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The impact of QE on sovereign bond liquidity

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ABSTRACT:
Previous literature has found different results regarding the effect of quantitative easing on sovereign bond liquidity. QE was introduced after the 2008 financial crisis to revive the economy and financial markets in a deflating economy, but growing literature on the topic has raised concerns about QE's harmful consequences on the bond market. The ECB has increased its balance sheet rapidly even in economically stable times, reducing the bond stock in the market. Empirical evidence suggest that QE can both increase and decrease bond liquidity, depending on which of the transmission channels of QE – scarcity or spotlight effect – is considered.

This thesis investigates the relationship between Eurozone 10- and 30-year government bond bid-ask spreads and the ECB's asset purchases during the PSPP programme and Covid-19 period. The thesis' main goal is to investigate whether the net asset purchases of public assets increase bond liquidity via the spotlight effect and whether the cumulative net asset purchases reduce bond liquidity via the scarcity effect. The study is motivated by the importance of government bond liquidity, which must be maintained in order for governments to maintain effective capital allocation and lower borrowing costs. This thesis contributes to the existing literature by offering the first regression results for the Covid-19 period that have not previously been investigated in terms of the influence of QE on government bond liquidity in Europe.

To address the thesis' four hypotheses, linear and panel regression models are used. The thesis employs monthly asset purchase and bid-ask spread data from 3/2015 to 10/2022 and 6/2020 to 10/2022. A *Purchase* variable is introduced to explain the net asset purchases, and a *Holding* variable is introduced to explain the ECB's balance sheet expansion. The liquidity is measured using 10- and 30-year maturity bid-ask spreads. The PSPP programme and the Covid-19 period, which includes both PSPP and PEPP purchases, are evaluated separately for each of the nine selected countries, as are the two bond maturities. To examine the differences between the periods and maturities, panel regression analysis is used. Control variables are also introduced to the models to verify the robustness of the results.

This thesis gives valid results for the pandemic period that contradict previous research. Different outcomes are obtained for the PSPP programme and the Covid-19 phase. According to the regression results, the spotlight effect of QE occurs in many European bond markets throughout the Covid-19 period, enhancing liquidity, but the scarcity effect does not appear. In turn, the PSPP programme, which ran from 2015 to 2022, primarily decreases liquidity in the bond markets via the spotlight and scarcity effects of QE. One probable explanation for the disparity between Covid-19 and PSPP findings is the severe impact of Covid-19 on the financial market, which stretched from the stock market to the bond market. Bond liquidity has already been damaged by Covid-19, which explains why QE has less of an impact during this period.

KEYWORDS: Bond liquidity, Quantitative easing, Monetary policy, Scarcity and spotlight effect

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1 Introduction

Central banks have increased their asset side of the balance sheets at a fast pace since the financial crisis in 2007-2008. Bank of Japan invented quantitative easing (QE) in the early 2000s to defeat deflation in the country, after which other central banks – European Central Bank (ECB), Federal Reserve, and Bank of England – began to use QE during the financial crisis in 2008. The primary goal of QE was to stimulate the economy and combat deflation by raising money supply in the economy and encouraging lending through central bank purchases of financial assets. Since the financial crisis, growing literature has raised negative effects of QE on the bond market. Karadi and Nakov (2021, p. 1097) claim that excessive quantitative easing, which does not seek to integrate the economy after a crisis, is unnecessary. From the banks' point of view, in times other than a crisis, quantitative easing is ineffective because the restrictions on banks' balance sheet constraints loosen, and the risk of a credit crunch becomes low (Karadi & Nakov, 2021, p. 1097). Hence, QE interferes with lending when bank reserves are filled with central bank money. This puts pressure on banks to lend extra money efficiently, especially if demand for credit is weak. The challenge for the central bank itself is to maintain a balance in the growth of holdings and the preservation of market liquidity.

The asset purchases by central banks have helped lower risk premiums of government bonds if the market yields rise too much. This happens because higher demand for bonds as a result of QE drives up prices and reduces yields. However, the impact of quantitative easing on bond liquidity is still under discussion and the consequences are unclear. This is particularly influenced by two opposite effects of quantitative easing, demand and supply effects (i.e., spotlight and scarcity effects) which are proven to have different effects on liquidity (Ferdinandusse et al., 2020). The demand effect is a positive effect that promotes market liquidity through the action that bond sellers can sell large amounts of securities to the central bank and quickly exchange them for cash. The supply effect, on the other hand, is negative and has been proven by many studies (e.g., Ferdinandusse et al., 2020; Schlepper et al., 2017; Pelizzon et al., 2018; Kandrac & Schlusche; 2013, Grimaldi et al., 2021; Han & Seneviratne, 2018) to deteriorate bond

liquidity on the market. This observation is the outcome of the central bank expanding its balance sheet and limiting the number of government bond securities on the market, which has resulted in weaker trading.

1.1 Motivation

Bond liquidity matters from a variety of perspectives, but in general, a liquid bond market ensures better market conditions. Liquidity affects the financial stability by influencing market volatility and borrowing costs. When there is a high demand for bonds, liquid markets ensure that the government borrows at a lower cost. Greater liquidity ensures that there is sufficient demand for the bond, in which case purchasers bid up the price and the government can request a lower interest rate. A liquid bond market can also enhance monetary policy transmission, which means that it is easier for the central bank to conduct monetary policy in a more liquid market where bonds are used as a monetary policy tool. Mohanty (2002) states that, even in terms of the effectiveness of monetary policy, decreasing market depth is harmful. From investors point of view, investors benefit from a liquid bond market during difficult market conditions because they may quickly transfer their portfolios to less risky instruments. Bonds with more liquidity have been observed to attract more investors during a crisis than high grade bonds (Beber et al., 2009; Goyenko et al., 2011). However, it is very crucial, if not the most important to consider market efficiency when considering the relevance of market liquidity. Liquidity improves market efficiency, which is critical for efficient capital allocation, but it also ensures that market prices accurately reflect supply and demand for debt instruments. By analyzing bond liquidity and the factors that influence it, it is possible to gain a better understanding of which factors influence liquidity the most and which have the most negative effects on it.

Although one goal of the European Central Bank's quantitative easing is also to promote government bonds' liquidity, QE does not show a clear effect on the debt market, and studies have discovered detrimental consequences of QE on the financial market.

Previous research on the subject has generated contradictory findings, as QE can both increase and decrease bond liquidity, depending on whether the perspective - demand or supply influence - is considered. This thesis addresses this issue since the effects of quantitative easing on the debt market deserve more research. There is still a scarcity of literature on government bond liquidity and QE from a wider perspective that takes both central bank net asset purchases and cumulative net asset purchases into account. In addition, the liquidity of debt markets in the European region during periods of quantitative easing has also received little attention, even though the region is particularly noteworthy in this regard. Namely, many differences between countries such as financial sustainability, debt market and size of countries make the research area interesting.

It is critical to understand how quantitative easing may affect the liquidity of different government bond markets in Europe, as well as how the quantitative easing affects bond liquidity of different maturities. By studying the topic, researchers can learn how the central bank's policies are conveyed to the economy and what the policy's side effects are on different maturity bonds. Bonds with longer maturities are considered riskier since their cash flows are realized far in the future, resulting in a longer bond duration. Some investors do not want their portfolio's duration to be too long, so they avoid long bonds, which can reduce liquidity and raise transaction costs. Because maturity is likely to alter the outcomes, it is important to consider when analyzing the effect of QE on bond liquidity.

The European region is unique in that the differences between countries that are governed by the same central bank can have a significant impact on the effects of quantitative easing. The implications can be more severe in smaller nations with less trade and more trade frictions. Because bond market events are reflected in other asset classes, the size of the bond market is also an important factor in the liquidity's relevance (Mohanty, 2002).

1.2 Purpose of the thesis

The thesis seeks to determine how the ECB's asset purchase programmes affect the liquidity of the European debt market during the PSPP programme and Covid-19 pandemic period. The fundamental purpose of the thesis is to investigate the impact of quantitative easing on government bond liquidity. This thesis concentrates on two government bond maturities, 10- and 30-year bonds, in nine European countries. Previous research has revealed two opposing effects of QE on bond liquidity – the spotlight and scarcity effects – which this thesis attempts to study as well. The goal is to see if the net asset purchases of public assets increase bond liquidity via the spotlight effect and if cumulative net asset purchases of the public assets reduce bond liquidity via the scarcity impact. Four hypotheses are tested in order to answer the research question.

In this thesis, the dependent variable is liquidity, and its fluctuations are explained using ECB's monthly net asset purchases and balance sheet growth in terms of public assets. The research will be conducted in the period between 2015-2022, with a focus on the Eurozone government bonds. More specifically, the purpose is to focus on the ECB's PSPP and PEPP asset purchase programmes. The PSPP was implemented from 2015 to 2022, while the PEPP was adopted after the onset of the Covid-19 epidemic from March 2020 to 2022. Hence, the goal is to focus on two time periods: 2015-2022, when the PSPP programme was implemented, and the Covid-19 era 2020-2022, when both the PEPP and the PSPP programmes were implemented. First the thesis investigates the periods separately, but the purpose is to also compare the two time periods. This thesis complements the existing literature by showing how asset purchases have affected the liquidity of the debt markets during the Covid-19 period in Europe which has not been studied before. One of the purposes of QE as a monetary policy tool is to influence long-term interest rates, which is why this study focus on 10- and 30-year government bonds in the Euro area. The purpose of the study is to compare the effect of QE on bond liquidity between the 10- and 30-year maturity bonds. The thesis focuses on the core

countries of Europe, but also on the peripheral area, so that the research highlights possible differences between these different types of economies and debt markets.

The thesis expects to receive two types of results referring to previous literature. First, the thesis expects the net asset purchases of the European Central Bank to improve sovereign bond liquidity:

H_0: *Bond market liquidity is not affected by the net asset purchases of the central bank.*
H_1: *Bond market liquidity improves as a result of the net asset purchases of the central bank.*

The first hypothesis designates the demand effect of quantitative easing where the dependent variable of liquidity, Liq_t, is expected to be negatively related to the independent variable of the net purchases, $Purchases_t$. For the bid-ask spread variable, which in the regression means a higher value of Liq_t, indicates lower liquidity level, one unit increase in the purchases should decrease bid-ask spreads. Similarly, the scarcity effect of quantitative easing is expected to affect bond liquidity, but negatively. As a result, the thesis anticipates that the ECB's cumulative net asset purchases (ECB balance sheet holdings) will reduce sovereign bond liquidity, and that there will be a negative relationship between the liquidity variable and the independent variable of cumulative net purchases, $Holding_{t-1}$. As a result, the second hypothesis will be presented as the following:

H_0: *Bond market liquidity is not affected by the increase in the central bank holdings.*
H_2: *Bond market liquidity worsens as a result of the increase in the central bank holdings.*

Additionally, it is expected that the Covid-19 period shows more severe results since both asset purchase programmes were conducted during the Covid-19 period and so the number of purchases made by ECB during this period is much higher compared to the time before Covid-19. The size of the PEPP programme is approximately 60 % of the PSPP

programme (see summary statistics) which shows that the size of the PEPP programme is impressive. This would imply that the $Purchases_t$ variable would increase bond liquidity more during the Covid-19 program than during the PSPP programme, while $Holding_{t-1}$ would degrade bond liquidity more during the Covid-19 programme than during the PSPP programme. The third hypothesis is the following:

H_0: *The impact of QE on bond liquidity is not severer during Covid-19.*
H_3: *The impact of QE on bond liquidity is more severe during Covid-19.*

The purpose of the fourth hypothesis is to examine the differences between the 10- and 30-year government bond bid-ask spreads during the ECB's asset purchases. It is expected that QE would affect severer on 30-year government bond bid-ask spreads compared to 10-year bid-ask spreads. The rationale for this is that when the ECB begins to employ QE as a monetary policy tool, it prioritizes purchases on longer-term maturities with the goal of decreasing longer-term market interest rates, lowering the cost of borrowing. This benefits governments and corporations, but in the market, investors are less interested in investing in longer-term bonds, where the return on investment for a longer period of time has now fallen. Therefore, it has been assumed that the liquidity of 30-year bonds in the market will weaken in relation to 10-year bonds. The fourth hypothesis is the following:

H_0: *The impact of QE on bond liquidity is not severer for 30-year bonds compared to 10-year bonds.*
H_4: *The impact of QE on bond liquidity is more severe for 30-year bonds compared to 10-year bonds.*

The structure of the thesis is the following. The second chapter presents an overview of the European debt markets and highlights the major pillars and differences of the bond markets. The theoretical foundation of the topic is focused on Chapters 3 and 4, making it easier to understand the theory of bond pricing, the role of market liquidity, the history

of quantitative easing, and the importance of efficient markets to the topic. Following that, the prior study is examined, indicating the previously identified impacts of quantitative easing on bond liquidity as well as the breadth of the research display, which is mostly focused on certain states. Chapter 6 introduces the data and method used to examine the impact of ECB's QE on bond liquidity. Finally, the outcomes are described in Chapter 7.

2 Description of the European bond market

The European debt capital markets are massive, with a total market value of 12,2 trillion euros in May 2020 but still roughly half the market cap of the US debt market, which was valued $22,4 trillion in August 2020 (ICMA, 2023). However, because the European bond markets are made up of several countries, the supply of bonds in Europe is significantly greater than in the United States. For example, bonds are available for countries of various sizes, maturities, and credit ratings. Bond markets are important because their market capitalization and trading volumes are substantially larger than that of equities markets (Abad et al., 2010, p. 2851; Cheung et al., 2005, p. 7). Prior to the establishment of the European Union's Economic and Monetary Union (EMU), the European bond markets were separated into their own national markets (Pagano & Von Thadden, 2004, p. 532).

Since the start of EMU, primary and secondary bond markets have become more integrated in Europe (Pagano & Von Thadden, 2004, p. 531). Abad and others (2010, p. 2851) states that debt market integration is an essential research topic because it can alter the outcome of debt deficit financing costs, long-term interest rate projections, bond investment portfolio diversification, and, most importantly, the independence of monetary policymaking. The European debt market differs in that the member countries have abandoned their independent monetary policy, which is now regulated by a single central bank, the ECB. Due to the lack of self-governing monetary policy in EMU countries, information on credit worthiness is highly relevant (Christiansen, 2014, p. 192).

Bond market trading varies from stock market trading in that each bond issuer offers a selection of tradable securities (Darbha & Dufour, 2013, p. 39). Also, the number of trades and the volume exchanged differ between the two instrument types. There are fewer trades but bigger trading volumes in the fixed-income market than in the stock market (Darbha & Dufour, 2013, p. 39). However, both, the bond and equity markets are classified as primary and secondary (Darbha & Dufour, 2013, p. 40). According to Darbha and Dufour (2013, p. 40), governments issue new treasury bonds in the primary market

and assign International Securities Identification Number, maturity year, and coupon rate to these instruments, or they auction additional batches to existing bonds that already have the instrument details. So, if a government wishes to raise more capital, one possibility is to increase the size of the bonds already issued. After the bond is issued, it begins trading in the secondary markets.

In the primary market, Eurozone governments decide their government financing and thereby the amount of debt securities they offer to the market (Cheung et al., 2005, p. 9). As a result, the primary market act as the key liquidity provider for debt securities in Europe, while the ECB serves as the dominant monetary liquidity provider for treasury instruments in the money market (Cheung et al., 2005, p. 9). The countries' treasuries most typically issue 1-30 maturity bonds in the primary market, however there can be exceptions, such as the Austrian 100-year bond issued in September 2017. In Europe, Italy has been the largest bond market with most outstanding debt due to the country's large budget deficits (Cheung et al., 2005, p. 11). The bond market also extends to become one of the largest debt markets worldwide. MTS, a well-known electronic trading system for bonds, was built by Bank of Italy in 1988 to trade Italian bonds because the large market needed a trading system.

This thesis focuses on the secondary market liquidity of European bonds since the ECB purchases bonds from the market. The secondary market determines the environment in which the issued bond can be traded (Cheung et al., 2005, p. 9). The trading occurs most frequently in the over-the-counter (OTC) market, which lacks an official exchange, or in the Interdealer market, in which dealers trade instruments using electronic trading platforms. As an example, the large-scale asset purchases under the PSPP are made mostly in the OTC market (Ferdinandusse et al., 2020, p. 18). On the secondary market, market makers act as key liquidity providers when they are obliged to keep records of bid and ask levels on the market. The establishment of the EuroMTS in November 2003 for European secondary markets has enabled electronic trading services for the largest and most liquid government bonds (5- and 10-year maturities) to improve the match of

buyers and sellers in the Interdealer market (Pagano & Von Thadden, 2004, p. 541). According to Pagano and Von Thadden (2004, p. 542), liquidity for bonds other than benchmark bonds is found to be lower in the MTS platform. Poor liquidity in the secondary market may be caused by a lack of market depth, which is a lack of continuous bid and ask offers and interest in trading (Mohanty, 2002, p. 63; Grimaldi et al., 2021, p. 11). When liquidity worsens, central bank may have to act as a market maker to maintain steady price levels (Mohanty, 2002, p. 50). Especially, in small countries where the degree of investors and market participants is low, liquidity can be poor, whereas the secondary market liquidity in larger countries has developed to more cost-effective due to larger number of market players and investors (Mohanty, 2002, p. 50 & 63). As a result, it is worthwhile to investigate bond liquidity in various-sized countries where liquidity may vary and reveal sensitivity differences to central bank monetary policy.

While the European Central Bank buys public securities symmetrically across the Eurozone based on countries' gross domestic product, the differences between countries remain significant (Ferdinandusse et al., 2020, p. 18). The outstanding central government debt of Austria, Belgium, Finland, Greece, Ireland, and the Netherlands totaled approximately 1 370 trillion euros since the start of the ECB's PSPP in 2015 whereas the central government debt of France, Germany, Italy, and Spain was much larger, 6 250 trillion euros (Eurostat, 2023a). In 2021, the total outstanding debt for Austria, Belgium, Finland, Greece, Ireland, and the Netherlands reached 2 015 trillion euros, while France, Germany, Italy, and Spain owed in total 7950 trillion euros (Eurostat, 2023a). If the amounts were announced in terms of the general government debt or public debt, which is slightly different to central government debt, the outstanding public debt of Austria, Belgium, Finland, Greece, Ireland, and the Netherlands in 2021 was a bit higher, approximately 2090 trillion euros and for France, Germany, Italy, and Spain approximately 9 400 trillion euros (Eurostat, 2023b). The general government debt aims at public debt that is the nominal value of outstanding liabilities which are government’s currency and deposit liabilities, debt securities and loans (Eurostat, 2023c). As illustrated in Figure 1, the Eurozone countries have significantly disparate debt levels. Italy has risen

to the top of the list with highest debt when correspondingly, Estonia has very little debt, only 5,5 billion euros. France, Spain, and Germany are also large nations in Europe which can be seen from the figure that their debt amounts are significantly higher compared to the other countries. Hence, the rest of the countries on the figure have debts less than €500 billion.

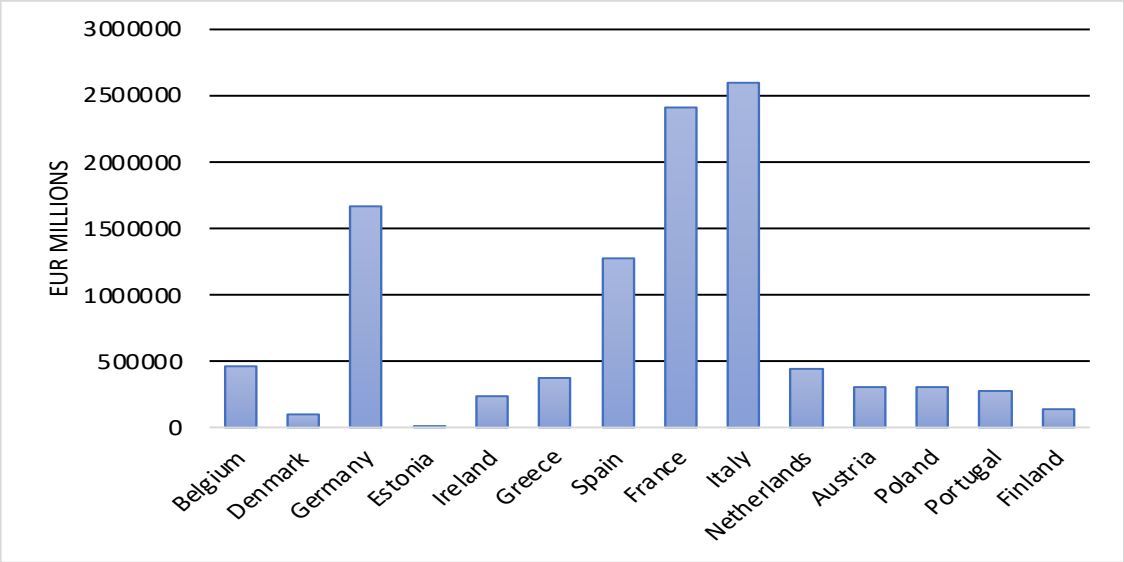


Figure 1. Central government debt 2021 (Eurostat, 2023a).

Government deficits have been increasing since the beginning of the ECB's PSPP programme, particularly during the Covid-19, as a result of increased expenses and decreased revenues (Eurostat, 2023e). Financing was mainly fixed with long-term bonds, which make up 3/4 of the outstanding amount of total liabilities in Europe (Eurostat, 2023e). Figure 2 depicts the general government deficits and surpluses between 2015 and 2021. The federal budget of Germany has shifted dramatically, going from a 30-billion-euro surplus in 2015 to a 135-billion-euro deficit in 2021. Fiscal deficits in France, Italy, Belgium, and Austria have also more than doubled in the same time period. Denmark is the only country that maintains a fiscal surplus. This explains the country's low debt levels as well. Estonia is in a similar scenario, with only a 750 million deficit, which explains the country's low public debt level.

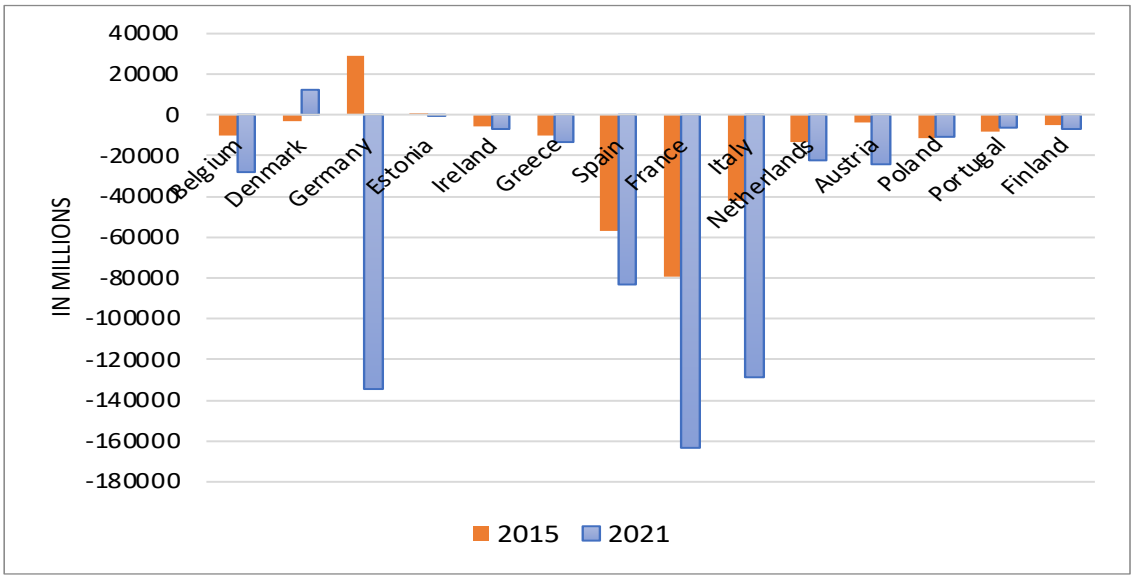


Figure 2. General government deficit/surplus (Eurostat, 2023d).

It is critical to also consider the debt-to-GDP ratio as a measure of government debt sustainability (Ferdinandusse et al., 2020, p. 18). The debt-to-GDP ratio compares a country's public debt to its total output. Although Greece's outstanding public debt in 2021 was only 353 trillion euros, compared to Germany, which owed 2 476 trillion euros of general government debt, Greece's debt-to-GDP ratio in 2021 was 193 %, compared to Germany's 69.3 % (Trading Economics, 2023a). There is great variability in the debt-to-GDP ratios in the Euro area (see Figure 3). Nations with debt-to-GDP ratios greater than 60 % in 2021 included at least Austria, Finland, and Germany, while countries with debt-to-GDP ratios greater than 100 % in 2021 included Belgium, France, Italy, Spain, and Portugal. Estonia, Poland, Ireland, and the Netherlands have managed to retain their debt-to-GDP ratio below 60 %, which is one of the criteria for membership in the EMU. Estonia had the lowest debt-to-GDP ratio, at 18.4 %. According to Trading Economics (2023b), only Austria, Germany and Netherlands own a triple A credit rating from the previously discussed European countries. Finnish government bonds own the second-best rating, AA+. Belgium, France, Ireland, and Spain have AA to A- ratings, whereas Greece and Italy have showed lower ability to repay their loans, with BB+/BBB ratings.

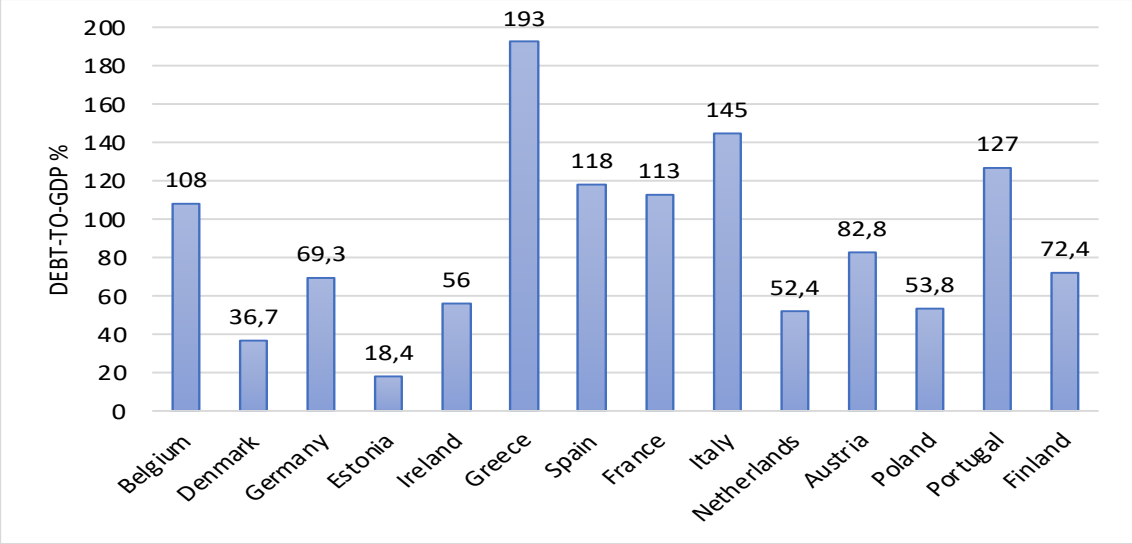


Figure 3. Debt-to-GDP 2021 (Trading Economics, 2023a).

According to Pagano and Von Thadden (2004, p. 531), the beginning of EMU has highlighted significant benefits in the primary and secondary markets, where investors and bond issuers can profit from increased competition and liquidity. The unified electronic trading system, of which the most used is the MTS platform, has had a significant impact on the European government bond secondary market integration process (Pagano & Von Thadden, 2004, p. 541). Moreover, the common currency has been the key element of bringing the Eurozone bond yields closer together (Pagano & Von Thadden, 2004, p. 532).

Yet, Euro area bonds are not perfect equivalents, and there are still variances in yield levels. Figure 4 on the MTS website shows recent bond yield differentials for some of the Eurozone government 10-year bonds. The yield disparities are compared to the reference country Germany, which is one of the European market's reference bonds, because German government bonds are the closest to a risk-free long-term fixed income investment. As of 14th of April 2023, the Germany's 10-year government bond yielded 2,43 percent. In the graph, Denmark and the Netherlands have relatively small spreads to Germany, implying that these countries may borrow from the market virtually as cheaply as Germany. The other end of the spectrum is Italy and Germany, where the

spread to Germany exceeds 100 basis points. These countries' financial stability is poorer, which impacts the market's perception of the country's solvency. The countries' bonds are deemed riskier in the sense that they may fail to meet their payment obligations, in which case the bonds must give greater yields to entice the investor to invest money in them.

Country	Yield	Spread*
Germany (2.30% 15 Feb 2033)	2.43	-
EU Next Gen (1% 06 Jul 2032)	3.03	+60
France (2.0% 25 Nov 2032)	2.94	+51
Belgium (3.0% 22 Jun 2033)	3.11	+68
Italy (4.40% 01 May 2033)	4.28	+185
Spain (3.15% 30 Apr 2033)	3.47	+104
Denmark (2.25% 15 Nov 2033)	2.72	+29
Finland (1.50% 15 Sep 2032)	2.99	+56
Netherlands (2.5% 15 Jul 2033)	2.80	+37
Austria (2.90% 20 Feb 2033)	3.06	+64

Figure 4. European 10-year Bond Yields and Spreads against the German benchmark on 14/04/2023 (MTS, 2023).

3 Theory of treasury bonds and bond liquidity

The underlying theories of bond market liquidity are presented in this section. The section begins by reviewing the fundamental theory of bond pricing. Following that, the chapter then moves on to present the liquidity preference theory and various liquidity measures formed afterwards. This thesis intends to use the bid-ask spread as a variable of bond market liquidity that will be determined in more detail.

3.1 Fixed-income bond characteristics

This thesis will investigate the liquidity of European government bonds. Regardless, bond illiquidity has been studied (e.g., Bernoth et al., 2012; Li et al., 2009; Longstaff, 2002) to have an impact on bond yield and pricing, which is why it is important to begin by determining the valuation of a treasury bond. According to Bodie and others (2013), a bond is a security that is issued as a loan facility to an entity such as the government or a corporation. In order to borrow a certain amount of money from the counterparty, the borrower (in this case, the government) sells the bond to the lender (that is, the investor) (Bodie et al., 2013, p. 446). However, the bond agreement requires the borrower to make annual, or more commonly, semi-annual interest rate payments to the lender until maturity (Bodie et al., 2013, p. 446). These continuous interest rate payments are called coupon payments which are obtained by multiplying the bond's nominal value (or face value) by the coupon rate.

This thesis focuses on fixed-income bonds that pay fixed interest payments to its holder until maturity. The fixed rate provides the lender with the same coupon rate throughout the loan term, whereas the coupon rate can also be bound to a floating rate of interest, such as some current market rates (Bodie et al., 2013, p. 449). The return of the fixed-income bond is determined by the continuing fixed interest payments and the price differential that is gained when an investor buys the bond below par value on its issue date. Hence, the face value of the bond is repaid to the investor at the end of maturity

(Bodie et al., 2013, p. 446). The total return of a bond is determined by a yield-to-maturity, which in accordance with its name, refers to the return that investor gets when the bond is held until maturity. The bond price and yield relationship depend largely on the current market rate of return. Bodie and others (2013) explain the idea behind the fair total rate of return or a compensation for a bond in accordance with the current market return. The bond must sell at a value that is equivalent to market interest rate. If the coupon rate of the bond is equal to market interest rate, the bond will sell at its face value because the coupon payments are enough to make investor the fair rate of return (or market level return) on the investment. If the coupon rate is lower than the rate offered on the market, the investor needs to be offered a price compensation on the investment by selling the bond under its par value. In this market position, the coupon rate is not able to offer a competitive return on the bond by itself compared to what returns would be available elsewhere on the market. In other way around, if the coupon rate exceeds the market rate, investors will bid up the price, causing its price to rise above the nominal value. This happens because the bond's yield exceeds the market yield, which causes market demand to push the yield down to the market level, which, in the case of a bond, increases its price. Hence, once again, the total yield of the bond will be equivalent to the market interest rate.

How the total yield-to-maturity of a bond is determined, depends highly on the risk premium demanded by investors. The risk premium of a bond stems from multiple risk factors that researchers have documented on the market. Traditionally the most common determinants of a corporate bond yield spreads have been the result of credit and liquidity risks (Ericsson & Renault, 2006). This is also the case for treasury bonds, yet the expected return of a government bond can be also result from the exchange rate and the risk of high indebtedness of a state (Bernoth et al., 2012, p. 975-978). In the case of European states, Bernoth and others' (2012, p. 976) study discovers a monetary union risk that central bank may increase the default risk of the member states. Also, the risk of interest rate changes and inflation risk affects bond yields (Bierman & Hass, 1975, p. 757). The interest rate risk comes from the inverse relationship between bond price and

interest rates. Namely, when interest rate rise, the price of the bond must fall in order to the yield to adjust in the level of the market interest rate. The price level risk is evident when inflation weakens the real rate of return of a bond. However, the purpose of the next chapters is to focus on credit and liquidity risks as they are the most common risk factors that determine the term structure of bond yields.

3.1.1 Bond pricing

The benefit of fixed-income bond pricing is that future cash flows are known in advance, at least without taking into account potential risk factors. Even with government bonds, there is a risk that the borrower will become insolvent and will be unable to repay the agreed-upon interest and capital (Bodie et al., 2013, p. 445). Bond prices, like most assets, are determined using the discounted cashflow method. The method is used because an investor is willing to pay for the bond equal to the present values of its future cash flows (Bodie et al., 2013, p. 452). Therefore, the bond value simply equals the present value of running coupon payments plus the present value of the denomination (Bodie et al., 2013, p. 452). The discounted cashflow method also requires a discount rate. According to Bodie and others (2013, p. 452), the discount rate is derived from the nominal risk-free interest rate, which is equal to the real risk-free interest rate plus a premium to account for future inflation. In addition to these, the discount rate takes into account risk factors that reflect bond characteristics, because most bonds, with the exception of high credit rating treasury bonds, are not risk-free. For example, the US government bonds are guaranteed by the state which means that in an extreme situation the government can print more money to repay the loan. However, the majority of states face the risk of default. As a result, the discount rate considers bond risk factors such as credit risk, liquidity, and tax features (Bodie et al., 2013, p. 452). Now, the coupon payments can be discounted using the appropriate discount rate until the bond's maturity and added to the discounted value of the principal payment. The following is the formula used for bond pricing:

$$Bond\ value = \sum_{t=1}^{T} \frac{Coupon}{(1+r)^t} + \frac{Par\ value}{(1+r)^t}, \quad (1)$$

where

T is the maturity date,

r is the discount rate or the YTM,

the first term of the right-hand side is the annuity factor, and

the second term is the present value of par value.

3.1.2 Term structure of interest rates

Bodie and others (2013) make a simplistic assumption in the earlier chapter of their study (p. 452) that the bond pricing formula's discount rate is derived by the equation of the nominal risk-free rate and the risk premium, without taking the term structure of interest rates into account. Consequently, the same discount rate would be used to any maturity bonds (Bodie et al., 2013, p. 487). They continue later by specifying that in the real world the prices of different maturities cannot be discounted with same interest rate. In general, longer-term maturities carry higher risk and different maturities must offer different yields (Bodie et al., 2013, p. 487). Risk premiums of different maturities occur because a short-term investor will not invest in a long-term bond if the expected returns are the same, so the longer investment must offer a higher expected return (Bodie et al., 2013, p. 496).

Described mathematically, an expected future short-term interest rate $E(r_2)$ must be *lower* than a forward rate f_2 for a short-term investor to hold long-term security, and the expected future short-term interest rate $E(r_2)$ needs to be *higher* than the forward rate f_2 for a long-term investor to hold short-term security (Bodie et al., 2013, p. 498). Under the circumstances, both investor types are willing to demand premium for their unpreferred investment outlook but if considering that most of the investors are short-term investors, the equation $f_2 > E(r_2)$ will hold. The forward rate needs to be higher to make the long-maturity investment more attractive to the short-term investment

(Bodie et al., 2013, p. 496). In other words, if buying and holding a 2-year interest rate (or a so-called spot rate), it should have the same return as if you first invested in 1-year interest rate and in the second year you reinvest in another interest rate. Then, the second-year rate – that is, the future expected short-term rate – must be higher to make the two investments equally attractive. However, for a risk averse investor, it is not enough that the returns of the two are equally attractive so, the forward rate must offer a premium over the expected future short-interest rate since the investor keeps the investment for a longer period of time (Bodie et al., 2013, p. 496).

The pattern of yield-to-maturities of different maturities is called a yield curve in which typically the increase of maturity increases the bond yield (Bodie et al., 2013). Thus, the most general pattern of yield curve is upward sloping (see Figure 5, yield curve in the middle) which requires the forward rate to be always higher than the spot rate and the expected future short rate (Bodie et al., 2013, p. 502). Hence, the equation of the forward rate is presented as the following: $f_n = E(r_n) + premium$, and so, f_n must be higher than $E(r_n)$ (Bodie et al., 2013, p. 502). A plot of yield to maturities can vary temporally according to market conditions and it can also turn into flat or inverted yield curve (Bodie et al., 2013, p. 487). Typically, in recessions, the yield curve starts to flatten (see Figure 5, yield curve on the left) and eventually invert (see Figure 5, yield curve on the right) when the short-term interest rates rise above the long-term interest rates. For fixed-income investors, the yield curve is key for evaluating future interest rates at the given moment and it is also used for bond pricing (Bodie et al., 2013, p. 487). The most typical yield curve presented on the market is the on-the-run yield curve which forms a curve of the most recently issued bonds which almost reflect their face value (Bodie et al., 2013, p. 490).

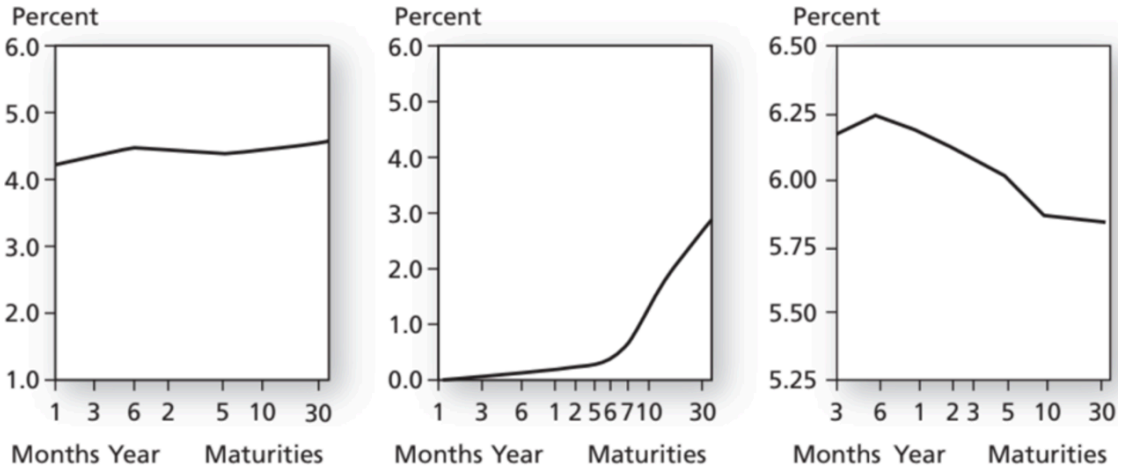


Figure 5. Treasury yield curves (Bodie et al., 2013, p. P. 487).

The premium over the expected future short rate reflects the risk characteristics of the asset, and most generally the default risk has been found to explain the premium on the bond market. Credit ratings are used to assess the risk of default on corporate and treasury bonds. Credit rating agencies such as Standard and Poor's and Moody's assign credit ratings to corporate and country loans based on their ability to repay their loan obligations. The lower the rating, the higher the risk and thus the yield of the bonds. The credit ratings vary between corporate and treasury bonds, and usually, corporate bonds are considered riskier (Bodie et al., 2013, p. 468). Nevertheless, not all treasury bonds are considered riskless; it is dependent on the government's credit risk. For example, US government bonds are considered the most risk-free assets, with a high credit rating, whereas Italian government bonds have a low credit rating.

3.2 Liquidity preference theory

The term structure of interest rates can be considered in terms of liquidity risk. Mathematically, the liquidity premium can be described as the excess on top of the expected future short interest rate as following: $f_n = E(r_n) + liquidity\ premium$ (Bodie et al., 2013, p. 498). Like described earlier, for short term investors the expected future short-term interest rate $E(r_2)$ must be lower than a forward rate f_2 for a short-

term investor to hold long-term security, and for liquidity preference theory, this condition is dominant. Thus, for the liquidity premium to exist, the f_2 must exceed $E(r_2)$ as in the Figure 6 illustrates, because the forward rate accounts for the liquidity risk that the bond can have. In Figure 6, the liquidity premium is constant, but it can also increase with maturity if the longer-term bonds are considered less liquid. Because the liquidity premium is constant in the Figure 6, it decreases as maturity increases, thus higher maturity bonds would only account for low liquidity premiums. Higher maturity bond yields would rise only if the liquidity premium increased with maturity. In an upward sloping yield curve, $E(r_2)$ will be higher than r_2, so that multiplying the two equals current spot rate for yield to maturity. However, for upward sloping liquidity premium yield curve the $E(r_2)$ changes into the f_2 that is higher than the $E(r_2)$, shifting the overall yield curve higher.

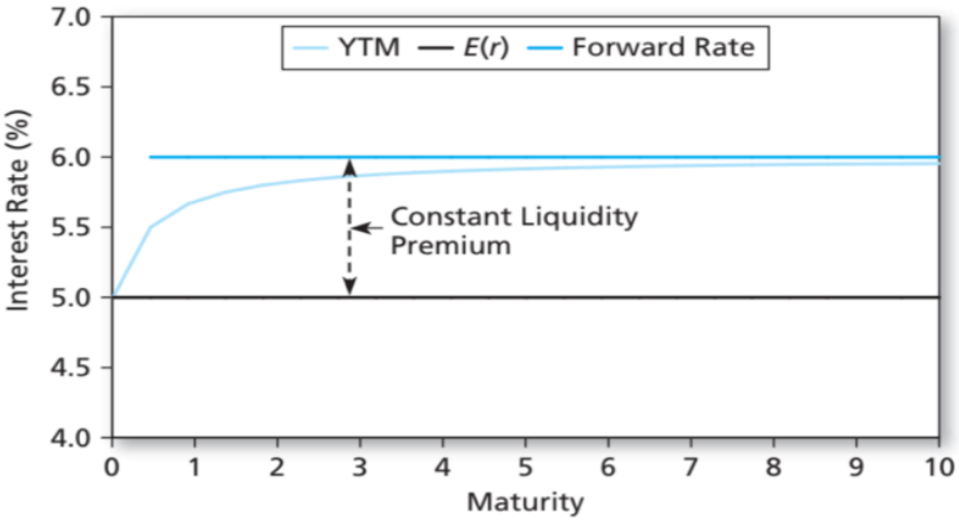


Figure 6. Constant liquidity premium (Bodie et al., 2013, p. 499).

John Maynard Keynes (1936) was the first one to interpret the theory of liquidity preference to describe a relationship between interest rates, cash, and liquidity preference. The Liquidity Preference Theory states that investor has an incentive to sacrifice their current liquidity to get a certain interest rate for keeping their money in longer-term debt securities instead of holding the money as a cash. Since cash is considered the most liquid asset, there must be an interest rate given for an investor as

a reward for prolonging their current liquidity and risking that the invested cash is more difficult to liquidate in the future. A given interest rate *r* will determine the amount of money *M* that investors will hold. If the rate of interest is too low, investors will prefer holding their cash rather than investing it. As the interest rate increases, the money will start to flow to interest rates. *L* represents the liquidity premium which determines the amount of money *M* held at given interest rate *r*. An equilibrium is found when M = L(r).

Keynes (1936) defines that the risk of liquidity appears if the need of liquidity arises before the expiry of debt security since the investment may be difficult to be exchanged quickly in the future compared that the money would have been held in cash. Thus, it is crucial for longer term maturities to generate higher yields in return for higher liquidity risk because the time sacrificed for collecting the money is longer compared to shorter maturities. The term structure of liquidity has been proved empirically by Li and others (2009) who discover that their liquidity risk factor affects differently to bond yields of different bond maturities. Consequently, it is noteworthy to study different maturity bonds in this thesis where the results of quantitative easing on bond liquidity may be obtained.

In his book, Keynes (1936) discusses why it would be reasonable to hold money in terms of cash if interest rates are never negative. In other words, why one would sacrifice a rate of return for holding cash? He finds three reasons: a transactions-motive, a precautionary-motive, and a speculative motive. The transactions-motive refers that there is a desire to hold cash for daily personal and business expenses, the precautionary-motive refers that a part of total assets is wanted to be secured and other part invested, and the speculative motive refers to the preference of maintaining a profit than taking a risk that the money may not be exchangeable in the future. Hence, according to the liquidity preference theory, liquidity is valuable, and sacrificing it for a period requires an appropriate return.

3.2.1 Liquidity trap

If the return on sacrificing liquidity in the market is very poor, investors have no incentive to invest their money, preferring to keep it in cash (Keynes, 1936). This event is called a liquidity trap where the monetary authority has no longer a control over the level of interest rates (Keynes, 1936). The liquidity trap occurs in recessions where the bond returns are so low that the public is willing to deposit their money instead of investing it to interest rates. Thus, the nominal rate of interest become zero due to which the bonds and cash become substitutes for each other (Krugman, 1998, p. 137). As per the Liquidity Preference Theory, when interest rates are positive, investors have an incentive to invest some of their capital in bonds, leaving only the necessary amount in cash. However, if the nominal rate of interest approaches zero, investors become indifferent about whether holding cash or investing it in bonds (Krugman, 1998, p. 157).

The problem with liquidity traps is that investors would rather retain their money in cash or deposits because they expect interest rates to grow in the future. In these circumstances, one would not be willing to invest in bonds because their prices would decline as interest rates rose. Moreover, the problem with liquidity trap and the way out of the trap is explicitly related to the public's expectations about the persistence of monetary policy (Krugman, 1998). According to Krugman (1998, p. 139), monetary policy and increasing the money supply is inefficient of boosting liquidity trap because cash and bonds are perfect substitutes on the market. The lower zero bound, which limits the nominal interest to zero, prevents it from being lowered any further (for the ECB until 2014, after which lowering interest rates below zero became possible). Practicing monetary policy will not lead to steady rise in interest rates because the public believes that the monetary policy is only temporary and the economy will sink into the same situation in the future (Krugman, 1998, p. 161). Ultimately, the solution for liquidity trap is for central banks to convince the public of future price stability and so, an ultimately higher price level. Hence, the role of quantitative easing of increasing money supply in the economy would be considered an effective tool for price development if it were considered permanent (Svensson, 2006, p. 1).

3.2.2 Liquidity risk and return

In addition to credit risk, an important determinant of bond yield is liquidity risk. In fact, credit risk can pose liquidity risk when insolvency causes bond illiquidity and an increase in the yield spreads (Ericsson & Renault, 2006, p. 2291) Based on the Liquidity Preference Theory, liquidity risk should be priced on the bond market. This means that investors should be compensated by taking additional risk when investing on treasury bond and converting it into cash (Keynes, 1936). As the research focuses on bond liquidity in European countries, the goal of this section is to discuss whether liquidity risk is priced on the bond market, what generates liquidity risk, and assess liquidity premium disparities between European countries.

According to Bernoth and others (2012, p. 975), liquidity premiums have vanished in Europe since the start of EMU, whereas yield spreads were still influenced by liquidity premiums prior to EMU. Nevertheless, not all studies agree on this, since Jankowitsch and others (2006, p. 153) claim that following EMU, yield spreads in the Eurozone remained significant, and academics are attempting to determine whether the yield differences are attributable to default or liquidity risk. Jankowitsch and others (2006) investigate the influence of liquidity on bond prices in Germany, France, Italy, Spain, the Netherlands, and Austria and find relatively minor effects. Small countries' bond prices appear to be more affected by liquidity. They observe that bonds with wider bid-ask spreads (for example, Italy) have lower bond yields, which contradicts how the liquidity premium should be reflected in yields (increase the yields).

An absolute liquidity in this study is referred as the ability to exchange the security quickly into cash on the market without any transaction costs and at a price that corresponds to the asset's intrinsic value (Ericsson & Renault, 2006, p. 2291). Inversely, in an illiquid market, transaction costs exist due to frictional market which requires the asset to be sold at discount (Ericsson & Renault, 2006, p. 2291). There are multiple

reasons why liquidity is important. Previous literature has studied liquidity risk to increasing extents and recognized it to be important for market functionality (Li et al., 2009, p. 467). Liquidity risk has been found to cause higher return expectations on the market (e.g., Acharya & Pedersen, 2005; Goyenko et al., 2011; Kinateder & Wagner, 2017; Eser & Schwaab, 2016) and perform as a safe haven during uncertain times (e.g., Beber et al., 2009; Goyenko et al., 2011; Acharya & Pedersen, 2005; Longstaff, 2002). Overall, liquidity is essential in every marketplace to ensure smooth trading but its importance on the bond market has a special meaning in a larger perspective. From the point of view of states and central banks, a liquid bond market means lower costs for financing budget deficits and more effective monetary policy (Mohanty, 2002, p. 49). Panagiotou and others (2022, p. 1) also state that a liquid bond market has a close relationship to the operations made by central bank such as setting interest rates and executing quantitative easing. A depth bond market acts as a benchmark for pricing other riskier securities on the market which is why central banks will try to promote their liquidity (Mohanty, 2002, p. 49). The depth of the market also functions as a determining factor in terms of the derivatives market and risk management (Mohanty, 2002, p. 49). Illiquid shocks on the bond market or in particular bond maturities can inflict spillover effects to other assets classes or bond types (Panagiotou et al., 2022, p. 1). According to Mohanty (2002, p. 49), a liquid bond market can also indicate important information about the yield curve for central banks when conducting monetary policy.

Multiple researchers have discovered different-size liquidity premiums and risk on the bond and stock market. Li and others (2009, p. 470) find that liquidity risk explains the bond yield levels for the US treasury securities on the maturity curve. A ten-percentage-point difference in liquidity risk result in a nine-basis-point difference in the yearly returns of US Treasury rates. Acharya and Pedersen (2005, p. 377) find that liquidity risk is considerable for illiquid assets, and liquidity commonality and sensitivity increase as market liquidity for illiquid assets increases. Goyenko and others (2011, p. 137) find that in economic downturns, liquidity risk increases for all maturities, but especially for short-term bonds. Ben-Rephael and others (2015, p. 197) discover that the liquidity premium

in the stock market has decreased over time, but it is most pronounced for tiny common stocks. They explain the low liquidity premium for equities with growing interest in investing in stocks. Darbha and Dufour (2013) witness that liquidity explains yield spreads both before and after financial crises.

Most commonly, investors are willing to demand liquidity premium for bonds since they carry risk that in the future and before the expiry date, the asset is not feasible to trade quickly into cash without a sizeable discount (Keynes, 1936; Ericsson & Renault, 2006). Equally, liquidity risk is an outcome of transaction costs which leads to investors demanding higher returns for the compensation of loss in a value (Amihud & Mendelson, 1986). Moreover, the liquidity risk may also be prone to other factors on the market. The sovereign bond liquidity considerably depends on the amount of the state's outstanding debt on the market which is larger or smaller depending on the country's prevailing fiscal policy (Beber et al., 2009, p. 926). Budget deficits increase the government's need for borrowing, which increases the number of government's bonds outstanding, and vice versa. However, central banks have the authority to manage the quantity of outstanding debt with their monetary policy operations. Mainly with quantitative easing, central banks can purchase bonds on the secondary market lowering the tradable amount of private and public debt. A sizeable amount of outstanding bonds means larger tradable quantity on the market, making it easier to buy and sell large quantities because more assets are trading. On the contrary, a smaller outstanding amount of debt makes it difficult for investors to trade large amounts.

A market size, an uncertain market environment, and bond characteristics have also been found to affect market liquidity. The close connection between the market size and liquidity is explained subsequently but let us first focus more accurately on the other two factors. According to Beber and others (2009, p. 925), in times of uncertain market environment, asset class returns often decline, leading to lower tradability. Weaker liquidity, on the other hand, causes the return of assets to decrease even more. Similarly, Goyenko and others (2011, p. 113) find that the economic environment impacts

substantially to market liquidity and during recession trading increases towards more liquid bonds inferring flight-to-liquidity phenomenon. More commonly known phenomenon is the flight-to-quality which occurs during increased market uncertainty causing selling pressure in stocks and buying pressure in bonds (Li et al., 2009, p. 469). This happens because stock market tends to move downwards and bond market upwards in bad market times, that is, the fixed-income assets are safer. The flight-to-quality phenomenon happens in an uncertain market situation resulting in investors shifting their portfolio to better credit quality assets (Beber et al., 2009, p. 925). However, Beber and others (2009, p. 925) also find investors to rather convert their portfolios into more liquid assets and notably into more liquid bonds than better credit rating as during market uncertainty. Moreover, they find that liquidity becomes more important element in these times referring that investors seek for liquidity over credit quality.

From bond characteristics, the on-the-run phenomenon and bond term structure have been found to have an impact on the bond liquidity. A so-called on-the-run liquidity phenomenon has been studied for example by Pasquariello and Vega (2009) and Goyenko and others (2011). The on-the run effect of fixed-income denotes that bonds with similar cashflows and maturity obtain different yields and liquidities (Pasquariello and Vega, 2009, p. 1). Off-the-run bond is a previously issued on-the-run bond that becomes off-the-run after a new instrument of the bond maturity is issued. The empirical results suggest that the most recently issued bonds – that is to say, the on-the-run bonds – trade with lower yields because they are more liquid (Pasquariello and Vega, 2009, p. 1). Hence, the liquidity premium mainly develops from the off-the-run bonds because on-the-run liquidity is not priced on the fixed-income market (Goyenko et al., 2011, p. 114). Bernoth and colleagues' (2012, p. 975) claim that liquidity premiums vanished after EMU may apply to the on-the-run bonds in Europe. Pasquariello and Vega (2009) demonstrate robust results indicating that the difference between the daily bid and ask price averages of off-the-run and on-the-run treasury securities is significantly positive, and that this difference cannot be explained by bond characteristics. As a result, their study show that on-the-run bonds have a lower bid-ask spread than off-the-run

bonds, allowing them to trade more easily. Benchmark bonds are the ones that are the most liquid outstanding bonds on the market, and they improve the market efficiency via their price discovery (Remolona & Yetman, 2019, p. 1). The on-the-run bonds usually act as benchmark bonds because they are the most liquid and less risky securities (Pasquariello & Vega, 2009, p. 1).

Maturity is an important factor when measuring bond liquidity risk. In line with the Liquidity Preference Theory, O'Sullivan and Papavassiliou (2020) examine the term structure of liquidity in the Euro-area bonds, and they document that the liquidity premium is higher for long maturity bonds than for shorter maturity bonds because they react more sensitively to liquidity shocks. Hence, the term structure of liquidity can be observed as, according to O'Sullivan and Papavassiliou (2020, p. 2), a positively sloped curve where the yield to maturity increases as maturity and liquidity risk increases but slows down at the end of the curve. Yet, the maturity does not clearly convey the liquidity of the treasury instrument. Amihud and Mendelson (1991) find interesting results about the term structure of liquidity between treasury bills and notes. The term "zero-interest" or "discount paper" is used for T-bills as their maturity is less than a year, in which case no cash flow is paid to them and so, the yield is paid as a single-payment, whereas treasury notes pay the coupon to its buyer until maturity, which varies from a year in most cases to a maximum of 10 years. Amihud and Mendelson (1991) compare US treasury bills and notes maturing in 6 months. In this case the T-note becomes also a single-payment security like the treasury bill, yet they continue to act as separate securities due to their different calculation of yield, quotation prices and amounts, and trading. The main finding in the study is that the T-bills are more liquid than T-notes even though their expiry date is the same. The reason for this is that treasury notes are issued in large quantities, but a large portion of the issued notes are already locked away in investors' investment portfolios, significantly reducing the tradable amount of notes in each issue, resulting in higher costs to arrange the desired amount to be traded for an investor (Amihud & Mendelson, 1991, p. 1413). As a result, because maturity is not an

unambiguous factor in terms of liquidity risk, the choice of the instrument type can become critical.

Separating the liquidity premium from the yield spreads highlights the lack of financial market integration (Bernoth et al., 2012, p. 976). What they mean is that if the liquidity premium is separable from the yields, the Eurozone bond market is not as coherent because the functioning of the Interdealer market is not completely frictionless. Bernoth and others (2012) study the yield differentials in the European government bond market and focus on the yield levels of the German government bonds or the so-called “bunds”. Compared to the sovereign bond yields of countries with better fiscal performance, the German government bond yields were found to be lower. According to their research (Bernoth et al., 2012), the bond yield differentials between the countries were not reflecting properly the fiscal performance of the countries but the size of the bond market. Germany benefits from low interest rate on their debt because their bond market is considered so large that the bonds are traded quickly with low transaction costs (Bernoth et al., 2012, p. 976). The market also reflects steady price levels due to efficient bid and ask prices and so, a single transaction does not impact the prices significantly compared to more illiquid and smaller market (Bernoth et al., 2012, p. 976). In the European government bond market, German bonds are indeed used as benchmark bonds to which the bonds of other member states are compared since high liquidity and credit quality makes them the most riskless assets in the Eurozone.

Panagiotou and others (2022, p. 1) examine liquidity commonality in the Euro-area government bond market and discovers that the liquidity commonality changes periodically and has a tendency to strengthen during recessions. Their study shows that liquidity risk has a systematic character that cannot necessarily be diversified on the market. Hence, if the market in general becomes illiquid, the assets will follow. The commonality of liquidity in certain bonds can also affect positively on the market (Panagiotou et al., 2022, p. 1-2). When a central bank provides liquidity to specific bonds, it may lead to a flight-to-liquidity effect but also to a spillover effect to other bond groups

due to the liquidity commonality which enhances the overall bond market liquidity. Yan and others (2018, p. 274) find that European sovereign debt markets reveal positive skewness. The effect is intense especially in Greece, Ireland and Portugal. They discover that throughout the financial crisis, there was positive skewness in liquidity amongst Eurozone countries, despite considerable variability in bid-ask spreads. Yan and colleagues (2018) agree in their analysis that liquidity plays a significant role during crisis periods by showing commonality among countries.

3.3 Measures of liquidity

Liquidity refers to how easily an asset can be exchanged on the market in relation to its market price just before placing a transaction (Grimaldi et al., 2021, p. 10). High liquidity means low transaction costs, quick tradability with large volumes, and no significant impact on the price level on the market (Grimaldi et al., 2021, p. 10). Low liquidity refers to the opposite. Grimaldi and others (2021, p. 10) presents five dimensions of liquidity which are tightness, immediacy, depth, breadth, and resilience that are generally presented in the literature. Tightness means transaction costs, immediacy the quickness of trading, depth the continuous placed orders on the asset and heavy interest in trading, breadth the volume of trades and interest, and resilience the ability of the asset's price to quickly adjust to its correct market price level from its imbalance.

For different securities it is profitable to use different measures of liquidity as the liquidity of an asset can be influenced for example by its residual time to maturity like for bonds or the trade frequency (Grimaldi et al., 2021, p. 11). Hence, a different liquidity measures are used for more frequently traded instruments such as bonds and stocks. There is not only one measure to describe liquidity, but it has been noticed that liquidity can be observed with several different measures. This is mainly because, due to the characteristics of liquidity, it cannot be directly measured (Grimaldi et al., 2021, p. 10). Liquidity is affected by its multiple dimensions, but it is also affected by data availability (Grimaldi et al., 2021, p. 11). For instance, most of treasury notes, bills, and bonds trade

via over-the-counter market (OTC) where the data is more difficult to obtain, is more prone to noise trading and which is not governed by similar rules that stock exchanges (Grimaldi et al., 2021, p. 11, Fleming & Remolona, 1999, p. 1902). Thus, the prices and bid-ask spreads can change without any limit (Fleming & Remolona, 1999, p. 1902).

This section presents the different liquidity measures that can be used to gauge liquidity. Fleming (2003) examines a large set of different liquidity measures in the US market which this section will refer to. The first liquidity measure, bid-ask spread, is the most commonly used measure of liquidity. It is measured by the difference between bid and ask prices and it measures the distance from the bid price to the ask price and is therefore called a bid-ask spread (Fleming, 2003, p. 85). The downside of the measure which Fleming (2003, p. 65) presents is that the measure only fits for smaller quantities and a limited time period. It only calculates the transaction cost for a smaller single trade. The thesis will utilize the bid-ask spread as the proxy of liquidity and the measure will be explained in more detail subsequently. The second measure, quote size, helps to count for the bid and ask offer sizes which means the amount of the security that can be traded with a certain bid and ask prices (Fleming, 2003, p. 85). Quote size thereby supplements the bid-ask spread measure. A quoted bid-ask spread is often used to measure market tightness that is the transaction costs (Grimaldi et al., 2021, p. 11). A downside of the measure is that the quote sizes are often misleading as the as full amounts of the quotes are often not reported (Fleming, 2003, p. 85). Other very similar measure to quote size is a trade size which measures the number of trades that can be made for the security. It reflects afterwards the sizes of the trades that were negotiated over the security (Fleming, 2003, p. 85). However, like quote size, trade size is misleading indicator as the quantity traded at a given market price is usually less than the quantity that could have been traded (Fleming, 2003, p. 85). Both quote and trade sizes are measures of market depth and substitute each other.

The next measure is highly relevant for the treasury market as it calculates the yield spread between more liquid and less liquid treasury securities (Fleming, 2003, p. 85). As

explained in previous chapter, the on-the-run bonds are considered more liquid securities than off-the-run bonds with same maturities. Thereby, the so-called “liquidity spread” spread calculates the yield difference between the on-the-run and off-the-run treasury securities with similar characteristics (Fleming, 2003, p. 85). Finally, Fleming (2003, p. 85) presents the last two liquidity measures, trading volume and trading frequency. Trading volume is another popular liquidity measure along with bid-ask spread. Trading volume reveals the traded amount of a given security during the trading hours that day and so, it accounts for the sizes of the trades. Trading volume is highly used measure especially for more liquid markets such as treasury markets (Fleming, 2003, p. 85). A merit of the measure is its easy availability as the trading volumes are regularly reported (Fleming, 2003, p. 85). Trading volume is correlated with market volatility which can make the implications of market liquidity unambiguous (Fleming, 2003, p. 85). Trading frequency informs about the number of trades made in a certain time frame, but it does not count in the size of the trades. Both high trading volume and frequency are linked with better liquidity, and it is used on more liquid markets. However, like trading volume, the frequency of trades is also correlated with volatility. Fleming (2003, p. 84) finds further evidence that the number of trades matter more when it comes to volatility and thus, the size of the trade does not impact on the relationship between the trade volume and volatility. Grimaldi and others (2021, p. 12) defines a fuller measure of the trading volume in their study, a turnover ratio, which calculates the traded volume of a bond during a specific day in relation to the total outstanding amount of the bond. A high turnover ratio means higher traded volume of a bond relative to its outstanding amount. The figure helps to identify the total amount of the bond on the market, and so, a high turnover ratio could also indicate future lower liquidity because the amount of freely tradable bonds on the market decreases (Grimaldi et al., 2021, p. 12).

Fleming (2003, p. 84) finds that during times of market crises, the correlation between these liquidity variables heightens. However, the trading volume and trading frequency show only a little correlation between other variables which points that the two liquidity

measures are only weak liquidity metrics. The bid-ask spread tends to increase during market crises (Fleming (2003, p. 84), but also quick and high price changes can also dramatically widen the bid-ask spread (Fleming & Remolona, 1999, p. 1902).

3.3.1 Bid-ask spread

The bid-ask spread is the metric for bond liquidity employed in the thesis. It is measured by the distance between the highest bid and ask price, and it is a straightforward approach to assess market liquidity (Yan et al., 2018, p. 276). The spread quickly informs the counterparty of the trade's transaction costs. If the spread widens, the liquidity of the asset weakens because of expanded transaction costs. The asset is very liquid and can be traded rapidly and without incurring any fees if the spread is close to or at zero. The average bid-ask spread of a given time frame *T* is calculated as the following (Yan et al., 2018, p. 276):

$$\frac{1}{T}\sum_{t=1}^{T}((A_1)_t - (B_1)_t) \qquad (2)$$

where,
A_1 is the best ask price,
B_1 is the best bid price, and
T is the observed time period.

A downside of the bid-ask spread is that it is susceptible to outliers during times of low market liquidity when there are not enough quotes available to cover up big spreads (Yan et al., 2018, p. 276). Fleming (2003, p. 90) finds that longer maturity securities tend to have more volatile price changes and thus more wider spreads. Efficient bid-ask spread, presented by Roll (1984, p. 1127-1128), aim at efficient market hypothesis. He proposes that in an informationally efficient market, the average of the bid-ask spread ranges according to random walk. Hence, if the market is fully efficient, the trading costs are zero and the market prices reflect all available information. Only if market

participants get unexpected information will there be a change in pricing. Trading expenses, however, cause a negative serial dependence in the subsequent market price changes. According to Roll (1984, p. 1127), the bid-ask spread = $\sqrt[2]{-Cov}$ can be used to calculate the effective bid-ask spread at a given level of market efficiency. The *Cov* variable measures a serial correlation of price changes of an asset. If the measure shows serial correlation between asset's returns, the prices are to somewhat correlated, and they do not flow randomly. The effective bid-ask spread has an inverse relationship with the serial covariance in price fluctuations, and the spread can be calculated from the sequence of price changes (Roll, 1984, p. 1130).

3.3.2 Market tightness

According to Ferdinandusse and others (2020, p. 6) bond liquidity is also determined by the tightness of the bond market. A tightness ratio in the market describes how many buyers there are compared to sellers or the ratio of demand to supply. A tightness ratio above 1 means that there are more buyers than sellers in the market meaning a tighter market and it leads to higher bond prices and lower yields when demand exceeds supply. Ferdinandusse and others (2020, p. 8) state that the match of buyers and sellers impact directly to the liquidity of bonds. Quantitative easing tightens the bond market by adding a central bank as a large buyer to the market. This means that sellers can easily find buyers in the market which is the traditional way of viewing liquidity. However, the tightness can be viewed also the other way around, that is, from the buyers' point of view in which case QE does not promote liquidity. Now, the market's tightness is determined by how easily a buyer can find a seller. Because the central bank holds its securities until maturity, it reduces market liquidity when buyers in the market are unable to find sellers for certain bonds.

4 Monetary policy and theory of efficient markets

This section attempts to define monetary policy and the theory of efficient markets in relation to the topic of this thesis. The monetary policy is viewed in terms of the European Central Bank. The chapter focuses mostly on the monetary policy tool, quantitative easing. The European Central Bank's quantitative easing and thus the asset purchase programmes will be illustrated in greater detail. The two influencing channels of quantitative easing are also considered. As a final theory, the Efficient Market Hypothesis is presented in this chapter, also from the point of view its criticisms and liquidity.

4.1 ECB and monetary policy

The primary goal of monetary policy is to control the cost and availability of money in the economy (European Central Bank, 2023i). In the case of the European Central Bank, the monetary policy implies keeping the inflation level at 2 % in the European economies which it is done by using the main monetary policy tool – the key interest rates. According to the European Central Bank (2023i), controlling the key interest rate influences the interest rate that commercial bank customers pay for borrowing money. It also affects what businesses and institutions pay for their loans. As a result, interest rates affect how customers spend and how businesses invest which in turn affects the inflation level in the economies (European Central Bank, 2023i & 2023f). The European Central Bank establishes three interest rates: refinancing operations, deposit facilities, and marginal lending facilities (European Central Bank, 2023f). The first one determines the interest rate at which the commercial banks can lend from the ECB. The two latter ones determine the overnight borrowing rate at which the commercial banks can lend from each other.

Aside from interest rates, European Central Bank employ a variety of other monetary policy instruments when conducting monetary policy, thereby improving price stability

and preserving the euro's value (European Central Bank, 2023e & 2023i). According to European Central Bank (2023f), controlling of the key interest rate was primarily used before the financial crisis. The crisis led to the short-term interest rates fall to the level of their so-called “effective lower bound”, below which the interest rate would no longer have an impact on economic development (European Central Bank, 2023f). In those circumstances, the transmission mechanism of monetary policy became ineffective as a result of the financial crisis, changes and additions to monetary policy tools had to be made. The new monetary policy tools consist of the ECB lending lends money to banks on a weekly basis at a fixed interest rate in exchange for collateral, enabling negative interest rates with which banks further lend to their customers more favorably, using targeted longer-term refinancing operations (TLTROs), in which banks re-lend to their customers at more favorable interest rates for a longer period of time, reviving financial assets by conducting asset purchases on private and public debt, as well as being open about future monetary policy decisions (European Central Bank, 2023f).

The ECB’s monetary policy tools can be divided into regulated and unregulated open market operations as well as into conventional and unconventional monetary policies. The regulated open market operations consist of main refinancing operations and longer-term refinancing operations (LTROs) (European Central Bank, 2023g). The non-regular open market operations consist of pandemic emergency and targeted longer-term refinancing operations (PELTROs and TLTROs), Asset Purchase Programme (APP) and Pandemic Emergency Purchase Programme (PEPP) (European Central Bank, 2023g).

When discussing monetary policy, it is important to distinguish between conventional and unconventional monetary policies, especially during economic downturns. In the financial crisis, both conventional and unconventional monetary policies were used widely by world’s central banks (European Central Bank, 2023b). The conventional monetary policy aims at setting the overnight interest rates – the deposit and marginal lending interests – on the basis of which adjust the money supply operations targeted to the overnight rates (European Central Bank, 2023b). It is used during normal times

because it is an effective and sufficient tool for managing price stability and liquidity conditions. Hence, the European Central Bank (2023b) does not either practice direct lending to private and public sector during stable times or booms but can only lend against collateral. Unconventional monetary policy comes into question precisely in economically bad times, when conventional monetary policy proves to be ineffective. Referring to the European Central Bank (2023b), the combination of economic shock and conventional monetary policy becomes ineffective because the extreme economic situation forces the central bank to lower the short-term interest rate down to zero. The interest rate has been bounded by zero which means that it has not been possible to lower it further. The European Central Bank, on the other hand, decided in June 2014 to add negative interest to its monetary policy toolbox by lowering the deposit facility rate below zero (Claeys, 2021, p. 6). A negative interest rate is an extreme technique used to combat deflation. It means that banks with substantial deposits at the ECB must pay interest on their deposits, and the cost has risen since the Pandemic Emergency Purchase Programme began in 2020 (Claeys, 2021, p. 6). When interest rates are zero or below zero, traditional monetary policy becomes ineffective, and the central bank must resort to unconventional monetary policy, such as balance-sheet expansion. As seen in Figure 7, the ECB has grown its balance sheet at a face pace since the policy rate hit zero and below zero in 2014. Hence, it can be concluded that the relationship between the ECB interest rates and increase of the balance sheet are inverted.

According to Joyce and others (2012, p. F271), the main focus of the monetary policy before the financial crisis was found to be the target of 2 percent inflation which was controlled by the short-term interest rates. However, this simple target no longer prevail as the central banks have started to focus on maintaining overall financial stability on top of the inflation level target. As per Joyce and others (2012, p. F271), the conventional monetary policy has been successful in maintaining stable inflation, but it has failed to prevent asset market bubbles and a stable economy. A so-called Tinbergen's Law states that, an authority's N amount of policy targets require at least N amount of policy tools meaning that the central banks have had to expand their policy instruments (Joyce et al.,

2012, p. F271). As a result, the unconventional monetary policy tools must have been put into practice by the central banks.

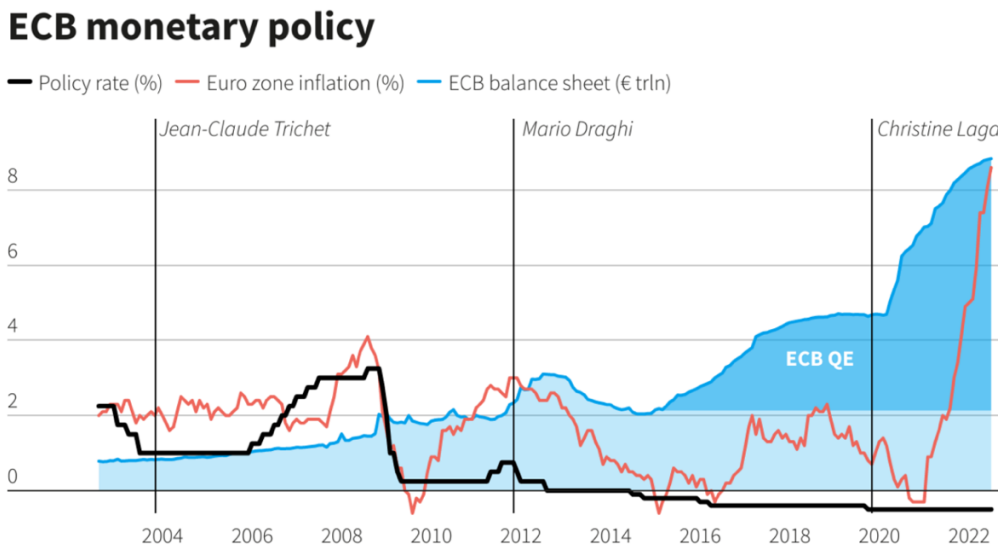


Figure 7. ECB policy rate and balance sheet (Ranasinghe et al., 2023).

The primary tool for this purpose is to change the structure of the ECB's balance sheet or to purchase additional assets to expand the balance sheet even further (European Central Bank, 2023b). In addition, the ECB can provide information about its future actions using its forward guidance concerning for example the medium-term interest rates (European Central Bank, 2023b). Hence, If the ECB announces the medium-term interest rates to stay at a low level in the future, it affects the medium-term interest rate set by the commercial banks. The central bank's future expectations for the economy are important in terms of the credibility and durability of the central bank's monetary policy tools, and thus the effectiveness of the economy's revival in downturns. Why it is important? One reason is that in the recession an economy would not sink into a liquidity trap where the nominal interest rate become so low that public will become indifferent in holding cash and bonds (Krugman, 1998, p. 139). According to Krugman (1998, p. 139), the only effective way out of the liquidity trap is that if the central bank will credibly seek to find a higher price stability in the future. Hence, the central bank's announcement regarding the level of futures prices will be the main tool for escaping the liquidity trap; as it is not anticipated that the open money supply will continue in the future, which will

prevent it from increasing future prices and render the effect of money expansion ineffective.

In times of economic distress, the ECB's balance sheet is a crucial tool for unconventional monetary policy. The ECB's direct asset purchases are referred to as quantitative easing (European Central Bank, 2023b). It can be used to buy private or government assets directly from the secondary market (European Central Bank, 2023b). However, there is a pertinent reason why the central bank prefers to purchase long-term government bonds from the market rather than other assets; when purchasing government bonds, the demand lowers the yield of the bonds, stimulating longer-term lending and thus investments (European Central Bank, 2023b). The other reason is that, because government bonds are regarded as benchmarks for the pricing of other riskier securities, purchasing sovereign bonds reduces the yield on private bonds. The expansion of the central bank's balance sheet indicates that its asset side expands because of increased bond holdings purchased from the secondary market by international banks (Joyce et al., 2012, p. F276). Furthermore, the liabilities on its balance sheet increase in proportion to the amount lent to banks (Joyce et al., 2012, p. F276).

4.1.1 Quantitative easing

The history of quantitative easing (QE) extends back to 2001 when the Bank of Japan established the use of large-scale asset purchases to boost a deflating economy where bond rates had fallen so low that people prefer to hold cash instead of debt (Matousek et al., 2019). The idea was that by buying government bonds at zero interest from the market, the Bank of Japan would inject a significant amount of money into the economy, believing that it would eventually trickle down to consumers via banks, resulting in more spending (Joyce et al., 2012, p. F272). Quantitative easing was introduced elsewhere – Europe, US, and England – during or right afters the financial crisis in 2007-2008, which also aimed to revive the economy and preserve functioning financial markets. The European Central Bank continued to practice quantitative easing after the financial crisis

but especially in March 2020 after the Covid-19 pandemic burst when it presented the Pandemic Emergency Purchase Programme (PEPP) (European Central Bank, 2023h).

According to the European Central Bank (2023j) the purpose of large-scale asset purchases (APP) is to boost the economy and maintain flowing financial markets in an economically stagnant time when interest rates and inflation are low. The object of quantitative easing is to support economic growth in the Euro area and help return inflation to the ECB's target of 2 percent (European Central Bank, 2023j). When the number of bank reserves increases, banks start to lend money with lower interest rates which encourage borrowing and promotes consumption and larger investments. Especially, Matousek and others (2019, p. 1) find that smaller local banks benefit the most from quantitative easing, which is reflected in gross domestic product and inflation. However, the risk of high inflation increases due to the increased money supply which is one of the concerns about the side effects of quantitative easing that have caused ambiguity about its profitability as a monetary policy instrument.

Joyce and others (2012) evaluate in their article the impact of quantitative easing and its effectiveness following the financial crisis in 2007. This time period is crucial for the assessment of quantitative easing because the financial crisis drove the economies into deep recession and posed challenges to central banks' monetary policy. The uppermost purpose of quantitative easing in England and US was not to provide liquidity to banks but to affect bond yields by lowering them (Joyce et al., 2012, p. F274). Joyce and colleagues (2012) perform a review of the literature on the influence of quantitative easing on government bond yields, which has been a hot research topic in the past. Joyce and others (2012, p. F282-F283) review that Gagnon and others (2011) find the US large-scale asset purchases to decrease the yield premium of 10-year bond securities by 30-100 basis points. They also review that Meier (2009) finds that the UK bond yields dropped by 35-60 basis points due to the Bank of England’s large-scale asset purchases. The effect of quantitative easing on bond yields has been found to be one-sided, lowering bond yield-to-maturities.

4.1.2 Scarcity and spotlight effect

Quantitative easing can affect financial markets through various transmission channels that can be divided into direct and indirect channels (Ferdinandusse et al., 2020, p. 5). The direct transmission channels include communication or signaling channel and portfolio rebalancing channel (Ferdinandusse et al., 2020; p. 5; Bank of England, 2023, European Central Bank, 2023d). These direct channels influence directly in financial conditions which is signaled to economic growth and inflation (European Central Bank, 2023d). The most studied are the indirect channels, which are duration risk, scarcity, and local supply channels, although they are still a part of the direct portfolio rebalancing channel (Ferdinandusse et al., 2020, p. 5, Bank of England, 2023).

According to Ferdinandusse and others (2020, p. 5), the indirect transmission channels focus on lowering the yields of assets that are part of the central banks large-scale asset purchases. When central bank purchases bonds from the market, it lowers the "free-float" or available supply of the selected bonds in the market which increases the bond prices and lowers their yields (Pelizzon et al., 2018; Bank of England, 2023). This so-called scarcity channel reduces the number of tradable bonds lowering their yields but also the yield of their substitutes (Bank of England, 2023; European Central Bank, 2023d). As a result, the effective market interest rate falls, making borrowing cheaper for businesses, banks, and the government, boosting spending in the economy (European Central Bank, 2023d). Lower yields cause investors to adjust their portfolios toward higher yielding bonds, which in this case are short-term bonds (Ferdinandusse et al., 2020, p. 5; Bank of England, 2023). When investors shift their portfolios to shorter assets, the duration risk channel of QE appears. Hence, quantitative easing reduces the duration risk of investors' portfolios (Bank of England, 2023). In order for the portfolio rebalance channel to work and to reduce bond yields, investors must not have preferences for specific maturity assets because otherwise they would not change their portfolio from long duration assets to shorter higher yield assets (Bank of England, 2023).

The local supply or scarcity channel is mostly known as the “scarcity”, “supply” or “stock” effect of quantitative easing. All the terms refer to the amount and supply of available bonds in the market that will decrease as a result of large-scale asset purchases. In terms of liquidity, the QE scarcity channel has been found to have a significant negative effect by lowering the tradeable amount of bonds in the market making it harder for investors to find a buyer for their investments (Grimaldi et al., 2021; Han & Seneviratne, 2018; Pellizzon et al., 2018; Ferdinandusse et al., 2020). Another well-known quantitative easing transmission channel is the liquidity channel, which influences the liquidity premium of bonds (Bank of England, 2023). As explained earlier, the liquidity premium of bond yields arises when investors demand a compensation that they may not be able to exchange their bond for cash – that is, sell the bond – immediately at the desired time in the future. When the central bank decides to begin purchasing assets, it improves bond liquidity by providing a large and credible buyer to the market, which reduces the liquidity risk of the owners of these bonds in the market (Bank of England, 2023). This is usually referred to as the “demand”, “spotlight” or “flow” effect of quantitative easing. It has been discovered to have an improving influence on bond liquidity, but only temporarily, because each period's new purchases temporarily help the sale of bonds on the market (Pelizzon et al., 2018; Ferdinandusse et al., 2020; Grimaldi et al., 2021). The spotlight effect occurs quickly as a result of the central bank's large demand for bonds in the market, resulting in better liquidity (Pelizzon et al., 2018, p. 1).

The scarcity and spotlight effects of quantitative easing on the government bond market are well-studied and the results are mostly unanimous. However, the scarcity effect has received more attention from researchers. Pelizzon and colleagues (2018, p. 3) discover that the scarcity effect causes greater bid-ask spreads and worse liquidity as the Bank of Japan’s holdings ratio increases, whereas the spotlight effect, narrows bid-ask spreads and improves liquidity through a large demand-supply imbalance. Similarly, Han and Seneviratne (2018) find that the scarcity effect has highly negative impact on bond liquidity in Japan’s government bond market and the effect is also dependent on the size

of the BoJ's holdings. Thus, they discover that QE improves liquidity when the Bank of Japan's holdings are small. The two opposing effects of QE take place through the market functioning channel that can be viewed also from the market micro-structure perspective (Han & Seneviratne, 2018, p. 5; Ferdinandusse et al., 2020, p. 5). The disruption in trading and search frictions determines the degree of market functioning channel, and quantitative easing can help lower trading frictions by boosting market-making activities (Han & Seneviratne, 2018, p. 5). On the other hand, Kandrac and Schlusche (2013) study the flow effects of large-scale asset purchases that may happen at the time of the purchases. They find no significant results of the flow effects of quantitative easing on bond liquidity. Grimaldi and others (2021) find that scarcity effect has a stronger effect on liquidity than the spotlight effect. The scarcity effect has five times stronger negative impact on bond liquidity than the spotlight effect. However, they also find that the spotlight effect has a positive and significant impact on liquidity. Ferdinandusse and others (2020) also find opposing effects of the scarcity and spotlight effect on liquidity which they designate as a price-liquidity trade-off. They explain that an increase in the central bank's asset holdings reduces not just the number of bonds on the market, but also the number of sellers. Not to mention, the decrease in bond yields slowly reduces the number of buyers for these bonds.

4.1.3 ECB's asset purchase programmes

The ECB started asset purchases under the Asset Purchase Programme (APP) in October 2014 in order to help to retain price stability along with other unconventional monetary policy measures (European Central Bank, 2023a). The ECB can use APP as a policy tool to ensure that low inflation does not last for too long (European Central Bank, 2023d). Prior to the APP, the ECB's asset purchase program was known as the "Securities Market Programme" (SMP), and it began purchasing debt securities in 2010, amid the financial crisis (European Central Bank, 2023a). The programme was terminated in 2012, but the securities purchased through it will be retained till maturity (European Central Bank, 2023a). The APP programme is divided into four programmes based on bond qualities:

Corporate Sector Purchase Programme (CSPP), Public Sector Purchase Programme (PSPP), Asset-Backed Securities Purchase Programme (ABSPP), and Covered Bond Purchase Programme 3 (CBPP3) (European Central Bank, 2023a). The CSPP is a corporate bond programme that began in June 2016 (European Central Bank, 2023a). The ECB has only purchased corporate bonds with credit ratings of AA, A, and BBB, with a highest focus on the utilities sector (European Central Bank, 2023a). The PSPP programme focuses on the public sector securities that started in March 2015. The purchases include nominal and inflation-linked central government bonds, and the bonds that are purchased have been issued mostly by local governments but also agencies, international organizations, and multilateral development banks (European Central Bank, 2023a). The ABSPP started in November 2014 and continued to 2018 but after that, the ECB only started to reinvest the coupon principal payments of maturing loans (European Central Bank, 2023a). The CBPP3 also started at the end of year 2014 continuing to 2018, and since then only the principal amounts have been reinvested (European Central Bank, 2023a).

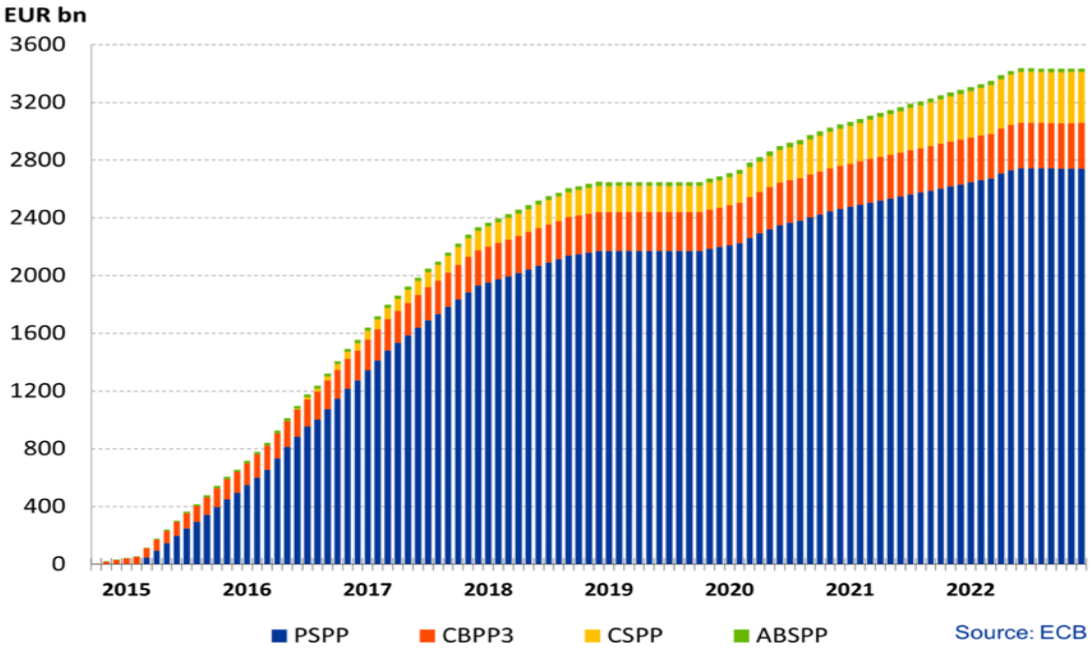


Figure 8. Cumulative net asset purchases of ECB (European Central Bank, 2023a).

Figure 8 illustrates the ECB's Asset Purchase Programme (APP) by the four programmes. It clearly illustrates the programme sizes, of which PSPP is the largest and the ABSPP smallest. The ECB's asset holdings under the APP's reached to a total of 3 252 000 million euros in January 2023 of which the PSPP's share is approximately EUR 2 585 000, CSPP's EUR 344 000, CBPP3's EUR 303 000, and ABSPP's EUR 20 800 million. The holding ratio indicates the present value of the ECB's PSPP asset portfolio, which fluctuates in value according to market conditions. In turn, the cumulative net asset purchases represent the total number of assets purchased under the programme that considers purchases and redemptions. Under the APP programme, ECB has purchased debt securities at time to time. As seen from the Figure 9 that illustrates the net asset purchases by programme, the net purchases have been at their greatest in 2015-2018 and lowest between 2019 and 2020. After 2020, the purchases clearly started again in the programme. The monthly net purchases range from approximately 10 billion to 80 billion euros.

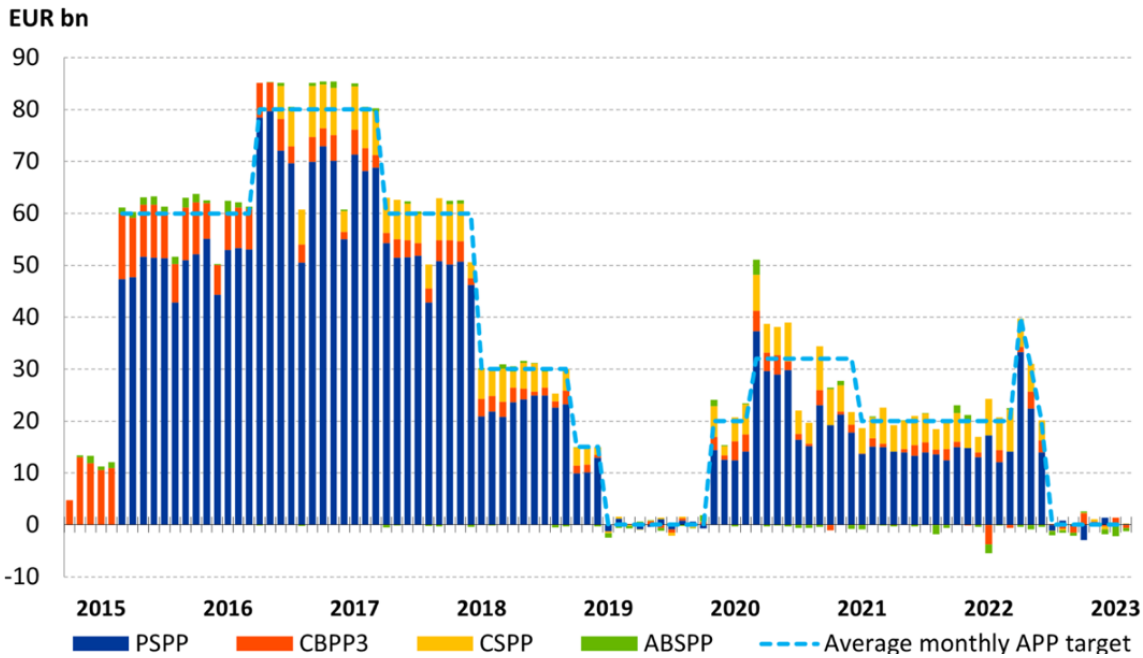


Figure 9. Net asset purchases of ECB (European Central Bank, 2023a).

This thesis focuses on the Public Sector Purchase Programme, which comprises 18 countries and Supranationals. The net purchases are made on monthly basis and are divided by nations according to ECB's capital key (European Central Bank, 2023c). The

capital key is based on the GDP percentages of Euro area countries and each of the purchase per issued amount of bond is limited to 33 % (Ferdinandusse et al., 2020, p. 18). The ECB's largest holdings are in the bonds of France, Germany, Italy, Spain, and the Netherlands (see Figure 10). Supranationals also account for a sizable share of the purchases. For Germany, the total net purchases account for almost EUR 700 billion between 2015 and 2022. As of 22nd of November 2022, the accumulated purchases under the PEPP programme reached to EUR 2 741 billion. This means that Germany's share of the ECB's purchases under the PSPP programme was 25.5 percent, or one fourth. France's share is almost 20 percent and Italy's approximately 16 percent. Hence, these three countries account for a massive share of the ECB's PSPP debt security purchases. The weighted average maturity (WAM) of the invested bonds under the PSPP is between 5.5 and 11 years (European Central Bank, 2023c). The public sector purchases are also limited by bond maturities which can vary between 1 and 30-year bonds (European Central Bank, 2023c). Hence, this means that the bond to be purchased needs to have a minimum remaining maturity of 1 year and maximum of 31 years. The PSPP started operating in March 2015 and continued to December 2018 after which the principals of maturing bonds were only reinvested mostly in 2019 (European Central Bank, 2023c). In November 2019, ECB continued the purchases until June 2022 after which the ECB has only reinvested the principal payments of the maturing assets in the PSPP portfolio (European Central Bank, 2023c).

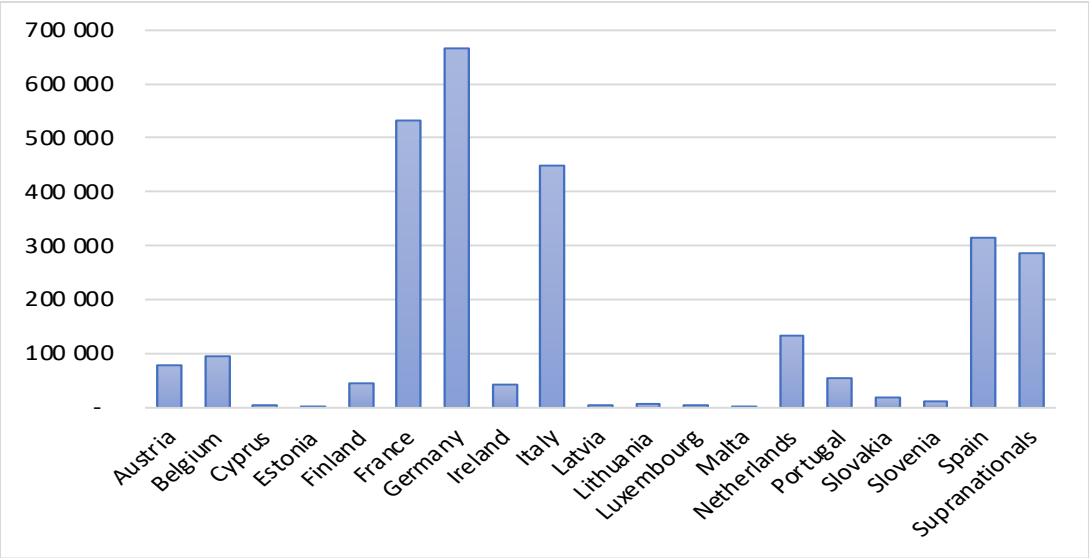


Figure 10. Total net purchases by the ECB under the PSPP programme by nations in 2022 (in millions).

Figure 11 breaks down the ECB's PSPP cumulative net purchases by country considered in this study. The graph clearly indicates the number of purchases made for each country. The purchases are made using the ECB's capital key, which takes into consideration the countries' gross domestic product. As a result, the ECB has purchased the most bonds from Germany, France, Italy, and Spain. Figure 11 also depicts how these countries' bond holdings on the ECB's balance sheet have increased in time.

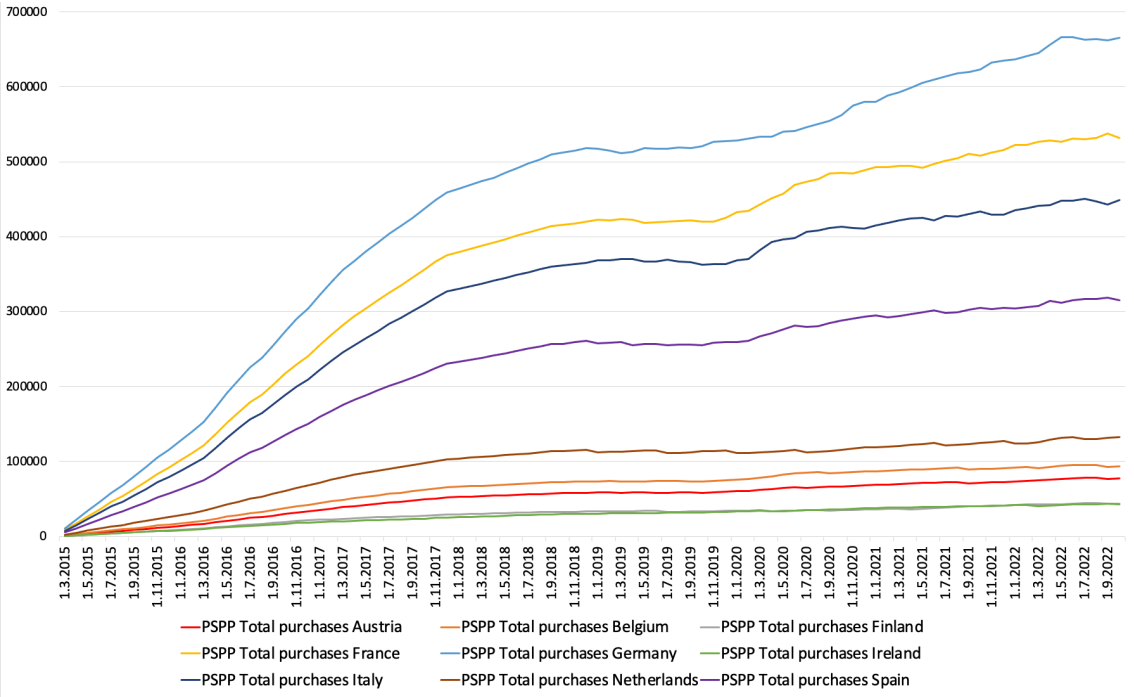


Figure 11. Cumulative net purchases under the PSPP programme by nations between 2015 and 2022 (in millions).

The ECB's APP Programme does not include the Pandemic Emergency Purchase Programme, which began following the outbreak of the Covid-19 pandemic. The PEPP programme is viewed as a separate program that was implemented as a temporary monetary policy intervention to mitigate the pandemic's severe risks to the economic outlook and monetary policy transmission mechanisms (European Central Bank, 2023h).

Hence, the purchases are made on top of the APP programme. The PEPP is made up of private and public sector securities such as covered bonds, corporate bonds, commercial paper, and public sector assets, but this thesis solely considers the public securities (European Central Bank, 2023h). The public sector asset purchases are also made based on the ECB's capital key in this programme. The PEPP's cumulative net purchases reached to a total of 1 714 000 million euros in January 2023 of which the public sector securities' share is approximately 1 661 000 million euros (European Central Bank, 2023h). The same PSPP directions apply to the PEPP programme, with the exception that purchases are done bimonthly, and the programme includes Greece to its purchases (European Central Bank, 2023h). Under the PEPP, the purchases were carried out from March 2020 to December 2021 after which the Governing Council decided to stop the purchases in March 2022 and only reinvest the principal payments of maturing securities until 2024 (European Central Bank, 2023h). According to European Central Bank (2023h), all the purchases are conducted flexibly according to the market situation.

4.2 Efficient Market Hypothesis

Liquidity plays an important role in enhancing efficient markets which is why the efficient market hypothesis theory is justified in being explained as part of the theoretical foundation of this thesis topic. An efficient marketplace is one in which prices fully reflect all available information (Fama, 1970, p. 383). This basic asset allocation theorem was found by Eugene Fama (1970) who's main proposition suggested that in an efficient market, investors can select among firms' issued securities whose value reflects all information available from the company at any given time. That is, the movement of the market capital is allocated efficiently through signals on the market (Fama, 1970, p. 383). In an efficient market, asset prices will follow a "random walk" where new information is fully based on a surprise and detached from the previous day's news. Assets will not follow a pattern or trend in a short-term and after the unpredictable news, prices can still move equally up or down in the next day because tomorrow's price is not dependent on today's information (Malkiel, 2003, p. 59).

According to the Efficient Market Hypothesis (EMH), available information is equally available to everyone and therefore using the information, all investors – uninformed and experts – will earn the same rate of return when randomly selecting a portfolio from the given assets. Public have access to the same information on the market, but each can interpret the information differently without it implying market inefficiency (Fama, 1970, p. 388). New information can be used to predict future stock prices but not consistently. Prices will quickly adjust to new information about which investors will be informed at the same time and the arbitrage opportunities will disappear rapidly. Some investors may have gained a profit by analysing the information differently than others, but on average it is just as likely to win as to lose when new information enters the market. Only a share of investors is enough making markets efficient (Fama, 1970, p. 388) because their competition is sufficient enough to bring bid and ask offers into alignment.

Fama (1970, p. 388) presents three forms of market efficiency to help determine what level of information is truly reflected in prices. Many researchers have accepted his propositions about market efficiency and confirmed his results. Especially, the *weak form* of market efficiency, which Fama (1970, p. 388) presents first, shows that researchers agree with Fama where merely historical information is at a given moment fully reflected in market prices and cannot be used to predict future price movements. Only new public information can give market participants the opportunity to predict a short-term price movement. In the *semi-stong form* market efficiency, the market reflects public information in addition to the historical data and only private information may be sufficient to predict coming price movements. This implies the second form of market efficiency by Fama (1970, p. 383). The semi-strong form of market efficiency analyses whether the market on average fully reflect an obvious public information. In the most extreme situation, market prices already reflect historical, public, and even private information which Fama (1970, p. 383) calls a *strong form* market efficiency. The purpose of the level is to consider if investors can access monopolistically to any form of information that may affect market prices (Fama, 1970, p. 383). In this kind of a

marketplace, the private information no longer brings investors an opportunity to earn profit because all relevant information is in the prices. He admits that the strongest market efficiency level mainly represents a benchmark for the other market efficiency level because only specialist and corporate insiders have this monopolistic leverage (Fama, 1970, p. 415). These specialists can get access to information about unexecuted limit orders which have been proved to predict short-term price movements by monitoring order flows.

4.2.1 Criticism of EMH

Not only the strong-form market efficiency has been considered false, but the entire idea of market efficiency has received wide criticism. After the Fama's (1970) first publication of EMH, authors continued to do research on the market efficiency and concluded in the 21st century that the idea of EMH do not totally qualify as the stock market prices are to some extent predictable (Malkiel, 2003, p. 60). Anomalies and stock patterns were discovered, fundamental analysis seemed to be useful for the future return prediction after all, and perhaps, economist suggested that investors could earn beyond the market return (Malkiel, 2003, p. 60). In his study, Malkiel (2003) intends to review the main literature of the most significant evidence against efficient markets, such as short-run and long-run correlations, valuation parameters used as return predictors and the resulting patterns like size effect et cetera, and lastly, market crashes and price bubbles. He examines these so-called "attacks" on market efficiency, and finds that on the contrary to expectations, stock markets are way more efficient and less predictable than what researchers show. Thus, gaining risk-adjusted excess returns on the market is indeed almost impossible despite the existing stock market patterns, price bubbles and predictive analyses.

Shiller (2003) discusses the transition from efficient markets towards behavioral finance in the 1990s. His idea of the market efficiency concludes that Fama's (1970) efficient market theory represents an ideal market which does not work in every market situation.

However, he agrees that markets' functionality is mostly efficient so that continuous immediate profits cannot be available. Shiller (2003) criticizes Fama for arguing against market anomalies caused by human psychology, which results in irrational investor behavior and existing price patterns. Fama's theory was that because stock prices in an efficient market do not follow any patterns and are independent from yesterday's news, these patterns should exist in an irrational market (Shiller, 2003, p. 101). However, because Fama notes that anomalies tend to disappear after a certain period, markets cannot be inefficient and so, they are efficient. Shiller (2003, p. 102) argue against Fama and states that not all market situations tend to last, not even random walk always occurs and so, in an inefficient marketplace, patterns do not have to be long lasting.

4.2.2 The impact of liquidity on market efficiency

The interaction between market efficiency and liquidity is mutual. Liquidity is a part of explaining intermittent market inefficiency but also an important factor when talking about enhancing market efficiency. Chordia and others (2008) prove in their study that intraday market efficiency is created partly by and is inversely related to market's capability to adapt order imbalances. Order imbalance refers to a situation where an asset receives too many buy or sell orders which can freeze the trading of the asset due the lack of opposing orders. If the market is inefficient, short-term returns are predictable from the buy and sell order imbalances which can create arbitrage trades for investors. This indicates larger transaction costs and thus, wider bid-ask spreads for the market. In turn, if the market is efficient, these arbitrage trades disappear, and the returns become non-predictable. The efficiency of the market is in connection with liquidity. When daily market liquidity is high and transaction costs decrease, the market is capable of accommodating order imbalances better making the predictability of the returns to disappear (Chordia et al., 2008, p. 250). Hence, the market becomes more efficient. The Chordia and others' (2008) findings are in line with Fama's (1970) criteria for market efficiency that in an efficient market, asset prices become unpredictable.

According to Li and others (2009), this informational asymmetry is observable on the government bond market. They state (Green, 2004) that government bond prices reflect mainly public information, but private information occurs because investors have different interpretation about the public information (Li et al., 2009, p. 469). The heterogenous view of the available information take place because some investors, for example large investment banks, can have more talented analysts to analyze the available information. Li and others (2009, p. 469) also suggest that these better-informed analysts are hence capable of monitoring their clients' order flows and their upcoming trades which gives the analysts an opportunity to predict short-term price movements. Li and others (2009) call this an information risk, which according to Chordia and others' (2008) research, would mean that to some extent arbitrage opportunities exist on the treasury market.

The relationship between market efficiency and liquidity can be also explained through the relation between transaction costs and a phenomenon called positive return autocorrelation. A positive autocorrelation of asset returns refers to price patterns which should not be inhibited in a fully efficient marketplace. In positive autocorrelation the coming price of an asset is correlated with the lagged value of the current price level. Steeley (2015, p. 308) finds quantitative easing to reduce bid-ask spreads and lowering transaction costs on the gilt market. It is expected that the reduction in market transaction costs will manifest as a decrease in positive return autocorrelation, implying less sluggish price formation and taking advantage of price prediction (Steeley, 2015, p. 308). This happens because lower transaction costs should speed up price formation. These findings would further support the importance of liquidity analysis, and that better liquidity is an important factor of relieving arbitrage and enhancing market efficiency.

5 Literature review

The theory part has now been covered, so it's time to move on to presenting earlier literature. The past literature on the effects of quantitative easing on bond market liquidity in various financial markets and countries is reviewed in this chapter. The most relevant studies are presented in more detail. The aim of this chapter is to create a general understanding of the existing literature on the chosen topic and to highlight possible gaps. The Covid-19 crisis is considered in this literature review as part of the topic and is discussed in its own chapter.

5.1 Quantitative easing and bond liquidity

Since the starting date of large-scale asset purchases by central banks, the literature of quantitative easing has expanded and the impacts of quantitative easing on the financial market have received a lot of attention. However, the empirical evidence on the effects of QE on bond liquidity has remained inconclusive and limited. The existing literature on the topic is relatively recent, which explains the spike in interest in quantitative easing and bond liquidity as a research topic, but it also illustrates that many of the area's significant studies are still working papers like Ferdinandusse et al., 2020, Grimaldi et al., 2021, Han & Seneviratne, 2018, and Schlepper et al., 2017. Previous studies on the effects of large-scale asset purchases on bond market liquidity has been conducted in the Euro area, the United States, Japan, Sweden, and the United Kingdom. First a general overview is given of the results that have been obtained from the studies regarding the topic and after that, the most relevant papers are reviewed more broadly.

Some studies find that QE improves bond liquidity (Todorov, 2020, De Pooter et al., 2018, Christensen & Gillan, 2022, and Iwatsubo & Taishi, 2018). Other studies find that QE weakens bond liquidity or find no significant results (Schlepper et al., 2017, and Kandrac & Schlusche, 2013). According to some of the studies, the different transmission channels of quantitative easing – demand and supply channels – show both positive and

negative effects on bond liquidity (Ferdinandusse et al., 2020, Grimaldi et al., 2021, Pelizzon et al., 2018, and Han & Seneviratne, 2018). The positive and negative results imply the nonlinear effect of quantitative easing on bond liquidity, in which the central bank's demand effect increases bond liquidity but, as the central bank's balance sheet grows to a certain level, the scarcity effect starts to dominate, reducing bond liquidity.

The previous literature is divided by nation as follows; for the Euro area, the top researchers studying the impact of quantitative easing on bond liquidity are Ferdinandusse and others (2020), De Pooter and others (2018), Todorov (2020), and Schlepper and others (2017). A search-theoretical framework of QE on OTC bonds is presented by Ferdinandusse et al., (2020) and De Pooter et al., (2018). In turn, Todorov (2020) study the liquidity of Euro area corporate bonds and focuses on the ECB's Corporate Sector Purchase Programme (CSPP). Schlepper and others (2017) however, study the scarcity effects of quantitative easing on German bonds. Kinateder and Wagner (2017), and Eser and Schwaab (2016) rather focus on the yield impact of the quantitative easing in the Euro area. For US, the top researchers on the liquidity effects of QE are Christensen and Gillan (2022) and Kandrac and Schlusche (2013). Christensen and Gillan (2022) focus on the Treasury inflation-protected securities (TIPS market) while Kandrac and Schlusche (2013) include in their research US Treasury securities. Kapoor and Peia (2021) study the liquidity creation by banks via Fed's quantitative easing and find that QE increases liquidity when banks transfer the increased reserved into illiquid assets. On the contrary, Mishra and others (2020) focus on the stock market and find that Fed's QE-1 programme increased the liquidity of stocks through the increased reserves of banks. For Japan, the most researchers focus on the spotlight and scarcity effects of quantitative easing on the bond market finding very similar results (Pelizzon et al., 2018; and Han & Seneviratne, 2018.). Iwatsubo and Taishi (2018) on the other hand study the effect of Bank of Japan's purchase policy changes in 2013 and find that they improved government bond liquidity. According to the study, there are three policy changes that affected the liquidity: BoJ started to purchase bonds more frequently, it lowered the purchased amount per auction, and reduced variability in purchase volumes.

Grimaldi and others (2021) narrow their research to the central bank of Sweden and the impact of the QE on the Sweden's government bonds. In UK, the effects of quantitative easing have been studied by Breedon (2018) and Steeley (2015). Breedon (2018) finds that a so-called "round trip" procedure of quantitative easing where the central banks purchase bonds from the secondary market and not directly from the government generates additional transaction costs in the process. Steeley (2015) discovers quantitative easing side effects on the UK bond market, where the bid-ask spreads of gilts fell, resulting in lower trading costs and hence better liquidity.

De Pooter and others (2018) study the European Central Bank's Securities Markets Programme between 2010 and 2012 and its impacts on sovereign bond liquidity premia in Portugal, Ireland, Italy, and Spain. They create a search-based asset pricing model that produces the liquidity premium for the study, and they find economically significant results that an increase in purchases lowers the liquidity premia. Their main result shows 32-40 basis point decrease in the liquidity premium of 5-year sovereign bonds. De Pooter et al. (2018) study different maturity bonds and they find the same results across the yield curve. Ferdinandusse and colleagues (2020) present a study that is very similar to De Pooter et al. (2018). They also use a search and matching model to investigate the effect of quantitative easing on bond yields and liquidity in the Euro area sovereigns. However, they examine a price-liquidity trade-off by which they mean the spotlight and scarcity effects of QE. In comparison to De Pooter and others (2018), their research is larger, focusing on the same 9 Eurozone countries as this thesis, but they also include Portugal in their study. Their study focuses on the PSPP programme between 2014 and 2015 and includes a Preferred Habitat Index score, which measures preferred habitat investors in the countries because it affects liquidity in the market. A larger share of PHIs means a smaller share of buyers and sellers in the secondary market, which means that liquidity is expected to worsen in this case. However, their model finds opposite results that fewer PHIs decreases liquidity. They distinguish the spotlight and scarcity effect of quantitative easing in their model and find opposite effects of the two on liquidity. They

find that as ECB works as a large buyer in the bond market it increases liquidity but because it holds the purchased bonds until maturity, it worsens the liquidity.

Todorov (2020), Schlepper and others (2017) and Kinateder and Wagner (2017) concentrate their research on the European debt market but not from a liquidity perspective alone. Kinateder and Wagner (2017) use a panel regression model to determine the pricing of bonds for EMU sovereign debt. According to their results, yield spreads widen due to quantitative easing but are also affected by country-specific liquidity premia and greater total market liquidity. Todorov (2020) focuses on the corporate debt markets and the focus is naturally on the European Central Bank's Corporate Sector Purchase Programme (CSPP). However, the focus is on the announcements of the programme rather than the actual purchases and the impact of them on bond prices and liquidity. The results are straightforward in that quantitative easing increased the corporate bond market liquidity and lowered the yields of the bonds. Bid-ask spreads of the corporate bonds dropped by 45 % indicating a considerable and even economically significant improvement in liquidity. Like Schlepper and others (2017), Todorov (2020) uses a transaction-based analysis from Euroclear where the data consist of volume of trading and bond holdings of all Euro area QE-eligible corporate bonds. The observed period for the turnover is between 2015-2016.

Schlepper and others (2017) also conduct research on the impact of ECB's asset purchases on bond liquidity in the period of 2015-2016 but for German bunds. They do, however, concentrate on the ECB's PSPP purchase programme, which the German central bank purchases from the German bond market. Their data consist of daily intra-day transaction-level data gathered from MTS platform. This allows them to examine the impact with event study method precisely within a day. Their study is unique in the sense that German bonds are considered as the benchmark bonds in European debt market and their credit rating is AAA level. Schlepper et al. (2017, p. 3) remarks that if the PSPP purchase programme affects the German bonds, it will inevitably affect the rest of the Euro area bond markets which are priced according to the German yield curve. Hence,

they find that bid-ask spreads of the German bonds widen, and market depth decreases as a result of the PSPP purchases.

Empirical research for the United States focuses on the Federal Reserve's large-scale asset purchase programmes (QE1-QE4) from 2008 to 2014. Only few US papers focus directly on the impact of quantitative easing on bond liquidity and equally the concentration of the papers is rather on the flow effect of QE than on the stock effect. Hence, the results of the studies were found insignificant due to the choice of the transmission channel of QE. Kandrac and Schlusche (2013) find insignificant results when studying the impact of Federal Reserve's QE-1 and QE-2 purchases on nominal (non-TIPS) US treasury security prices and liquidity between 2009-2012. They use bid-ask spreads as a liquidity measure and discover that the impact of the purchases on liquidity is minor but still positive. Due to the insignificancy of their results, they conclude that the flow effects are not present in the treasury market.

In turn, Christensen and Gillan (2022) conducts research on the opposite, Treasury inflation-protected (TIPS) US treasury securities and examine how the Federal Reserve's second asset purchase program QE-2 affects the liquidity premium of these assets. They also study the flow effect of QE like Kandrac and Schlusche (2013) with a similar time period from November 2010 to June 2011. Their results are promising as they manage to find quantitative easing to reduce trading friction in the TIPS market, in other words, improving liquidity. When trading friction is high, it is reflected as a higher liquidity premium (Christensen & Gillan, 2022, p. 1). However, through the liquidity channel of QE, trading frictions will be reduced when the Fed operates as a large credible buyer for the QE eligible securities. According to Christensen and Gillan (2022, p. 1), the central bank as buyer will promote the bargaining power of sellers on the market. The purpose of their work is to document the liquidity channel in the US treasury market, and they find positive relationship between QE and TIPS' trading volumes, but the outcome is insignificant. They acknowledge the other transmission channel of QE, the scarcity effect, that impairs market liquidity and hence, may have impacted debilitatingly on their

results. Their results show that the Fed's QE-2 reduced liquidity premiums in the TIPS market temporarily, only appearing to the targeted securities when Fed proceeds with the purchases. They also show that the liquidity premiums on high-quality US corporate bonds have not dropped since QE.

Steeley (2015) is the only author to study the impact of QE on the liquidity on the UK government bond market, that is, the gilts market. Steeley (2015) is motivated to find out about the side effects of QE for investors and issuers. The findings of the study are substantial. He finds that quantitative easing of the Bank of England resulted in a significant reduction of the transaction costs and thus, bid-ask spreads in the market resulting a better liquidity and functioning markets. More specifically his results show that bid-ask spreads fell by one half after the onset of asset purchases. However, the method of the paper is rather different compared to the previously mentioned studies. He investigates 46 government bonds in time period 2004-2013 that is divided into sub-periods. This breakdown is made to examine the transaction costs of the bonds before, during and after QE.

Grimaldi and colleagues discover a nonlinear relationship between quantitative easing and bond liquidity (2021). As a result, the main finding of the paper is that the Central Bank of Sweden's holdings and treasury bond market liquidity have a nonlinear relationship, implying that central bank asset purchases improved Sweden's government bond liquidity to a limited extent. Liquidity on the bond market begins to decline more heavily once central bank holdings exceed 40 % of the issued amount. This nonlinear relationship explains the inconsistency of existing findings on the overall effect of quantitative easing on government bond liquidity (Grimaldi, et al., 2021, p. 4). The purpose of their study is to investigate whether the large-scale asset purchases and holdings of the Swedish Central Bank affect the liquidity of Swedish government bonds. They use a transaction data from MiFID reporting system for the periods of 2012-2017 and 2018-2020. Their data consist of Swedish nominal and inflation-linked bonds, whose liquidity they measure with several (five) liquidity measures. However, compared to this

thesis, they do not measure liquidity with bid-ask spreads. Their hypotheses are similar to this thesis, and they find that QE impacts positively on market liquidity through the demand effect (i.e., the purchases), and negatively through the scarcity effect (i.e., the holdings). What is interesting about their results is that the scarcity effect turns out to be more significant compared to the demand effect. They find that the scarcity effect is five times higher than the demand effect and that all five liquidity measures showed significant negative impact on liquidity through the holding ratio, but only four of the five liquidity measures showed significant and positive effect on liquidity through the purchases -variable. Another factor that makes the scarcity effect stronger is that when the central bank buys bonds it holds them until maturity, while when making purchases the increase in trading volumes is only momentary (Grimaldi et al., 2021, p. 21).

5.2 Quantitative easing and bond liquidity during the Covid-19

By now, the Covid-19 is known as the global coronavirus pandemic that started on March 2020 spreading around the world also as a life-threatening disease, and also causing a worldwide shock in the financial markets. Because the event is recent, its impact on the financial market is still under investigation and the research evidence is quite limited. There is a considerable study gap in the literature on the impact of QE on bond liquidity after the onset of Covid-19. The bond pricing effect, on the other hand, has received little attention.

Hondroyiannis and Papaoikonomou (2022) studies the Euro area Asset Purchase Programme (APP) on government bond yields during the Covid-19 period in 11 Euro area countries and find that the bond yields dropped after the onset of the Covid-19 as a result of ECB's large-scale asset purchases. They document a 58-76 basis point drop in the yields. They also find significant differences at the country level by calculating a cross-country average and that the effect of APP varies significantly based on country characters. For example, a high difference in results is seen between Germany and

Greece. Similarly, their analysis focuses on 10-year sovereign bonds, although their study period is shorter, running from January to December of 2020.

Similarly, Nozawa and Qiu (2021) incorporate the Covid-19 pandemic into their research, but they examine the impact of quantitative easing on corporate bond market credit spreads during the coronavirus pandemic. They regress the change in credit spread on the change in bid-ask spreads and trading volume and taking into account bond characteristics. They study these effect in two periods; during the financial crisis and after the onset of Covid-19 during which time the Fed made announcements on quantitative easing. However, the study finds that the liquidity measures are not significant enough to explain the credit spread changes during the QE announcements around Covid-19. In turn, they find that default risk channel rather explains the changes in credit spreads instead of liquidity. The authors point out that the liquidity channel of quantitative easing should affect credit spreads indirectly through liquidity measures so that when QE improves liquidity via the liquidity channel, credit spreads fall. However, based on their findings, this suggestion is not found to be present in the market.

There have been few studies on the liquidity impact of US corporate bonds in the Covid-19 crisis (Kargar et al., 2021; O'Hara & Zhou, 2021). Both papers find that the Covid-19 caused a shock in the corporate bond market and weakened their liquidity. Kargar and others (2021) find that the cost of trading increased dramatically and that a large demand of immediacy (dash for cash) by customers was an important factor of explaining illiquidity. Whereas, for dealers the shock increased the marginal cost of supplying immediacy causing them to rather keep capital in their balance sheets. The Fed's entry into the bond market and thus the start of QE mitigated this supply-demand shock, but more so from the customers' point of view. O'Hara and Zhou (2021) find that trading for large quantities became difficult and transaction costs rise by 90bsp. Both investors and dealers began to exert significant selling pressure. Liquidity deteriorated after the beginning of the pandemic but the effect of quantitative easing on the bond

market during the period remains unclear. Overall, the literature shows a significant research gap in this area of the topic which creates a good contribution to this thesis.

6 Data and methodology

The previous chapters have provided a wide introduction to the topic. By now, the theoretical basis for the subject is well known, as is the existing literature, on the basis of which the quantitative research part of this work can be started. The purpose of this chapter is to present the data and regression approach employed. First, the chapter will describe the data that is used and following that, the chosen regression methods for the study are introduced.

6.1 Data description

The data consist of two sample periods from March 2015 to October 2022 (PSPP programme) and June 2020 to October 2022 (Covid-19 period). This thesis focuses on the 10- and 30-year sovereign bonds of nine Euro area countries. The following countries have been chosen for the study based on their reasonable share in the ECB's PSPP and PEPP purchase programmes: Austria, Belgium, Finland, France, Germany, Ireland, Italy, Netherlands, and Spain (see Figure 10). These nations were also chosen since bid and ask price data for both 10- and 30-year on-the-run bonds is only fairly available for these countries.

The dataset is divided into two parts. First part of the data contains the European Central Bank's net asset purchases and cumulative net asset purchases of government bonds issued by the nine Euro area countries that are used as the independent variables in this study. Because the thesis focuses on the PSPP and PEPP programmes of the EBC's large-scale asset purchase programme, the data have been collected separately for the two programmes. Table 1 presents the descriptive statistics of the ECB’s asset purchase programmes and the collected data sample used in the thesis. The asset purchases of ECB are made monthly for the PSPP programme and every two months for the PEPP programme and so, the frequency of the data is monthly. Daily data would bring an advantage to the study in terms of its accuracy, but accurate daily data of purchases is

not available, which is why monthly data is therefore more reasonable. One disadvantage of the ECB's QE data is that the ECB does not publish country-specific data on purchases such as purchases by maturity, which is why a precise instrument-specific examination of purchases cannot be carried out in this work. Nevertheless, the purchases are solely limited to public debt instruments issued by governments and distributed between countries, but they include all bonds with maturities ranging from 1 to 30 years. The initial purchases, on which this thesis concentrates on, amounted to 3 765 billion euros over 91 months (April 2015 until October 2022) with approximately 41 billion government bonds bought each month. The PSPP purchases formally stopped in June 2022, but the ECB has reinvested the principal payments of maturing assets in the PSPP portfolio after the last purchase date for which data is available after June 2022. The same is applies for the PEPP programme.

Table 1. Descriptive statistics of the ECB's PSPP and PEPP asset purchase programmes (amounts in millions). The PSPP data consist of 91 monthly observations from 30/4/2015 to 31/10/2022 for each country. The PEPP data consist of 29 daily observations from 30/6/2020 to 31/10/2022 for each country. The data consist of all ECB's public debt securities purchases during the periods.

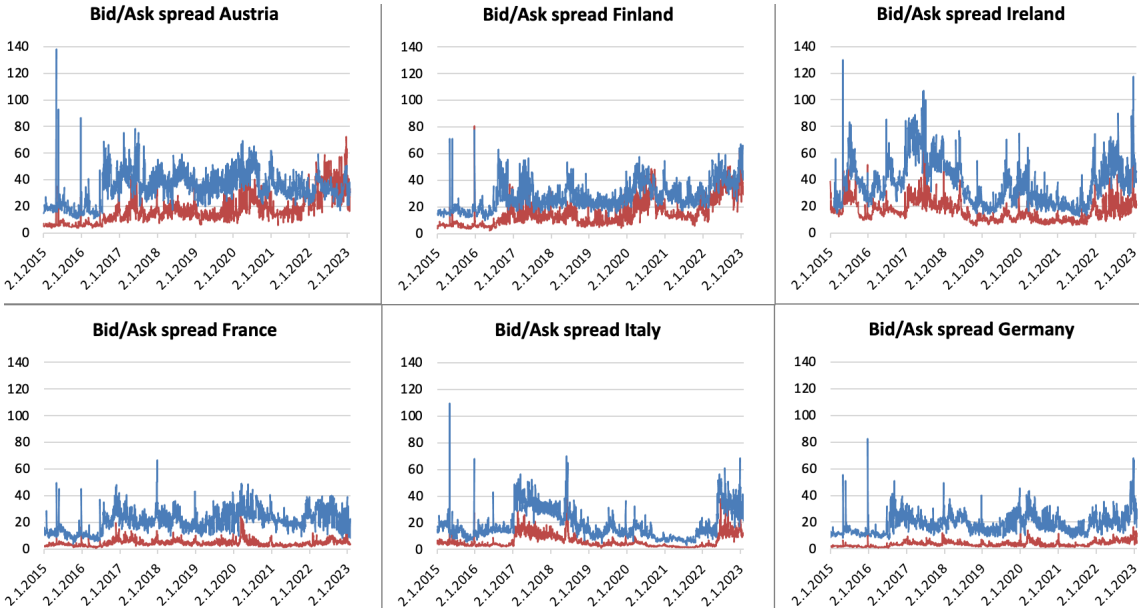
	Public debt securities PSPP	**Public debt securities PEPP**
Number of observations (in this sample)	91	29
First purchase date of the programme	31/3/2015	18/3/2020
Last purchase date of the programme	30/6/2022	31/3/2022
First purchase date (in this sample)	30/4/2015	30/6/2020
Last purchase date (in this sample)	31/10/2022	31/10/2022
Total purchased amount per programme	2 740 773	1 660 593
Total purchased amount per programme (in this sample)	2 349 888	1 415 460
Maximum purchased amount (in this sample)	19 573	46 749
Remaining WAM in years	7.22	7.54
Number of purchases (in this sample)	91	15
Max purchase amount of bond issuance	33.0 %	33.0 %
Number of countries	19	20
Number of countries (in this sample)	9	9

The second set of data includes monthly bid and ask prices for 10- and 30-year on-the-run government bonds from the start of the PSPP programme in April 2015 through the end of October in 2022, which are used as the dependent variable in this analysis. The data set includes all 10-year and 30-year on-the-run bonds issued by each of the nine countries, implying that the bond type changes each time the country issues a new 10- or 30-year bond. Table 2 presents the summary statistics of the data for each country separately. The minimum and maximum bid-ask spreads for both bond maturities and each country are shown in Table 2. The statistics clearly show that bid-ask spreads for bonds with maturities of 30 years are higher than for 10-year maturity bonds. The data has been gathered entirely from the Bloomberg terminal. All of the data utilized in the regression result has also been standardized, which means that the average of a data set has been subtracted from each data point and divided by the standard deviation. When all values are on the same scale, it is easier to make decisions based on the regression results.

Table 2. Descriptive statistics of government bond bid-ask spreads from 30/4/2015 to 31/10/2022 for nine Euro area countries. The data consist of 91 daily observations for each country. The data consist of 10Y and 30Y on-the-run bonds. The bid-ask spreads are multiplied by 100.

	AU	**BE**	**FI**	**FR**	**DE**	**IE**	**IT**	**NL**	**ES**
10Y Benchmark bonds									
Observations	91	91	91	91	91	91	91	91	91
Mean	17,3	7,55	14,82	4,67	3,51	16,33	6,02	8,42	8,5
Median	15,5	6,8	12,75	4,54	3,35	15,12	4,21	8,25	6,43
SD	8,7	3,1	8,37	1,96	1,45	6,8	4,32	3,5	5,71
Min	4,95	2,68	4,09	1,32	1,17	7,41	1,59	2,55	2,06
Max	44,04	18,94	40,71	13,67	8,04	36,56	17,79	18,06	27,34
30Y Benchmark bonds									
Observations	91	91	91	91	91	91	91	91	91
Mean	34,84	27,37	27,94	21,55	18,53	37,54	18,45	25,48	22,92
Median	25,22	26,83	26,33	21,47	17,96	35,55	14,74	25,31	21,47
SD	9,54	7,28	8,27	6,6	5,17	15,48	10	7,66	11,33
Min	13,21	12,4	13,48	7,39	9,29	15,73	5,62	9,29	6,4
Max	54,44	45,55	44,75	34,34	32,44	81,20	44	41,91	55,31

Figure 12 illustrates the 10- and 30-year bid-ask spreads of six Eurozone government bonds from 2015 to the beginning of 2023. Austria, Finland, and Ireland have the widest bid-ask spreads among the nine nations studied, as seen in the first row of the image, with Ireland having the widest spreads. The countries with the smallest bid-ask spreads in this study are listed in the next row, with Germany having the smallest spreads. The graph depicts the disparities across maturities, with 10-year bonds (shown in red) having lower bid-ask spreads than 30-year bonds (shown in blue).



Red series= 10Y bonds, Blue series= 30Y bonds.

Figure 12. Bid-ask spreads of European government bonds 2015-01/2023.

Table 3 indicates the number of datasets utilized in the linear regression model in this thesis, four for each country. The maturity-period combinations for each country are examined using linear regression to determine the exact effect of QE on bond liquidity in the country. The maturities are evaluated individually to determine the actual effect of QE on 10-year and 30-year bond liquidity. The linear regression models make use of time-series data described above, which means the data contains a single unit at numerous points in time. However, the data described previously in this chapter will also be restructured as panel data, which will be used in this thesis to conduct a panel

regression to discover the differences between the two study periods and two maturities. Panel data is a type of data that mixes time-series data with cross-sectional data, meaning, it is collected from several units at multiple points in time. Each country dataset in the panel regression will include two units: 10- and 30-year government bond bid-ask spreads analyzed over both the Covid-19 and PSPP time periods. This enables comparison in the study with additional dummy variables. As a result, the panel data will only contain nine datasets, one for each country.

Correlation matrices are computed for each of the 36 datasets used in the linear regression, and the results are summarized as the following. The datasets that include PSPP programme purchases and are separated into 10- and 30-year government bond bid-ask spreads show strong correlations between PSPP net asset purchases and PSPP cumulative net asset purchases -variables. The correlation for each country is roughly -0.60 to -0.70, causing some multicollinearity issues in the regressions between the two main independent variables. The countries' debt-to-GDP ratios and the PSPP cumulative net asset purchases -variable also exhibit a substantial negative association, ranging from -0.70 to -0.80 for each. For the Covid-19 datasets, the similar high negative correlations appear between PSPP net asset purchases and PSPP cumulative net asset purchases -variables, and countries' debt-to-GDP ratios and the PSPP cumulative net asset purchases -variable. In addition, the Stress-Euribor dummy and the STOXX 50 VIX variables display high positive correlations approximately 0.80 in each country dataset that are divided between 10- and 30-year government bonds. As a result, inferences drawn from regression should be considered with caution.

Table 3. Number of datasets used for the linear regression.

Number of datasets	PSPP programme	Covid-19 period
10-year maturity bonds	9	9
30-year maturity bonds	9	9
In total	18	18

6.2 Method

This thesis employs two regression techniques to determine a profound impact of QE on bond liquidity in Europe. First, a linear regression approach is used in order to answer the first two hypotheses. To answer the third hypothesis, a second method – panel regression – is utilized to compare the Covid-19 period with the PSPP programme. The panel regression also enables comparison between the two maturities. The methods in this paper are motivated by Grimaldi et al. (2021). This thesis follows their research as they study the effect of Sweden's Central Bank large-scale asset purchases on the bond market liquidity in Sweden. Grimaldi and colleagues (2021, p. 18) propose the panel regression model described below as their research approach, which this thesis will imitate:

$$Liq_{i,t} = \beta_0 + \gamma_t + \delta_i + \beta_1 Purchases_{i,t} + \beta_2 Holding_{i,t-1} + \beta_3 SLF_{i,t-1} + \beta_4 X_t + \varepsilon_{i,t.} \quad (3)$$

The model will be slightly adjusted to fit the object of the thesis. The first method of the thesis will be a linear regression model:

$$Liq_t = \beta_0 + \beta_1 Purchases_t + \beta_2 Holding_{t-1} + \beta_3 X_t + \varepsilon_t, \quad (4)$$

where Liq_t measures the bond liquidity at time t of a chosen country and bond maturity. $Purchases_t$ is the amount of net purchases of a given country's public assets at time t made by the ECB. $Holding_{t-1}$ is the value of the ECB's holdings, measured as the previous month's cumulative net purchases of a country's public assets. Unlike Grimaldi and others (2021), this thesis will not observe the variable $SLF_{i,t-1}$ which measures central bank's security lending facility. The security lending facility is used to improve bond market liquidity during times when liquidity is weak with so-called repo deals. For the sake of simplicity, this thesis will leave it out. In line with Grimaldi and others' (2021)

model, X_t is used as a control variable which summarizes macro and financial variables into a vector variable. This study mitigates and employs a few of the control variables proposed by Grimaldi et al., (2021), with the exception that this thesis employs eurozone-specific metrics. The X_t will contain STOXX 50 Volatility index which measures fear and uncertainty through option prices in the financial market, the central government debt-to-GDP ratio, and a Stress-Euribor indicator (see De Renzis et al., 2018, p. 22) which is a stress indicator in terms of market liquidity and credit risk. It is measured as the spread between 3-month Euribor and 3-month Overnight Index Swap rate and is used as a dummy variable which takes the value one when the stress increases over to its median value (De Renzis et al., 2018, p. 22).

The two independent variables are both measured in the current time period, with one variable (current month's ECB net purchases) representing the current level of net purchases and the other variable (previous month's value of accumulated net purchases) representing the previous level of accumulated net purchases. This study differs from Grimaldi and colleagues' work in that it uses primarily a linear regression model rather than the panel regression to examine the exact impact of the ECB's purchases on the liquidity in each country. Hence, the panel regression is rather used as a secondary method in this thesis. The linear regression is run separately for each country-maturity combination and purchase programmes. In total, 36 linear regressions are run in R studio. However, the regression will be first run without the control variables and then with the control variables. Here are examples of how the regression is run in R studio for the Public Sector Purchase Programme

1. $Liq_{t\text{(AU-10Y)}} = \beta_0 + \beta_1 Purchases_{t\text{(AU-PSPP)}} + \beta_2 Holding_{t-1\text{(AU-PSPP)}} + \beta_3 X_t + \varepsilon_t,$
2. $Liq_{t\text{(AU-30Y)}} = \beta_0 + \beta_1 Purchases_{t\text{(AU-PSPP)}} + \beta_2 Holding_{t-1\text{(AU-PSPP)}} + \beta_3 X_t + \varepsilon_t,$
3. $Liq_{t\text{(BE-10Y)}} = \beta_0 + \beta_1 Purchases_{t\text{(BE-PSPP)}} + \beta_2 Holding_{t-1\text{(BE-PSPP)}} + \beta_3 X_t + \varepsilon_t,$

...

18. $Liq_{t\text{(ES-30Y)}} = \beta_0 + \beta_1 Purchases_{t\text{(ES-PSPP)}} + \beta_2 Holding_{t-1\text{(ES-PSPP)}} + \beta_3 X_t + \varepsilon_t,$

and for the Covid-19 period:

1. $Liq_{t\text{(AU-10Y)}} = \beta_0 + \beta_1 Purchases_{t\text{(AU-Covid-19)}} + \beta_2 Holding_{t-1\text{(AU- Covid-19)}} + \beta_3 X_t + \varepsilon_t,$
2. $Liq_{t\text{(AU-30Y)}} = \beta_0 + \beta_1 Purchases_{t\text{(AU- Covid-19)}} + \beta_2 Holding_{t-1\text{(AU- Covid-19)}} + \beta_3 X_t + \varepsilon_t,$
3. $Liq_{t\text{(BE-10Y)}} = \beta_0 + \beta_1 Purchases_{t\text{(BE- Covid-19)}} + \beta_2 Holding_{t-1\text{(BE- Covid-19)}} + \beta_3 X_t + \varepsilon_t,$

...

18. $Liq_{t\text{(ES-30Y)}} = \beta_0 + \beta_1 Purchases_{t\text{(ES- Covid-19)}} + \beta_2 Holding_{t-1\text{(ES-Covid-19)}} + \beta_3 X_t + \varepsilon_t.$

The second method of the thesis is a fixed effects panel regression model with time and bond fixed effects. Interaction terms are used to describe the effect of ECB net asset purchases on government bond bid-ask spreads between the Covid-19 and PSPP periods, and between the 10- and 30-year maturities. The following two panel regression models are developed:

$$Liq_{i,t} = \beta_0 + \beta_1 Purchases_t\text{*Covid-19\_dummy} + \beta_2 Holding_{t-1}\text{*Covid-19\_dummy} + \beta_3 X_t\text{*Covid-19\_dummy} + \beta_4\text{Maturity\_dummy*Covid-19\_dummy} + \gamma_t + \delta_i + \varepsilon_t, \quad (5)$$

$$Liq_{i,t} = \beta_0 + \beta_1 Purchases_t\text{*Maturity\_dummy} + \beta_2 Holding_{t-1}\text{*Maturity\_dummy} + \beta_3 X_t\text{*Maturity\_dummy} + \beta_4\text{Maturity\_dummy*Covid-19\_dummy} + \gamma_t + \delta_i + \varepsilon_t, \quad (6)$$

where $Liq_{i,t}$ is the liquidity measure – bid-ask spread – of bond i at time t. Again, the $Purchases_t$ is the number of net purchases of a given country's public assets at time t made by the ECB. The $Holding_{t-1}$ is the value of the ECB's holdings, measured as the previous month's cumulative net purchases of a country's public assets. The control variables in Xt are the same as those in the linear regression model. The Covid-19_dummy defines two time periods, with a value of 1 if the time period falls between 30/6/2020 and 31/10/2022 (the Covid-19 period) and a value of 0 if the time period falls between 30/4/2015 and 29/5/2020 (the PSPP period). Unlike the linear regression, the PSPP period in the panel regression analysis ends on May 29, 2020, so that there are no overlaps with the Covid-19 period in the dummy variable. The Maturity_dummy

variable describes the two bond maturities, with a value of 1 for a 10-year maturity bond and a value of 0 for a 30-year maturity bond. The formulas (5) and (6) show the used interaction terms between the independent variables and the Covid-19_dummy and Maturity_dummy variables. Lastly, a Maturity_dummy*Covid-19_dummy variable is added to the models to discover the relationship between the government bond maturities and bid-ask spreads between the Covid-19 and PSPP periods. The Covid-19 period is the reference category (level 1) in the Covid-19-dummy variable, while 10-year maturity is the baseline (level 1) in the Maturity_dummy variable.

For the panel regression, a fixed effects model is adopted after several tests. First, for Austria data, multiple panel data variations are tested. Pooled OLS estimator, between estimator, first different estimator, fixed effects estimator, and random effects estimator are some of the panel regression versions that are tested. All of the estimators were conducted using data from Austria. Following the execution of the models, an LM test (Langrange Multiplier test) is used to assess the quality of the models, such as the presence of serial correlation or heteroscedasticity. First, the "plmtest(pooling)" test is done, which compares the OLS estimator to the random effects that produced significant effects. It means that the pooled OLS estimator is insufficient, and that the random effects model should be used instead. The presence of significant effects from the plm test shows that there are individual-specific effects or heterogeneity that the pooling model does not effectively reflect. The pooled OLS estimator is then tested against the fixed effects estimator using the "pFtest(fixed, pooling)" function. The test yields substantial results, implying that individual-specific effects contribute considerably to the model's explanatory power and are not captured by the pooling estimator. As a result, the fixed effects model is applicable. Finally, a Hausman test is performed with "pFtest(random, fixed)" to determine the significance of random versus fixed effects. The significant results show that the random effects model does not adequately capture the individual effects, whereas the fixed effects model does. This implies that the fixed effects model will be selected.

7 Empirical results

This chapter reports the regression results of this research, which examines the influence of the ECB's quantitative easing on the liquidity of European government bonds for 10- and 30-year maturities. The results will be in response to four hypotheses, all of which are one-tailed. This chapter contains six tables. The key regression results for hypotheses one and two are shown in Tables 4, 5, 6, and 7, with each column reporting the results for each country's liquidity measure, bid-ask spread, for government bonds. The tables 4, 5, 6, and 7 results are without control variables and the corresponding results with control variables are shown in four tables in the Appendices. Tables 4 and 5 provide the outcomes for the Covid-19 era, whereas Tables 6 and 7 show the results for the PSPP programme. The key regression results for hypothesis three are shown in Table 8 with control variables. Table 8 provides results that compare the Covid-19 and PSPP programme time periods in each country. Lastly, Table 9 provides results for the fourth hypothesis that compare the effect of QE on bond liquidity between the two maturities in each country. The table 9 also includes the control variables.

Table 4. 10-year government bond bid-ask spreads explained by changes in PSPP and PEPP (Covid-19 period) net and cumulative net asset purchases, June 2020-October 2022. Standard errors are reported in parentheses.

Dependent variable:					
Bid/Ask spread					
	Austria	*Belgium*	*Finland*	*France*	*Germany*
$Purchases_t$	**-0.457****	-0.028	**-0.707*****	-0.354	**-0.685*****
	(0.205)	(0.231)	**(0.175)**	(0.261)	**(0.163)**
$Holding_{t-1}$	0.219	0.347	-0.111	0.044	0.154
	(0.205)	(0.231)	(0.175)	(0.261)	(0.163)
Constant	-0.000	-0.000	0.000	-0.000	0.000
	(0.151)	(0.179)	(0.146)	(0.178)	(0.116)
Adj. R-squared	0.343	0.067	0.385	0.084	0.611
Number of Obs.	29	29	29	29	29
F-statistic	**8.304*****	2.000	**9.773*****	2.286	**22.994*****
	Ireland	*Italy*	*Netherlands*	*Spain*	

Purchases$_t$	-0.191	**-0.643*** **	**-0.639*** **	**-0.616** **
	(0.167)	**(0.218)**	**(0.187)**	**(0.232)**
Holding$_{t-1}$	**0.627*** **	0.062	-0.051	-0.111
	(0.167)	(0.218)	(0.187)	(0.232)
Constant	0.000	0.000	0.000	0.000
	(0.124)	(0.139)	(0.152)	(0.162)
Adj. R-squared	0.556	0.437	0.327	0.241
Number of Obs.	29	29	29	29
F-statistic	**18.525*** **	**11.881*** **	**7.788*** **	**5.456** **

Note: *p<0.1; **p<0.05; ***p<0.01

The main finding in Table 4 is that the ECB's PEPP and PSPP net purchases improved government bond liquidity for 10-year bonds during the Covid-19. Except for Belgium, France, and Ireland, the results are highly significant for almost all countries. The coefficients for the *Purchases* variable are highly significant at the 1 % level in Finland, Germany, Italy, and the Netherlands. In turn, the regression output for Austria and Spain shows a significant coefficient at the 5 % level. As shown in Table 4, one unit increase in the ECB's net asset purchases during the Covid-19 reduces the bid-ask spread in Austria by -0.457 standard deviations. The ECB's net asset purchases appear to have reduced the 10-year Finnish government bond bid-ask spreads the greatest among the countries, by -0.707 standard deviations. In the regression, the relationship between the *Purchases* and the dependent variable – *Liquidity* – is reverse. As a result, a lower bid-ask spread value suggests a higher amount of liquidity. A negative coefficient for the *Purchases* variable shows that the ECB's net asset purchases have improved the countries' bond liquidity. The findings are consistent with earlier literature in that the demand effect of quantitative easing, that is the central bank's monthly net asset purchases, should boost government bond liquidity. The results for Belgium, France, and Ireland, on the other hand, are insignificant, but they reveal a positive influence on liquidity, as in the Kandrac and Schlusche (2013) study. To summarize, the spotlight effect of QE is not present in the treasury market in these three countries.

The *Holding* variable does not show as persistent outcomes during the Covid-19 period for 10-year government bonds like the *Purchases*. Only for Ireland, the effect of ECB's

cumulative net asset purchases under the PSPP and PEPP programme on 10-year bond liquidity demonstrates extremely significant and favorable outcomes at 1 % significance level. A unit increase in the ECB's balance sheet for Irish public assets raises the bid-ask spreads on Ireland's 10-year government bonds by 0.627 standard deviations. This result is also consistent with previous literature, which suggests that the supply effect of central banks' asset holdings should widen the bid-ask spreads and reduce liquidity. A positive *Holding* variable coefficient indicates that the explanatory variable reduces liquidity. According to past research, the scarcity impact should outweigh the spotlight effect. However, under this assumption, these results do not yield similar outcomes because the *Purchases* variable appears to have a heavier effect on liquidity than the *Holding* variable.

The scarcity effect of quantitative easing shows no effect on the liquidity of 10-year maturity government bonds in Austria, Belgium, Finland, France, Germany, Italy, Netherlands, and Spain. The Covid-19 era results are interesting because they contradict what authors have previously discovered. According to Schrimpf and others (2020), government bonds often serve as a safe haven during market turmoil when stock prices fall, but when the Covid-19 burst, the government bond markets experienced unexpected volatility and hampered market functioning. For example, the US treasury yields dropped dramatically in March 2020, and the spread between 30-year US treasury yields and swap spread curve widened enormously. In addition, Fleming and Ruela (2020) present in their article that the bid-ask spreads of the US 30-year treasury bond widened the most dramatically (sixfold) in March 2020, while the 10-year maturity spreads doubled. These dramatic changes in the economic sentiment during the Covid-19 crisis may have already influenced the bid-ask spreads on Eurozone treasury bonds, implying that the scarcity effect of QE has no longer had a significant impact on bond liquidity during this era.

As seen in Table 4, Belgium and France show no significant results at all on the effect of QE on liquidity for the 10-year maturity during the Covid-19. The explanatory power of

the model for these countries is very low (less than 10%). This means that QE explains only about 10 percent of the variation in countries' 10-year bid-ask spreads. While focusing on the explanatory rates of Germany and Ireland, the model explains the variation of bid-ask spreads for 10-year bonds by more than 50%. Hence, the disparities between nations as an explanatory factor of QE for bid-ask spread variance are enormous.

Table 5. 30-year government bond bid-ask spreads explained by changes in PSPP and PEPP (Covid-19 period) net and cumulative net asset purchases, June 2020-October 2022. Standard errors are reported in parentheses.

Dependent variable:					
Bid/Ask spread					
	Austria	*Belgium*	*Finland*	*France*	*Germany*
$Purchases_t$	-0.163	-0.317	**-0.618*** **	-0.172	**-0.462***
	(0.207)	(0.205)	**(0.192)**	(0.281)	**(0.252)**
$Holding_{t-1}$	**-0.711*** **	0.311	-0.123	-0.090	-0.154
	(0.207)	(0.205)	(0.192)	(0.281)	(0.252)
Constant	0.000	0.000	0.000	0.000	0.000
	(0.152)	(0.159)	(0.159)	(0.191)	(0.179)
Adj. R-squared	0.330	0.266	0.263	-0.060	0.072
Number of Obs.	29	29	29	29	29
F-statistic	**7.889*** **	**6.068*** **	**5.996*** **	0.202	2.089

	Ireland	*Italy*	*Netherlands*	*Spain*
$Purchases_t$	-0.244	**-0.545** **	0.035	**-0.521** **
	(0.177)	**(0.210)**	(0.213)	**(0.224)**
$Holding_{t-1}$	**0.550*** **	0.208	**-0.419***	0.088
	(0.177)	(0.210)	**(0.213)**	(0.224)
Constant	0.000	0.000	-0.000	-0.000
	(0.131)	(0.135)	(0.173)	(0.156)
Adj. R-squared	0.502	0.475	0.131	0.293
Number of Obs.	29	29	29	29
F-statistic	**15.119*** **	**13.675*** **	**3.117***	**6.788*** **

Note: *p<0.1; **p<0.05; ***p<0.01

The findings for 30-year government bonds during Covid-19 (see Table 5) are similar to the 10-year bonds but not as consistent. The *Purchases* variable has a very significant and negative effect on Finland's 30-year government bonds at 1 % statistical significance level, and at the 5 % level for Italy and Spain. In turn, the ECB's net asset purchases also significantly boost Germany's 30-year government bonds but at 10 % significance level. The ECB's cumulative net asset purchases – the *Holding* variable – do not show any persistent results for the 30-year government bonds. Hence, this study documents that the scarcity effect of quantitative easing is not present in the 30-year government bond markets in Belgium, Finland, France, Germany, Italy, and Spain. The results for Ireland are consistent with earlier literature, with one unit increase in the ECB's balance-sheet holding increasing bid-ask spreads by 0.550 standard deviations at the 1 % significance level, respectively. Nonetheless, the two significant negative outcomes of the *Holding* variable for Austria and the Netherlands are conflicting, which was not expected in this study. As a result, the opposite outcomes indicate that the ECB's cumulative net asset purchases appear to boost liquidity in Austria and the Netherlands, implying that the scarcity effect would improve bond liquidity.

Table 6. 10-year government bond bid-ask spreads explained by changes in PSPP net and cumulative net asset purchases, March 2015-October 2022. Standard errors are reported in parentheses.

Dependent variable:					
Bid/Ask spread					
	Austria	*Belgium*	*Finland*	*France*	*Germany*
$Purchases_t$	**0.187****	**0.389*****	-0.079	**0.407*****	-0.055
	(0.092)	**(0.119)**	(0.096)	**(0.138)**	(0.133)
$Holding_{t-1}$	**0.831*****	**0.545*****	**0.589*****	**0.493*****	**0.437*****
	(0.092)	**(0.119)**	**(0.096)**	**(0.138)**	**(0.133)**
Constant	-0.000	0.000	-0.000	-0.000	0.000
	(0.072)	(0.095)	(0.082)	(0.099)	(0.093)
Adj. R-squared	0.524	0.177	0.388	0.110	0.210
Number of Obs.	91	91	91	91	91
F-statistic	**50.476*****	**10.692*****	**29.473*****	**6.544*****	**12.988*****
	Ireland	*Italy*	*Netherlands*	*Spain*	

Purchases$_t$	-0.044	**0.336****	0.040	**0.375*****
	(0.111)	**(0.141)**	(0.102)	**(0.138)**
Holding$_{t-1}$	**-0.476*****	0.233	**0.659*****	0.099
	(0.111)	(0.141)	**(0.102)**	(0.138)
Constant	0.000	0.000	0.000	0.000
	(0.094)	(0.103)	(0.082)	(0.101)
Adj. R-squared	0.189	0.039	0.391	0.079
Number of Obs.	91	91	91	91
F-statistic	**11.454*****	**2.820***	**29.855*****	**4.875*****

Note: *p<0.1; **p<0.05; ***p<0.01

For the PSPP programme, the regression output shows interesting results. The key finding of Table 6 is that the *Holding* variable is significant and positive in Austria, Belgium, Finland, France, Germany, and the Netherlands at the 1 % level. In other words, an increase in the ECB's balance-sheet holdings of these countries' public assets reduces 10-year government bond liquidity through widening the bid-ask spreads. This finding is consistent with earlier research indicating the scarcity effect reduces government bond liquidity. In the case of Ireland, the result for the *Holding* variable is contradictory from what is expected but still significant. Furthermore, when looking at the *Purchases* variable, the regression output displays results that are contrary of what is predicted. Compared to the Covid-19 period results, the *Purchases* variable now displays positive coefficients for almost all countries. The results for Austria, Belgium, France, Italy, and Spain are favorable and significant, but the effect of PSPP net asset purchases on bid-ask spreads is conflicting. Thus, a one unit increase in the PSPP net asset purchases by the ECB, increases the bid-ask spread of Belgium 10-year government bonds by 0.389 standard deviations meaning lower liquidity for the country's debt. This result contradicts the spotlight effect theory. According to the QE's spotlight effect, the ECB will give a significant buyer to the debt market, easing the selling of bonds for investors and enhancing liquidity.

In the instance of the PSPP program, the *Holding* variable now has a bigger effect than the *Purchases* variable. This is understandable given that the beneficial effect of the ECB's net purchases is only temporary and noticeable in the market right when the ECB

purchases bonds from sellers, improving liquidity. The effect of cumulative net purchases, that is, the expansion of the ECB's balance sheet, on the other hand, is long-lasting because the ECB keeps the purchased bond on its balance sheet until its expiration.

Table 7. 30-year government bond bid-ask spreads explained by changes in PSPP net and cumulative net asset purchases, March 2015-October 2022. Standard errors are reported in parentheses.

Dependent variable:					
Bid/Ask spread					
	Austria	*Belgium*	*Finland*	*France*	*Germany*
$Purchases_t$	0.183	**0.201***	0.002	**0.406*****	0.206
	(0.118)	**(0.114)**	(0.104)	**(0.107)**	(0.143)
$Holding_{t-1}$	**0.574*****	**0.601*****	**0.550*****	**0.911*****	**0.437*****
	(0.118)	**(0.114)**	**(0.104)**	**(0.107)**	**(0.143)**
Constant	0.000	-0.000	-0.000	0.000	-0.000
	(0.093)	(0.091)	(0.089)	(0.076)	(0.100)
Adj. R-squared	0.217	0.240	0.285	0.468	0.085
Number of Obs.	91	91	91	91	91
F-statistic	**13.457*****	**15.242*****	**18.970*****	**40.587*****	**5.196*****

	Ireland	*Italy*	*Netherlands*	*Spain*
$Purchases_t$	0.001	**0.401*****	0.065	**0.380*****
	(0.119)	**(0.139)**	(0.110)	**(0.134)**
$Holding_{t-1}$	**-0.304****	**0.268***	**0.598*****	-0.012
	(0.119)	**(0.139)**	**(0.110)**	(0.134)
Constant	0.000	-0.000	0.000	-0.000
	(0.101)	(0.101)	(0.088)	(0.098)
Adj. R-squared	0.072	0.065	0.299	0.131
Number of Obs.	91	91	91	91
F-statistic	**4.499****	**4.129****	**20.238*****	**7.794*****

Note: *p<0.1; **p<0.05; ***p<0.01

In terms of the PSPP program, the regression results for 30-year bonds are similar to those for 10-year maturity bonds. The outcomes are comparable to the 10-year results, although slightly better. Italy now has a significant coefficient for the *Holding* variable as well, indicating that the ECB's asset holdings impair Italian government bond liquidity.

The results for the *Holding* variable are consistent with previous studies, while the outcome for the *Purchases* variable is not as expected. For 30-year government bonds, all countries have positive coefficients for the Purchases variable, similar to the 10-year maturity. In Table 7, Austria no longer has a significant result for the *Purchases* variable, but the rest of the countries are in line with results in Table 6.

The results are also robust when control variables are added to the models. The results are shown in tables in the appendices in the same order as above. The controls considered are macroeconomic indicators and factors related to the government bond market. After controlling the regression for the 10-year government bonds during the Covid-19 period (Table 4), the influence of the *Purchase* variable on bid-ask spreads remains still negative and significant in several countries. In addition, when control variables are introduced to the model, the results of the *Holding* variable also improve (see Appendices). Austria, Belgium, and Ireland all exhibit large positive coefficients for the *Holding* variable, as expected. The model's explanatory power improves following the control variables, as expected. The adjusted R-squared in Table 4 shifts the most for Belgium (from 0.067 to 0.659), where the regression model without controlling factors fails to adequately explain bid-ask spreads. The results remain stable even for the 30-year bonds during Covid-19 (Table 5). Significance disappears with the *Purchases* variable for Germany, but otherwise remains unchanged. The value of the *Holding* variable is strengthened for Ireland. In this case, the explanatory power also improves in the model when control variables are added. In the case of the PSPP program, the results remain consistent and significant, but the model's explanatory power increases in each country after controlling variables are added to each regression (Table 6 and 7). However, it is worth mentioning the multicollinearity problem between the two explanatory variables, which may affect the outcome of the results. Therefore, the findings must be interpreted with caution.

Both the STOXX 50 Volatility index and the Stress-Euribor indicator exhibit significant positive coefficients for the dependent variable during the Covid-19 asset purchases,

indicating that when the volatility index rises as anxiety rises in the European stock market, bond liquidity falls, indicating a market spillover. Furthermore, as the stress indicator for market liquidity and credit risk in Europe rises, bond liquidity weakens, as expected. On the other hand, the Stress-Euribor dummy variable improved liquidity during the PSPP period, which could indicate that during the stress periods preceding the Covid-19, the European 10- and 30-year government bond markets were used as a safe haven for investors, increasing bond demand and lowering bid-ask spreads. When the Covid-19 outbroke, this relationship shifted, and investors lost incentive to invest in government bonds. This could have been due to central banks' monetary policy efforts, which aimed to lower market interest rates during Covid while also having a detrimental effect on the yield on government bonds.

Table 8. European government bond bid-ask spreads explained by the difference between the ECB's PSPP programme purchases and Covid-19 period purchases: a panel regression analysis with control variables and Maturity*Covid-19 dummy. Reference category in Covid-19_dummy is Covid-19 period (PSPP= 0). Each independent variable has been transformed into interaction term with Covid-19_dummy. Standard errors are reported in parentheses.

Dependent variable:					
Bid/Ask spread					
	Austria	*Belgium*	*Finland*	*France*	*Germany*
*Purchases$_t$*Covid*	-0.265	0.035	**-0.536*** **	0.008	-0.297
	(0.183)	(0.177)	**(0.126)**	(0.200)	(0.191)
*Holding$_{t-1}$*Covid*	-0.350	**0.560** **	0.065	0.139	0.125
	(0.223)	**(0.256)**	(0.148)	(0.193)	(0.181)
*STOXX 50VIX*Covid*	0.177	**0.886*** **	**0.675*** **	**0.638** **	**0.610** **
	(0.287)	**(0.288)**	**(0.210)**	**(0.266)**	**(0.269)**
*Stress-Euribor*Covid*	**0.805***	0.358	0.478	0.159	-0.223
	(0.444)	(0.454)	(0.340)	(0.437)	(0.430)
*Debt-to-GDP*Covid*	-0.203	0.336	**0.407*** **	0.289	-0.293
	(0.289)	(0.220)	**(0.150)**	(0.183)	(0.208)
*Maturity*Covid*	**1.018*** **	**-0.603** **	**0.535** **	**-0.981*** **	0.349
	(0.256)	**(0.265)**	**(0.230)**	**(0.302)**	(0.283)
Adj. R-squared	0.210	0.155	0.448	0.079	0.137
Number of Obs.	182	182	182	182	182
F-statistic	**9.168*** **	**6.700*** **	**25.626*** **	**3.763*** **	**5.958*** **

	Ireland	*Italy*	*Netherlands*	*Spain*

*Purchases$_t$*Covid*	0.083	**-0.612*****	-0.212	-0.178
	(0.193)	**(0.180)**	(0.184)	(0.174)
*Holding$_{t-1}$*Covid*	**0.973*****	-0.129	-0.049	**-0.493****
	(0.214)	(0.201)	(0.271)	**(0.191)**
*STOXX 50VIX*Covid*	**0.642****	**0.482****	0.581	-0.117
	(0.316)	**(0.241)**	(0.373)	(0.245)
*Stress-Euribor*Covid*	0.408	-0.153	-0.166	0.024
	(0.406)	(0.398)	(0.452)	(0.410)
*Debt-to-GDP*Covid*	**0.895*****	**-0.622*****	0.260	**-1.036*****
	(0.229)	**(0.173)**	(0.610)	**(0.158)**
*Maturity*Covid*	-0.153	0.043	**0.454***	0.337
	(0.273)	(0.274)	**(0.258)**	(0.267)
Adj. R-squared	0.214	0.238	0.040	0.256
Number of Obs.	182	182	182	182
F-statistic	**9.368*****	**10.569*****	**2.427****	**11.524*****

Note: *p<0.1; **p<0.05; ***p<0.01

Table 8 provides evidence for the third hypothesis, which aims to compare the effect of QE on bond liquidity during the Covid-19 period and PSPP programme. To assess the effect of ECB's net and cumulative net asset purchases on government bond bid-ask spreads during the Covid-19 and PSPP periods, interaction terms between the independent variables and a Covid-19_dummy variable have been developed. The interaction terms allow us to see if the effect of the ECB's asset purchases on government bond bid-ask spreads varies significantly between the two time periods. If the coefficient for the interaction term is statistically significant, it implies that the ECB's net and cumulative net asset purchases had a different influence on government bond bid-ask spreads between the Covid-19 and PSPP periods. Here is an example how to interpret the coefficients. For example, for Austria, the coefficient estimate -0.265 for Purchases*Covid-19 dummy interaction term suggest that during the Covid-19 period, there is a 0.265 standard deviation decrease in government bond bid-ask spreads associated with an increase in ECB's net asset purchases compared to the PSPP period. This means that during the Covid-19 period the bid-ask spreads of Austria's government 10- and 30-year government bonds were a little bit tighter compared to PSPP period. However, the result is not statistically significant which means that the net asset

purchases in Austria do not show significantly differential effects on government bond bid-ask spreads when comparing the Covid-19 period to the PSPP period.

One of the key results of the Table 8 is that in Finland and Italy, the government bond bid-ask spreads decreased by -0.536 (Finland) and -0.612 (Italy) standard deviations compared to the PSPP programme period as a result of the net asset purchases by ECB. This means that during Covid-19, the ECB's PSPP and PEPP programme net asset purchases managed to enhance government bond liquidity in Finland and Italy better than during the PSPP programme, that is the Covid-19 period net asset purchases had a favorable impact on bond liquidity. This result is as expected, and the third null hypothesis can be rejected at 1 % significance level for Finland and Italy. Other countries show no significant results which means that the two periods do not show any significant different effects on government bond bid-ask spreads and the third null hypothesis can be accepted.

The second main result of Table 8 is that the cumulative net asset purchases by ECB widened the Belgium and Ireland government bid-ask spreads by 0.560 (Belgium) and 0.973 (Ireland) standard deviations during the Covid-19 period compared to the PSPP period. The result is in line with the third hypothesis which indicates that during the Covid-19 period, the ECB's PSPP and PEPP programmes managed to deteriorate government bond liquidity in Belgium and Ireland more than during the PSPP programme, that is the Covid-19 period purchases had a weakening impact on bond liquidity. In turn, in Spain, the *Holding* variable shows results contrary to expectations, where the Covid-19 period would not have as much of a weakening effect on bond liquidity as the PSPP, that is, in other words, the cumulative purchases during the Covid-19 period would rather improve liquidity. This result is contradictory, as it was expected that during Covid-19, when the PSPP and PEPP programmes were run at the same time, the *Holding* variable would show even stronger deterioration of liquidity than during the PSPP programme.

Table 8 also provides evidence for the control variables. The STOXX 50 Volatility Index exhibits significant positive coefficients for Belgium, Finland, France, Germany, Ireland, and Italy. This indicates that during the Covid-19 period, the rise of the volatility index and anxiety in the European stock market increased bond bid-ask spreads compared to PSPP programme, indicating a market spillover during the corona pandemic. The stress indicator for market liquidity and credit risk in Europe widens the bid-ask spreads significantly in Austria during the Covid-19 period compared to PSPP programme. In other countries the stress indicator does not show discrepancies in the bid-ask spreads between the Covid-19 and PSPP periods. In turn, the effect of debt-to-GDP ratio on bid-ask spreads varies a lot between countries. In Finland and Ireland, an increase in the debt-to-GDP widens the bid-ask spreads significantly more during the Covid-19 than during the PSPP, but in Italy and Spain it lowers the bid-ask spreads significantly more during the Covid-19 than during the PSPP period. Lastly, the significant positive coefficients for the Maturity*Covid-19_dummy variable (Austria, Finland, Netherlands) suggest that during the Covid-19 period, for 30-year government bond maturity there is a standard deviation increase of 1.018 (Austria), 0.535 (Finland), and 0.454 (Netherlands) in government bond bid-ask spreads compared to the PSPP period, holding other variables constant. Hence, longer government bond maturity in these countries during the Covid-19 period is associated with a larger increase in government bond bid-ask spreads compared to the reference category of 10-year maturity bonds. In Belgium and France, the effect is opposite that shorter term government bonds are associated with a larger increase in government bond bid-ask spreads during the Covid-19.

Table 9. Comparison of the bid-ask spreads on European 10- and 30-year government bonds explained by the ECB's asset purchases between 2015 and 2022: a panel regression analysis with control variables and Maturity*Covid-19 dummy. Reference category in Maturity_dummy is 10-year bonds (30-year= 0). Each independent variable has been transformed into interaction term with Maturity_dummy. Standard errors are reported in parentheses.

Dependent variable:					
Bid/Ask spread					
	Austria	*Belgium*	*Finland*	*France*	*Germany*
*Purchases$_t$*Maturity*	0.049	**0.311****	**-0.286****	0.073	-0.180
	(0.145)	**(0.156)**	**(0.122)**	(0.153)	(0.147)

*Holding$_{t-1}$*Maturity*	**0.537*** **	**0.653*** **	0.170	**0.511*** **	**0.520*** **
	(0.151)	**(0.140)**	(0.126)	**(0.157)**	**(0.157)**
*STOXX 50VIX*Maturity*	**0.372*** **	**0.502*** **	**0.288** **	**0.520*** **	**0.522*** **
	(0.116)	**(0.125)**	**(0.116)**	**(0.121)**	**(0.120)**
*Stress-Euribor*Maturity*	-0.176	**-0.598** **	**-0.386***	**-0.771*** **	**-0.774*** **
	(0.224)	**(0.247)**	**(0.220)**	**(0.261)**	**(0.239)**
*Debt-to-GDP*Maturity*	-0.157	-0.066	-0.085	0.129	-0.029
	(0.171)	(0.155)	(0.140)	(0.176)	(0.165)
*Maturity*Covid*	**0.733*** **	**-0.671** **	**1.029*** **	**-1.401*** **	**-0.539***
	(0.260)	**(0.289)**	**(0.305)**	**(0.376)**	**(0.309)**
Adj. R-squared	0.307	0.177	0.271	0.180	0.249
Number of Obs.	182	182	182	182	182
F-statistic	**14.538*** **	**7.675*** **	**12.391*** **	**7.767*** **	**11.151*** **

	Ireland	*Italy*	*Netherlands*	*Spain*
*Purchases$_t$*Maturity.*	-0.131	-0.026	-0.087	0.121
	(0.160)	(0.151)	(0.135)	(0.145)
*Holding$_{t-1}$*Maturity.*	0.452	**0.313** **	0.237	0.163
	(0.281)	**(0.143)**	(0.187)	(0.140)
*STOXX 50VIX*Maturity*	0.124	**0.302** **	**0.516*** **	0.190
	(0.124)	**(0.129)**	**(0.116)**	(0.123)
*Stress-Euribor*Maturity*	-0.401	**-1.151*** **	**-0.597** **	**-1.103*** **
	(0.256)	**(0.261)**	**(0.241)**	**(0.252)**
*Debt-to-GDP*Maturity*	**0.872** **	**-0.463*** **	**-0.415** **	**-0.311** **
	(0.367)	**(0.167)**	**(0.204)**	**(0.154)**
*Maturity*Covid*	0.129	-0.513	-0.309	**-0.935*** **
	(0.549)	(0.367)	(0.259)	**(0.337)**
Adj. R-squared	0.081	0.181	0.247	0.180
Number of Obs.	182	182	182	182
F-statistic	**3.822*** **	**7.842*** **	**11.038*** **	**7.768*** **

Note: *p<0.1; **p<0.05; ***p<0.01

Table 9 provides information about the bid-ask spreads of European 10- and 30-year government bonds during the ECB's asset purchases period from 2015 to 2022. Interaction terms between the independent variables and Maturity_dummy variable have been developed to see if the effect of the ECB's asset purchases on government bond bid-ask spreads varies significantly between the two bond maturity groups. If the coefficient for the interaction term is statistically significant, it implies that the ECB's net and cumulative net asset purchases had a different influence on the 10- and 30-year

government bond bid-ask spreads. Here is an example how to interpret the coefficients. For example, for Austria, the coefficient estimate of 0.049 for the Purchases*Maturity_dummy variable suggest that one unit increase in the ECB's net asset purchases increases the 30-year government bid-ask spreads by 0.049 standard deviations compared to the reference category (10-year maturity). However, the coefficient is not significant which means that the two maturities do not show differences in Austria in terms of the *Purchases* variable.

Table 9 shows that only in Belgium and Finland there are differences in the bid-ask spreads between the two maturities as a result of the net asset purchases (*Purchases* variable). In Belgium, the net asset purchases significantly increase the 30-year bond maturity bid-ask spreads by 0.311 standard deviations, but in Finland, the 10-year maturity bid-ask spreads widen more (30-year bid-ask spreads are 0.286 stdvs tighter compared to 10-year maturity). The outcome for Belgium is contradictory, but the outcome for Finland is in accordance with expectations. The growth of the ECB's balance sheet from the purchase of public assets (*Holdings* variable) increases the bid-ask spreads of the 30-year maturity bonds more than for the 10-year maturity in Austria, Belgium, France, Germany, and Italy. The results are highly significant at 1 % level for Austria, Belgium, France, and Germany, and at 5 % level for Italy. For other countries, differences are not documented between the two maturities which indicates that the null hypothesis four is accepted for these countries.

When the maturity is adjusted, the results show somewhat consistency in terms of the other variables. The STOXX Volatility Index shows highly significant and positive results for almost all countries (except for Ireland and Spain) which indicates that higher stock market volatility and anxiety in the European stock market increases the 30-year government bond bid-ask spreads more compared to the 10-year bid-ask spreads. However, the Stress-Euribor dummy documents the opposite between the maturities. According to the results, higher liquidity and credit risk in financial market can be seen more in the 10-year maturity than in the 30-year maturity bid-ask spreads in almost

every country. Hence, a one unit increase in the Stress-Euribor indicator result in lower bid-ask spreads for 30-year bond bid-ask spreads compared to 10-year maturity. The debt-to-ratio shows inconsistent results between the two maturity groups.

Table 10. Results for the statistical hypotheses.

	AU	**BE**	**FI**	**FR**	**DE**	**IE**	**IT**	**NL**	**ES**
Null hypothesis is rejected at 1 %*, 5 %** or 10 %*** significance level:									
H1: Purchases $\beta_1 < 0$ (Covid-19, 10-year government bonds)									
	Yes**	No	**Yes*****	No	**Yes*****	No	**Yes*****	**Yes*****	**Yes****
H1: Purchases $\beta_1 < 0$ (Covid-19, 30-year government bonds)									
	No	No	**Yes*****	No	**Yes***	No	**Yes****	No	**Yes****
H1: Purchases $\beta_1 < 0$ (PSPP, 10-year government bonds)									
	No	No	No	No	No	No	No	No	No
H1: Purchases $\beta_1 < 0$ (PSPP, 30-year government bonds)									
	No	No	No	No	No	No	No	No	No
H2: Holding $\beta_2 > 0$ (Covid-19, 10-year government bonds)									
	No	No	No	No	No	**Yes*****	No	No	No
H2: Holding $\beta_2 > 0$ (Covid-19, 30-year government bonds)									
	No	No	No	No	No	**Yes*****	No	No	No
H2: Holding $\beta_2 > 0$ (PSPP, 10-year government bonds)									
	Yes***	**Yes*****	**Yes*****	**Yes*****	**Yes*****	No	No	**Yes*****	No
H2: Holding $\beta_2 > 0$ (PSPP, 30-year government bonds)									
	Yes***	**Yes*****	**Yes*****	**Yes*****	**Yes*****	No	**Yes***	**Yes*****	No
H3: Purchases $\beta_{1\text{Covid-19}} <$ *Purchases* $\beta_{1\text{PSPP}}$									
	No	No	**Yes*****	No	No	No	**Yes*****	No	No
H3: Holdings $\beta_{2\text{Covid-19}} >$ *Holdings* $\beta_{2\text{PSPP}}$									
	No	**Yes****	No	No	No	**Yes*****	No	No	No
H4: Purchases $\beta_{1\_30Y} <$ *Purchases* β_{1_10Y}									
	No	No	**Yes****	No	No	No	No	No	No
H4: Holdings $\beta_{2\_30Y} >$ *Holdings* β_{2_10Y}									
	Yes***	**Yes*****	No	**Yes*****	**Yes*****	No	**Yes****	No	No

Table 10 provides results for the statistical hypotheses for each country. The table displays the alternative hypothesis for each hypothesis but reports the outcome in terms of the null hypothesis. If the answer is Yes, the alternative hypothesis in the table remains valid. Hypotheses are presented with statistical significance levels. The first null hypothesis which states that bond liquidity would not improve as a result of the ECB's net asset purchases, is rejected in multiple countries and for both 10- and 30-year bond maturities in the Covid-19 period. For the PSPP programme, the first null hypothesis is accepted in each country and for both bond maturities. The second null hypothesis is accepted in each country for the Covid-19 period expect for Ireland where it is rejected at 1 % significance level. The second null hypothesis is rejected in the majority of nations and at the 1 % level for the PSPP programme.

The third hypothesis evaluated in a separate regression is based on the findings in Table 8 that compares the Covid-19 and PSPP periods. The third null hypothesis which states that the impact of QE on bond liquidity is not severer during Covid-19 is accepted in terms of the *Purchases* variable in most countries but rejected in Finland and Italy at 1 % significance level. The third null hypothesis in terms of the *Holding* variable is rejected for Belgium at 5 % and Ireland at 1 % significance level. For the rest of the countries the third null hypothesis in terms of the *Holding* variable is accepted. The fourth null hypothesis which states that the impact of QE on bond liquidity is not severer for 30-year maturity is accepted in terms of the *Purchases* variable in most countries but rejected in Finland at 5 % significance level. The fourth null hypothesis in terms of the *Holding* variable is rejected for Austria, Belgium, France, and Germany at 1 % significance level and at 5 % significance level for Italy. For the rest of the countries the fourth null hypothesis in terms of the *Holding* variable is accepted.

8 Conclusion

Since the 2008 financial crisis, quantitative easing has been used as a monetary policy tool to stimulate a deflating economy during and after a recession. QE's main goals have been to lower long-term interest rates, stabilize the economy by providing market liquidity, and help the economy fulfill its inflation targets. However, these goals have not always been met in a perfectly controlled manner, as QE has been shown to have unintended consequences in the debt markets. It has been eventually established that QE can worsen liquidity in the financial markets via its transmission channels.

Based on past research, this thesis attempts to investigate the two effects of quantitative easing, the scarcity and spotlight effects, on European bond market liquidity. Researchers have paid little attention to the impact of the PSPP programme on government bond liquidity in Europe, and similarly, the PEPP programme has not yet been investigated on government bond liquidity. As a result, this thesis adds to the existing literature by demonstrating the implications of the ECB's PSPP and PEPP asset purchases on government bond liquidity in several European countries. In addition, this thesis provides first evidence in the current literature on the influence of QE on bond liquidity in Europe during the Covid-19. The empirical part of the thesis is two-fold. First, the impact of QE on government bond liquidity is investigated separately during the PSPP programme era and the Covid-19 period, which are likewise divided by maturities. The second section of the study compares the two study periods and bond maturities using a panel regression analysis, which allows for a comparison of the two study periods and bond maturities.

The linear regression results correspond to the first two hypotheses generated based on the prior literature. Tables 4, 5, 6, and 7 can thus be compared to existing literature. In summary, the ECB's net asset purchases had a positive influence on European countries' 10- and 30-year government bond bid-ask spreads over the Covid-19 period, indicating that the spotlight effect occurred during the crisis. However, the ECB's cumulative net purchases did not have the same consistent effects on European bond liquidity during

the Covid-19. The effect of the ECB's balance sheet expansion on bond liquidity was minimal, and no meaningful outcomes were found for 10- and 30-year government bonds during the Covid-19. This finding suggests that QE did not have a substantial negative effect on bond liquidity in Europe during the Covid-19. This work has previously revealed one plausible explanation for why QE had no effect on bond liquidity during the pandemic. Liquidity had already weakened from earlier levels as a result of the pandemic, which is why QE no longer had the same eroding effect on liquidity during this period, when liquidity was already low due to the crisis.

The scarcity effect, on the other hand, is evident during the PSPP programme. QE has a decreasing influence on government bond bid-ask spreads in Europe for both 10-year and 30-year bonds. However, the ECB's net asset purchases, which should boost liquidity, lower liquidity in European debt markets during the PSPP programme. As a result, it can be argued that the Covid-19 results are consistent with earlier literature on net asset purchases, and the PSPP results are consistent with previous literature on cumulative net asset purchases. The other findings are in conflict with earlier research.

The panel regressions show interesting results. The ECB's net asset purchases had a greater influence on liquidity in Finland and Italy during the Covid-19 compared to PSPP programme. The cumulative net asset purchases in the ECB's balance sheet had a greater influence on liquidity in Belgium and Ireland during the Covid-19. Other countries' net and cumulative net purchases are not significantly severer during the Covid-19 than in the PSPP period. Finally, it is proven that when the maturity is changed, the 30-year government bond bid-ask spreads react primarily more sensitively to the ECB's cumulative large-scale asset purchases and the Covid-19 period.

There are a few issues in the study that can be addressed in the future. The data on the ECB's asset purchases is not separated by maturity, making it difficult to document the precise impact of QE on bonds of a certain maturity. Due to this reason, the analysis could not also employ the *Holdings ratio* as in the Grimaldi and others' (2021) study,

where their *Holding* variable describes the volume purchased of that bond maturity in relation to the bond's total outstanding amount (Grimaldi et al., 2021, p. 30). Likewise, the *Purchases* variable is proportional to the bond's outstanding amount in their work. This thesis relies solely on the ECB asset purchase data, with no rationing. Finally, the lack of maturity-specific data for the ECB's asset purchases prevented this analysis from investigating the different levels of ECB's cumulative asset purchases in relation to the outstanding amounts of the bonds, as in the Grimaldi and others' (2021) study. They analyze various levels when the *Holding ratio* increases by more than 30 % or 50 %, demonstrating that QE has a non-linear influence on liquidity.

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Appendices

Appendix 1. Regression results with control variables. Dependent variable: 10Y Bid/Ask spread, Covid-19 period.

Dependent variable: Bid/Ask spread					
	Austria	*Belgium*	*Finland*	*France*	*Germany*
Purchases$_t$	-0.197	**0.286***	**-0.475*****	-0.038	**-0.491*****
	(0.150)	**(0.148)**	**(0.149)**	(0.270)	**(0.158)**
Holding$_{t-1}$	**0.598***	**0.657***	0.386	0.084	0.178
	(0.303)	**(0.335)**	(0.320)	(0.473)	(0.160)
STOXX 50VIX	**0.465****	**1.089*****	0.104	0.297	**0.446****
	(0.182)	**(0.193)**	(0.193)	(0.283)	**(0.172)**
Stress-Euribor	0.841	-0.536	**1.204*****	0.386	-0.498
	(0.494)	(0.417)	**(0.414)**	(0.676)	(0.616)
Debt-to-GDP	0.411	0.272	0.540	-0.135	-0.190
	(0.378)	(0.362)	(0.354)	(0.566)	(0.340)
Adj. R-squared	0.690	0.659	0.643	0.236	0.721
Number of Obs.	29	29	29	29	29
F-statistic	**13.468*****	**11.834*****	**11.090*****	**2.729****	**15.452*****

	Ireland	*Italy*	*Netherlands*	*Spain*
Purchases$_t$	0.100	**-0.590*****	**-0.535****	**-0.473****
	(0.192)	**(0.201)**	**(0.204)**	**(0.212)**
Holding$_{t-1}$	**1.103*****	-0.205	0.446	-0.012
	(0.343)	(0.411)	(0.368)	(0.412)
STOXX 50VIX	**0.494****	-0.133	0.363	0.024
	(0.233)	(0.217)	(0.242)	(0.246)
Stress-Euribor	0.070	**0.872***	0.842	**1.022***
	(0.465)	**(0.427)**	(0.583)	**(0.588)**
Debt-to-GDP	0.406	-0.289	0.631	0.078
	(0.374)	(0.369)	(0.487)	(0.503)
Adj. R-squared	0.635	0.548	0.499	0.432
Number of Obs.	29	29	29	29
F-statistic	**10.755*****	**7.783*****	**6.587*****	**5.263*****

Note: *p<0.1; **p<0.05; ***p<0.01

Appendix 2. Regression results with control variables. Dependent variable: 30Y Bid/Ask spread, Covid-19 period.

Dependent variable: Bid/Ask spread					
	Austria	*Belgium*	*Finland*	*France*	*Germany*
Purchases$_t$	-0.074	-0.114	**-0.389****	0.191	-0.125
	(0.206)	(0.186)	**(0.174)**	(0.268)	(0.248)
Holding$_{t-1}$	**-0.865****	0.155	-0.162	0.212	-0.135
	(0.416)	(0.421)	(0.375)	(0.470)	(0.250)
STOXX 50VIX	**0.549****	0.353	**0.516****	0.432	**0.544***
	(0.251)	(0.243)	**(0.225)**	(0.281)	**(0.270)**
Stress-Euribor	-0.814	0.174	0.101	0.680	-0.725
	(0.679)	(0.525)	(0.484)	(0.671)	(0.966)
Debt-to-GDP	-0.237	-0.249	-0.067	0.182	-0.455
	(0.520)	(0.455)	(0.414)	(0.563)	(0.534)
Adj. R-squared	0.415	0.461	0.511	0.246	0.312
Number of Obs.	29	29	29	29	29
F-statistic	**4.969*****	**5.795*****	**6.862*****	**2.828****	**3.538****

	Ireland	*Italy*	*Netherlands*	*Spain*
Purchases$_t$	0.119	**-0.476****	-0.175	**-0.383***
	(0.171)	**(0.181)**	(0.266)	**(0.202)**
Holding$_{t-1}$	**0.820****	-0.0001	-0.296	0.219
	(0.306)	(0.371)	(0.479)	(0.392)
STOXX 50VIX	**0.415***	-0.078	**0.561***	0.009
	(0.208)	(0.196)	**(0.316)**	(0.235)
Stress-Euribor	0.414	**0.904****	-0.905	**1.076***
	(0.415)	**(0.386)**	(0.760)	**(0.560)**
Debt-to-GDP	0.123	-0.227	0.329	0.123
	(0.334)	(0.334)	(0.635)	(0.480)
Adj. R-squared	0.710	0.630	0.149	0.485
Number of Obs.	29	29	29	29
F-statistic	**14.678*****	**10.554*****	1.979	**6.264*****

Note: *p<0.1; **p<0.05; ***p<0.01

Appendix 3. Regression results with control variables. Dependent variable: 10Y Bid/Ask spread, PSPP period.

Dependent variable: Bid/Ask spread	*Austria*	*Belgium*	*Finland*	*France*	*Germany*
$Purchases_t$	**0.166***	**0.420*****	-0.098	**0.412*****	-0.038
	(0.085)	**(0.115)**	(0.087)	**(0.136)**	(0.133)
$Holding_{t-1}$	**0.728*****	**0.481*****	**0.533*****	**0.990*****	**0.289****
	(0.100)	**(0.123)**	**(0.100)**	**(0.193)**	**(0.144)**
STOXX 50VIX	**0.403*****	**0.432*****	**0.427*****	**0.461*****	**0.547*****
	(0.084)	**(0.110)**	**(0.094)**	**(0.119)**	**(0.109)**
Stress-Euribor	-0.107	**-0.382***	**-0.433****	-0.204	**-0.572****
	(0.166)	**(0.220)**	**(0.172)**	(0.226)	**(0.223)**
Debt-to-GDP	**-0.179****	**-0.352*****	-0.064	**-0.707*****	**-0.414*****
	(0.089)	**(0.108)**	(0.098)	**(0.168)**	**(0.108)**
Adj. R-squared	0.627	0.295	0.520	0.264	0.377
Number of Obs.	91	91	91	91	91
F-statistic	**31.238*****	**8.525*****	**20.498*****	**7.470*****	**11.889*****

	Ireland	*Italy*	*Netherlands*	*Spain*
$Purchases_t$	-0.051	0.201	0.035	**0.302****
	(0.103)	(0.129)	(0.097)	**(0.123)**
$Holding_{t-1}$	**-1.794*****	**0.408*****	0.299	0.141
	(0.346)	**(0.152)**	(0.196)	(0.141)
STOXX 50VIX	-0.003	**0.234***	**0.397*****	0.081
	(0.093)	**(0.122)**	**(0.088)**	(0.111)
Stress-Euribor	**-0.839*****	**-0.855*****	-0.251	**-0.862*****
	(0.215)	**(0.216)**	(0.205)	**(0.215)**
Debt-to-GDP	**-1.219*****	**-0.712*****	**-0.406****	**-0.531*****
	(0.333)	**(0.139)**	**(0.174)**	**(0.120)**
Adj. R-squared	0.325	0.335	0.499	0.341
Number of Obs.	91	91	91	91
F-statistic	**9.651*****	**10.085*****	**18.894*****	**10.332*****

Note: *p<0.1; **p<0.05; ***p<0.01

Appendix 4. Regression results with control variables. Dependent variable: 30Y Bid/Ask spread, PSPP period.

Dependent variable: Bid/Ask spread	*Austria*	*Belgium*	*Finland*	*France*	*Germany*
$Purchases_t$	0.204	0.185	0.007	**0.417*** **	**0.292***
	(0.123)	(0.115)	(0.100)	**(0.116)**	**(0.152)**
$Holding_{t-1}$	**0.516*** **	**0.477*** **	**0.561*** **	**1.073*** **	**0.396****
	(0.144)	**(0.123)**	**(0.116)**	**(0.164)**	**(0.165)**
STOXX 50VIX	-0.086	**0.303*** **	**0.354*** **	0.154	**0.408*** **
	(0.121)	**(0.110)**	**(0.108)**	(0.101)	**(0.125)**
Stress-Euribor	-0.190	**-0.556****	-0.168	0.005	-0.267
	(0.239)	**(0.220)**	(0.199)	(0.192)	(0.256)
Debt-to-GDP	-0.089	**-0.205***	-0.082	-0.203	**-0.393*** **
	(0.128)	**(0.108)**	(0.114)	(0.142)	**(0.124)**
Adj. R-squared	0.221	0.295	0.357	0.470	0.183
Number of Obs.	91	91	91	91	91
F-statistic	**6.104*** **	**8.532*** **	**10.997*** **	**16.931*** **	**5.028*** **

	Ireland	*Italy*	*Netherlands*	*Spain*
$Purchases_t$	-0.020	**0.292****	0.059	**0.391*** **
	(0.112)	**(0.126)**	(0.112)	**(0.112)**
$Holding_{t-1}$	**-1.473*** **	**0.528*** **	**1.074*** **	**0.223***
	(0.377)	**(0.148)**	**(0.226)**	**(0.128)**
STOXX 50VIX	-0.045	**0.256****	-0.077	0.021
	(0.102)	**(0.119)**	(0.102)	(0.102)
Stress-Euribor	**-0.857*** **	**-0.713*** **	0.261	**-0.480****
	(0.234)	**(0.211)**	(0.237)	**(0.196)**
Debt-to-GDP	**-1.053*** **	**-0.778*** **	**0.514****	**-0.654*** **
	(0.363)	**(0.135)**	**(0.201)**	**(0.110)**
Adj. R-squared	0.198	0.366	0.328	0.452
Number of Obs.	91	91	91	91
F-statistic	**5.453*** **	**11.399*** **	**9.781*** **	**15.829*** **

Note: *p<0.1; **p<0.05; ***p<0.01