 MODEL 3: INTEREST RATE RISK-TAKING

Regression model 3 is applied to test the third hypothesis H3 on interest rate risk-taking of the theoretical representation of the risk channel:

H3: There is a negative relationship between the central bank's monetary policy rate of interest and risk-taking in terms of interest rate risk in the balance sheet of commercial banks (ceteris paribus). $RTAK_{IRR} = f(-MPR)$

The specified regression model for the causal relationship between the ECB interest rate on main refinancing operations and interest rate risk-taking of German commercial banks takes the following form:

$$NAD_t = \alpha + \delta_1\, BG.SB_t + \delta_2\, BG.LSI_t + \delta_3\, BG.SMCB_t + \beta\, ECB.MRO_t + e_t, \quad t = 1, \dots, N \tag{4.31}$$

Before the significance of the single model parameters is investigated, the overall significance of the regression model is tested. The results of the right tail quasi F Wald test are summarised in Table 4.57.

TABLE 4.57:
M3 IRRT - QUASI F WALD TEST OF MODEL

Test	Wald on significance of model (right tail)
Regression model	$NAD_t = \alpha + \delta_1\, BG.SB_t + \delta_2\, BG.LSI_t + \delta_3\, BG.SMCB_t + \beta\, ECB.MRO_t + e_t$
Null hypothesis	$H_0: \alpha = \delta_1 = \delta_2 = \delta_3 = \beta = 0$ $(parameter\ are\ zero\ \rightarrow$ $estimated\ model\ is\ statistically\ insignificant)$
Alternative hypothesis	$H_1: at\ least\ one\ of\ the\ parameters\ in\ H_0 \neq 0$ $(at\ least\ one\ estimate\ is\ statistically\ significant)$
Degrees of freedom	$df1 = 4$ $df2 = 115$
Rejection union	$F \geq 2.45$ $p \leq 0.05$
Test statistic	$F = 676.96$
Probability	$p < 0.001$
Conclusion	H_0 is rejected: at least one estimate is significant

The test results are visualised in Figure 4.57, which shows that the calculated test statistic falls inside the rejection union of the F distribution and a distributional probability of $p < 0.001$.

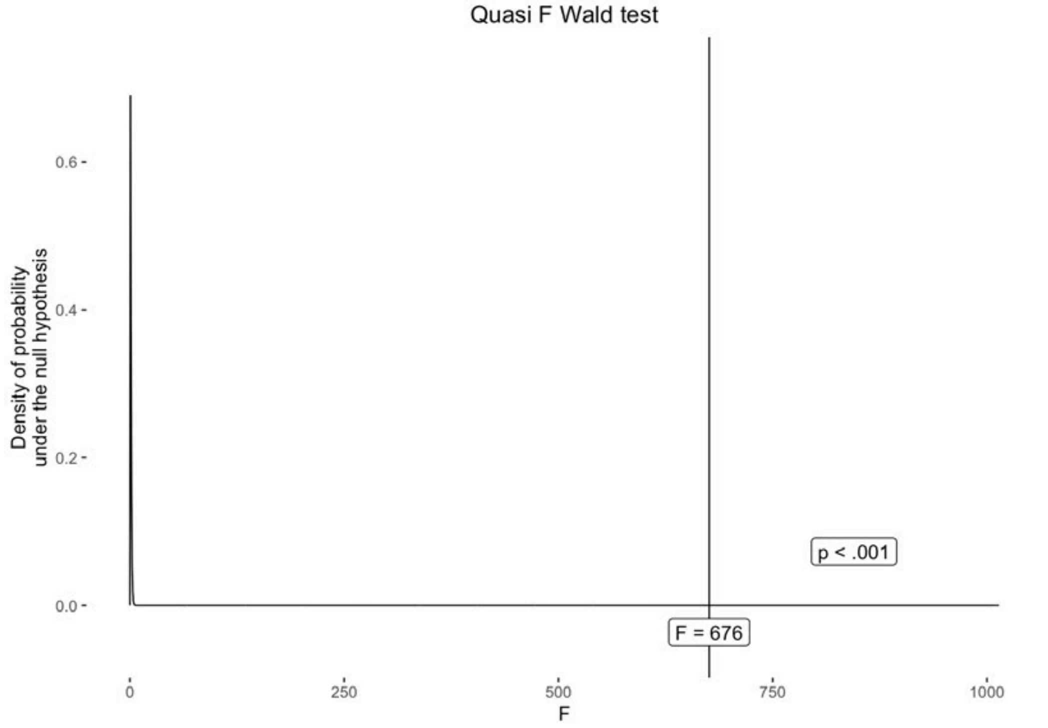


FIGURE 4.57:
M3 IRRT - QUASI F WALD TEST OF MODEL

Source: author's R output

A quasi F Wald test based on the estimated HAC covariance matrix is used to test the statistical significance of the regression model. If the null hypothesis is true, then the test statistic has an F-distribution, and its values fall in the nonrejection union with probability $p = 1 - \alpha$. The test statistic falls inside the rejection union, the distributional probability $p < 0.001$ is below the 95% confidence level with $\alpha = 0.05$ applied in this research. Therefore, at a confidence level of even 99.9%, the null hypothesis of all the parameters being zero is rejected and the alternative hypothesis of at least one parameter being nonzero is accepted. This statistical evidence leads to the conclusion, that the regression model for interest rate risk-taking is statistically significant.

In that statistically significant regression model, the coefficients of particular interest with respect to hypothesis H3 are the ones that relate to the

independent variable ECB MRO, that is the slope parameter β. The results of the two-sided quasi t Wald test are summarised in Table 4.58.

TABLE 4.58:
M3 IRRT - QUASI T WALD TEST OF COEFFICIENTS

Test	Wald on significance of coefficients (two tail)
Regression model	$NAD_t = \alpha + \delta_1\, BG.SB_t + \delta_2\, BG.LSI_t + \delta_3\, BG.SMCB_t + \beta\, ECB.MRO_t + e_t$
Null hypothesis	$H_0: \beta\ = 0$ $(parameter\ is\ zero$ $\rightarrow estimate\ is\ statistically\ insignificant)$
Alternative hypothesis	$H_1: \beta\ \neq 0$ $(parameter\ is\ different\ from\ zero$ $\rightarrow estimate\ is\ statistically\ significant)$
Degrees of freedom	$df = 115$
Rejection union	$t \leq -1.98\ or\ t \geq 1.98$ $p \leq 0.05$
Test statistic	$t = -4.23$
Probability	$p < 0.001$
Conclusion	H_0 is rejected: estimate is statistically significant

The test result is visualised in Figure 4.58, which shows that the calculated test statistic for each of the parameters falls inside the rejection union of the t distribution and a distributional probability of $p < 0.001$.

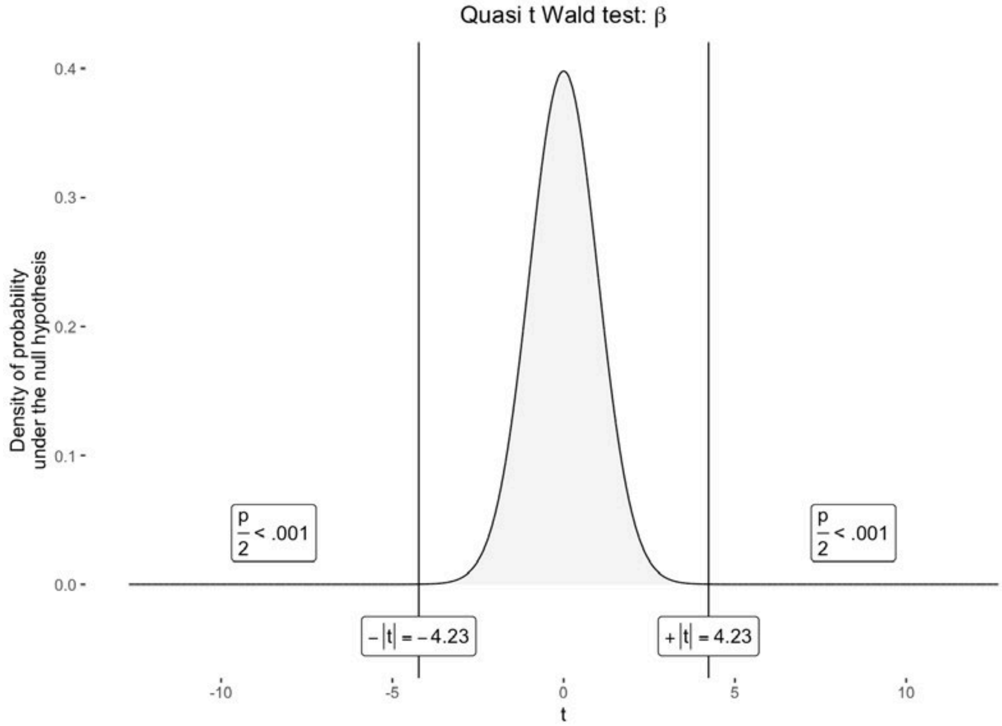


FIGURE 4.58:
M3 IRRT - QUASI T WALD TEST OF COEFFICIENT

Source: author's R output

A quasi-t Wald test based on the estimated HAC covariance matrix is used to test the statistical significance of the coefficients that correspond to hypothesis H3. If the null hypothesis is true, then the test statistic has a t-distribution, and its values fall in the nonrejection union with probability $p = 1 - \alpha$. For parameter β the respective test statistic falls inside the rejection union, the distributional probability $p < 0.001$ is below the 95% confidence level with $\alpha = 0.05$ applied in this research. Therefore, at a confidence level of even 99.9% the null hypothesis of the parameter being zero is rejected and the alternative hypothesis of the parameter being nonzero is accepted. This statistical evidence leads to the conclusion, that there is a statistically significant causal relationship between the independent variable ECB MRO and the dependent variable net asset duration for each of the bank groups.

The quasi t Wald test on the significance of coefficients was applied for all coefficients of regression model 3 IRRT, that means also for the bank group specific intercept coefficients. Table 4.59 presents the t-statistic and p-value for each of the coefficients.

TABLE 4.59:
M3 IRRT - QUASI T WALD TEST OF ALL COEFFICIENTS

Dependent variable: Net Asset Duration (years)

	Estimate	Robust SE	t statistic	p value
Intercept	8.26	0.28	29.82	0.00***
ECB.MRO (%)	-1.29	0.30	-4.23	0.00***
BG.SB	-0.82	0.27	-3.00	0.00***
BG.LSI	-6.06	0.30	-20.42	0.00***
BG.SMCB	-6.69	0.35	-19.09	0.00***

Significance codes: *p<0.05; **p<0.01; ***p<0.001

For all parameters of the regression model, the null hypothesis of the respective parameter being zero is rejected at a confidence level of 99.9% and the alternative hypothesis of the respective parameter being statistically significant is accepted.

4.8 REGRESSION RESULTS

This subchapter aims to outline the central results of the regression analysis by presenting the estimated regression model and its economic interpretation. The regression summary table outlines the estimates, robust standard errors, the test statistic and p value of the quasi t Wald test, the confidence intervals and variance inflation factor (VIF) of the coefficients as well as number of observations (N), R-squared (R^2), residual standard error, the test statistic as well as the p value and corresponding degrees of freedom of the quasi F Wald test for the regression model. The visual presentation of the results is carried out by a plot of the regression fit and the corresponding hypothesis figure, both pointing out the estimated relationship.

4.8.1 MODEL 1: CREDIT RISK PERCEPTION

Regression model 1 on the causal relationship between the independent variable ECB interest rate on main refinancing operations representing the monetary policy rate of interest and the dependent variable RWA density indicating credit risk perception of German IRBA banks for time period 2008 to 2019 is estimated as follows:

$$\begin{aligned} RWAD_t = \alpha + \beta\, ECB.MRO_t + \gamma\, BA.ETP_t \\ + \delta_1\,(BA.ETP_t \times ECB.MRO_t) \\ + \delta_2\,(BA.ETP_t \times ECB.MRO_t^2) + e_t, \\ t = 1, \dots, N \end{aligned} \tag{4.32}$$

$$\begin{aligned} \widehat{RWAD} = 21.81 + 2.34\, ECB.MRO + 10.62\, BA.ETP \\ + 17.98\,(BA.ETP \times ECB.MRO) \\ - 4.41\,(BA.ETP \times ECB.MRO)^2 \end{aligned} \tag{4.33}$$

By solving for the categorial dummy parameters, the estimated regression model becomes for each business area:

$$\begin{aligned} &Retail\ loans: \\ &RWAD_t = \alpha + \beta\, ECB.MRO_t + e_t \\ &\widehat{RWAD}_{RTL} = 21.81 + 2.34\, ECB.MRO \end{aligned} \tag{4.34}$$

$$\begin{aligned} &Loans\ to\ enterprises: \\ &RWAD_t = (\alpha + \gamma) + (\beta + \delta_1)\, ECB.MRO_t + \delta_2\, ECB.MRO_t^2 + e_t \\ &\widehat{RWAD}_{ETP} = (21.81 + 10.62) + (2.34 + 17.98)\, ECB.MRO \\ &\qquad - 4.41\, ECB.MRO^2 \\ &\widehat{RWAD}_{ETP} = 32.44 + 20.33\, ECB.MRO - 4.41\, ECB.MRO^2 \end{aligned} \tag{4.35}$$

While the interpretation of the estimated relationship for the business area of retail loans is straight forward since it reflects a simple linear relationship, the nonlinear relationship for the business area of loans to enterprises requires some further calculation. For loans to enterprises, the marginal effect on the estimated RWA density $\widehat{RWAD}_{ETP}$ depends on the level of the ECB interest rate on main refinancing operations $ECB.MRO$. Geometrically, it is the slope of the tangent line at a certain value of $ECB.MRO$. Its economic interpretation is the marginal effect of an infinitesimal change of the ECB MRO on RWA density for loans to enterprises at a certain level of ECB MRO. The marginal effect is calculated by taking the derivative on the explanatory variable $ECB.MRO$.

$$\frac{d\widehat{RWAD}_{ETP}}{dECB.MRO} = (\hat{\beta} + \hat{\delta}_1) + 2\hat{\delta}_2\, ECB.MRO$$
$$\frac{d\widehat{RWAD}_{ETP}}{dECB.MRO} = (2.34 + 17.98) + 2(-4.41) ECB.MRO \qquad (4.36)$$
$$\frac{d\widehat{RWAD}_{ETP}}{dECB.MRO} = 20.33 - 8.81\, ECB.MRO$$

The vertex, where the nonlinear function reaches its maximum, economically representing the turning point, is estimated at an ECB MRO of 2.31% with an estimated RWA density for loans to enterprises of 55.87%. At this point, the infinitesimal change in the estimated RWA density for the business area of loans to enterprises is zero. The corresponding calculation is as follows:

$$\frac{d\widehat{RWAD}_{ETP}}{dECB.MRO} = (\hat{\beta} + \hat{\delta}_1) + 2\hat{\delta}_2\, ECB.MRO = 0$$
$$\widehat{ECB.MRO}_{vertex} = \frac{-(\hat{\beta} + \hat{\delta}_1)}{2\hat{\delta}_2}$$
$$\widehat{ECB.MRO}_{vertex} = \frac{-(2.34 + 17.98)}{2(-4.41)} \qquad (4.37)$$
$$\widehat{ECB.MRO}_{vertex} = \frac{-20.33}{-8.81}$$
$$\widehat{ECB.MRO}_{vertex} = 2.31, \qquad \widehat{RWAD}_{ETP|vertex} = 55.87$$

The estimated effect of a change in the ECB MRO at different levels on RWA density for the business area of loans to enterprises is shown in Table 4.60.

TABLE 4.60:
M1 CRP - EFFECT OF CHANGE IN ECB MRO

$\Delta\, ECB.MRO$	$\Delta\, \widehat{RWAD}_{ETP}$
0 % to 1 %	15.92 %
1 % to 2 %	7.11 %
2 % to 3 %	-1.71 %
3 % to 4 %	-10.52 %

The estimated change $\Delta\widehat{RWAD}$ is obtained by predicting $\widehat{RWAD}$ based on the different levels of $ECB.MRO$ by plugging the values for t_0 and t_1 of $ECB.MRO$ into the estimated regression model and determining the change by subtracting the predicted values $\widehat{RWAD}$ before and after the change in ECB MRO.

$$\begin{aligned}\Delta\widehat{RWAD}_{ETP} = {} & 21.81 + 2.34\, ECB.MRO_{t0} + 10.62\, BA.ETP \\ & + 17.98\,(BA.ETP \times ECB.MRO_{t0}) \\ & - 4.41\,(BA.ETP \times ECB.MRO_{to})^2 - \\ & (21.81 + 2.34\, ECB.MRO_{t1} + 10.62\, BA.ETP \\ & + 17.98\,(BA.ETP \times ECB.MRO_{t1}) \\ & - 4.41\,(BA.ETP \times ECB.MRO_{t1})^2)\end{aligned} \tag{4.38}$$

For both business areas, Table 4.61 consolidates the geometric properties along with their economic interpretation and estimate.

TABLE 4.61:
M1 CRP - ECONOMIC INTERPRETATION

Geometric Property	Economic Interpretation	Estimate
Retail loans		
Intercept	RWA Density when ECB MRO is zero	$\hat{\alpha} = 21.81$
Slope	Marginal effect of ECB MRO	$\hat{\beta} = 2.34$
Loans to enterprises		
Intercept	RWA Density when ECB MRO is zero	$(\hat{\alpha} + \hat{\gamma}) = 32.44$
Slope (tangent)	Marginal effect of ECB MRO at ECB MRO level	$(\hat{\beta} + \hat{\delta}_1) + 2\hat{\delta}_2\, ECB.MRO =$ $20.33 - 8.81\, ECB.MRO$
Vertex (maximum)	Turning point	$\widehat{max}(2.31 \vert 55.87)$

When the ECB MRO is at 0%, the estimate of the intercept parameter $\hat{\alpha}$ predicts an RWA density in the business area of retail loans of 21.81% and parameters $(\hat{\alpha} + \hat{\gamma})$ an RWA density in the business area of loans to enterprises of 32.44%, respectively. As the ECB MRO increases by 1 percentage point, the estimate of slope parameter $\hat{\beta}$ predicts an increase in RWA density in the business area of retail loans by 2.34% over time. The marginal effect of an infinitesimal change in the ECB MRO on RWA density in the business area of loans to enterprises depends on the level of ECB MRO and is $20.33 - 8.81\, ECB.MRO$%. The maximum estimated RWA density for loans to enterprises at which the direction of the effect changes is at an ECB MRO of 2.31% with an estimated RWA density of 55.87%.

Table 4.62 summarises the OLS regression findings on the causal relationship of the ECB interest rate on main refinancing operations on credit risk perception of German IRBA banks. For each parameter, the table reports the coefficient estimates of the regression model, the Newey West heteroscedasticity and autocorrelation robust standard errors, the t-value and p-value based on the quasi t Wald test on the significance of the respective coefficient, its lower (95% CI LL) and upper (95% CI UL) limit of the 95% confidence interval as well as the variance inflation factor (VIF). For the regression model, the table reports the number of observations (N), the R-squared (R^2) and adjusted R-squared (adjusted R^2) value, the residual standard error (residual SE), the test statistic and p-value based on the quasi F Wald test on the significance of the regression model as well as the corresponding numerator degrees of freedom $df = K$ from the number of restrictions $K - 1$ and the denominator residual degrees of freedom $df = N - K$.

TABLE 4.62:
M1 CRP – OLS REGRESSION RESULTS

Dependent variable: RWA Density (%)

	Estimate	Robust SE	t statistic	p value	95% CI LL	95% CI UL	VIF
Intercept	21.81	0.35	62.51	0.00***	21.12	22.51	
ECB.MRO (%)	2.34	0.22	10.49	0.00***	1.90	2.79	2.00
BA.ETP	10.62	0.94	11.30	0.00***	8.76	12.49	1.87
BA.ETP x ECB.MRO (%)	17.98	2.64	6.81	0.00***	12.73	23.24	14.01
BA.ETP x ECB.MRO^2 (%)	-4.41	0.65	-6.81	0.00***	-5.69	-3.12	11.00
Observations (N)	92						
R^2	0.93						
Adjusted R^2	0.93						
Residual SE	2.81						
F statistic	222.12			0.00***			
df (K)	4						
df (N-K)	87						

Significance codes: *p<0.05; **p<0.01; ***p<0.001

The corresponding plot of the regression fit is presented in Figure 4.59. The regression model that categorizes the causal relationship by the business area seems to match well with the sample observations, which exhibit a linear relationship for retail loans and a quadratic relationship for loans to enterprises.

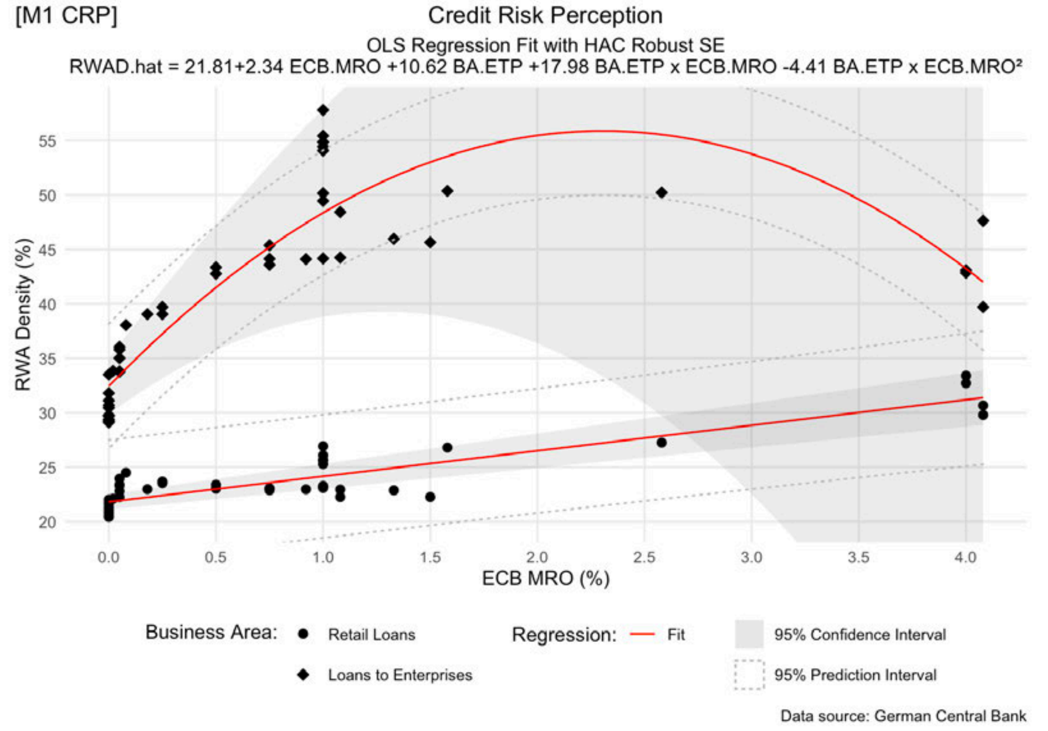


FIGURE 4.59:
M1 CRP - REGRESSION FIT

Source: author's R output

Finally, Figure 4.60 adds the estimated relationship to the initial illustration on hypothesis H1 of the theoretical representation on the risk channel in monetary transmission.

H1: There is a positive relationship between the central bank's monetary policy rate of interest and the perception of credit risk in the balance sheet of commercial banks (ceteris paribus). $RPER_{CRR} = f(+MPR)$

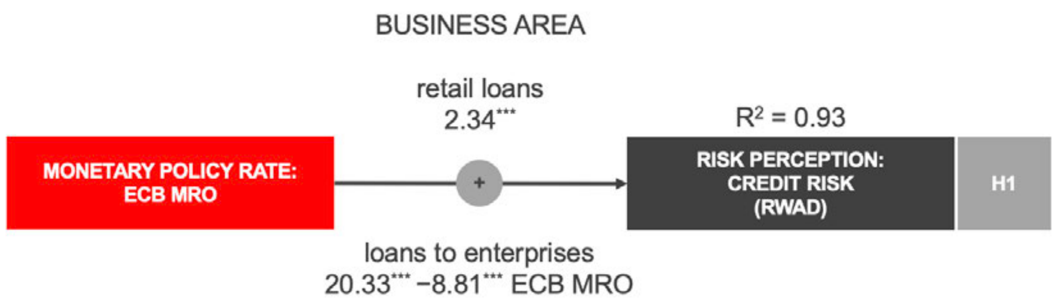


FIGURE 4.60:
M1 CRP - HYPOTHESIS H1

Source: author's illustration

The empirical test of hypothesis H1 based on the regression model M1 CRP verified a statistically significant, positive relationship between the monetary policy rate of interest and the perception of credit risk in the balance sheet of German IRBA banks for the business area of retail loans. In the business area of loans to enterprises, the perception of credit risk in the balance sheet of German IRBA banks responds to changes in the monetary policy rate of interest with the magnitude depending on the initial level of the policy rate. The nonlinear relationship approximated by the quadratic function together with the positive sign of an estimated parameter for the policy rate and the positive sign for the squared policy rate, imply that policy rate reductions lead to lower credit risk perception and that the size of this effect is larger when policy rates are low. The estimated effect on RWA density in the business area of loans to enterprises is positive for low levels and negative for high levels of the monetary policy rate with $\frac{d\widehat{RWAD}_{ETP}}{dECB.MRO} = 20.33 - 8.81\, ECB.MRO$ for an infinitesimal change in the ECB MRO. The negative effect of high levels in the ECB MRO on RWA density in the business area of loans to enterprises was not hypothesised. It might arise from the circumstance that these higher ECB MRO are underrepresented in the respective time period. The economic model suggests that the method of risk measurement affects risk perception, as well: $RPER = f(+MPR, +MRM)$. The empirical result supports that more sophisticated methods, which are typically applied in the business area of loans to enterprises, correspond to greater effects on risk perception as compared to less sophisticated methods, which are typically applied in the business area of retail loans. Hence, the development in the sophisticated methods might be an explanation for the nonlinearity.

Overall, the specified regression model explains 93% of the observed variability in RWA density by business area indicating credit risk perception distinguished by the method of risk measurement. To a great extent, the empirical regression analysis supports the hypothesis from theory with respect to credit risk perception of commercial banks (H1). In this static form, the regression model is focused on the test of the hypothesis on the risk channel mechanism rather than making precise predictions on changes of the monetary policy rate.

4.8.2 MODEL 2: CREDIT ALLOCATION RISK-TAKING

Regression model 2 on the causal relationship between the independent variable ECB interest rate on main refinancing operations representing the monetary policy rate of interest and the dependent variable risky loan share indicating credit allocation risk-taking of German commercial banks for time period 2002 to 2018 is estimated as follows:

$$RLS_t = \beta_0 + \beta_1 ECB.MRO_t + \beta_2 ECB.MRO_t^2 + e_t, \quad t = 1, \dots, T \tag{4.39}$$

$$\widehat{RLS} = 44.03 - 7.06\, ECB.MRO + 1.41\, ECB.MRO^2 \tag{4.40}$$

In the nonlinear model for credit allocation risk-taking, the marginal effect on the estimated risky loan share RLS depends on the level of the ECB interest rate on main refinancing operations $ECB.MRO$. Geometrically, it is the slope of the tangent line at a certain value of ECB MRO. The economic interpretation is the marginal effect of an infinitesimal change of the ECB MRO on the risky loan share at a certain level of ECB MRO. The marginal effect is calculated by taking the derivative on the explanatory variable ECB MRO.

$$\begin{aligned} \frac{d\widehat{RLS}}{dECB.MRO} &= \hat{\beta}_1 + 2\hat{\beta}_2\, ECB.MR \\ \frac{d\widehat{RLS}}{dECB.MRO} &= -7.06 + 2(1.41)\, ECB.MRO \\ \frac{d\widehat{RLS}}{dECB.MRO} &= -7.06 + 2.82\, ECB.MRO \end{aligned} \tag{4.41}$$

The vertex, where the function reaches its minimum, economically representing the turning point, is at an ECB interest rate on main refinancing operations $ECB.MRO$ of 2.5% with an estimated risky loan share RLS of 35.19%. At this point, the infinitesimal change in the estimated risky loan share is zero. The corresponding calculation is as follows:

$$\frac{d\widehat{RLS}}{dECB.MRO} = \hat{\beta}_1 + 2\hat{\beta}_2\, ECB.MRO = 0$$
$$\widehat{ECB.MRO}_{vertex} = \frac{-\hat{\beta}_1}{2\hat{\beta}_2}$$
$$\widehat{ECB.MRO}_{vertex} = \frac{-(-7.06)}{2(1.41)} \tag{4.42}$$
$$\widehat{ECB.MRO}_{vertex} = \frac{7.06}{2.82}$$
$$\widehat{ECB.MRO}_{vertex} = 2.50, \qquad \widehat{RLS}_{vertex} = 35.19$$

The estimated effect of a change in the ECB MRO at different levels on the risky loan share is shown in Table 4.63.

TABLE 4.63:
M2 CART - EFFECT OF CHANGE IN ECB MRO

$\Delta\, ECB.MRO$	$\Delta\, \widehat{RLS}$
0 % to 1 %	-5.65 %
1 % to 2 %	-2.83 %
2 % to 3 %	-0.01 %
3 % to 4 %	2.81 %

The estimated change $\Delta\widehat{RLS}$ is obtained by predicting $\widehat{RLS}$ based on the different levels of $ECB.MRO$ by plugging the values for t_0 and t_1 of $ECB.MRO$ into the estimated regression model and determining the change by subtracting the predicted values $\widehat{RLS}$ before and after the change in ECB MRO.

$$\Delta\widehat{RLS} = (44.03 - 7.06\, ECB.MRO_{to} + 1.41\, ECB.MRO_{t0}^2) - (44.03 - 7.06\, ECB.MRO_{t1} + 1.41\, ECB.MRO_{t1}^2) \tag{4.43}$$

Table 4.64 consolidates the geometric properties along with their economic interpretation and estimate.

TABLE 4.64:
M2 CART - ECONOMIC INTERPRETATION

Geometric Property	Economic Interpretation	Estimate
Intercept	Risky loan share when ECB MRO is zero	$\hat{\beta}_0 = 44.03$
Slope (tangent)	Marginal effect of ECB MRO at ECB MRO level	$\hat{\beta}_1 + 2\hat{\beta}_2\, ECB.MRO$ $= -7.06 + 2.82\, ECB.MRO$
Vertex (maximum)	Turning point	$\widehat{min}(2.50 \vert 35.19)$

When the ECB MRO is at 0%, the estimate of the intercept parameter $\hat{\beta}_0$ predicts a risky loan share of 44.03%. The marginal effect of an infinitesimal change in the ECB MRO on the risky loan share depends on the level of ECB MRO and is $-7.06 + 2.82\ ECB.MRO\%$. The maximum share of estimated risky loans at which the direction of the effect changes is at an ECB MRO of 2.50% with an estimated risky loan share of 35.19%.

Table 4.65 summarises the OLS regression findings on the causal relationship of the ECB interest rate on main refinancing operations on credit allocation risk-taking of German commercial banks. For each parameter, the table reports the coefficient estimates of the regression model, the Newey West heteroscedasticity and autocorrelation robust standard errors, the t-value and p-value based on the quasi t Wald test on the significance of the respective coefficient, its lower (95% CI LL) and upper (95% CI UL) limit of the 95% confidence interval as well as the variance inflation factor (VIF). For the regression model, the table reports the number of observations (N), the R-squared (R^2) and adjusted R-squared (adjusted R^2) value, the residual standard error (residual SE), the test statistic and p-value based on the quasi F Wald test on the significance of the regression model as well as the corresponding numerator degrees of freedom $df = K$ from the number of restrictions $K - 1$ and the denominator residual degrees of freedom $df = N - K$.

TABLE 4.65:
M2 CART – OLS REGRESSION RESULTS

Dependent variable: Risky Loan Share (%)

	Estimate	Robust SE	t statistic	p value	95% CI LL	95% CI UL	VIF
Intercept	44.03	0.53	82.51	0.00***	42.96	45.09	
ECB.MRO (%)	-7.06	1.20	-5.90	0.00***	-9.45	-4.67	11.12
ECB.MRO² (%)	1.41	0.30	4.67	0.00***	0.81	2.01	11.12
Observations (N)	68						
R^2	0.72						
Adjusted R^2	0.71						
Residual SE	2.12						
F statistic	34.89			0.00***			
df (K)	2						
df (N-K)	65						

Significance codes: *p<0.05; **p<0.01; ***p<0.001

The corresponding plot of the regression fit is presented in Figure 4.61. The regression model seems to match well with the sample observations, which exhibit a quadratic relationship with only a small number of outliers.

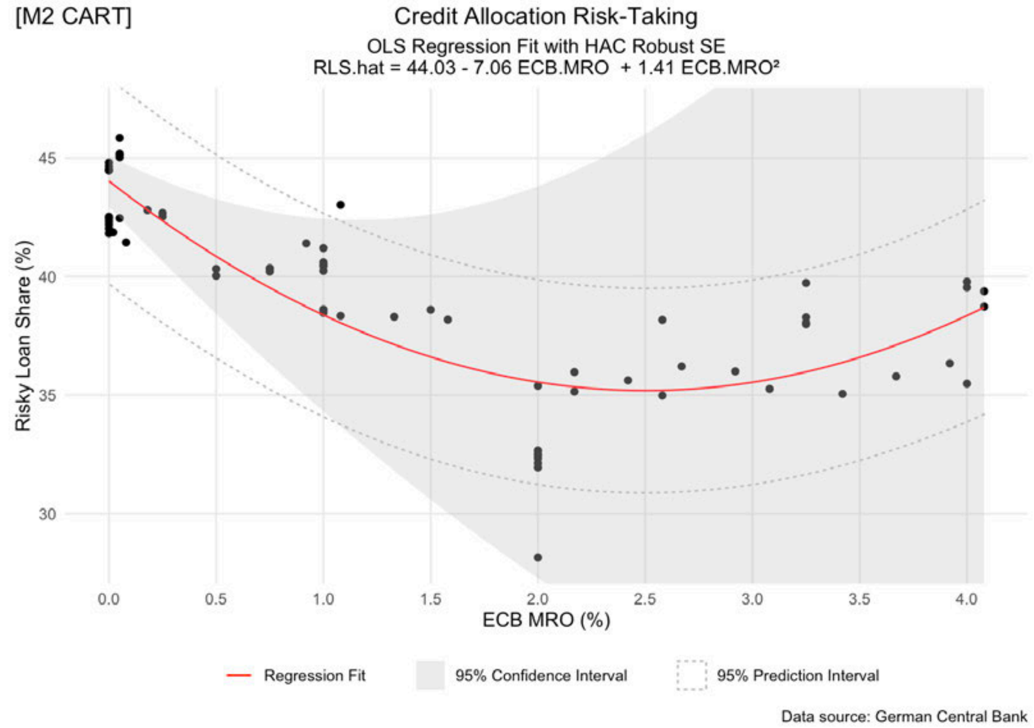


FIGURE 4.61:
M2 CART - REGRESSION FIT

Source: author's R output

Finally, Figure 4.62 adds the estimated relationship to the initial illustration on hypothesis H2 of the theoretical representation on the risk channel in monetary transmission.

H2: There is a negative relationship between the central bank's monetary policy rate of interest and risk-taking in terms of credit risk in the balance sheet of commercial banks (ceteris paribus). $RTAK_{CRR} = f(-MPR)$

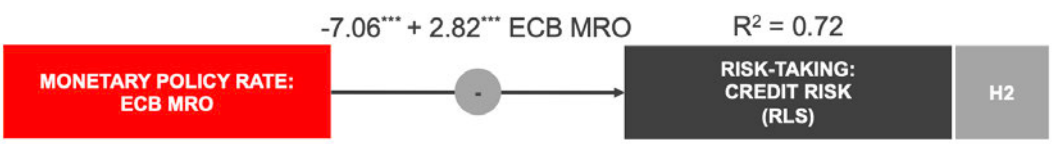


FIGURE 4.62:
M2 CART - HYPOTHESIS H2

Source: author's illustration

Credit risk-taking in the balance sheet of German commercial banks responds to changes in the monetary policy rate of interest with the magnitude depending on the initial level of the policy rate. The nonlinear relationship approximated by the quadratic function together with the negative sign of an estimated parameter for the policy rate and the positive sign for the squared policy rate, imply that policy rate reductions lead to higher credit risk-taking and that the size of this effect is larger when policy rates are low. The empirical test of hypothesis H2 based on the regression model M2 CART verified a statistically significant, negative relationship between low levels of the monetary policy rate of interest and risk-taking in terms of credit risk in the balance sheet of German commercial banks. The estimated effect of high levels of the monetary policy rate of interest is positive with $\frac{d\widehat{RLS}}{dECB.MRO} = -7.06 + 2.82\, ECB.MRO$ for an infinitesimal change in the ECB MRO. Hence, the regression results indicate nonlinearity. The positive effect of high levels in the ECB MRO on the risky loan share was not hypothesised. The economic model $RTAK = f(-MPR, -MRM, +PTAR)$ indicated that risk-taking depends also on the method of risk measurement and the profit target. While the former is negligible for the measure risky loan share due to the absence of variety in its calculation, the profit target which is not included in the regression due to a lack of data might explain the positive effect on credit risk-taking.

Overall, the specified regression model explains 72% of the observed variability in the risky loan share indicating credit allocation risk-taking. To a great extent, the empirical regression analysis supports the hypothesis from theory with respect to credit risk-taking of commercial banks (H2). Based on the theory of the risk channel mechanism and on the residual analysis, some omitted variable bias in the coefficient estimates seems likely with respect to the profit target as omitted independent variable, which is presumed to affect credit risk-taking, as well. In this static form, the regression model is focused on the test of the hypothesis on the risk channel mechanism rather than making precise predictions on changes of the monetary policy rate.

4.8.3 MODEL 3: INTEREST RATE RISK-TAKING

Regression model 3 on the causal relationship between the independent variable ECB interest rate on main refinancing operations representing the monetary policy rate of interest and the dependent variable net asset duration indicating interest rate risk-taking of German commercial banks in time period 2012 to 2019 is estimated as follows:

$$NAD_t = \alpha + \delta_1\, BG.SB_t + \delta_2\, BG.LSI_t + \delta_3\, BG.SMCB_t + \beta\, ECB.MRO_t + e_t,\ t = 1, \dots, N \tag{4.44}$$

$$\widehat{NAD} = 8.26 - 0.82\, BG.SB - 6.06\, BG.LSI - 6.69\, BG.SMCB - 1.29\, ECB.MRO \tag{4.45}$$

By solving for the categorial dummy parameters, the estimated regression model becomes for each bank group:

$$\begin{aligned} &\mathit{Credit\ cooperatives}: \\ &NAD_t = \alpha + \beta\, ECB.MRO_t + e_t \\ &\widehat{NAD_{CC}} = 8.26 - 1.29\, ECB.MRO \end{aligned} \tag{4.46}$$

$$\begin{aligned} &\mathit{Savings\ banks}: \\ &NAD_t = (\alpha + \delta_1) + \beta\, ECB.MRO_t + e_t \\ &\widehat{NAD_{SB}} = (8.26 - 0.82) - 1.29\, ECB.MRO \\ &\widehat{NAD_{SB}} = 7.44 - 1.29\, ECB.MRO \end{aligned} \tag{4.47}$$

$$\begin{aligned} &\mathit{Large, systemically\ important\ banks}: \\ &NAD_t = (\alpha + \delta_2) + \beta\, ECB.MRO_t + e_t \\ &\widehat{NAD_{LSI}} = (8.26 - 6.06) - 1.29\, ECB.MRO \\ &\widehat{NAD_{LSI}} = 2.20 - 1.29\, ECB.MRO \end{aligned} \tag{4.48}$$

$$\begin{aligned} &\mathit{Small\ and\ medium\ sized\ commercial\ banks}: \\ &NAD_t = (\alpha + \delta_3) + \beta\, ECB.MRO_t + e_t \\ &\widehat{NAD_{SMCB}} = (8.26 - 6.69) - 1.29\, ECB.MRO \\ &\widehat{NAD_{SMCB}} = 1.57 - 1.29\, ECB.MRO \end{aligned} \tag{4.49}$$

Table 4.66 consolidates the geometric properties along with their economic interpretation and estimate for the regression model with bank group specific intercept parameters and a common slope parameter.

TABLE 4.66:
M3 IRRT - ECONOMIC INTERPRETATION

Geometric Property	Economic Interpretation	Estimate
Slope	Marginal effect of ECB MRO	$\hat{\beta} = -1.29$
Credit cooperatives		
Intercept	Net asset duration when ECB MRO is zero	$\hat{\alpha} = 8.26$
Savings banks		
Intercept	Net asset duration when ECB MRO is zero	$(\hat{\alpha} + \hat{\delta}_1) = 7.44$
Large, systemically important banks		
Intercept	Net asset duration when ECB MRO is zero	$(\hat{\alpha} + \hat{\delta}_2) = 2.20$
Small and medium sized banks		
Intercept	Net asset duration when ECB MRO is zero	$(\hat{\alpha} + \hat{\delta}_3) = 1.57$

When the ECB MRO is at 0%, the estimate of the intercept parameters predicts a net asset duration for credit cooperatives of 8.26 years ($\hat{\alpha}$), for Savings banks of 7.44 years ($\hat{\alpha} + \hat{\delta}_1$), for large, systemically important banks of 2.2 years ($\hat{\alpha} + \hat{\delta}_2$) and for small and medium sized commercial banks of 1.57 years ($\hat{\alpha} + \hat{\delta}_3$). As the ECB MRO increases by 1 percentage point, the estimate of the slope parameter $\hat{\beta}$ predicts for all bank groups a decrease in net asset duration of 1.29 years over time.

Table 4.67 summarises the OLS regression findings on the causal relationship of the ECB interest rate on main refinancing operations on interest rate risk-taking of German commercial banks. For each parameter, the table reports the coefficient estimates of the regression model, the Newey West heteroscedasticity and autocorrelation robust standard errors, the t-value and p-value based on the quasi t Wald test on the significance of the respective coefficient, its lower (95% CI LL) and upper (95% CI UL) limit of the 95% confidence interval as well as the variance inflation factor (VIF). For the regression model, the table reports the number of observations (N), the R-squared (R^2) and adjusted R-squared (adjusted R^2) value, the residual standard error (residual SE), the test statistic and p-value based on the quasi F Wald test on the significance of the regression model as well as the corresponding numerator degrees of freedom $df = K$ from the number of restrictions $K - 1$ and the denominator residual degrees of freedom $df = N - K$.

TABLE 4.67:
M3 IRRT – OLS REGRESSION RESULTS

Dependent variable: Net Asset Duration (years)

	Estimate	Robust SE	t statistic	p value	95% CI LL	95% CI UL	VIF
ECB.MRO (%)	-1.29	0.30	-4.23	0.00***	-1.89	-0.68	1
BG.SB	-0.82	0.27	-3.00	0.00**	-1.36	-0.28	1.5
BG.LSI	-6.06	0.30	-20.40	0.00***	-6.65	-5.47	1.5
BG.SMCB	-6.69	0.35	-19.10	0.00***	-7.39	-6.00	1.5
Intercept	8.26	0.28	29.80	0.00***	7.72	8.81	
Observations (N)	120						
R^2	0.97						
Adjusted R^2	0.97						
Residual SE	0.52						
F statistic	675.96			0.00***			
df (K)	4						
df (N-K)	115						

Significance codes: *p<0.05; **p<0.01; ***p<0.001

The corresponding plot of the regression fit is presented in Figure 4.63 wrapped by bank group. The regression model that categorizes the causal relationship by the bank group seems to match well with the sample observations, which exhibit a linear relationship.

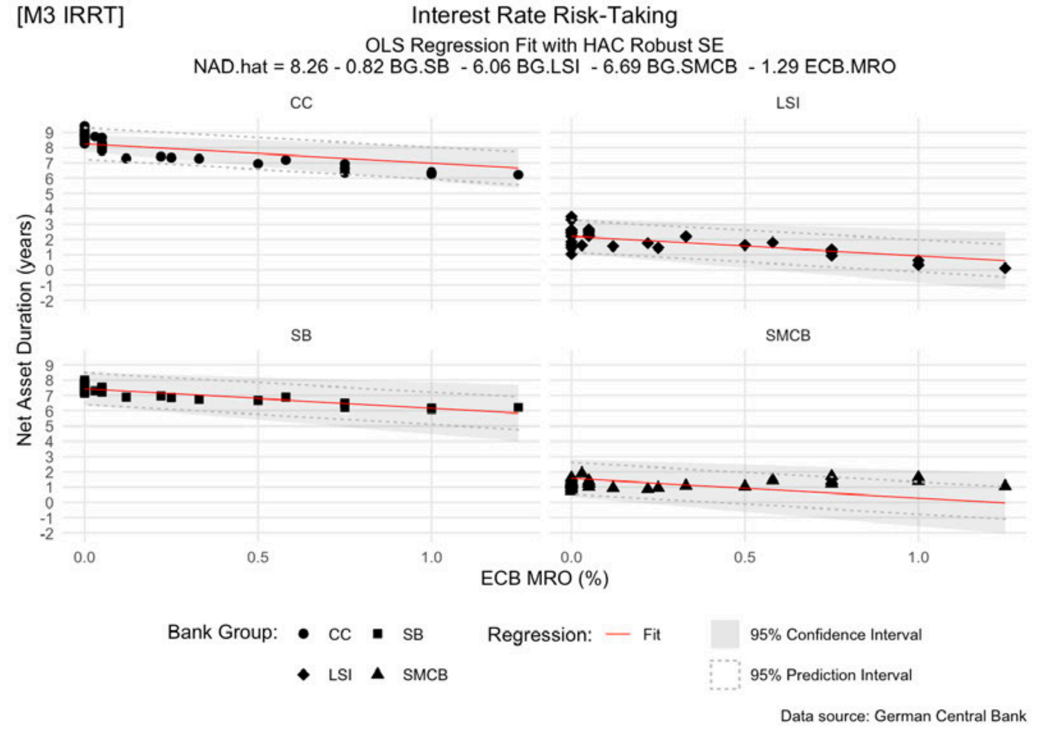


FIGURE 4.63:
M3 IRRT - REGRESSION FIT

Source: author's R output

Finally, Figure 4.64 adds the estimated relationship to the initial illustration on hypothesis H3 of the theoretical representation of the risk channel in monetary transmission.

H3: There is a negative relationship between the central bank's monetary policy rate of interest and risk-taking in terms of interest rate risk in the balance sheet of commercial banks (ceteris paribus). $RTAK_{IRR} = f(-MPR)$

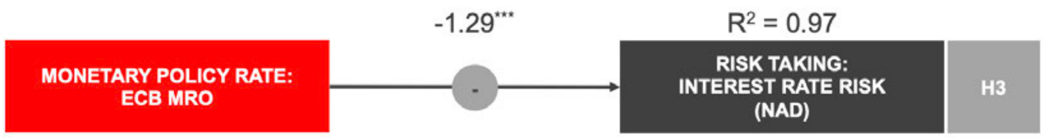


FIGURE 4.64:
M3 IRRT - HYPOTHESIS H3

Source: author's illustration

The empirical test of hypothesis H3 based on the regression model M3 IRRT verified a statistically significant, negative relationship between the central bank's monetary policy rate of interest and risk-taking in terms of interest rate risk in the balance sheet of commercial banks. The estimated effect on the risky loan share for all bank groups is negative with -1.29 years for a change in the ECB MRO of one percentage point.

Overall, the specified regression model explains 97% of the observed variability in the risky loan share for all observed bank groups indicating their risk-taking in terms of interest rate risk. The empirical regression analysis supports the hypothesis from theory with respect to interest and risk-taking of commercial banks (H3). The economic model $RTAK = f(-MPR, -MRM, +PTAR)$ indicates that risk-taking depends also on the method of risk measurement and the profit target. While the former is negligible for the measure net asset duration due to the absence of variety in its calculation, the profit target which is not included in the regression due to a lack of data might cause some omitted variable bias in the coefficient estimates. In this static form, the regression model is focused on the test of the hypothesis on the risk channel mechanism rather than making precise predictions on changes of the monetary policy rate.

4.9 REGRESSION EVALUATION

The following step in the orderly procedure of the quantitative research based on the method of regression analysis is the regression evaluation. The assessment follows the evaluation of quantitative research by Lincoln and Guba (1985), where objectivity, reliability internal validity and external validity are considered as presented in Table 4.68.

TABLE 4.68:
EVALUATION OF QUANTITATIVE RESEARCH

Evaluation	Criterion
Objectivity	Neutrality
Reliability	Consistency
Internal validity	Truth of value
External validity	Applicability

OBJECTIVITY: Objectivity of this study is ensured through the methodological approach. Objectivity is essential for this research as it is conducted under the research paradigm of Post-Positivism. Accordingly, the researcher takes a neutral, outside standing position throughout the whole research process, that means also in the empirical analysis part. This research follows a nomothetic objective which a detached use of secondary data of the German Central Bank, which promotes the objectivity of this study.

The concepts of validity and reliability play a central role for the evaluation of quantitative research. They provide an indication on how well a method, technique or test measures something. The two concepts are closely related but have different meanings. As Wooldridge (2008) outlines, reliability refers to the consistency of a measure, validity refers to the accuracy of a measure. A measurement can be reliable but not valid, while a valid measurement is usually also reliable.

RELIABILTY: Reliability describes how consistently a method measures something. If the same result can consistently be achieved by using the same method under the same circumstances, the measurement is considered reliable (Saunders, Lewis & Thornhill, 2007). Reliability is assessed based on reproducibility, that is comparing different versions of the same measurement. Reliability can be threatened by failures in the process of data collection or in the procedure of the regression analysis, in particular with respect to the diagnostics of model assumptions and instruments on statistical inference. The reliability of this research will be ensured by the choice of a quantitative method, which is applied in an objective, value-free manner with reproducible results. First, the regression analysis exclusively builds up on secondary data of the German Central Bank, therefore the researcher had no direct impact on the collection of data. However, all of the data samples are collected by a governmental institution in the context of bank regulation, where high reporting standards apply for the commercial banks through the regulatory framework. Therefore, it can be assumed that reliability is given with respect to the process of data collection. Second, with respect to the regression analysis procedure, reliability is ensured though careful execution and the reproducibility of the regression results. Since coefficient estimates are subject to sampling uncertainty, the 95% confidence interval estimates are an important indicator for the reliability of estimates. This interval has a probability of 95% to contain the true value of the parameter. That means in 95% of all samples that could be drawn from the population, the estimated confidence interval will cover the true value of the parameter. The narrower the 95% confidence interval, the greater the reliability of an estimate. In Chapter 4.8 “Regression Results”, the 95% confidence interval is reported for each coefficient and allow for the conclusion of overall reliability of the estimates.

Validity refers to how accurately a method measures what it is intended to measure (Saunders, Lewis & Thornhill, 2007). If research has high validity, that means it produces results that correspond to real properties, characteristics, and variations in the physical or social world. The term validity is closely related to the verifiability of data, which means “prove to be true” or “test the correctness”. In the context of this research, validity refers to how well the applied quantitative regression method measures what is intended to measure, that is the effect of the monetary policy rate on credit risk perception and risk-taking in terms of credit risk and interest rate risk of German commercial banks. It is distinguished between internal validity and external validity of research. Grix (2004) outlines the distinction as follows: Internal validity refers to the extent to which researchers can demonstrate they have evidence for the statements and descriptions they make based on the research design. External validity refers to the generalisability of a study, that is the relevance of the studies statements over and above the case-study used.

INTERNAL VALIDITY: The internal validity of the empirical analysis is carefully ensured by the research approach (chapter 3.3 “Research Approach”) in general and the identification approach (chapter 3.5 “Data Collection”) in particular, as well as the model diagnostics presented in chapter 4.6 “Regression Model Diagnostics”. The latter includes the check of model assumptions based on a residual analysis, such as zero mean, homoscedasticity, non-autocorrelation and normal distribution as well as an examination on the stationarity of variables, non-multicollinearity of independent variables and the absence of extreme outliers. Accordingly, internal validity of the regression analysis is ensured through the research approach and careful model diagnostics along with the corresponding adjustments in the coefficient standard errors for valid statistical inference, as well as the inclusion of categorial dummy variables and outlier analysis.

EXTERNAL VALIDITY: External validity is closely related to the population sample and refers to the generalisability of a study. The monetary policy of the ECB applies for all countries of the EMU. From the theoretical insights in chapter 2 “Literature Review”, it is supposed that the underlying mechanism of the risk channel of monetary transmission applies to member states of the EMU and possibly even to monetary policy in general as a similar design of the institutional framework of macroprudential bank regulation, particularly on capital requirements, exists. The empirical analysis of this research builds up on representative samples of a subpopulation “German commercial banks” of the population “EMU commercial banks”. Representativity for the subpopulation “German commercial banks” is established since the data samples cover for regression model 1 all German IRBA banks, which are the ones with the greatest portfolios, and for the other 2 regression models all German commercial banks. Therefore, external validity of the empirical results is given at least for the subpopulation of German commercial banks. Furthermore, empirical studies on risk-taking in other countries of the EMU indicate similar empirical evidence, as the chapter 5 “Discussions” will outline.

In association with the findings in the literature review on theory and existing empirical studies, there is strong indication that the conclusions of this research are generalisable for the TMMP within the European Monetary Union.

4.10 CHAPTER CONCLUSION

This chapter 4 “Empirical Analysis” follows the objective to empirically test the hypotheses, which are derived in chapter 3.4.2 “Hypotheses” based on the theoretical representation of the risk channel in the TMMP in the EMU. In a Post-Positivist approach, the quantitative method of regression analysis is applied as outlined in chapter 3 “Methodology”. The empirical analysis is conducted objectively by the researcher, whereby the OLS regression analysis covered by this chapter follows the orderly procedure of sample description, regression model specification, time series diagnostics, regression model diagnostics, hypothesis test, regression results and regression evaluation.

The three hypotheses relate to the causal relationship between the monetary policy rate, represented by the independent variable ECB interest rate on main refinancing operations, and credit risk perception or risk-taking in form of credit risk and interest rate risk of German commercial banks, indicated by the dependent variables RWA density, risk loan share and net asset duration which were econometrically captured by three separate regression models. The statistical tests of the hypotheses on the risk channel of monetary transmission in chapter 4.7 “Hypotheses Tests” support the hypotheses on the risk channel mechanism for low levels of the ECB interest rate on main refinancing operations by indicating significant effects at a confidence level of 99.9% for the population of German commercial banks. Furthermore, empirical evidence points to a non-linear nature of the risk channel in monetary transmission.

The following chapter is dedicated to the discussion of the empirical findings against the background of the findings from theory in the literature review.

5 DISCUSSIONS

5.1 CHAPTER INTRODUCTION

This chapter synthesises the findings of the empirical and theoretical part of this research in order to evaluate the research findings. The structure of this chapter is as follows: First, the empirical findings are discussed in relation to the theoretical representation proposed by the researcher. Second, the outcomes of the empirical analysis are compared to the previous studies with respect to the economic model, the identification strategy, and the empirical findings on the risk channel in the TMMP.

5.2 EMPIRICAL FINDINGS IN RELATION TO THEORY

This subchapter evaluates the results of the empirical regression analysis against the findings of the theoretical representation of the risk channel in the TMMP. The first subchapter discusses the empirical findings on the risk perception and the second subchapter focuses on the risk-taking of German commercial banks.

5.2.1 POSITIVE EFFECT OF THE MPR ON RISK PERCEPTION

The theoretical representation of the risk channel indicates that risk perception of commercial banks ($RPER$) may depend positively on the monetary policy rate of interest (MPR) and on the method of risk measurement (MRM) (Gambacorta, 2009; Borio & Zhu, 2012). Macroprudential bank regulation tends to enhance risk perception due to the requirements on methods of risk measurement through the capital framework effect (Borio & Zhu, 2012; BCBS, 2022).

The empirical analysis based on regression model 1 Credit Risk Perception [equation (4.11) M1 CRP] examined the causal relationship between the monetary policy rate of interest (MPR) proxied by the ECB interest rate on main refinancing operations and credit risk perception ($RPER$) proxied by the regulatory measure RWA density of German commercial IRBA banks, calculated as ratio of risk-weighted assets (RWA) to the original gross exposures for the respective loans (EAD) (BCBS, 2022). Differences in the method of risk measurement (MRM) are captured by the business area, for which loans to enterprises are typically associated to more sophisticated methods of risk measurement and retail loans are associated to less sophisticated methods of risk measurement (Bessis & Bessis, 2015).

The regression results (Table 4.62) in the context of hypothesis H1: $RPER_{CRR} = f(+MPR)$ support the theoretical proposition of a positive relationship between the monetary policy rate of interest and credit risk perception in the business area of retail loans. In the business area of loans to enterprises, the empirical evidence points to a nonlinear relationship: For the low MPR, the data supports the theoretical proposition of a positive relationship between the monetary policy rate of interest and credit risk perception. For the high MPR, the data indicates a negative relationship with an estimated turning point of 2.31% in the MPR. That means the effect of changes in monetary policy rate of interest on commercial banks credit risk perception in the business area of loans to enterprises depends on the initial level of the monetary policy rate of interest. As expected from theory, the estimated size of this effect is larger for low MPR.

The empirical evidence of a negative relationship between the monetary policy rate of interest and credit risk perception in the business area of loans to enterprises above the turning point in the nonlinear model is hardly explainable from a theoretical point of view. It is to note that monetary policy rates above the estimated turning point of 2.31% are underrepresented in the sample as shown in the descriptive statistics: For the series ECB MRO, the 75th percentile is at an interest rate of 1%. Moreover, in the covered period between 2008 and 2019, only 10.87% (5 out of 46) observations exceed the turning point of 2.31%. Therefore, the empirical evidence of higher monetary policy rates is rather underrepresented in the sample so that this part of the empirical outcome should be interpreted with caution.

In consideration of the insights from the theory and the empirical results, it seems reasonable to conclude that the risk channel mechanism relies on a positive effect of low monetary policy rates on credit risk perception of commercial banks with potential nonlinearities that alter the direction and strength of the effect for high monetary policy rates. Moreover, the empirical result to a certain extent supports the economic model $RPER = f(+MPR, +MRM)$, in that the business area of loans to enterprises representing more sophisticated methods of risk measurement corresponds to a higher level of risk perception compared to the business area of retail loans representing less sophisticated methods of risk measurement. However, this might partly be owed to the fact that loans to enterprises are naturally associated to higher risk, so that differences in risk perception may not exclusively be attributable to the methods of risk measurement.

5.2.2 NEGATIVE EFFECT OF THE MPR ON RISK-TAKING

The theoretical representation of the risk channel indicates that risk-taking of commercial banks ($RTAK$) may depend negatively on the monetary policy rate of interest (MPR) and the methods of risk measurement (MRM), and positively on the profit target ($PTAR$). Macroprudential bank regulation tends to affect risk-taking through the capital wedge effect, which implies potential nonlinearities with respect to the strength and direction of the effects (Borio & Zhu, 2012).

In the empirical analyses, risk-taking of German commercial banks is examined for the 2 predominant classes of risk in lending business: credit risk-taking and interest rate risk-taking following Kuritzkes and Schuermann (2010) based on specific regression models for each class of risk.

5.2.2.1 CREDIT RISK-TAKING

The regression analysis based on regression model 2 Credit Allocation Risk-Taking [equation (4.14) M2 CART] examined the causal relationship between the monetary policy rate of interest (MPR) indicated by the ECB interest rate on main refinancing operations and credit risk-taking ($RTAK$) measured by the share of loans to relatively risky enterprises (RLS), which is based on enterprises whose interest coverage ratio (ICR) is in the worst 30th percentile. The interest coverage ratio is calculated from the enterprise's ratio of EBITDA to interest expenditure (German Central Bank, 2021). The distinction on methods of risk measurement (MRM) is not relevant, because there is only one method of calculating the measure risky loan share based on ICR. The profit target ($PTAR$) is not included in the regression due to data constraints.

The regression results (Table 4.65) in the context of hypothesis H2: $RTAK_{CRR} = f(-MPR)$ yield the evidence of a nonlinear relationship: For the low MPR, the data supports the theoretical proposition of a negative relationship between the monetary policy rate of interest and credit risk-taking of commercial banks. For the high MPR, the data indicates a positive relationship with an estimated turning point of 2.5% in the MPR. That means the effect of changes in monetary policy rate of interest on commercial banks credit risk-taking depends on the initial level of the monetary policy rate of interest. An increase above the estimated turning point causes credit allocation risk-taking of commercial banks to increase, as well. As expected from theory, the estimated size of this effect is larger for low MPR.

The nonlinearity may not be clearly predicted by the existing theory, but there are indications that the risk channel is of nonlinear nature: (1) The regulatory capital wedge promotes nonlinearity due to its option like nature. (2) The economic model suggests that a rise in the profit target or a profit gap of commercial banks, which is not included in the regression, would tend to increase their risk-taking, ceteris paribus. (3) Some studies discuss that higher interest rates may increase the risk-taking incentives of borrowers due to moral hazard (Stiglitz & Weiss, 1981), increasing the opportunity costs for banks to hold cash, thus making risky alternatives more attractive (Smith, 2002), or even reduce the banks' net worth enough to make a "gambling for resurrection" strategy attractive (Keeley, 1990). These are all signs from the literature review that point to a nonlinear nature of the risk channel. Moreover, a study of Chmielewski, Lyziak and Stanislawska (2020) comes to similar results based on evidence for commercial banks in Poland. They identify nonlinearity in credit risk-taking in the business line of large loans to non-financial firms. Hence, the risk channel in monetary transmission seems indeed to render a nonlinear nature.

5.2.2.2 INTEREST RATE RISK-TAKING

The analysis based on regression model 3 Interest Rate Risk-Taking [equation (4.18) M3 IRRT] examined the causal relationship between the monetary policy rate (MPR) indicated by the ECB interest rate on main refinancing operations and interest rate risk-taking ($RTAK$) indicated by the regulatory duration of net assets. While the distinction on methods of risk measurement (MRM) is not relevant for that risk measure, the profit target ($PTAR$) was not included in the regression due to data constraints.

The regression results (Table 4.67) in the context of hypothesis H3: $RTAK_{IRR} = f(-MPR)$ support the theoretical proposition of a negative relationship between the monetary policy rate of interest and interest rate risk-taking of commercial banks. That means a decrease in the MPR corresponds to an increase in interest rate risk-taking.

In contrast to the empirical findings on credit risk-taking, no nonlinearity is detected for interest rate risk-taking of commercial banks. This might be explained with the macroeconomic background conditions of an exceptional expansionary monetary policy regime of the ECB in that time period. The literature review points out that expansionary monetary policy has an adverse effect on profits in such a regime of long-lasting, very low interest rates (Adrian, Estrella & Shin, 2019). It causes long term market interest rates to decline and reduces market volatilities, the return from interest rates and speculation on rising prices. The low interest rates reduce the rate of return in the interest book in the balance sheet. This can exhibit an additional effect the risk tolerance of commercial banks because the gap between the profit target and actual profits widens. In order to reach the profit target further on, commercial banks have an incentive to increase risk tolerance in order to compensate for lower interest-earnings, which corresponds to the search for yield effect. Hence, German commercial banks seem to have linearly increased maturity transformation and hence interest rate risk-taking in order to counteract falling profits caused by decline of interest earnings.

5.3 COMPARISON WITH PREVIOUS STUDIES

This subchapter compares the current research to the previous studies by evaluating differences in the empirical approach and the empirical findings.

5.3.1 EMPIRICAL APPROACH

Differences between this and the previous studies predominantly relate to the identification strategy for risk-taking and the econometric model. The identification of measures to capture risk-taking of commercial banks and the access to the respective data is a challenging task. The analysis of the previous studies shows that the applied proxies for credit risk-taking in the data samples vary widely in terms of the origin (survey data, balance sheet data and regulatory reporting), the level of aggregation (loan level, aggregated to the bank level, pooled to bank groups), the time dimension (ex-ante and ex-post risk assessment), the portfolio (risk in new loans and legacy loans), the business line (loans to enterprises and loans to households) and the isolation of credit supply side effects. The following sections outline the variety in risk measures to identify risk-taking as well as differences in the econometric models.

DATA ORIGIN AND LEVEL: Many studies like that of Maddaloni and Peydró (2011) rely on survey data based on loan officer surveys. A loosening of lending standards is interpreted as improved access to credit for borrowers of low creditworthiness. However, typical lending surveys such as the ECB Bank Lending Survey or the Federal Reserve’s SLOOS provide information only about whether lending standards have changed relative to the recent past, not about the absolute level of strictness of lending criteria. Moreover, a decline in lending standards may reflect an improvement in the quality of the borrowers, not an increased risk-taking of commercial banks. Other studies use bank balance sheet data, which brings the advantage to incorporate bank-specific characteristics such as size, liquidity, capitalisation, profitability, lending growth and degree of securitisation activity (Gambacorta, 2009; Dell'Ariccia et al., 2017). Some studies employ confidential micro data based on credit registers, containing comprehensive bank-borrower level data on loan applications and outcomes (Jiménez et al., 2014; Ioannidou et al., 2015; Dell'Ariccia et al., 2017, Delis et al., 2017; Segev, 2020). Such approaches are potentially quite efficient but impose significant data requirements and therefore might not be feasible in some countries, including Germany, due to legal data constraints that protect confidentiality. This study as well as the one of Chmielewski, Lyziak and Stanislawska (2020) employ the bank data from the regulatory reporting. The advantage is that this kind of data is collected on a regular basis by the regulatory authorities from all banks in the EMU and it is publicly available. The level of aggregation is tightly related to the origin of the data. Credit registers allow to analyse risk at the lowest possible level of the loan including all borrower characteristics. Balance sheet data is aggregated to the balance sheet positions. Lending survey data and regulatory reporting data usually have its origin at some aggregated level, which is often the bank level, and may be pooled to higher clusters such as bank groups. This study applies the regulatory reporting data collected in the context of macroprudential bank supervision that is aggregated to the business area, and pooled to bank groups or all German banks, respectively.

TIME DIMESNION: One important distinction of risk measures is on the time of the risk assessment. Ex-ante risk measures such as internal ratings of borrowers refer to the risk assessment at the time of bank loan decision, while ex-post risk measures such as non-performing loans refer to the risk assessment during loan maturity. Ioannidou, Ongena and Peydró (2009) apply a combined approach looking at several risk measures at the loan level: ex-ante internal credit ratings, ex-post loan performance and time to default as well as loan characteristics such as loan rate, maturity, and collateral. Some studies use exclusively ex-post risk measures, such as nonperforming loans (Delis & Kouretas, 2011), which is seen problematic due to the fact that they reflect ex-post realised risk, not the ex-ante risk taken by banks at the moment of the loan decision, which is a key element in the risk channel. Jiménez et al. (2014) account for that by taking the loan volume of ex-ante risky firms measured based on the presence of bad credit history of non-performing loans along with required collateral. Market-based risk measures such as the expected default frequency of a bank applied by Gambacorta (2009) and

Altunbas et al. (2014) are potentially forward-looking but reflect changes in total riskiness of banks arising from risk in new lending and the change in risk of the pre-existing portfolio. This approach does not allow to isolate the effect of the current interest rate environment on the current risk-taking decisions in lending. Moreover, market-based measures such as the firm's distance to default (Segev, 2020) assume validity of the efficient market hypothesis. If this assumption is not met, market-based measures might be biased due to waves of excessive optimism or pessimism in the financial markets. Other studies employ the ex-ante loan spread as the difference between the loan rate and a risk-free rate of same maturity indicating the risk premium (Delis et al., 2017) or the term spread as the difference between short-term and long-term yields indicating the marginal profitability of loans (Adrian, Estrella & Shin, 2019). Chmielewski, Lyziak and Stanislawska (2020) calculate ex-ante and ex-post risk weights. The ex-ante risk weight implies the expected loss and is calculated from net interest margin minus the minimum required return proxied by bank's return on assets (ROA) assuming a positive link between interest margin and credit risk. The ex-post risk weight is calculated from the loan loss reserve ratio. However, these risk weights are proxies that do not correspond to the risk measures that a bank actually applies for decisions on the balance sheet composition. In contrast, the current research deploys RWA density as proxy for credit risk perception, the share of risky loans as proxy for credit risk-taking and the duration of net assets as proxy for interest rate risk taking. These are ex-ante regulatory measures of risk that banks actually apply in their risk management with a magnitude depending on the degree of their alignment with the regulatory framework.

PORTFOLIO: Another distinction is on risk measures of new loans as a result of the current business decisions and changes in the risk measures relating to the pre-existing loan portfolio being a result of past decisions. To construct a measure of new risk taken by banks some studies make use of confidential internal credit ratings of each loan (Ioannidou et al., 2015; Dell'Ariccia et al., 2017), credit spreads of individual loans (Delis et al., 2017; Segev, 2020) or other data based on credit registers, containing comprehensive bank-borrower level data on loan applications and outcomes (Jiménez et al., 2014). Such approaches are preferrable but impose significant data requirements. The current study does not distinguish between pre-existing and new loans, since the applied regulatory data does not reflect the new loans in the portfolio.

BUSINESS LINES: It stands out that the majority of studies focuses on risk measures of the business line of loans to non-financial firms (Buch et al., 2014; Dell'Ariccia et al., 2017; Ioannidou et al., 2015; Jiménez et al., 2014; Paligorova and Santos, 2017, Segev, 2020). Exceptions are the studies of Maddaloni and Peydró (2011), Chmielewski, Lyziak and Stanislawska (2020) as well as this study, which analyse risk measures for both business lines in banking, loans to firms (enterprises) and to households (retail loans). Kandrac and Schlusche (2021) investigate the share of risky loans identified by finer distinctions in the type of loan: commercial real estate, construction, commercial and industrial (C&I), and consumer loans. They use the Hirschman-Herndahl Index (HHI), which takes values between 0 and 1, and measures the concentration of banks' lending activities, such that banks that primarily engage in a single type of lending report higher HHIs. The other extreme to the restriction to one business line is the approach of Altunbas et al. (2014), who use a measure for total bank risk based on expected default frequency of a bank, which by construction is a proxy of risk of all bank activities, not only related to loan extension. In contrast, the current study adopts a mixed approach: RWA density as proxy for credit risk perception relates to the total loan portfolio, the share of risky loans as proxy for credit risk-taking relates to loans to enterprises because it is calculated based on firm's interest coverage ratio, and the duration of net assets as proxy for interest rate risk taking refers to the interest book.

SUPPLY SIDE EFFECTS: The isolation of supply side effects from demand side effects allows for deeper insights into the risk channel mechanism but is an empirical challenge, especially given constrains in data availability. Demand side effects relate to the change in demand for loans of riskier borrowers, while supply side effects directly relate to risk perception, risk tolerance, risk-taking of commercial banks. The first empirical paper on the impact of monetary policy on the composition of the supply of loans is from Gertler and Gilchrist (1994). They use micro data from credit registers which allows to isolate changes in the composition of credit supply distinguishing the changes in volume and quality between loan supply and loan demand. The precondition to control for demand side effects is the availability of information on loan applications of potential borrowers. Jiménez et al. (2014) control for similar structures of loan applicants in low interest rate and high interest rate periods and conclude that in this case any resulting changes in the bank risk-taking arise from an active bank decision to change the structure of loan applicants accepted. However, the access to full information on loan applications is a quite rare situation. Chmielewski, Lyziak and Stanislawska (2020) check for a systematic relationship between bank characteristics and risk-taking to identify supply side effects. This research does not share the endorsement of an isolated consideration of supply side effects, because the theoretical representation of the risk channel indicates the relevance of both demand side and supply side effects. Instead, this approach focuses on the distinction between risk perception and risk-taking of commercial banks.

NONLINEARITY IN THE ECONOMETRIC MODEL: Another outstanding aspect in the previous studies is that the focus is on the impact of low monetary policy rates of interest on the risk-taking of banks. While the applied econometric models differ in the dependent variables that consist in measures aiming to proxy risk-taking, they have in common that they capture only linear effects. To the knowledge of the author, the only exception are the econometric models of Chmielewski, Lyziak and Stanislawska (2020) and this study, which do not only consider low interest rates and allow for nonlinear effects by including a quadratic term of the monetary policy rate of interest. This approach widens the attention to the full range of policy rates of interest observed in the respective time period and allows the direction and strength of effect to change with the initial level of the monetary policy rate of interest.

5.3.2 EMPIRICAL FINDINGS

The previous studies differ in the empirical approach as well as the country and time period under investigation. However, their empirical findings on risk-taking of commercial banks are quite consistent, as outlined in what follows.

The work of Ioannidou, Ongena and Peydró (2009) is the first to investigate the impact of monetary policy on banks' risk-taking. They find for banks in Bolivia during the period 1999 to 2003 that when the U.S. federal funds rate decreases, banks do not only increase new risky loans, but also lower the rates banks charge risky borrowers relative to those they charge less risky ones, implying a fall in risk premia for risky borrowers. The reduction in the corresponding loan spread and hence the extra risk is higher for banks with lower capital ratios and more risky loans. The empirical papers of Gambacorta (2009) as well as of Altunbas, Gambacorta and Marqués-Ibañez (2014) analyse data of listed banks in the EU and the USA for the period prior to the world financial crisis from 1999 to 2008 and 2001 to 2007, respectively. Both studies find that low interest rates over an extended period cause an increase in the expected default frequency of a bank.

Delis and Kouretas (2011) contribute empirical insights on banks in the Euro area for the years 2001 to 2008. They conclude that low interest rates increase risky assets and non-performing loans in the portfolio of banks.

Jiménez, Ongena, Peydró and Saurina (2014) use micro data of the Spanish Credit Register over the period 1984 to 2006. They find that low interest rates affect the riskiness of the loan portfolio of Spanish banks in two conflicting ways. In the short term, low interest rates reduce the probability of default of outstanding variable rate loans by lowering the burden of interest expenditures of existing borrowers. In the medium term, however, due to the higher collateral values and search for yield, in particular lowly capitalised banks tend to grant more loans to ex-ante risky firms with larger volume and generally soften their credit standards in terms of collateral requirements.

Dell'Ariccia, Laeven and Suarez (2017) use confidential data on internal ratings as well as balance sheet data of USA banks on new loans to businesses over the period 1997 to 2011. They present evidence that a decrease in the federal funds rate leads to an increase in the rating of newly granted loans and hence a fall in credit standards that banks apply. Paligorova and Santos (2017) study corporate loan pricing policies of banks in the USA for the period 1996 to 2016. They find that loan spreads for riskier firms become relatively lower during periods of monetary policy easing compared to tightening, implying a negative relationship between the monetary policy rate and risk premia. According to the Senior Loan Officers Opinion Survey this effect is driven by banks with greater risk appetite.

Neuenkirch and Nöckel (2018) investigate banks in the Euro area between 2003 and 2016. They show that banks react aggressively to an expansionary monetary policy shock by lowering their lending standards. Bikker and Vervliet (2018) analyse banks in the USA during 2001 to 2015 and present evidence that the low interest rate environment impairs bank performance and compresses net interest margins. Nonetheless, banks have been able to maintain their overall level of profits, due to lower provisioning, which in turn may endanger financial stability. Banks did not compensate for their lower interest income by expanding operations to include trading activities with a higher risk exposure.

Adrian, Estrella and Shin (2019) provide some empirical insights for the USA indicating that expansionary monetary policy depresses the term spread and hence net interest margins and profits, which incentivises banks to increase risk-taking in the supply of new loans.

Chmielewski, Lyziak and Stanislawska (2020) consider the banks in Poland between 2008 to 2018. Their results indicate that in the business line of large loans to non-financial corporations lowering short-term interest rates leads to increased risk of new loans. They show that the loosening of monetary policy has nonlinear effects depending on the initial level of interest rates, and that this effect is different across banks, depending on their size, liquidity and funding structure. Segev (2020) investigates the risk sensitivity of banks in the USA from 1996 to 2008 based on loan-level data in order to disentangle the risk channel from other monetary channels. He shows that banks change their behaviour towards risk following changes in monetary policy where loose monetary policy reduces banks’ sensitivity to risk.

Kandrac and Schlusche (2021) investigate US banks between 2006 and 2014 focusing on the effect of reserve accumulation as a result of quantitative easing by the central bank. Similar to the studies on changes in the monetary policy rate of interest, they find evidence that quantitative easing causes the share of riskier loans to increase, as well. This indicates that the risk channel mechanism may not only apply for changes in the monetary policy rate of interest, but also for changes in the quantity of money and hence monetary policy measures in general.

Regarding bank characteristics that influence the strength of the risk channel, empirical studies suggest that some characteristics have indeed an impact on banks' risk-taking: Smaller capital buffers, higher deposit ratios and abundant liquidity tend to increase risk-taking of banks (Acharya & Naqvi, 2012; Jiménez et al. 2014; Laeven et al., 2016; Khan et al., 2017). In the case of bank size, the empirical evidence appears mixed (Boyd & Runkle, 1993; de Haan & Poghosyan, 2012; Laeven et al., 2016).

As it is shown above, the previous studies investigate primarily credit risk-taking of commercial banks in the USA and in the EU for different periods of time. The studies are consistent in that they identify a negative relationship between low monetary policy rates of interest and risk-taking of commercial banks. To the knowledge of the author there is only one other study that allows for nonlinear effects. In comparison, this study puts the empirical research one step forward by contributing (1) first and current empirical insights on German commercial banks, (2) the extension of credit risk-taking to interest rate risk-taking, (3) the distinction between credit risk perception and credit risk-taking, and (4) econometric models that capture the nonlinear nature of the risk channel. The empirical results of this study are consistent with the majority of the previous studies in that for low monetary policy rates, the empirical evidence supports a negative relationship between the monetary policy rate of interest and credit risk-taking of German commercial banks.

5.4 CHAPTER CONCLUSION

This chapter discusses the empirical results of the current research in the light of the theoretical findings in the theoretical representation derived through the literature review and compared them to that of former studies on the risk channel in the TMMP with respect to the empirical approach and the empirical findings.

The empirical findings of the current research based on data of German commercial banks broadly confirm the 3 hypotheses derived from the theoretical representation of the risk channel: The empirical evidence supports the hypothesis of a positive relationship between the monetary policy rate of interest and credit risk perception with an indication of nonlinearity for loans to enterprises. It also supports the hypotheses of a negative relationship between the monetary policy rate of interest and both credit risk-taking and interest rate risk-taking with an indication of nonlinearity for credit risk-taking.

In comparison with previous studies, the current research differs by undertaking an innovative empirical approach to the risk channel mechanism in 3 aspects. First, it considers not only risk-taking but also risk perception, the latter is proxied by regulatory measure Risk Weighted Assets (RWA) density of the loan portfolio calculated by commercial IRBA banks based on internal ratings. Second, risk-taking is not limited to credit risk-taking. Interest risk-taking is also included since maturity transformation in lending business bears interest rate risk, as well. Credit risk-taking is proxied by the regulatory measure share of risky loans based on the interest coverage ratio of firms, while interest rate risk-taking is proxied by the regulatory measure duration of net assets in the interest book. Third, this research allows for nonlinear effects by including a quadratic term of the monetary policy rate of interest in the econometric model. Despite the heterogeneity in the empirical approach in the research on the risk channel, the empirical findings are consistent with respect to the evidence of a negative relationship between low monetary policy rates of interest and credit risk-taking of German commercial banks. The current research enriches the evidence with the empirical results on German commercial banks, their credit risk perception, their interest rate risk-taking and the nonlinear nature of the risk channel.

6 CONCLUSION

6.1 CHAPTER INTRODUCTION

This chapter has the objective to conclude the research study by summarising the key points of the different stages of this research. It presents an overview on the baseline of this research project including the research context, the research gap, the corresponding aim and questions of the research, the paradigm that led this research as well as the methodology and the hypotheses of the empirical analysis. Furthermore, it highlights the research findings as well as the implications and recommendations that follow from the research findings. This chapter outlines the contributions of this research to theory and knowledge, to research methodology as well as to policy and practice. Moreover, it addresses the limitations of this research and ends with suggestions for further research.

6.2 RESEARCH OVERVIEW

The real economy is vulnerable to disturbances of the financial system, which can arise from an unnoticed pile up of risk in the balance sheet of commercial banks in association with monetary policy. Central bankers are increasingly confronted with fluctuations in the business cycle, resulting from a long-lasting increase in risk-taking followed by a sudden recession, where long periods of apparent stability give way to sudden, potentially highly disturbing financial tensions. The primary objective of monetary policy of the ECB is to ensure price stability in the European Monetary Union, the secondary objective is the support of real economy targets such as full employment and GDP growth. The use of the monetary policy rate of interest as monetary instrument triggers a variety of mechanisms, which finally affects macroeconomic variables like output and prices. This process is of high complexity and is termed the transmission mechanism of monetary policy. Whereas several traditional channels of monetary transmission were identified, research points to the existence of another channel that is termed the risk channel (Borio & Zhu, 2008; de Groot, 2014).

The risk channel of monetary transmission represents the effect of a change in the base rate of interest controlled by the central bank on risk-taking of commercial banks, as reflected by the amount of risk in their balance sheets as well as the price and non-price conditions of credit extension. The change in the financial system, the increase in macroprudential regulation as well as the long lasting low-interest environment in the EMU made the risk channel become more important within the monetary transmission mechanism, that means relative to the traditional channels. There is a gap in research on the functioning of the underlying mechanism as well as on empirical insights on the risk channel for banks in the EMU and in particular in Germany.

The aim of this research is to explain the risk channel in the transmission of monetary policy for the EMU by identifying the operating mechanism in a conceptual representation and to complement this with empirical insights on the German bank sector. In the light of that research aim, this study addresses the following 3 research questions:

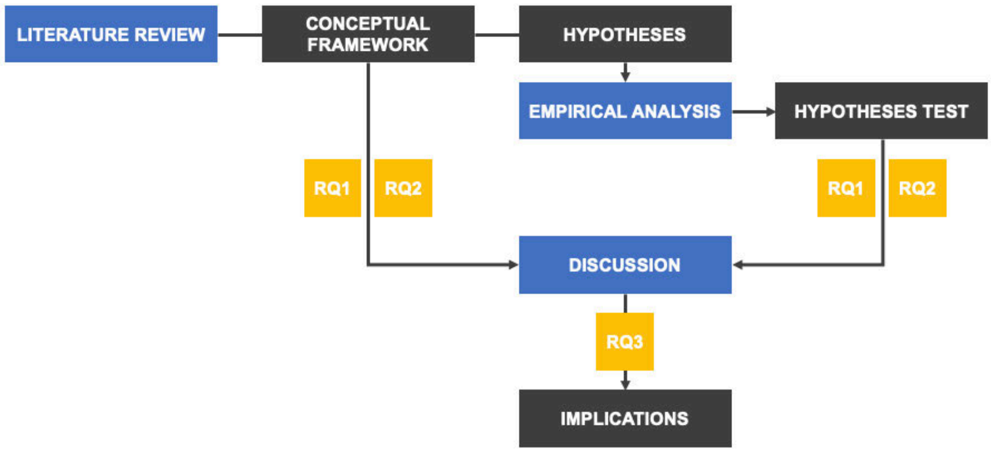
RQ1:	What is the underlying mechanism of the risk channel in the transmission of monetary policy within the EMU?
RQ2:	What is the role of macroprudential bank regulation in the risk channel in the transmission of monetary policy within the EMU?
RQ3:	What are the implications of the risk channel for the decision makers of monetary policy for the EMU?

The scope of this research is delimited to monetary transmission through the risk channel in the EMU and therefore to the transmission of monetary policy conducted by the European Central Bank (ECB) through the economies of the 19 member states[33]. Consequently, the theoretical analysis focuses on explaining the risk channel mechanism of monetary transmission in contrast to that of other traditional channels of monetary policy such as the interest rate channel or the credit channel. Furthermore, the empirical analysis focuses on commercial banks in Germany as a member state of the EMU and covers the time period between 2002 and 2019, whereby the starting point corresponds to the early beginning of the EMU with the introduction of the Euro as common cash money.

To answer the research questions the research design is formulated under the Post-Positivist paradigm as shown in Figure 6.1, which reflects the relation between the research questions along with the corresponding chapters of this research.

[33] With the start of the EMU on 01.01.1999, the ECB became responsible for the common monetary policy (ECB, 2022a). As of 2022, the member states of the EMU include: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden.

RESEARCH AIM
To explain the risk channel of monetary policy in the EMU by identifying the operating transmission mechanism.



RESEARCH QUESTIONS
RQ1: What is the underlying mechanism of the risk channel in the transmission of monetary policy within the EMU?
RQ2: What is the role of macroprudential bank regulation in the risk channel in the transmission of monetary policy within the EMU?
RQ3: What are the implications of the risk channel for the decision makers of monetary policy for the EMU?

FIGURE 6.1:
RESEARCH APPROACH

Source: author's illustration

The 3 hypotheses that reflect propositions on the relationship between monetary policy rate of interest and risk perception or risk-taking of commercial banks, respectively, are tested based on data of German commercial banks for the period between 2002 and 2019 (Figure 6.2).

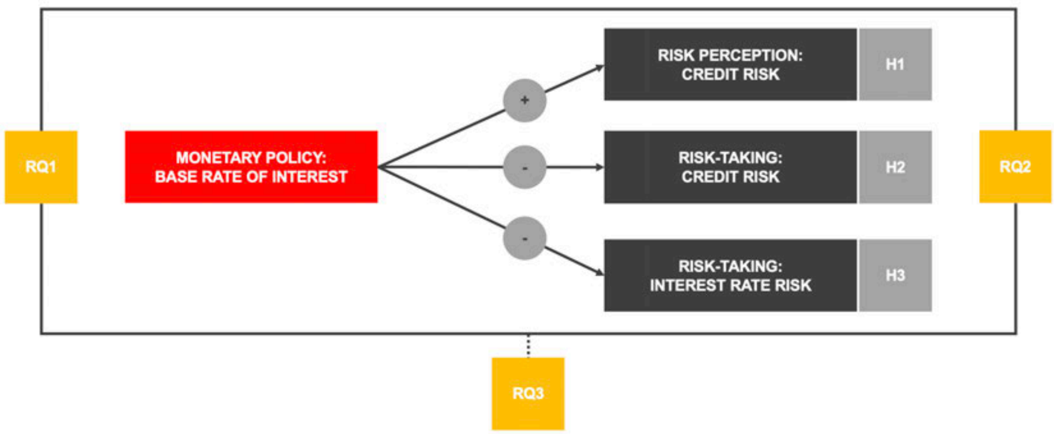


FIGURE 6.2:
HYPOTHESES

Source: author's illustration

6.3 RESEARCH FINDINGS

This research offers a unique theoretical representation of the risk channel in the TMP in the EMU that highlights the underlying mechanism. The risk channel reflects the relationship between changes in the monetary policy rate of interest and risk in the balance sheet of commercial banks incorporating the role of macroprudential bank regulation as well as macroeconomic and financial background conditions.

The risk channel of monetary transmission is pioneered by the idea of Borio and Zhu (2008, 2012) and notable empirical contributions of Adrian, Estrella and Shin (2009, 2010a, 2010b, 2011, 2014 and 2019). The risk channel is distinct from other channels of monetary transmission as it relies on the effects of monetary policy on the attitude of commercial banks towards risk, including risk perception, risk tolerance and risk-taking. In contrast, in the traditional, expectations driven interest rate channel, monetary policy is transmitted as increases in short term interest rates lead to increases in longer term interest rates, which ultimately affect real activity through investment decisions. The credit channel theories of monetary policy highlight the demand side effects on the balance sheet of lenders. One credit channel theory explains monetary transmission based on reserve holdings (Bernanke & Blinder, 1992). The balance sheet channel or broad credit channel of monetary policy builds up on the net worth and creditworthiness of borrowers with monetary policy being transmitted through its effects on the balance sheet of borrowers (Bernanke & Gertler, 1995). The bank lending channel or narrow credit channel represents the impact of monetary policy on the balance sheet of lenders through the external finance premium that affects the access of banks to loanable funds and hence the supply of loans at the credit market (Bernanke & Blinder, 1988). Hence, these theories are related but neglect the role of risk and its tight interrelation with liquidity, as well as the role of the regulatory capital wedge.

The theoretical representation of the risk channel addresses this gap by highlighting the balance sheet composition of lenders with respect to liquidity, procyclical measures of risk and the regulatory capital wedge. In this risk channel, monetary policy is transmitted though the effect on risk perception and tolerance of commercial banks. Figure 6.3 illustrates the underlying mechanism for the scenario of monetary expansion. In contrast, monetary contraction works just in the opposite direction, but with potentially asymmetric effects.

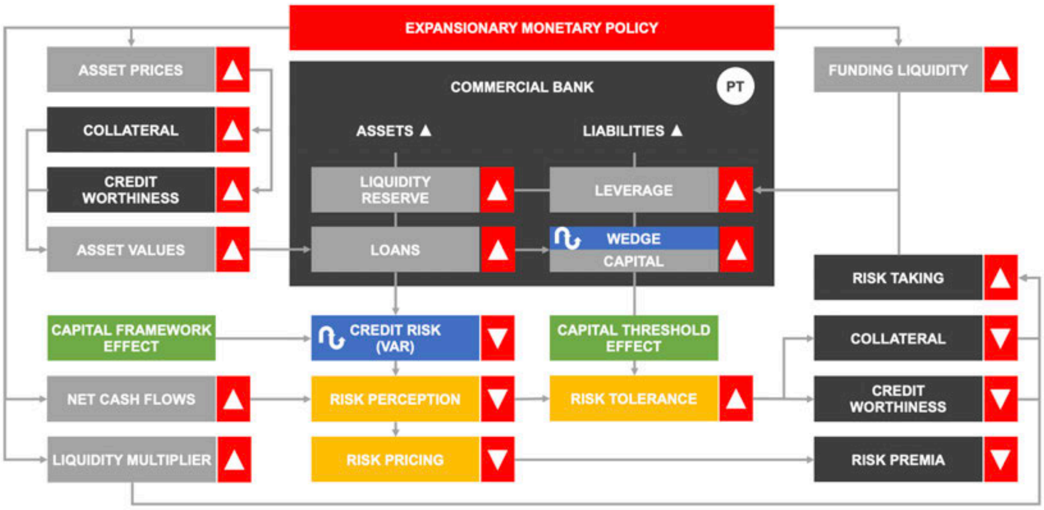


FIGURE 6.3:
THE RISK CHANNEL OF MONETARY POLICY

Source: author's illustration

The corresponding transmission scheme that highlights the main stages of the expansionary monetary policy through the risk channel can be expressed as follows:

$$\begin{aligned} &MPR_{ECB}\downarrow \\ &\Rightarrow LIQ_{CB}\uparrow\Rightarrow A\uparrow\Rightarrow CW_B\ \&\ CV_B\uparrow\Rightarrow L_D\uparrow\Rightarrow RPER_{CB}\downarrow\Rightarrow RPRM_{CB}\downarrow \\ &\Rightarrow CAP_{CB}\uparrow\Rightarrow RCW_{CB}\uparrow\Rightarrow RTOL_{CB}\uparrow \\ &\Rightarrow L_S\uparrow\Rightarrow SCW_{CB}\ \&\ CR_{CB}\downarrow\Rightarrow RTAK_{CB}\uparrow \end{aligned} \tag{6.1}$$

In short, a decrease in the monetary policy rate of interest by the central bank (MPR_{ECB}) lifts constraints on funding liquidity for commercial banks (LIQ_{CB}) and borrowers. In balance sheets of firms and households, the fall in interest expenses along with rising in asset values (A), raises net cash flows and net worth. This implies an increase in the creditworthiness and collateral values of borrowers (CW_B & CV_B) and hence in creditworthy demand for loans (L_D). Depending on the regulatory capital framework effect, the fall in procyclical measures of risk along with the ease in funding liquidity diminish risk perception of commercial banks ($RPER_{CB}$), which is reflected in risk pricing by a fall in risk premia ($RPRM_{CB}$) in the supply of new loans. In the balance sheet of commercial banks, the capital position (CAP_{CB}) and hence the risk bearing capacity grows. The simultaneous decline in the regulatory capital threshold causes the regulatory capital wedge (RCW_{CB}) to increase, which weakens the regulatory capital threshold effect and incentivises commercial banks to increase risk tolerance ($RTOL_{CB}$). If so, the further extension of loan supply (L_S) is accompanied by an increase in risk-taking of commercial banks ($RTAK_{CB}$).

The strength of the risk channel depends crucially on financial background conditions including liquidity and capital in the balance sheet of commercial banks, as well as on macroeconomic background conditions, that is the broader dynamics at the aggregate level with respect to interest rates and asset prices.

Liquidity functions as a multiplier or accelerator of the risk-channel mechanism because liquidity and risk-taking are closely interrelated and can potentially reinforce each other (Adrian & Shin, 2009). Lower perceptions of risk and higher risk tolerance weaken external funding and transferability constraints. In tun, weaker liquidity constraints promote risk-taking. Conversely, as perceptions of risk increase, risk tolerance of commercial banks fades and overall liquidity conditions tighten, with the aggravation of funding liquidity and market liquidity mutually reinforcing each other. The risk channel of monetary policy is stronger under extreme liquidity conditions, that is either abundant liquidity or extraordinary tight liquidity conditions.

The sensitivity of commercial banks to changes in the monetary policy rate of interest should vary with the size of capital due to the option like nature of the regulatory capital threshold effect (Borio & Zhu, 2012). A balance sheet with low capital and a high amount of risk-weighted assets implies a close to zero capital wedge. In this case, a commercial bank is exposed to a strong capital threshold effect, implying a small monetary contraction would exhibit a great impact on the bank’s behaviour that corresponds to radical deleverage. The risk channel of monetary policy is stronger under weak capital conditions, that is a small regulatory capital wedge.

Interest rates directly affect the strength of the risk channel, not at least because the regulatory capital threshold is sensitive to macroeconomic conditions. One reason is the impact of interest rates on valuations, incomes and cashflows in the balance sheet of commercial banks (Adrian & Shin, 2010a). For example, a long period of extraordinary low interest rates along with inflated prices in particular asset classes and extraordinary low measures of risk, possibly even underestimated risk, provides perfect conditions for the operation of the risk channel. Another reason is the close relation between market rates and target rates of return (Adrian, Estrella & Shin, 2019). Reductions in interest rates interact with sticky rates of return, the search for yield effect increases the risk tolerance of commercial banks, which aim to reach their profit targets (Rajan, 2005). Since very low nominal rates have a negative impact on profits, a prolonged period of close to zero nominal rates can amplify the impact of the risk channel. The risk channel is stronger under extreme macroeconomic conditions, such as very low nominal interest rates over a long period of time.

Central bank behaviour affects the strength of the risk channel, as well: A repetitive bail out of commercial banks by the central bank can give rise to expectations of commercial banks that diminish the perception of liquidity risk due to the moral hazard effect (Diamond & Rajan, 2009). The risk channel is stronger under widespread expectations of commercial banks on a bailout by the central bank.

The regulatory framework of macroprudential bank regulation affects the risk channel through requirements on capital, leverage and liquidity as well as the standards on methods of risk measurement and management (BCBS, 2022). The indirect and more general effect arises from the capital framework effect, that depends on the degree of integration of the standards of the regulatory framework on risk measurement and risk management by commercial banks into their operative practice (Borio & Zhu, 2012). A stronger capital framework effect implies a stronger influence of macroprudential bank regulation on the behaviour of commercial banks including decisions on the composition of the balance sheet, risk management and not at least the perception of risk. The direct effect arises from the capital threshold effect through the costs related to the violence of the threshold (Borio & Zhu, 2012). Since macroprudential bank regulation restricts balance sheet decisions of a bank, it is not capital alone, but also the regulatory capital wedge, that changes the scope for risk tolerance. Hence, macroprudential bank regulation affects the sensitivity of commercial banks towards changes in the monetary policy rate of interest: A stronger capital framework or threshold effect corresponds to a higher sensitivity.

The empirical analysis in this study builds up on a regression analysis on data of German commercial banks for the time period between 2002 and 2019. The economic models are derived from the economic model implied by the theoretical representation of the risk channel in monetary transmission. The economic model indicates that (1) risk perception ($RPER$) depends positively on the monetary policy rate of interest (MPR) and the method of risk measurement (MRM) and (2) risk-taking ($RTAK$) depends negatively on the monetary policy rate of interest (MPR) and the method of risk measurement (MRM) and positively on the profit target (MPR):

$$\begin{aligned} RPER &= f(+MPR, +MRM) \\ RTAK &= f(-MPR, -MRM, +PTAR) \end{aligned} \tag{6.2}$$

The regression analysis is focused on 3 hypotheses on the causal relationship between the monetary policy rate of interest (MPR) and risk perception ($RPER$) or risk-taking ($RTAK$) of commercial banks, respectively.

H1:	There is a positive relationship between the central bank's monetary policy rate of interest and the perception of credit risk in the balance sheet of commercial banks (ceteris paribus). $RPER_{CRR} = f(+MPR)$

H2:	There is a negative relationship between the central bank's monetary policy rate of interest and risk-taking in terms of credit risk in the balance sheet of commercial banks (ceteris paribus). $RTAK_{CRR} = f(-MPR)$

H3:	There is a negative relationship between the central bank's monetary policy rate of interest and risk-taking in terms of interest rate risk in the balance sheet of commercial banks (ceteris paribus). $RTAK_{IRR} = f(-MPR)$

The regression results provide strong evidence in support of the theoretical propositions on the nature of the risk channel mechanism:

- Low ECB interest rates on main refinancing operations exhibit a statistically significant, positive effect on credit risk perception of the German commercial IRBA banks.
- Low ECB interest rates on main refinancing operations display a statistically significant, negative impact on credit risk-taking in the balance sheet of German commercial banks.
- The ECB interest rate on main refinancing operations has a statistically significant, negative effect on interest rate risk-taking in the balance sheet of German commercial banks.

Furthermore, the empirical evidence of Germany in this research points to nonlinearities in the effect of the ECB interest rate on main refinancing operations on credit risk perception and credit risk-taking, which is consistent with the findings of Chmielewski, Lyziak and Stanislawska (2020). That means, the direction of the effect depends on the initial level of the monetary policy rate of interest. In line with the theory, the effect is stronger for low levels of the monetary policy rate of interest. It is concluded that the data of German commercial banks empirically validates the theoretical representation of the risk channel in the TMMP in the EMU. The findings of this research are in line with other empirical studies on other countries such as Bolivia, the Euro area and the USA, in that they point to the existence of the risk channel in the TMMP.

6.4 RESEARCH IMPLICATIONS AND RECOMMENDATIONS

The key finding of the theoretical representation of the risk channel that is supported by the empirical results of this research is that monetary policy affects the risk-taking of commercial banks. More precisely, this research points to a negative relationship between the monetary policy rate of interest and the risk-taking of commercial banks: $RTAK = f(-MPR)$. This subchapter highlights the implications and recommendations that follow from this finding for the decision makers of monetary policy for the EMU.

6.4.1 IMPLICATIONS

The implications of the findings on the risk channel in monetary transmission in the EMU are relevant to the decision makers of monetary policy in the EMU and correspond to research question 3.

RQ3: What are the implications of the risk channel for the decision makers of monetary policy for the EMU?

The risk channel is one of various channels in the TMMP. It reflects the link between monetary policy and risk-taking of commercial banks. The risk channel is non-malignant as long as risk assessments are accurate and financial stability is given, which is the case in most of the times. However, the theoretical representation of the risk channel in the transmission mechanism of monetary policy derived in this research demonstrates how, under certain macroeconomic and financial background conditions, an unnoticed pile up of risk in the financial sector can occur under the illusion of a seemingly flourishing economy and lead to a “low probability – high cost” tail event that results in cumulative, excessive risk-taking of commercial banks, financial instability and finally damage to the real economy. This implication arises from the findings on the underlying mechanism of the risk channel in the TMMP: the positive relationship between the MPR and risk perception, the negative relationship between the MPR and risk-taking of commercial banks, the self-reinforcing dynamics between liquidity and risk-taking as well as the impact of macroprudential bank regulation.

The failure of the central bank to account for a pile up of risk in the financial system and to assess policy measures in the light of the risk channel mechanism can occasionally be associated with undesired outcomes for inflation, the financial system and finally the real economy. The theoretical representation of the risk channel implies that under certain macroeconomic and financial background conditions, such as long lasting low interest rates and abundant liquidity, high risk-taking of commercial banks can turn into extremely excessive risk-taking, without the institutional setting deploying sufficient resistance. Cumulatively, extremely excessive risk-taking can lead to overleveraged balance sheets of commercial banks and financial instability, that at some point unwinds due to contagion effects in the banking system. As risks materialise and unexpected losses occur in the balance sheet of several commercial banks, such "low probability – high cost" tail events can result in output disturbances as well as disinflation or even deflation in the form of a boom-and-bust cycle. This reflects the fragility of the financial sector and its tight interrelation with the real economy. Without accounting for risk-taking of commercial banks, monetary policy may unknowingly contribute to or fail to offset risk-related fluctuations in the business cycle. The message is not that monetary policy is the source of excessive risk-taking in the financial sector. However, under certain conditions, in which risk is underestimated and individual incentives counteract desirable outcomes in the aggregate, the stabilising forces of the economy may not unfold sufficient persistence. As extremely excessive risk-taking evolves, the failure of monetary policy to adjust might exclude a potential defence of the dynamics.

The literature review shows that the development of the Basel framework points to an increasing relevance of macroprudential bank regulation for the transmission of monetary policy, which arises mainly from the capital framework effect. As the regulatory framework tends to promote risk assessment at longer time horizons, it leads commercial banks to greater prudence, which may weaken the impact of monetary policy on aggregate expenditures. The promotion of through-the-cycle rather than point-in-time parameters, such as conservative loss given default estimates or statistical loan provisioning could make commercial banks less sensitive to changes in the monetary policy rate of interest. The capital threshold effect contributes to the well-known asymmetry between contractionary and expansionary measures of monetary policy. In times of economic contraction, in which the regulatory capital wedge of commercial banks tends to be close to the threshold, a small adjustment in the monetary policy rate can unfold an outright impact on the behaviour of commercial banks in the form of deleverage. In contrast, prolonged times of economic expansion tend to increase the regulatory capital wedge of commercial banks, which may or may not respond with a rise in risk-taking and loan extension.

6.4.2 RECOMMENDATIONS

The recommendations that follow from this research are relevant to the decision makers of monetary policy in the EMU as well. The key message is that monetary policy should account for risk-taking of commercial banks in order to prevent unwanted outcomes with respect to the primary inflation target, the secondary real economy targets such as output and employment, as well as the general aim for stability of the banking system. That means the monetary reaction function should account for risk-taking of commercial banks because this would promote the stability of the financial system by affecting the balance sheet of commercial banks. The reason is that the risk channel mechanism explained by the theoretical representation points to a potential trade-off between monetary policy objectives, that is inflation and output on the one hand, and its effect on risk-taking of the bank sector on the other hand. Furthermore, the decision makers of monetary policy should anticipate the impact of macroprudential bank regulation on the transmission of monetary policy through the changes in the attitude of banks towards risk.

In an expansionary monetary policy regime with abundant funding liquidity, rising regulatory capital buffers, declining perceptions of risk and highly leveraged positions in commercial bank’s balance sheets, a further decrease in the monetary policy rate of interest would promote the inflation target but might also fuel even more risk-taking of commercial banks so that the financial stability is threatened. Similarly, in a contractionary monetary policy regime where commercial banks face shortages in funding liquidity, declining regulatory capital buffers, and rising perceptions of risk, only a small increase in the monetary policy rate of interest could trigger a dangerous downward spiral of deleverage in which risks cumulatively materialise and liquidity diminishes. In both scenarios, the aim of financial stability should be considered against the targets on inflation and output, so that decision makers of monetary policy might rule against further expansion or contraction of monetary policy in order to promote the stability of the banking system. If the risk channel mechanism is not endogenized in the monetary reaction function, the central bank might fail to recognise a build-up of risk in the financial system.

6.5 RESEARCH CONTRIBUTIONS

The contributions of this research include the contribution to theory and knowledge, the contribution to research methodology and the contribution to policy and practice, which are outlined in what follows.

6.5.1 CONTRIBUTION TO THEORY AND KNOWLEDGE

This research extends the economic theory by offering a unique theoretical representation of the risk channel in the TMMP for the European Monetary Union. To the knowledge of the author, it is the first theory that provides an in-depth explanation of the underlying mechanism of the risk channel by highlighting the role of macroprudential regulation as well as macroeconomic and financial background conditions.

The theoretical representation of the risk channel of monetary policy transmission in this research integrates (1) economic theory with respect to the effect of monetary policy on asset values, cash flows and profits, (2) finance theory with respect to the impact on risk measurement on risk perception and risk pricing as well as the link between the balance sheet composition toward risk tolerance and risk-taking of commercial banks. Moreover, it incorporates (3) the institutional framework of macroprudential bank regulation, which affects the risk channel through the capital framework effect that arises mainly from the requirements on methods of risk measurement as well as the broader regulations on risk management, and the capital framework effect that arises from the regulatory capital buffer with an option-like nature. This link contributes the insight that the development of the institutional framework of macroprudential bank regulation has an impact on the sensitivity of commercial banks towards monetary policy measures. Finally, the theoretical representation highlights (4) the tight interrelation between liquidity and risk-taking, which bears a self-reinforcing dynamic that adds to the strength of the risk channel as a liquidity multiplier.

6.5.2 CONTRIBUTION TO RESEARCH METHODOLOGY

This research applies an innovative empirical approach to the risk channel mechanism with respect to the identification of risk and the econometric model. The previous empirical studies on the risk channel predominantly capture only credit risk-taking with linear effects, which are often restricted to the banks' business line of loans to firms and measured by the volume, the duration and the rating of loans in the balance sheet of commercial banks. This approach neglects the distinction between risk perception risk-taking, excludes interest rate risk and does not account for the nonlinear nature of the risk channel. In contrast, the current research addresses these weaknesses through an advance in the identification strategy and the econometric model.

First, in contrast to other studies that solely focus on credit risk, which refers to potential losses from the deterioration in the credit standing or default of borrowers, this research is not limited to one type of risk. The finance theory indicates that interest rate risk is also relevant in the risk channel of monetary transmission. The reason lies in the maturity transformation of the lending business. Interest rate risk, which refers to a potential decline in net interest income due to movements of interest rates, increases as commercial banks engage in higher maturity transformation in order to counteract falling interest margins.

Second, the dependent variables included in the econometric models are unique. While other studies focus only on credit risk-taking, this research considers credit risk perception of commercial banks, as well. The incorporation of both risk perception and risk-taking of commercial banks is important for the explanation of the risk channel because the fundamental relationship that drives the mechanism relies on the positive effect of monetary policy on risk perception with negative downstream effects on risk-taking of commercial banks.

Third, this research applies a novel identification approach based on regulatory data. (1) Credit risk perception is proxied by regulatory Risk Weighted Assets (RWA) density of the loan portfolio calculated by German commercial IRBA banks based on internal ratings. In contrast to RWA measured by the regulatory standard approach, the IRBA measure is able to reflect changes in credit risk perception due to its reliance on market input, in particular the value of balance sheet assets. Moreover, the measure RWA density is superior to the measure RWA, because it also accounts for changes in loan assets. (2) Credit risk-taking is proxied by the share of risky loans based on the interest coverage ratio of firms in the portfolios of German commercial banks, which allows to capture the allocation of credit risk. (3) Interest rate risk-taking is proxied by the regulatory measure net asset duration (NAD) of the interest book of German commercial banks calculated based on the regulatory Basel interest rate coefficient.

Fourth, the regression analysis introduces new econometric models that unveil nonlinearities of the risk channel in monetary transmission. The nonlinear effects are captured by a quadratic term of the monetary policy rate of interest. Hence, the direction and strength of the effect on risk perception or risk-taking depends on the initial level of the monetary policy rate of interest. Most of the previous studies exclude nonlinearities by applying linear econometric models.

Overall, it can be concluded that the development of a comprehensive theoretical representation of the risk channel in monetary transmission in this research offers an in-depth explanation of the underlying mechanism. This in turn promotes the enhancements in the empirical approach to capture the mechanism of the risk channel. The methodological contributions entail improved tools to the decision makers of monetary policy in the EMU for the analysis of monetary policy measures and encourages the validity of empirical conclusions.

6.5.3 CONTRIBUTION TO POLICY AND PRACTICE

The insights of the risk channel in the TMMP for the EMU of this research contribute to a novel analytical base for decision makers of monetary policy. The empirical analysis presents first evidence on the risk channel of monetary transmission for Germany. Moreover, the data samples reflect the contemporary time period between 2002 and 2019. The empirical findings shed light on nonlinearities in the risk channel of monetary transmission, which were neglected in most of the studies so far. Hence, this research supports monetary institutions in understanding and anticipating the accumulation of risk in the financial sector for their decision-making processes, promoting them to unfold sufficient resistance to a potential instability of the financial system. This may help to prevent the type of boom-bust-cycle that has its origin in the unnoticed pile up of risk in the balance sheet of commercial banks.

This research on risk channel enhances the awareness of monetary policy makers that their decisions not only affect real variables (output, employment) and nominal variables (prices), but also the risk-taking of commercial banks. It is a call for particular cautiousness of monetary policy makers as certain macroeconomic and financial background conditions occur: Under very low nominal interest rates over a long period of time, extremely tight or abundant liquidity and weak bank capital even a small change in the monetary policy rate of interest can have an outsized impact on the risk-taking of commercial banks that may lead to unintentional disturbances of the financial and real economy. The findings emphasise the crucial role of liquidity, which operates as an accelerator in the transmission mechanism. Hence, monetary policy makers should anticipate in their decisions that liquidity and risk-taking tend to reinforce each other.

Furthermore, the insights prepare monetary policy makers that commercial banks prospectively become less sensitive to changes in the monetary policy rate of interest in the direction of monetary expansion. The magnitude depends on the extent to which macroprudential bank regulation proceeds in promoting the risk sensitivity of commercial banks and in constraining their risk-taking.

6.6 RESEARCH LIMITATIONS

Some notes and limitations concerning the empirical analysis are outlined in these sections. The use of secondary data from the German Central Bank promotes the objectivity of the Post-Positivist research but it is also associated to some imperfections.

First, it is to note that the methodological approach is aligned to the research aim of explaining the risk channel, that is the effect of changes in the monetary policy rate of interest on risk in the portfolio of commercial banks. Accordingly, the regression models are specified with the objective to test the hypotheses derived from the theoretical representation of the risk channel in monetary transmission in contrast to that of making predictions. The applied econometric models are restricted to the variables that represent cause (monetary policy rate of interest) and effect (credit risk perception, credit risk-taking and interest rate risk-taking) in the corresponding economic model of the risk channel. That means the individual impact of each of the numerous multicollinear factors that operate within the complex mechanism, such as asset values, capital, liquidity, and the profit target is not investigated in the empirical analysis. This relates to the extension of this research as recommended in chapter 6.4.2 and requires another methodological approach, such as a structural equation model that could be estimated with SPSS Amos. The reason for omitting the multicollinear factors within the mechanism is not only driven by the research aim and objectives but also by limitations in data availability. The specified regression models in this research have a narrower focus on the objective of empirical hypothesis testing of causal relationships rather than forecasting or exploring the isolated contribution of each factor. However, the omission of variables is considered in the interpretation of the empirical results.

Second, the three sets of data are restricted to German commercial banks. These banks are representative for the research population of commercial banks in the EMU, but they are not perfectly identical due to methodological reasons: The data sample on credit risk perception is restricted to German commercial IRBA banks, namely those German banks applying the regulatory internal ratings-based approach. The methodological reason is that their measures of RWA are able to reflect changes in risk perception due to their reliance on market input. The remaining fraction of German commercial banks that applies the alternative regulatory standard approach is excluded from that data sample for credit risk perception, because the measures on RWA rely on fixed risk weights and external ratings calculated as through the cycle estimates and not able to capture changes in risk perception arising from business cycle movements.

Third, the time period of the three sets of data is not identical: There are small deviations of the time period under consideration of the research, that is the time period between 2002 and 2019. Some data sets fall below that period by some years, which relates to the gradual development of the of the risk measures in the regulatory framework and the process of data collection by the German Central Bank. Furthermore, the time period under consideration is dominated by low monetary policy rates of interest, since the ECB largely applied an expansionary monetary policy regime in the EMU with the ECB MRO even reaching the zero lower bound between 2016 to 2019. A more balanced mix level of ECB interest rates is desirable for the purpose of the regression analysis.

However, altogether it can be stated that these imperfections in data samples are rather marginal in their magnitudes and do not affect the validity of the empirical results.

6.7 SUGGESTIONS FOR FURTHER RESEARCH

The study of the risk channel in monetary transmission points to a complex mechanism that involves a path over many variables and different stages. Hence, it provides many entry points for further empirical research.

As research follow-up, it is recommended to extend the regression analysis by an advancement of the data basis and of the econometric model. An extension of the data basis may include (1) the coverage of more banks, at best all commercial banks within the EMU, (2) additional independent variables such as the profit target and the regulatory capital wedge based on the risk bearing capacity analysis of commercial banks and (3) a longer time horizon that captures more variation in the monetary policy rate. A development of the econometric model could depend in the integration of the different stages of the risk channel in one dynamic regression model that captures the lag structure and builds up on a broader set of independent variables. Hence, a Structural Equation Model (SEM) may be helpful.

From a scientific point of view, the current changes in macroeconomic conditions in Germany that started in 2022 are predestined for an extension of the research on the underlying mechanism: High inflation and economic deceleration can potentially trigger a spiral of risk materialisation and deleverage, which threatens the stability of the financial sector. This creates an environment in which the risk channel deserves particular consideration by decision makers of monetary policy. In its press release of 9th June 2022, the ECB announced the first increase of the ECB interest rate on main refinancing operations after more than half a decade of a zero-interest regime. The intention of the monetary policy makers is to counteract rising inflation. The empirical analysis of the effects of these contractionary monetary policy measures on risk perception and risk-taking under the stressed macroeconomic background conditions offers much potential for a validation and extension of these findings on the risk channel mechanism.

Another suggestion for further research is to investigate the reaction of monetary policy makers to the outcome of this research with a focus on the extend to that risk-taking of commercial banks is considered in their decision on changes in the monetary policy rate of interest.

6.8 CHAPTER CONCLUSION

The literature review on the TMMP unveils a research gap in the explicit focus on (1) the interaction between monetary policy and risk-taking, (2) the interaction of bank regulation and risk-taking, and (3) the interrelation of accounting and risk-taking. Research seems not jet focused enough on the risk channel: in the current generation of theoretical monetary policy models, the element of risk is neglected or treated as exogenous. A comprehensive theory of the underlying mechanism that drives monetary transmission through the risk channel is absent so far. However, empirical investigations of the link between monetary policy and risk-taking of banks strongly point to the existence of a risk channel. This study narrows this research gap by explaining the underlying mechanism of the risk channel in the transmission of monetary policy for the EMU based on data of German commercial banks. Although the contribution to knowledge has been detailed in this chapter, the key contribution is highlighted in this conclusion.

The risk channel in monetary transmission reflects the relationship between changes in the monetary policy rate of interest and the amount of risk in the balance sheet of commercial banks by taking a consideration of the role of macroprudential bank regulation as well as macroeconomic and financial background conditions. Through changes in the monetary policy rate of interest, the central bank affects liquidity, risk perception and risk-taking of commercial banks. In general, macroprudential bank regulation affects the risk channel through (1) the capital framework effect, that is the effect of standards on methods of risk measurement on risk perception, and through (2) the capital wedge effect, that is the effect of capital regulation on risk tolerance. Liquidity takes a crucial role in the risk channel mechanism as it functions as an accelerator, with liquidity and risk-taking being tightly interrelated and potentially reinforcing each other.

The empirical evidence of this research reveals the existence and the mechanism of the risk channel: First, low ECB interest rates on main refinancing operations exhibit a statistically significant, positive effect on credit risk perception of the German commercial IRBA banks. Second, low ECB interest rates on main refinancing operations display a statistically significant, negative impact on credit risk-taking of German commercial banks. And third, the ECB interest rate on main refinancing operations has a statistically significant, negative effect on interest rate risk-taking of German commercial banks.

The transmission mechanism of the risk channel demonstrates how, under certain macroeconomic and financial background conditions, an unnoticed pile up of risk in the financial sector can occur under the illusion of a seemingly flourishing economy and lead to a “low probability – high cost” tail event, that can result in cumulative, excessive risk-taking of commercial banks, financial instability and finally damage to the real economy. Without accounting for risk-taking of commercial banks, monetary policy may unknowingly contribute to, or fail to offset, risk-related boom-bust-cycles. Therefore, the central bank should endogenize the risk channel mechanism in its monetary reaction function and assess monetary policy measures in the light of the risk channel mechanism.

THE END

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VIII LIST OF ABBREVIATIONS

AT1	Additional Tier 1 capital
BaFin	Federal Financial Supervisory Authority ("Bundesanstalt für Finanzdienstleistungsaufsicht")
BBk	German Central Bank ("Deutsche Bundesbank")
BCBS	Basel Committee on Banking Supervision
CART	Credit allocation risk-taking
CC	Credit Cooperatives
CCF	Credit Conversion Factor
CET1	Common Equity Tier 1 capital
CIR	Cost-Income-Ratio
CRD	Capital Requirements Directive
CRM	Credit risk mitigation
CRP	Credit risk perception
CRR	Capital Requirements Regulation
CVA	Credit Value Adjustment
EAD	Exposure at Default
EBA	European Banking Authority
EBITDA	Earnings before interest, taxation, depreciation and amortisation
ECB	European Central Bank
ECB MRO	European Central Bank interest rate on main refinancing operations
EDIS	European Deposit Insurance Scheme
EFP	External Finance Premium

EL	Expected Loss
EMU	European Monetary Union
ESCB	European System of Central Banks
ESFS	European System of Financial Supervisors
ETP	Loans to enterprises
EU	European Union
FBC	Financial background conditions
FRTB	Fundamental Review of the Trading Book
G-SII	Global Systemically Important Institution
GDP	Gross Domestic Product
HAC	Heteroscedasticity and autocorrelation
HGB	German Commercial Code ("Handelsgesetzbuch")
HQLA	High Quality Liquid Assets
IRBA	Internal Ratings-Based Approach
IRRT	Interest rate risk taking
IS/LM	Investment Saving / Liquidity Money
IST	Implementing Technical Standards
KWG	Banking Act (“Kreditwesengesetz”)
LCR	Liquidity Coverage Ratio
LGD	Loss Given Default
LR	Leverage Ratio
LSI	Less Significant Institutions
MBC	Macroeconomic background conditions
MFI	Monetary Financial Institution
MPR	Monetary policy rate of interest / base rate of interest

MRM	Method of risk measurement
NAD	Net Asset Duration
NSFR	Net Stable Funding Ratio
O-SII	Other Systemically Important Institution
OLS	Ordinary Least Squares
PD	Probability of Default
PK	Post-Keynesian
PTAR	Profit target of commercial banks
RCP	Risk Coverage Potential
RechKredV	Financial Institutions Accounting Regulation ("Kreditinstituts-Rechnungslegungsverordnung")
RLS	Risky Loan Share
RMEA	Risk measures in the balance sheet of commercial banks
RO	Research objective
RoE	Return on Equity
RPER	Risk perception of commercial banks
RQ	Research question
RTAK	Risk-taking of commercial banks
RTL	Retail loans
RTOL	Risk tolerance of commercial banks
RWA	Risk-Weighted Assets
RWAD	Risk-Weighted Assets Density
SA	Standardised Approach
SB	Savings Banks
SI	Significant Institutions
SMCB	Small and Medium-sized Commercial Banks
SP	Sampling properties

SREP	Supervisory Review and Evaluation Process
SRM	Single Resolution Mechanism
SSM	Single Supervisory Mechanism
T2	Tier 2 capital
TFEU	Treaty on the Functioning of the European Union
TMMP	Transmission mechanism of monetary policy
UL	Unexpected Loss
USA	United States of America
VAR	Value at Risk