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ECB policies' impact on the euro area sovereign bond yields and channels

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Abstract

The aim of this research is to disentangle the effect on the yield curve of the monetary policy measures of the ECB during the years of the pandemic and the Russian conflict in Ukraine. In particular, we look at three of the euro area economies (Italy, Spain, and Germany) to understand which were the main transmission channels at play and if they differed among jurisdictions. To do so, we implement a two-step analysis. First, we perform an event study considering the ECB's main announcements as our event dates. We consider mainly two programs: the Pandemic Emergency Purchase Program (PEPP) and the Targeted Longer Term Refinancing Operations (TLTRO III). Through this, we are able to observe the yields' reaction to program announcements. Second, we decompose the observed effect on the government bond yields in the different transmission channels composing the term structure, namely the expectations channel, the default risk channel, the redenomination risk channel, and the segmentation risk channel. Because some of these channels are unobservable, we will use the Kalman filter methodology. This allows us to separate the different risk premia and remove noise in the estimates. We find that generally, program announcements caused a fall in government yields across all three jurisdictions. The fall was mainly driven by the expectations channel followed by the segmentation channel. We observe that Italy was the only country with significant movements caused by the default risk, while Spain had a relatively stronger redenomination risk. Instead, these two turned out to be rather quiet in Germany. These results are useful in identifying the different concerns that were present in the markets during these years compared to the previous crisis.

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Introduction

In this study, we will try to answer the question of how the ECB's measures taken as a response to the COVID crisis, and the Russian conflict influenced the yield curve. To do so, we will consider two aspects: first, we will look at the effects of the ECB's communication and the programs it established on government bond yields, and second, its transmission channels.
We will start by looking at the effect that the ECB's announcements had on the term structure of interest rates through an event study approach. This will help us understand how daily yield changes were different around announcement dates compared to normal times, thus giving us an idea of the impact of the announcements. It will also give us an indication of the magnitude and direction of the impact on the yield curve. We will also observe whether European economies had different reactions to monetary policy communications. In particular, our study will consider three of the major euro area economies: Germany, Italy, and Spain.
Secondly, we will analyze which transmission channels played a dominant role in the yield reduction caused by the ECB's programs. To this end, we will decompose the sovereign yield into five components: the expectations risk premium, the duration risk premium, the default risk premium, the segmentation risk premium, and the redenomination risk premium.

The study of these propagation mechanisms is very useful not only because it enables a greater understanding of what are the dynamics that ultimately cause movements in the yield curve, but also because it highlights what the market saw as main concerns and how monetary policy response was perceived by market participants. It also gives a way for policymakers to ponder their decision based on which channels are more dominant according to the economic situation and thus enables them to take more efficient measures. In doing so, the understanding of these mechanisms can help in preventing policies that cause the risk premia to move against the intended direction of monetary intervention. As shown in previous studies (i.e., Corradin et al. 2021), it can also be found that countries with certain types of economies can be affected in different ways by similar monetary policy. This issue can be very relevant in the context of the euro area where different countries with their own economic and risk profiles are subject to the same central bank measures. Because monetary decisions adopted by the ECB have to be uniform, they can create asynchronous responses. It is then useful to see how and to what extent common measures can differ in response and if these may even turn out to be detrimental in some instances.

In the next sections, we will start by summarizing the work that has been done in the field by previous authors. In the *Literature review*, we will go through the theory to understand the different items under our study. We will analyze both the theory behind the study of the yield curve and the functioning of the unconventional monetary policy. We will also highlight the relevant research that has already been carried out on the topic, focusing on that literature aiming at explaining the transmission channels of the term structure.

We will briefly review the monetary policy actions that have been taken by the ECB in recent years, with a close look at the measures started especially as a response to the pandemic. Then, in the *Empirical strategy*, we will focus on the models that have been adopted in similar studies. In particular, we will discuss the attempt to quantify the impact of monetary policy announcements on the yield curve and on the transmission channels of Krishnamurthy et al. (2017). We will evaluate the key features of their model and motivate the methodology we decided to use to tackle our research question. We will explain the Kalman filter, a tool useful to disentangle the unobservable transmission channels that we aim to include in our analysis, and then describe the data we used for this purpose. Finally, we will analyze the results of our estimation and explain the conclusions we get from these. We will look at the effect caused by the single announcements, but also on the aggregate results per program. We will observe that indeed the countries we analyze show results that differ both in magnitudes and relative importance of the transmission channels. This can be attributed to the differences in their economies and how they viewed the introduction of new tools. All in all, the results are in line with those of previous research and highlight how transmission channels change their relative importance as determinants of the yield curve over time. These are interesting to observe in different economic scenarios and thus it is important to investigate new tools and methods that can ensure better identification of the yield curve components.

Literature Review

Before starting our analysis, we collect the theories and studies that are at the root of the discussion in the field. We start by analyzing one of the main types of unconventional monetary policy tools, which triggered this new phase of central banking: the asset purchase programs, or quantitative easing. The introduction of asset purchase programs has caused significant effects on the yield curve. These measures introduced by the ECB, aimed at lowering long-term interest rates in order to ease market conditions and increase output. As the ECB buys bonds, in particular those issued by the private sector (i.e., covered or asset-backed securities), their demand increases. These bonds are linked to loan issuance, thus as demand increases, the price rises, and banks are encouraged to make more loans and lowering bank lending rates. This shows a different way in which the central bank can intervene in the economy: instead of influencing the short-term side of the term structure by manipulating the policy rate, as done under conventional monetary policy, the central bank can also act on the long-term side of the curve decreasing the duration risk and credit risk (Altavilla, et al., 2015).

Furthermore, government bond yields are affected by different factors in different ways. They can be thought of as an aggregate of different components which are hard to disentangle and analyze separately from one another. These components are at the root of yield variations and are the term premium, the default risk premium, the duration risk premium, the redenomination risk premium, and the segmentation premium. Apart from these, other channels can be observed, however, these have long been considered the main ones by the literature.

It is hard to understand which of these components makes up most of the currently observed yield: the different risk premia can have different dominance according to the economic situation in which yields are being observed. Hence, it is important to understand how the ECB's measures work and how differently they affected the term structure during the pandemic and the Russian-Ukrainian conflict compared to the previous crisis. Moreover, due to the different nature of the crisis and the reasons why the programs were introduced, some transmission channels could have proven to be more relevant than what was observed after the Global Financial Crisis (GFC) and then the sovereign debt crisis.

Because the transmission channels react to different inputs and reflect different drivers for investors' decisions, for monetary policy effectiveness it is essential that they do not conflict with each other. Understanding the underlying mechanisms can help in developing a better targeted monetary policy response and identify incentives needed to foster or limit movements in the different channels as transmission itself could be compromised if these factors are not taken into account (Corradin, et al., 2021).

In this chapter, we will learn about the work that has already been done in the field and how it could be enriched by our research. Firstly, we will analyze the yield curve by exploring the different theories that attempt to describe its behavior and stylized facts. In particular, we will look at the drivers of changes in its slope and the size of the term premium and explain why it is important to look at these items.

We will then describe the different tools adopted by the ECB, with a special focus on those adopted as a response to the pandemic. We will consider some transmission channels through which these programs affected the term structure: we will observe what factors cause movements in these channels and how they could have been relevant during the last years.

Finally, we will look at previous studies that attempted to identify the transmission channels of monetary policy programs and we will discuss the methods used. In particular, we will look at the findings of Krishnamurthy and Vissing-Jorgensen (2011) applied to the US market after the GFC, and Krishnamurthy et al. (2017) which instead look at the euro area in the aftermath of the sovereign debt crisis. This last research will be very important throughout our study as we will look at their model, keeping their choice for channels and estimators, and apply it to the context of the pandemic and the Russian war. It will be important to observe whether some channels played a more (or less) prominent role compared to the one they had during the sovereign debt crisis.

To conclude, we will look at Corradin et al. (2021) who took the methodology outlined in Krishnamurthy et al. (2017) and applied it to the early months of the pandemic to explore the effect of monetary policy together with that of fiscal policy. We will look at their work for comparison and we will enrich it not only by including observations for the later stage of the pandemic but also by considering the months of the Russian-Ukranian conflict. This caused another crisis in the euro area and therefore other measures being introduced and existing ones being prolonged. Differently again from Corradin et al. (2021), our focus will be uniquely on monetary policy, without considering individual member states fiscal measures which do not fall under the scope of this research.

The Yield Curve and its Stylized Facts

The yield curve shows the relationship between the interest rate yields on bonds with different maturities but the same risk and liquidity. For this reason, it is also referred to as the term structure of interest rates (Mishkin, 1990). One can interpret the yield curve as a reflection of the market's view on future inflation and business cycle by considering the long-term rates and its slope. Over the years, it has served as a good indicator of GDP growth, as well as a signal for the imminence of a recession. In normal times, central banks aim at influencing short-term rates by adjusting the policy rate according to macroeconomic conditions. By manipulating short-term interest rates, they are able to influence various aspects of economic activity, ranging from asset prices to lending of banks and, most importantly, the money market. However, also long-term rates play a significant role in influencing the behavior of firms and banks. For example, aggregate demand has been proven to depend mainly on long-term rates rather than short-term ones (Geiger, 2011).

The difference between long- and short-term yields is called the term spread. This constitutes the slope of the yield curve. Generally, the slope is positive, to reflect compensation of interest rate risk for holding bonds with longer maturities. However, the term spread may turn negative, causing the yield curve to be downward sloping. In this case, we talk about an inverted-shaped term structure. For many years, the yield curve inversion has been considered to be a signal for an imminent recession. Because of this, the slope of the term structure is closely monitored by market participants. However, the whole term structure is deemed to be a relevant indicator in driving monetary policy decisions: from its level and slope to its curvature which gives further information on a medium-term outlook (Diebold & Li, 2005). To be able to act on the entirety of the term structure, it is important to understand what short-term dynamics are important in influencing long-term rates.

In order to develop a theory that explains fully how this curve behaves, three empirical facts need to be explained, namely:

I. Interest rates of bonds that have different maturities move together
II. If short-term rates are low the curve tends to be upward sloping and, vice versa, if they are high the curve will be facing downwards
III. The yield curve is generally upward sloping, meaning that the term spread is positive (Angelo, 2017).

Three are the theories that have been the most successful in explaining at least some of these stylized facts, namely the Expectations theory, the Segmented markets theory, and the liquidity premium theory.

The *Expectations Theory* is considered to be the basic theory of the yield curve. It has as main assumption that investors are risk neutral and thus indifferent between holding bonds of short- or long-term maturities. In fact, short-term bonds and long-term bonds are considered perfect substitutes and so, investment decisions depend uniquely on the interest rate level.

It relies heavily on the relative pricing approach and in particular on the no-arbitrage concept. Thus, the pricing of the two assets, short- and long-term bonds, needs to be equalized to avoid arbitrage opportunities. For this to be true, investors will sell short-term bonds if their expected yield is lower than that of long-term bonds, and they will in turn buy the long-term bonds (and vice versa). The increased demand for long-term bonds will increase their price and consequently lower their yield. At the same time, short-term yields will rise. This mechanism will continue until the average expected yield of the two is equal. According to this theory, interest rates must be able to adjust rapidly to offset any initial difference across bonds of different maturities: in such a way, the expected returns from short- and long-term investments are equal.

The slope of the yield curve shows market expectations on the future interest rate. In particular, according to the *Expectation theory*, long-term rates are determined by short-term ones: long rates are the weighted average of expected future short rates (Geiger, 2011). This relation has some interesting implications. For example, it can happen that when long rates are unusually high at the same time short rates are rising. However, the latter increase at such a speed that the spread starts to shrink instead of widening as one would expect (Campbell, 1995).

Despite being able to explain different features of the term structure, the *Expectations Theory* does not explain why the yield curve is then generally upward sloping: if investors are indifferent between maturities, they will not require a term premium for holding bonds of longer maturities. Hence, the term structure of interest rates should in principle be flat as the difference between long and short-period returns would be around zero (Geiger, 2011). This goes against the stylized fact that normally the shape of the curve is upward-sloping, meaning that the bond yield increases with maturity.

The *Segmented Market Theory* starts from an assumption contrary to that of the *Expectations Theory*: investors have strong preferences for maturities, to the point that the short-term and long-term maturity bonds can be considered as two different markets. In particular, investors are risk-averse, thus short- and long-term bonds are not substitutable: market participants have a strong preference for holding short-term assets as less subject to duration and credit risk. As a consequence, the theory departs from the *Expectations Theory* in stating that there is no relationship between short-term rates and long-term ones.

The fact that investors will require a higher compensation to hold long-term maturity bonds in order to account for the extra risk, explains the upward-sloping structure of the yield curve. An inverted shape could instead be the result of uncertain current economic times where the future appears less risky, thus investors view the long-term bonds as safer (Stafford, et al., 2010). However, by considering long and short-term yields as independent, this theory does not explain the first stylized fact: the co-movement between short- and long-term yields.

The third theory, which is successful in explaining all the stylized facts, is the *Liquidity Premium Theory*. It agrees with the *Expectations Theory* in stating that long-term rates are determined by short-term ones. However, investors are risk averse and therefore will require a liquidity premium as compensation for the interest rate risk they bear when holding long-term securities.

This explains why, in times of crisis, the yield curve is inverted: the decrease in current interest rates causes long rates to fall at a higher speed than how much they increase due to the liquidity premium.

In practice, holders of long-term bonds will not be willing to take the duration risk in uncertain times and will start to sell their bonds, lowering their interest rate. They will substitute them for short-term bonds, increasing their interest rates. This implies that the spread can turn negative in such circumstances and thus the term structure can become downward sloping.
Overall, this theory proves to be the most complete in explaining the movements of the term structure (Angelo, 2017). It is very important as it also shows how monetary policy can influence the yield curve via different transmission channels. In particular, there are many factors that can explain how the compensation required for holding a longer maturity bond can change according to the economic scenario. Adjusting expectations on the future short rates, monetary policy can influence long rates (Engsted, 1993). Starting from the assumptions of the *Liquidity premium theory*, we can disentangle different factors that affect the size of the term premium over time. The channels which affect different parts of the term premium are called transmission channels.
In the next section, we will outline the main monetary tools adopted by the ECB in recent years, and then we will analyze the transmission channels that were triggered by them and in which ways they might have influenced the yield curve.

The Asset Purchase Program and the Pandemic stimulus package

Quantitative easing is a monetary policy tool meant to promote borrowing and spending in times of crisis. It consists of the large-scale purchase of securities by the central bank. The assets bought within this program mainly consist of long-term government bonds but include also corporate and covered bonds. If the policy rate is already close to or at the zero-lower bound, this tool is useful in sustaining asset prices, thus lowering long-term interest rates so that investment and economic activity are sustained. The decrease in the yield of government and corporate bonds causes lending rates for households and businesses to decrease, boosting economic spending. This causes the balance sheet of the central bank to change both in terms of the assets it holds, which now have longer maturities, and in terms of reserves held at the central bank which increase in size (Benigno, et al., 2022).
In a market without frictions, as stated by the former Fed's governor Bernanke, quantitative easing shall have no reason to work because all securities are substitutable by investors. However, because investors have preferences for more liquid securities, it actually proves to be successful. In fact, Bernanke believed that QE worked also via the rebalancing that investors carried out in their portfolios by using the money earned through the asset purchase to invest in profitable securities (Dell'Ariccia, et al., 2018).

Apart from the Fed, many central banks have used quantitative easing, especially in the aftermath of the GFC. A prominent example is the ECB. On September 4th, 2014, the ECB launched two programs: the Covered Bonds Purchase Program (CBPP3) and the Asset-Backed Securities Purchase Program (ABSPP). On January 22nd, 2015 the ECB announced the addition of the Public Sector Purchase Program (PSPP) where it became possible for the central bank to buy sovereign bonds and securities from supranational institutions with investment-grade status. In June 2016, it was launched one more program called the Corporate Sector Purchase Program (CSPP). Together they are commonly referred to as the Asset Purchase Program (APP) which was announced on January 22nd, 2015 (Claeys & Leandro, 2016).

The APP is a monetary policy stimulus meant to address deflation risks by easing borrowing to households and firms. At the same time, its purpose is to anchor and support asset prices. It consists of monthly purchases of both public and private sector securities and it was initially set to run until September 2016, with the official start of the purchases announced on March 5th, 2015. The announcements caused a sharp decline in yields of euro area countries, in particular for those economies with lower credit ratings, such as Italy and Spain (Altavilla, et al., 2021). Because the purchases mainly involve assets with long-term maturities, longer-term rates fell, causing a decline in real interest rates and an increase in aggregate demand. The ECB announced on March 12th, 2020 that the program would continue at a pace of €20 billion in monthly purchases until the inflation outlook would be consistent with its mission (Altavilla, et al., 2015).

When the pandemic started, the ECB was then called to act to sustain economic growth during an inevitable slowdown. In particular, it had to address the issue of market stabilization, protect credit supply and address deflationary concerns. Two types of programs were adopted to address these points: lending programs and further asset purchases. Together with these provisions, the ECB also introduced some tolerance for capital/liquidity requirements and supervisory standards to allow for some stress relief (Lane, 2020).

The main lending programs that targeted the pandemic crisis were the TLTRO III and the Pandemic Emergency Long Term Refinancing Operations (PELTROs). Both the TLTROs and the PELTROs aim at increasing the supply of liquidity in the market, the TLTRO-III more directly addressed the risk of a credit crunch, while the PEPP provided for market stabilization (Lane, 2021). TLTROs were first announced on 5th June 2014 and aimed at increasing the amount of lending in the economy. How much a bank can borrow under this program depends on the amount it lends to non-financial corporations and households. To this day, three series of TLTROs have been announced: in addition to the first program, TLTRO II was announced on 10th March 2016 (starting in June 2016) and TLTRO III on 7th March 2019 (starting in September 2019). In these last two operations, the amount of loans issued by banks was relevant also to calculate the interest rate of their TLTROs' repayments: the more loans to firms and households, the most favorable the interest rate at which the bank had to repay its loan (European Central Bank, s.d.). When the pandemic started, the program was first amended with an increase in the volume of TLTRO borrowing (TLTRO III), then with a reduction of the interest rate, and finally an extension of the program with new lending targets (Mooij, 2021). This was essential in making sure that monetary policy was transmitted also through the banking sector.

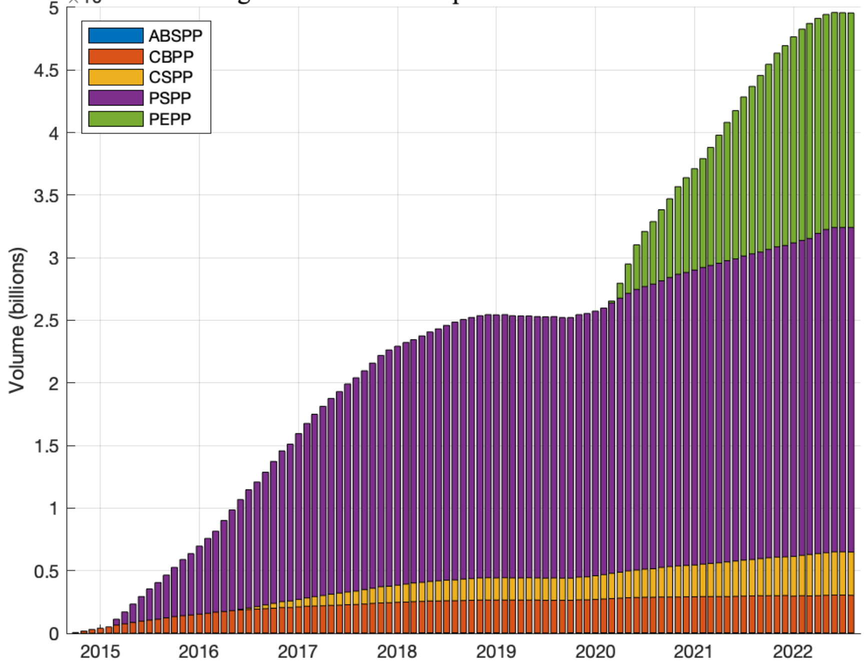
PELTROs instead, were specifically introduced as a consequence of the pandemic. These are long-term refinancing operations that were meant to preserve the functioning of money markets (European Central Bank, 2020). The program was announced on 30th April 2020 and further extended in December 2020. It consists of seven additional longer-term refinancing operations, this time with no lending target and interest rate 25 b.p. below the average MRO rate over the life of the operation (European Central Bank, 2020).

On the asset purchase side, the PEPP was announced on March 18th, 2020, together with an extended envelope of the ongoing APP consisting of an extension of €120 billion. The most substantial measure taken in response to the Covid-19 crisis is considered to be the PEPP. It aims at preserving monetary policy transmission channels as well as addressing the difficult economic situation (European Central Bank, 2021).

Four types of assets can be purchased under the PEPP: marketable debt securities, corporate bonds, covered bonds, and asset-backed securities. It is defined as temporary as it was meant to end once the impact of the pandemic could be considered under control. This is a purchase program, very much similar in structure to the APP. For instance, the assets eligible for the PEPP include also all those eligible under the APP, which is still considered as a separate program. In fact, differently from the APP, securities issued by Greece were granted a waiver in order to be able to be purchased by central banks under the PEPP. In the other programs, they were excluded as they did not receive from any external credit assessment institution a public credit rating that was at investment grade level (Mooij, 2021). Furthermore, the ECB could more freely allocate its purchases as the capital key share, which defines the amount of securities that can be purchased for each National Central Bank (NCB), which needed to be met only at the end of the program (Benigno, et al., 2022).

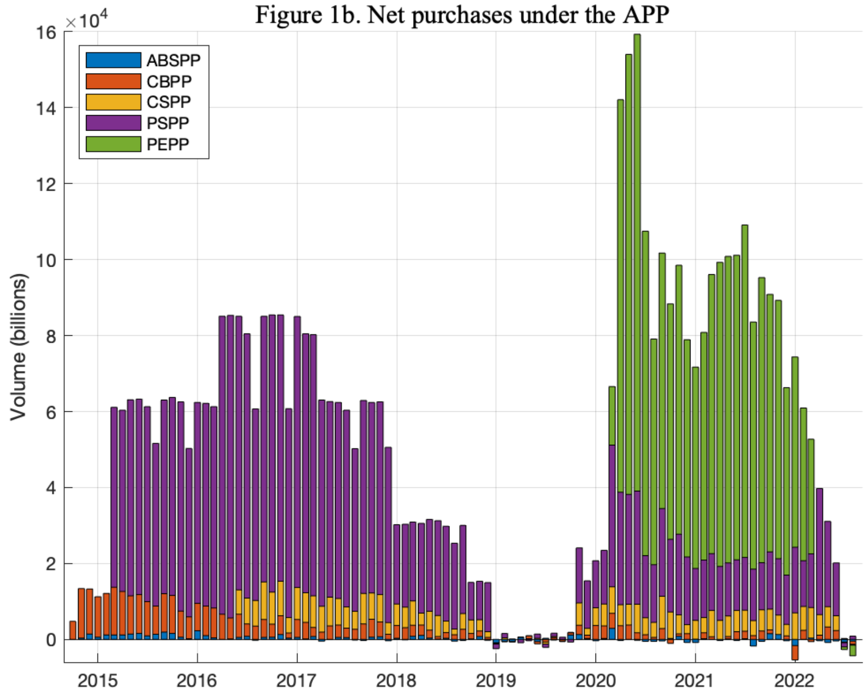
On 18th March 2020, the Governing Council decided to launch this program which initially had a €750 billion envelope. On 4th June, another announcement followed with the decision to increase the envelope by €600 billion. After a recalibration of monetary policy measures, announced to the public on 29th October, the ECB finally decided on 10th December that the PEPP's envelope be further increased by €500 billion, for a total amount equal to €1,850 billion (European Central Bank, s.d.).

Figure 1a. Cumulative purchases under the APP



In Figure 1a, we can observe the magnitude of the overall participation in the different programs. Looking at the cumulative purchases we see that during the pandemic the overall volume of the purchases reached around €4.977 billion, an increase of around 80% compared to the volume at the end of 2019. The PSPP accounts for 52% of these holdings, while PEPP for 35%. However, after the introduction of PEPP, PSPP's volume has increased only by 20%, which corresponds to a contribution of only 23% to the overall 80% change. Thus, the biggest share of the increase is related to a rise in PEPP's purchases.

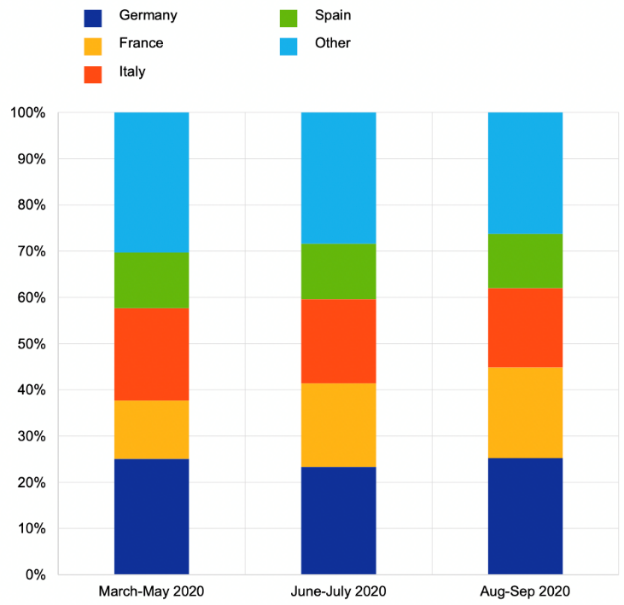
Figure 1b. Net purchases under the APP



This is better observed in Figure 1b, from which we see the evolution in the volume of net purchases over time. The biggest PEPP net increase occurred in the early stages of the program, around May and June 2020. After that, PEPP's net purchases fluctuated minorly with an average of €65 billion per month.

Below, in Figure 2a, is a chart showing the distribution of participation in the PEPP, by country. As we can observe, Germany, Italy, France, and Spain are the main economies that were active in the PEPP purchases. We shall keep this in mind as likely the yields of these countries were the ones most affected by the programs.

Figure 1a. Eurosystem purchases under the PEPP



This can also be seen in figure 2b which gives a clearer idea of the individual weight of each country participating in the program. The chart shows the volume of cumulative purchases broken down by country, as of November 2022. We observe that Germany counts for the highest volume of purchases, followed by France, then Italy and Spain. We will consider this fact when choosing the countries for our estimation. Having largely made use of the program, the effects of program announcements in their economies are expected to be significant in these jurisdictions.

Overall, the PEPP gave the Eurosystem a way to more flexibly allocate funds over a wider range of maturities which was important given the uncertainty raised by the pandemic (Runkel, 2022).

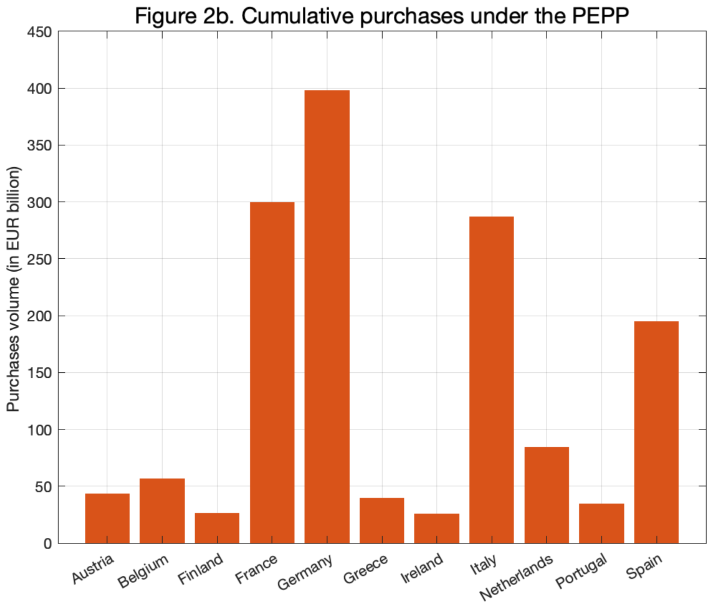
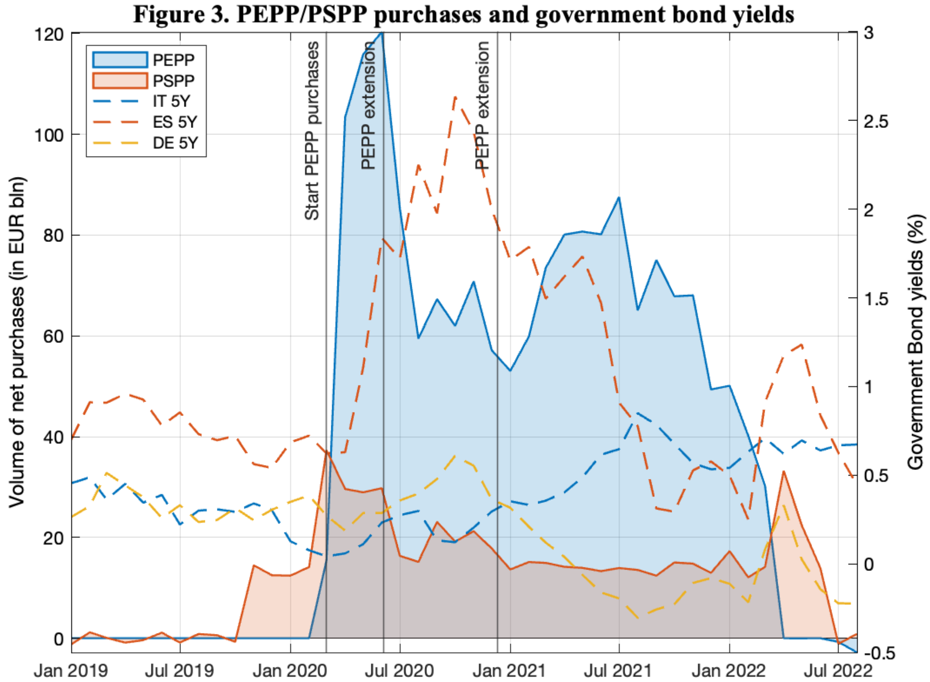


Figure 3 shows the co-movement between PEPP and PSPP net purchases and the 5 years government bond yields of Germany, Italy, and Spain. We can observe that there is co-movement, especially for higher-yield countries like Italy and Spain. In particular, following the launch of the initial PEPP envelope, where net purchases were high, yields have drastically decreased with some lag. This is stronger when looking at PEPP rather than PSPP.

Figure 3. PEPP/PSPP purchases and government bond yields



In the next section, we will analyze the channels through which quantitative easing works to affect the term structure.

Transmission channels

To understand how these tools work in practice and how they can modify the shape of the yield curve, we need to analyze different transmission channels through which quantitative easing operates. To do so, we follow the analysis done by Krishnamurthy et al. (2017) who identify several channels that together contribute to spreading the effect of these policies on interest rates.

The first is the *Expectations Channel*. This is related to monetary policy announcements which give a signal to the future path of the ECB stance (i.e., a signal of a future reduction in the policy rate). It is also a channel that is associated with both APP/PEPP and TLTRO programs as they influence expectations on short-term rates and so bond prices and the economy (van Dijk & Dubovik, 2018). This channel is very important when making monetary policy decisions: when considering a policy rate change, how the spot rates and the implied forward rates move gives a signal of how market participants price the measure (Geiger, 2011). For this reason, usually, monetary policy measures follow the "Brainard uncertainty principle": in times of uncertainty, policy changes shall be gradual, to understand how sensitive the bond yield's reaction is (Söderström, 2000).

Very important in this context is also that the central bank maintains credibility, in the sense that market participants need to trust that the central bank will maintain its commitment to the monetary policy stance. Market participants play an important role as they can anticipate a sequence of policy rate changes, letting monetary policy work through the expectations channel. Because of this, the yield curve is also a reflection of whether monetary policy is being well understood by investors (Geiger, 2011).

A powerful tool of unconventional monetary policy used to influence markets through the expectations channel is forward guidance. Through the communication of the future direction of monetary policy, the central bank can influence private expectations. Forward guidance has become a central tool as it helped in managing expectations, especially in times when monetary easing is needed. It proved to be beneficial in terms of monetary policy outcome: the central bank gives information not only on the current status of the economy but also on the future path of monetary policy and on the likely economic outcomes that will follow. This causes markets to be less responsive to macroeconomic shocks, thus lowering interest rate volatility as expectations are anchored (Ehrmann, et al., 2019).

Because of these benefits, in the last years, central banks have increased their transparency and fostered clear communication to shape private expectations and optimize the outcome of monetary policy decisions (Hubert & Labondance, 2018). Now, this fostered communication has become a key feature of modern central banking.

The mechanism by which this works is explained through the liquidity premium theory: because short-term rates influence long-term ones, then by acting on short-term expectations, forward guidance is able to influence the long-term path of the economy (Hubert & Labondance, 2016).
Hubert and Labondance (2018) have shown that ECB's forward guidance announcements cause a decrease in interest rates which is higher the longer the maturity and which is also persistent. They show that what matters the most is the stance that is communicated, not so much the macroeconomic information, which further proves the importance of the signaling channel.
Ehrmann et al. (2019) identified three types of forward guidance that have been used at different times by different central banks: open-ended, time-contingent, and state-contingent. While the open-ended type is strictly limited to giving indications on the policy path, the last two refer to a time horizon of the future policy that can depend either on a specific calendar date or on the achievement of a certain target or a specific economic outcome. Since March 2016, ECB's forward guidance has been time-contingent, at least for policy rates as their path was linked to the end of the APP. However, since the introduction of the PEPP, it has been more associated with the completion of an economic objective (namely, the decrease in the concerns raised by the pandemic) and thus it could now be considered as state contingent. Both these types of forward guidance have been shown to decrease market responsiveness to economic shocks the most if over long horizons (Ehrmann, et al., 2019).

Another important channel is the *Duration Risk Channel*. As we explained in the previous sections, in general, long-term rates account for compensation which is represented by the term premium. Part of the term premium is related to intertemporal compensation due to the interest rate risk of longer maturity bonds. Interest rate risk is the risk that, due to market conditions, changes in interest rates may reduce the market value of a fixed-income investment. For the uncertainty that investors of long-term bonds face in this regard, they require a premium to compensate for it. This is a deviation from the *Expectations Hypothesis* according to which long-term rates should equal compounded current and future short-term rates (Callaghan, 2019).
For this to be true, we must allow for a *preferred habitat* to enter our model assumptions, meaning that we take into account that investors have preferences for bonds of a certain maturity compared to others (Krishnamurthy & Vissing-Jorgensen, 2011). From this, it follows that, according to the direction and impact of monetary policy measures, the term premium can be time-varying: if the ECB buys long-term securities, this reduces their risk, and thus lowers the term premium requested by investors to bear the interest rate risk (or duration risk). This implies that long-term rates could even become lower than short-term ones giving rise to an inverted yield curve.
This channel affects all EU member states independently of whether their sovereign bonds are high or low risk (Krishnamurthy, et al., 2017).

The *Default Risk Channel* works through the default risk premium and is another component of the term premium. This is related to the possibility that the issuer of the bond, in the case of sovereign bonds this will be a country, may not be able to meet its contractual obligations at maturity. The default risk premium has two components: firstly, a compensation dependent on the expected loss from default, and secondly a credit risk premium component that reflects the probability that this loss might be larger than expected. This means that risk premium accounts for the possibility that the final loss might be larger than what is expected given past experience (Geiger, 2011).

Because APP contributes to stimulating economic growth, the probability of default decreases, causing the related risk premium to shrink and investors' risk aversion to fall. After the GFC, the default risk premium increased greatly in all jurisdictions and central banks carefully monitor it as it is pivotal for financial stability (Geiger, 2011). In particular, this was true for GIIPS countries, where sovereign bond spreads decreased greatly thanks to the ECB programs. Within the context of quantitative easing, the central bank is seen as a possible lender of last resort. As a consequence, market participants rely on the assumption that, in case of illiquidity, the government will turn to the central bank and ask it to buy its debt. This causes the perception of the likelihood of the event of default to fall. However, it has also been noted that this presumption can increase moral hazard and therefore increase the default risk component at times (Krishnamurthy, et al., 2017).

Credit Default Swap (CDS) rates are a useful proxy to study the magnitude of this channel. Through these instruments, investors hedge against the probability of default: the buyer and seller trade the credit risk of a reference entity. In case of default of the entity, the seller of the CDS contract will provide insurance to the buyer (Geiger, 2011). Hence, CDSs represent a measure of how much investors believe in the probability of default of certain assets. As an example, after the APP, Italian CDS spreads greatly declined, accounting for the majority of the decrease in sovereign spreads. This suggests that credit risk is a fundamental component of bond price fluctuations (Altavilla, et al., 2021). Given arbitrage considerations, CDSs should be equivalent to the credit spread: the difference between the defaultable and the default-free government bond yield (Geiger, 2011).

This and the duration risk channel have been shown by Altavilla et al. (2021) to be the ones that were responsible for the greatest reduction in long-term yields. The Default risk channel is also one that is intrinsic to each country and so it can vary according to the country-specific risk (i.e., in the case of Italy and Germany).

Then, we have the *Segmentation* Channel. Segmentation arises when investors have different valuations of a bond, causing constraints in the participation and market price to be different from the actual value as only a subset of investors participates (Krishnamurthy, et al., 2017). Bond yields reflect this segmentation.

The segmentation component can be positive or negative: when negative, it can be interpreted as a "convenience yield", meaning that it represents the value investors attach to non-pecuniary benefits of government bonds. The more negative, the more investors benefit from owning the bond rather than from receiving its cash flows. This can happen, for example, due to the safety of the asset (Corradin, et al., 2021). The size of the negative segmentation component has been found to be positively correlated to the extent to which the central bank purchases sovereign debt: this increases the specialness of the bonds bought, as they become scarcer and markets more illiquid. Furthermore, owners of scarce bonds, benefit from lower refinancing rates as the scarce bond can be used as collateral and thus, it should trade at a premium. The supply decrease causes prices to rise and therefore yields to fall (Corradin & Maddaloni, 2017).

Finally, the *Redenomination* Channel reflects the risk that a currency may default, and the government may redenominate its debt at a depreciated exchange rate (Corradin, et al., 2021). In the case of the euro area, if a country or a group of countries decides to exit the euro to form a new currency, the contracts under the exiting country's jurisdiction will be redenominated. Investors account for the risk that the new currency might depreciate vis-à-vis the euro, creating a spread between securities that otherwise are different only because of the jurisdiction they fall under. This spread will reflect how likely it is that a country will exit the euro area.

This is somewhat similar to the default risk as in both cases lenders suffer the losses. However, redenomination has a direct impact on private borrowers as it reduces their debt obligations in the involved currency. Thus, the redenomination component reflects the likelihood of redenomination, the depreciated value once the currency is redenominated, and the cost of redenomination (Krishnamurthy, et al., 2017).

Altogether, these channels influence the current value of the sovereign bond yields, with magnitudes that vary according to the size of each component. It must be noted that this can also vary over time, meaning that some effects may dominate in certain economic eras, and become negligible in others. Given that their identification is not trivial, different methods have been used to study the channels separately.

In the next section, we will observe what methodologies have been used to measure their role and size in the context of quantitative easing policies.

Previous research

Krishnamurthy and Vissing-Jorgensen (2011) try to evaluate the role of the transmission channels following the quantitative easing programs implemented in the United States (US) after the GFC. They consider seven different transmission channels and use an event study methodology to isolate the effect after QE announcements. They include a few more transmission channels other than the ones described above. For example, they also consider a *safety channel* which is the increased willingness to pay a higher premium for safety as the supply of safe assets gets lower. Thus, in the presence of QE, the yield on safe assets such as Treasury bonds is lower. Another channel considered is the *inflation channel*: QE can raise inflation expectations, thus creating uncertainty on policy outcomes. The direction of the effect on interest rates is debatable.

One of the benefits of adopting an event study model is that it allows to abstract from defining a specific equilibrium or an arbitrage-free model, making the results robust to misspecification. For this reason, we decided to also adopt this methodology. Krishnamurthy and Vissing-Jorgensen (2011) test whether the changes in interest rates on announcement days are different from those occurring on days separate from the announcements using F tests: if we accept the null that the changes are the same, then there is no effect pursuing the announcement that is different from regular rates fluctuations.

For the method to work, it is essential that two assumptions hold: firstly, the announcement was not leaked before the official date, and secondly, the price impact is instantaneous. This shall generally be true, however, in the case for example of LTROs, different national announcements followed the ECB's, causing possible noise in the estimation (Krishnamurthy, et al., 2017). To allow for some delay in the price reaction of less liquid assets, they accounted for 2-day changes.

They found that for the first program (QE1) a critical role was played by the signaling channel, together with the default risk channel in the case of riskier bonds. For QE2, the dominant channel was instead the flight-to-safety, followed by the signaling and the inflation channel. According to their research, these appear to be the most prominent ways in which the effects of QE are transmitted to the yield curve and the economy in the US after the GFC. Thus, in Krishnamurthy and Vissing-Jorgensen (2011) the duration risk channel does not play a prominent role. This appears surprising. One possible explanation for this finding is that the duration risk premium was small during the GFC due to the effect of the deflation risk: having the Fed increased the policy rate due to inflationary pressures, the deflation risk might have outweighed the duration risk. The circumstances could however be different in the APP that took place in Europe.

In another relevant study, Krishnamurthy et al. (2017) looked at the transmission channels following bond purchases, this time focusing on the ECB's policies in response to the sovereign debt crisis. In particular, they focused on the effects of the Securities Market Programme (SMP), the Outright Monetary Transmission (OMT), and the LTROs in three EU countries, namely Italy, Spain, and Portugal. These countries were the ones most involved in the above programs. This research considered the same channels as the ones we described in the previous section.

Krishnamurthy et al. (2017) decompose the government bond yields into a component that is common to all euro-area countries, and some country-specific components which could vary across different jurisdictions. The latter consists of the redenomination, segmentation, and default risk channels which are not directly observable. Thus, to disentangle their effects, the Kalman filter methodology is used. This is augmented via VAR to account for some delay in the reaction of asset prices to monetary policy announcements. The Kalman filter method will be explained more thoroughly in the following chapter. This is combined with an event-study approach, using 2-day changes to again allow for a delay in price changes as done in Krishnamurthy's previous analysis.

A relevant point to be noted is that the effects found in the research likely only reflect how the programs were initially perceived by the markets: because the initial announcements of the SMP and the OMT did not include information on their magnitude, the evidence does not likely represent their likely outcome or impact. This marks a possible limitation of the outcome of their estimation.

It is found that, differently from Krishnamurthy and Vissing-Jorgensen (2011), the Signaling and the Duration Risk channel did not play such an important role. Instead, the Default Risk Premium and the Segmentation channels were very relevant for the transmission of the SMP and the OMT. The redenomination risk was also generally very small, and more present only at specific times. It was more relevant during the SMP and OMT for Spain and Portugal, but not for Italy.

Significant reductions in bond yields are found for all countries related to the SMT and the OMT (at around 200 b.p.), while for LTROs yields in Portugal do not seem to be impacted, while the largest reduction amounts to 50 b.p. but not significant. The channels involved in the decrease in bond yields are slightly different depending on the country under analysis. For Italy, the dominant channel is the Default Risk channel: the default risk premium component is found to decrease by 31-117 b.p. for each of the SMP and OMT. Secondly, also the redenomination channel saw important decreases, however not significant. For LTROs, they observe lower effects with a reduction of only 34-40 b.p.

For Spain, the picture is somewhat similar to the Italian one: also here the main reductions are caused by the Default Risk channel, followed by the redenomination and segmentation channels. Default risk premia fall by 44 – 96 b.p. for SMP and OMT, while the redenomination premium falls by 20 -56 b.p., this time the result being robust. Also in this case, for LTROs the reduction is much smaller, but with an increase in the relevance of the role of the segmentation component which falls by 69-83 b.p. This can be explained by the fact that purchases in Spain were much larger. The Default Risk channel is the most relevant also in Portugal, with similar results as those for Italy and Spain for the SMP and the OMT. However, the effects of the LTROs are non-significant for all yield components in this case.

We will for the most part adopt the methodology and the lessons of this paper. We will try to achieve a similar analysis to evaluate the transmission channels at play during the policies undertaken to address the pandemic and, to some extent, also the Russian-war crisis by the ECB. We will look at three representative economies to compare the different outcomes and draw some conclusions.

Corradin et al. (2021) took the model used by Krishnamurthy et al. (2017) and applied it to study the effects of monetary but also fiscal policy measures taken during the early months of the pandemic. They kept all the channels considered in Krishnamurthy et al. (2017) and introduced a *Liquidity risk premium Channel*: this reflects the difficulty of investors in selling the bond before maturity. Despite the results showing that also the new liquidity risk premium channel played a role in the propagation of monetary policy, it was not one of the most relevant and for this reason, we will not include it in our analysis which will remain more in line with the original model by Krishnamurthy et al. (2017). Corradin et al. (2021) found that during the pandemic the most relevant movements were those in the redenomination, segmentation, and default risk channels. The first two were more pronounced in southern Europe countries (such as Italy and Spain) and the latter in countries such as Germany and France. Furthermore, they find that the effects of monetary policy announcements were perceived differently among countries. For example, the PEPP announcement despite causing a decrease in Italian and Spanish spreads caused an increase in France and Germany. Differently from Krishnamurthy et al. (2017), new data to estimate the default channel was adopted: they preferred to use sovereign CDS spreads denominated in euros to take advantage of the greater availability of data for different countries.

Our analysis will use a larger event window: Corradin et al. (2021) consider announcements taking place only up to June 2020 while we aim to consider all announcements related to TLTRO, PELTRO, and PEPP until the end of 2022. We will restrict our research to only monetary policy-related announcements, so not include fiscal policy communication. This decision is taken for simplicity, given the diverse countries under our analysis, and to focus on the specific effects of monetary policy. In the next chapter, we describe in depth the empirical strategy we intend to adopt to analyze our research question.

Empirical Strategy

Having outlined the theories and research that are behind the yield curve and its determinants, we can now turn the discussion to how we intend to address our research question. Namely, our purpose is that of identifying the transmission channels that were the most relevant for the transmission of monetary policy during the years of the pandemic and the Russian conflict in Ukraine.

To achieve this, we will first use an event study approach to observe the impact of the ECB's communication on the yield curve. Then, we will disentangle the channels through which the pandemic programs operated in the economy. We will focus on some European countries and on ECB policy announcements. We expect to find that certain channels were more active than others and with differences in their relative importance according to the jurisdictions.

We will look at Krishnamurthy et al. (2017) and adopt their methodology to replicate their study in the years of the pandemic. We will consider Italy, Spain, and Germany for the analysis as these countries were greatly involved in the PEPP program (see Figure 2) and thus will enable us to have enough data for a sound estimation. They are interesting to look at also because of how their economies compare to each other. For example, we can imagine that Italy and Spain will behave in a more similar way, having more comparable economies, while Germany should return somehow different results. We will pay close attention to any difference in impact and magnitude that monetary policy could have had on these economies and try to link it to their characteristics.

In the next sections, we will describe the main components of our model. In doing so, we will highlight in which ways our model will mirror those used in previous research and how it deviates. We will also provide a detailed explanation of the approaches adopted in particular regarding the identification of the transmission channels analyzed. We will thoroughly explain the methodology through which Kalman filtering operates. This will help us understand the decision of using it to quantify the transmission channels. Finally, we will indicate the type of data we chose to use and the motivation for differing from other choices made in previous research when applicable.

The model

Firstly, we will define the channels we aim to identify. Similar to Krishnamurthy et al. (2017), we decided to consider four channels. We consider channels that could have played a relevant role during the pandemic and in its aftermath. Because of this, we decided to keep channels that in Krishnamurthy et al. (2017) appeared to be less active in the propagation of monetary policy as now we believe they might have played a bigger role. Namely, we kept the redenomination risk, which in previous research appeared smaller, as for some countries it might have been very relevant now. In fact, the worldwide economic slowdown could have caused increased concerns regarding the strength of the Euro, and so fostered the redenomination risk channel.

Therefore, we focus on:

I. Expectation and Duration risk channel
II. Default Risk channel
III. Segmentation risk channel
IV. Redenomination risk channel

We expect that for Italy and Spain, the redenomination component could be one of the most prominent premia: given the crisis generated by the pandemic and the consequences of the war initiated by Russia, summed up with the existing high government debt, we believe these markets were more impacted by the thought of an exit from the euro-area. In Germany instead, these effects should be relatively smaller as it is a core country in the monetary union.

We will use an event study approach to document the reduction in government bond yields caused by ECB's policies during the pandemic. An event study analysis is based on the assumption that market prices are efficient and incorporate all available information. Then, following an announcement, prices will adjust to reflect the newly available information. If this is true, then we can study how announcements, in particular monetary policy announcements, can impact the term structure of interest rates. We will use a time window of two days changes, also for the day after the announcement, to allow for some delay in market reactions.

In the event study, we will estimate the following equation:

$$\Delta \boldsymbol{y_t}^{\boldsymbol{c}} = \boldsymbol{\alpha_0^c} + \boldsymbol{\alpha_1^c}\, \mathbb{I}_{\{\boldsymbol{monetary\ policy\ announcement}\}} + \boldsymbol{\varepsilon_0^c} \quad (1)$$

$\Delta y_t{}^c$ represents the daily change in the 5-year yield. The α_i^c terms with $i = 0{,}1$ are respectively the constant and slope parameters. More precisely, α_1^c represents the surprise component of the announcements: this will give us a magnitude of the effect of the announcements on yield movements. α_0^c represents the effect under yield fluctuations on days when no announcement took place.

Finally, we have the indicator function which is equal to one on the days of the monetary policy statements. To be specific, following the model of Krishnamurthy et al. (2017), this will equal 0.5 on the day of, and on the day after the announcement so that the estimate for α is approximately the sum of these two observations (Corradin, et al., 2021). This is done to allow for some delay in price reaction.

Then, our analysis will turn to the identification of the different term premia that contribute to influencing the yield to quantify to what extent they participated in the transmission of monetary policy to financial markets.
The bond yield can be decomposed as follows:

$$\boldsymbol{y_T^C = \frac{1}{T}\int_0^T E[i_t]dt + Duration_T + Default_T^C + Segmentation_T^C + Redenominaiton_T^C} \qquad (2)$$

Notice that the first two components, which identify respectively the Expectations and Duration Risk channel, are not country dependent. This means that their estimators will be the same across all regions in the euro area. They will be considered together through the euro swap rate.
The latter are the Default Risk, the Segmentation, and the Redenomination channels which are instead country dependent. The segmentation and redenomination risk premia are harder to disentangle because not directly observable and because they do not have one specific estimator. Intuitively, we can start by noting that their sum shall equal bond yields net of the expectation and default risk components, however, identification will still be difficult.
For this purpose, we will adopt the Kalman Filter methodology. Through the filter, we are able to separate these components, solve the measurement error in observed prices caused by illiquidity, and account for the lag of the price reaction to policy announcements. We will explain this further in the following section.

The Kalman filter

Kalman filtering is particularly useful when we want to estimate a value that contains measurement errors, high variance, and uncertainty. It is used when estimating the state of a discrete-time controlled process (x) governed by a linear stochastic difference equation. One characteristic of x, also referred to as state vector, is that it is not directly observable but can be inferred from other measurable variables (Kleinbauer, 2004).
We assume that x_t follows a first-order vector autoregressive model (see Equation 3). This is also called the dynamic/state model. The vector x will be the vector of the latent components: in this case, the risk premia. Because x_t is not observable, we will make use of y_t (observable), which in our case is the vector of government bond yields and the other estimators.
The components of the two vectors are shown below:

$$y_t = \begin{bmatrix} Gov.yield - EUR\ swap \\ US\ Gov.yield - \ USD\ swap \\ Corp.yield - USD\ swap \\ CDS\ swap \end{bmatrix} \qquad x_t = \begin{bmatrix} term\ premium \\ default\ risk\ premium \\ redenomination\ risk\ premium \\ segmentation\ risk\ premium \end{bmatrix}$$

We thus define y_t as a linear combination of x_t , the latent components, and some heteroscedastic measurement error w_t (see Equation 4, the observation model). This allows us to estimate the unobserved x_t through the observed y_t.

$$x_t = a + Tx_{t-1} + v_t \qquad v_t \sim N(0, H_t) \tag{3}$$

$$y_t = Zx_t + w_t \qquad w_t \sim N(0, Q) \tag{4}$$

Because we make inference on x based on the new data we introduce into the system, the Kalman filter can be viewed as an application of Bayes theorem. In fact, we update our estimate of the effect of x, given the new information we include in the equations.

The following holds:

$$P(x_t|y_t) \propto P(y_t|x_t, y_{t-1}) \times P(x_t|y_{t-1})$$

v_t and w_t, respectively the state equation error and the measurement error, are assumed to be independent, White and normally distributed (Welch & Bishop, 1997).

$Z(i, j)$ is the state transition matrix and it is very important for identification. It links elements of the observed asset price y_t (represented by the i rows) and of the latent component x_t (represented by the j columns). For its construction, we will follow the example set by Krishnamurthy et al. (2017). In particular, we consider the fact that, while CDS contracts under CR clauses do not comprehend the risk of redenomination, those under the CR14 clause do. The latter are contracts issued after 2014 and protect against the risk that the debt is redenominated in a new currency (Bonaccolto, et al., 2019). Thus, because this applies for all three countries, to estimate the redenomination channel we use the fact that the yield of the corporate foreign-denominated bond (namely, USD-denominated) net of the USD swap rate, captures the default risk. This subtracted from the CDS, will result in the redenomination risk. Thus, we will set for Germany, Italy, and Spain $\eta_1 = 0$ and $\eta_2 = 1$.

$$Z = \begin{pmatrix} 1 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & \eta_1 & 0 \\ 0 & 1 & \eta_2 & 0 \end{pmatrix}$$

$T = I_4$ where I_4 is a 4 by 4 identity matrix.

The filter works through two groups of equations: time update and measurement update equations. Time update equations forecast the current state and can be thought of as predictor equations. These predict the future state through a dynamic model. Instead, measurement update equations make ex-ante estimates. The state vector can also be decomposed into an *a priori* and an *a posteriori* value, reflecting the change in value after applying the measurement equations.

The filter is a feedback mechanism where the system estimates the process state at time t, and gets feedback in terms of measurement noise. Measurement updates incorporate the new observation into the ex-ante estimate for a better ex-post estimate and to minimize the covariance of the estimator (Kleinbauer, 2004). Time update equations are also called predictor equations, while measurement equations are also referred to as corrector equations (Welch & Bishop, 1997).

To understand how this works in practice, we can identify three steps which can be summarized by three equations. These equations will then be repeated in a recursive way. We start off by having an arbitrary original error in the estimate and an original estimate. However, as we go through the process, the equations will be updated with the output from each loop, which is fed into the equations iteratively.

The first step consists in calculating the Kalman Gain (KG). This estimate is useful as it shows the relative size of the measurement error compared to the error in the estimate. The error in the estimate regards how much the observation deviates from our current estimate (i.e., $\beta - \hat{\beta}$ where $\hat{\beta}$ is our estimate and β is the new estimate after introducing the new data point). The measurement error has instead more to do with v_t and is related to the error of the 'instrument' we use for estimation.

The KG tells us how much the measurement changes the estimate. It is defined as:

$$KG = \frac{Error_{Estimate}}{Error_{Estimate} + Error_{Measurement}} \tag{5}$$

By construction then, the KG is a value between zero and one. It represents how big the error in our estimate is compared to that in the measurement (data). Equation 5 belongs to the measurement equations.

The next step is to take the value obtained for the KG and use it to calculate the current estimate, through the following update equation:

$$Est_t = Est_{t-1} + KG \cdot (Measurement - Est_{t-1}) \tag{6}$$

The difference term in parenthesis in Equation 6, is called measurement residual and represents the discrepancy between predicted and actual measurement (Kleinbauer, 2004).

Observe that, if the KG is close to 1, this means that $Error_{Measurement}$ is low compared $Error_{Estimate}$ (see Equation 5) and thus the measurements are fairly accurate. As a consequence, in Equation 6, $Est_t \sim Error_{Measurement}$ and thus there can be a lot of uncertainty in the value of the estimate. So, with KG close to 1, measurements are accurate and so we want them to account for much of the updated estimate Est_t. With a small KG, the error in measurement is large, thus in computing the new estimate we put a lower weight on the part considering the measurement. This also means that as we are moving forward, the estimated values are becoming more stable, and we can place a higher weight on Est_{t-1} to update Est_t. In this way, the measurement doesn't throw off our forecast too much.

Over time, the KG should decrease as we get closer to the true value of the estimate. This is intuitive: at the beginning, as we incorporate new data to estimate our process, the estimates are very volatile as data contains much different information that is not yet incorporated. Thus, initially, Equation 3 will be the best estimator for the value of x_t (Meinhold & Singpurwalla, 1983). The more data is stored in our estimate, the less the new estimate will change once we add further observations, and its historical value is more reliable than in the beginning.

Finally, as a last step, we calculate $Error_{Est,t}$ defined as:

$$Error_{Est,t} = \frac{Error_{Mea} \cdot Error_{Est,t-1}}{Error_{Mea} + Error_{Est,t-1}} \tag{7}$$

or

$$Error_{Est,t} = (1 - KG) \cdot Error_{Est,t-1} \tag{8}$$

Once this is calculated, we start back from Equation 5 until we get to a good compromise value between $Error_{Estimate}$ and $Error_{Measurement}$. A large KG implies that the error in measurement (in the data) is relatively small, thus the more data we incorporate, the better our estimate gets. By Equation 8, we also see that the higher the KG, the lower the error of the estimate at time t. Our aim is in fact that of reducing the error in the estimate as we move forward with the estimation. Because of this, the estimator that the Kalman filtering finds is a Best Linear Unbiased Estimator (BLUE).

The data

In this section, we will briefly describe the data we decided to use to perform our analysis and the rationale behind such choices.

The interest swap rate incorporates the market perception of factors like market liquidity, supply, and demand. Thus, it serves as an important benchmark for the expectations channel. The expectation and duration component will thus be found by using the Euro swap rate and will be analyzed together as done by Krishnamurthy et al. (2017). We will use the Euro Overnight Interest Average (EONIA) OIS rate and the Euro Short Term rate (€STR). EONIA is a weighted average of the interest rates on unsecured overnight loans contracted in the euro interbank market. EONIA swap rates were considered to be the main benchmark for the short end of the term structure, and they represented the most liquid segment of the money market (Remolona & Wooldridge, 2003). However, the EONIA was discontinued after the end of 2021 as by that time it lacked concentration and transactions to be considered compliant under the EU Benchmark Regulation (Macquarie Group Limited, 2021). Due to this, for the period following December 31st, 2021 we will use the newly introduced €STR which became the new overnight unsecured benchmark rate for the euro area (Nicoloso & Tsonchev, 2019).

To identify the default risk premium component, we will use US government bond yields denominated in dollars. Foreign government bonds can't be redenominated through euro changes and thus they are not affected by redenomination risk. Netting for the US dollar swap rate, representing the expectation and duration component, they should only capture the default risk premium component of sovereign bond yields. This difference is also referred to as the swap spread, and it is known as an indicator of the market's willingness to hedge for risk, market liquidity, and as a measure of systemic risk. We preferred this proxy over sovereign CDS rates because the latter runs into the risk of underestimating the default risk if market participants do not believe they would be triggered in case of default. To avoid this, we prefer to consider US government yields following the assumption that foreign-law sovereign bonds have the same default risk premium as the domestic ones (Krishnamurthy, et al., 2017).

We also rely on the assumption that redenomination risk affects all securities issued by a given country equally, as subject to the same law. Krishnamurthy et al. (2017) argue that yields of Euro-denominated government bonds and of Euro-denominated corporate bonds of the same duration shall be uniformly affected by this channel. Then, the yield of risk-free Euro-denominated corporate bonds can be used to identify the redenomination component together with the corporate CDS rate in countries where this covers only the default risk. However, as mentioned, according to the jurisdiction and contract clause, CDSs can at times cover also for the redenomination risk, causing issues in estimation. Because we consider in all three countries CDS contracts under the CR14 clause, the redenomination risk will be the difference in the yield of the USD-denominated (swap-adjusted) corporate bond net of the corporate CDS rate.

For the choice of eligible corporate bonds, we decided to focus on those of safe non-financial companies with the same duration so that they identify solely the riskless interest rate and are not closely associated with the sovereign default risk. Namely, these are ENI S.P.A. for Italy, Telefonica S.A.U. for Spain, and Mercedes for Germany.

Finally, the segmentation component reflects limits to arbitrage, and it is calculated as the residual of the yield, net of the other components. This will be identified by the difference between the government yields and all the other channels previously mentioned.

To summarize, the identification would go as follows:

$$\text{Expectation/Duration component} = \text{Euro swap rate}$$

$$\text{Default component} = \text{swap adjusted yield on USD denominated bond}$$

$$\text{Redenomination component} = \text{corporate bond yield} - \text{USD swap rate} - \text{CDS rate}$$

$$\text{Segmentation component} = \text{Yields} - \text{Euro swap rates} - \text{Default} - \text{Redenomination}$$

We will focus on 5-year maturity mainly because this best reflects the average maturity of euro area sovereign debt among the different countries which is 6 years (Corradin, et al., 2021).

We will try to enrich previous findings by estimating the model over a larger time window: data will comprehend data from 1st January 2019 to 2nd December 2022. As data sources, we have mainly used Bloomberg for data on bond yields, Refinitiv for data on corporate CDSs, and the ECB's Statistical Data Warehouse for data on the Euro swap rate.

In the next chapter, we will discuss the findings of our estimation.

Estimation results

In this chapter, we will look at the data and disentangle the impact of the ECB's program announcements on government yield and its components. In the table below, is a summary of the event dates we consider with a short description of the content of the announcement. Each date has been linked to a program category (either TLTRO or PEPP). When announcements on different programs were made on the same day, the category chosen is the one where the announcement was more valuable (i.e., the program was introduced or substantially changed).

Program	*Date*	*Description*
TLTRO	7 Mar 2019	Initial announcement
TLTRO	6 Jun 2019	Technical details
TLTRO	29 Jul 2019	Legal acts
TLTRO	12 Sep 2019	Changed interest rate
TLTRO	12 Mar 2020	Easing conditions
TLTRO	30 Apr 2020	Rate reduction
TLTRO	29 Jan 2021	Technical changes
TLTRO	30 Apr 2021	Technical changes
TLTRO	27 Oct 2022	Interest rate recalibration
PEPP	18 Mar 2020	Initial announcement
PEPP	4 Jun 2020	Extension
PEPP	10 Dec 2020	PEPP extension

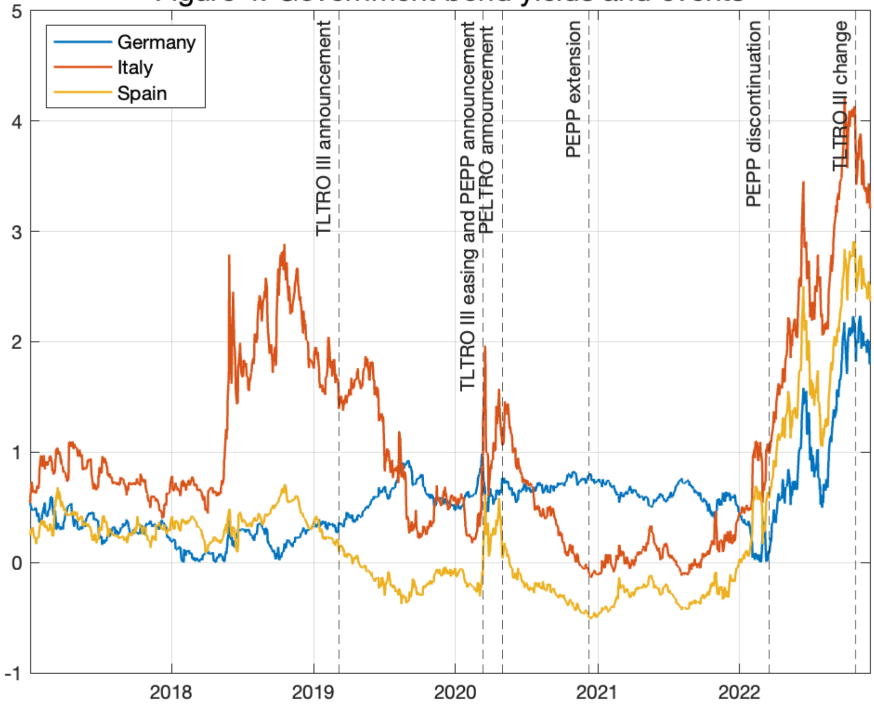
Firstly, we will use an event study approach to visualize the effect of the program announcements on government bond yields. This will give us an overview of which programs and in particular which events may have had a higher impact on the overall yield curve level. Secondly, we will use the Kalman filter to identify the unobservable channels, namely the default, redenomination, and segmentation components. With the filtered estimates we will perform a second event study to identify the channels mainly responsible for yield fluctuations.

To have an idea of what we can expect from the estimation we first have a look at the data. In Table 1 we show some descriptive statistics. What we notice is that in general, the variance in Italy and Spain is higher than in Germany, as expected. We also notice that corporate bond yields are much lower in Germany, while CDS rates are somewhat comparable.

Table 1: General statistics			
Country	*Rate*	*Mean*	*s.d.*
	Euro Swap Rate	-0.37	0.35
	US Government yield	1.54	1.07
	US Swap Rate	1.09	1.19
Italy	Government yield	0.97	1.03
Italy	ENI bond yield	3.34	1.12
Italy	ENI CDS rate	0.75	0.27
Spain	Government yield	0.22	0.83
Spain	Telefonica bond yield	2.89	1.24
Spain	Telefonica CDS rate	0.81	0.20
Germany	Government yield	-0.27	0.75
Germany	Mercedes bond yield	0.97	0.87
Germany	Mercedes CDS rate	0.76	0.31

In Figure 4, we observe the fluctuations of the 5-year government bond yields, together with the main announcement dates. From the graph, the impact of the first TLTRO III announcement in Italy is clear. Very evident are the decreases following the announcements on TLTRO III easing and PEPP introduction in all bond yields. We can also observe that pursuing the final PEPP extension there no major changes in yields.

Figure 4. Government bond yields and events



Figures 5, 6, and 7 show the rates used for the estimation of the default, redenomination, and segmentation channels for the three countries, namely the corporate bond and CDS swap rates. These are shown together with some main event dates for which we observe an evident reaction in the data.

For all countries, we see that the start of PEPP purchases corresponds to evident increases in corporate rates, while the last TLTRO III announcement caused a decrease. From this, we expect the following dates to have significant coefficients in the event study estimation. We can also see that Germany's rates are less subject to high volatility compared to Italy and Spain.

Figure 5. Italy - Rates overview

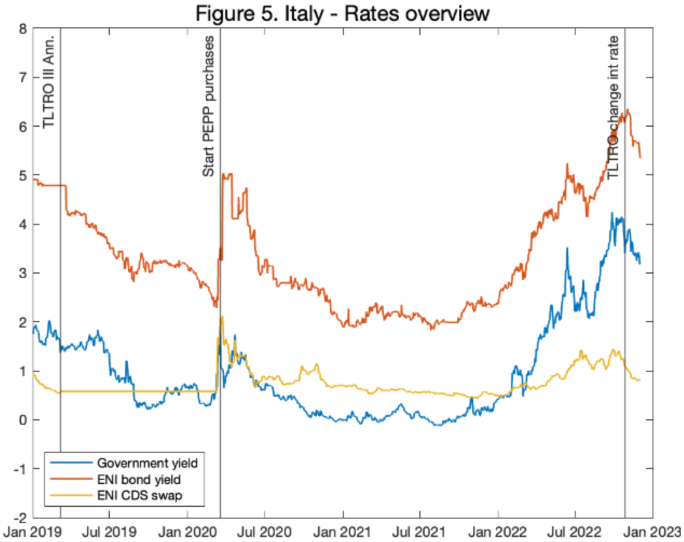


Figure 6. Spain - Rates overview

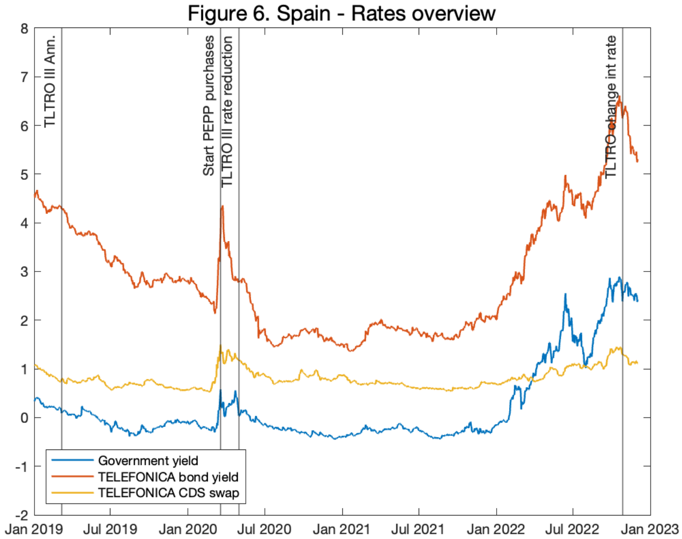
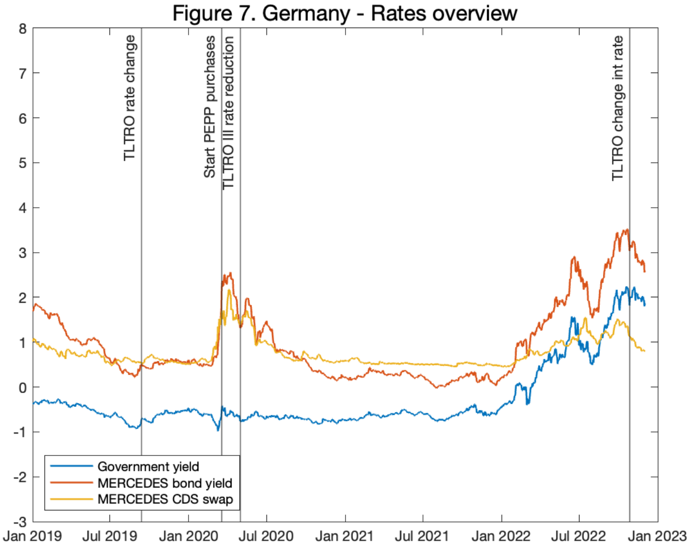


Figure 7. Germany - Rates overview



Event Study Analysis on Government bond yields

To begin, we observe the results related to government bond yields broken down by program announcements. This is to discern the differences in influences on yield movements among countries and within programs. It should be noted that PELTRO had two main announcements which were incorporated respectively in the TLTRO and in the PEPP effects as they coincided with dates of announcements also in these groups. The results are shown in Table 2. The coefficient should be interpreted as how the program-related announcement affected the government bond yield. In particular, it shows how movements in yield were different on announcement days rather than on other days. This is expressed in basis points.

Table 2: Event Study Results

Program	α_1^{Spain}	α_1^{Italy}	$\alpha_1^{Germany}$
TLTRO	-5.16*	-2.46	-4.3*
PEPP	4.44	-31.5***	11.6***
Total	-2.8	-9.8***	-7.78***

The most significant impact in yield movements caused by program-related announcements (total row) is registered in Italy and Germany. Both register highly significant downward changes on announcement days. For Spain, the movement is also negative, although not significantly different than normal yield fluctuations on non-announcement days.

PEPP announcements caused significant changes in Germany and Italy but, while for Italy the impact is still negative, for Germany it is positive. This is in line with the findings of Corradin et al. (2021) which explain that market participants might have been expecting a reduction in the deposit facility rate instead of the introduction of another purchase program, causing an increase in expected future rates and the term premium. TLTRO III announcements appear to have had a negative effect in all countries, but with lower significance in Spain and Germany and non-significant in Italy.

Table 3: Event Study Results - PEPP

Date	α_1^{Spain}	α_1^{Italy}	$\alpha_1^{Germany}$
18 Mar 2020	43.7***	-51.8***	15.6*
4 Jun 2020	8.79	-29.2**	-7.58
10 Dec 2020	-1.82	-4.99	-3.18

In Table 3, we look at the single event dates for PEPP. We see that the first announcement was the one causing the biggest effect on bond changes while the last communication on the final envelope extension had no major impact. The announcement on 18 March caused a large decrease in Italian yields, while in Spain and Germany, the effect was positive. The fact that only the first announcement in Germany caused a positive effect seems to confirm the hypothesis that this was due to the original expectation of a reduction in the policy rate. Instead, the last announcement appears to have generally caused a weaker market reaction.

We then look at the results for TLTRO III announcements (Table 4), and we see that only a few announcements caused significant reactions in every country. In Italy, these dates correspond to the first announcement, the communication of easing conditions, and the final change in TLTRO III's interest rate calculation. Given this, we may assume that their effect was dampened in the overall analysis by the less impactful communications.

Table 4: Event Study Results - TLTRO

Date	α_1^{Spain}	α_1^{Italy}	$\alpha_1^{Germany}$
7 Mar 2019	-12.7	-40.0**	-11.4
6 Jun 2019	-3.45	-16.9	0.49
29 Jul 2019	-4.85	4.23	0.49
12 Sep 2019	12.8	-11.39	22.2***
12 Mar 2020	37.7***	116***	22.7***
30 Apr 2020	-36.2***	-16.6	20.5***
29 Jan 2021	1.76	6.13	-4.02
30 Apr 2021	1.55	-3.58	1.39
27 Oct 2022	-39.5***	-59.9***	-23.3**

For Spain and Germany, the announcement of the easing conditions (12 March 2020) and the final announcement of the change of interest rate (27 October 2022) caused large and significant fluctuations. In both Germany and Spain, the announcement of rate reductions due to the pandemic and of PELTROs (30 April 2020) accounted for a significant impact on yields. Only in Germany, the announcement of 12 September 2019 of changes in interest rates caused a significant increase in yields. In all countries, sovereign yields decreased following the last announcement.

An interesting fact is that the German results appear to be at times more significant than those of the countries which we expect could have benefitted more from the pandemic relief programs. We shall remember that Germany was the country with the highest involvement in the PEPP purchases. Another fact that could cause this result is that in Italy and Spain, other events could have influenced yield movements outside of the monetary policy announcement dates (i.e., political turmoil). German yields, being in general more stable and probably under lower stress than Italian and Spanish markets, could constitute a cleaner sample which then better reflects shock following the announcements.

Event study post Kalman Filter

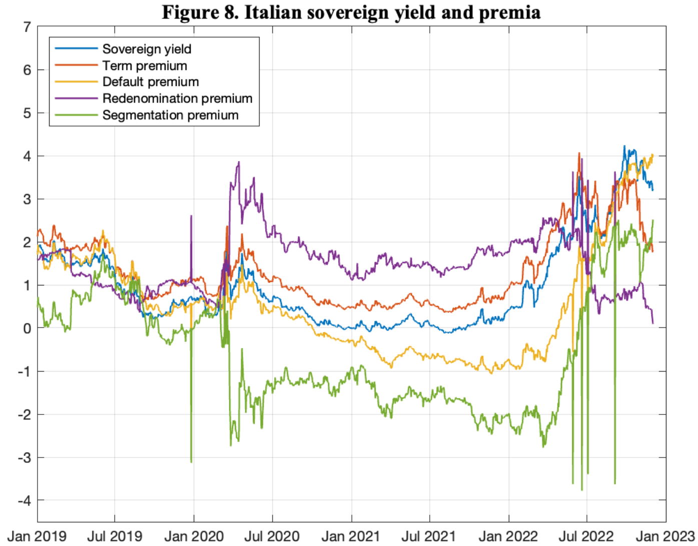
We now break down the yield into the four components that we have decided to analyze: expectation, default, redenomination, and segmentation channels.

First, we calculated estimates for the channels of interest with data on corporate bond yields and CDSs. Then, we filtered out the noise in the estimators via the Kalman filter. With the cleaned series, we performed the event study to observe the contribution of each risk premium to the overall yield movement. We divided the results according to the program category they belong to, to observe the aggregate significance of movements in the different channels, and by date, to observe the individual announcement effects. Finally, we performed the event study for each announcement date to have more granular results and an overview of the main channels at play. The total row shows the results aggregating both TLTRO III and PEPP announcements to give an overall picture of the channels' contribution and significance.

Italy

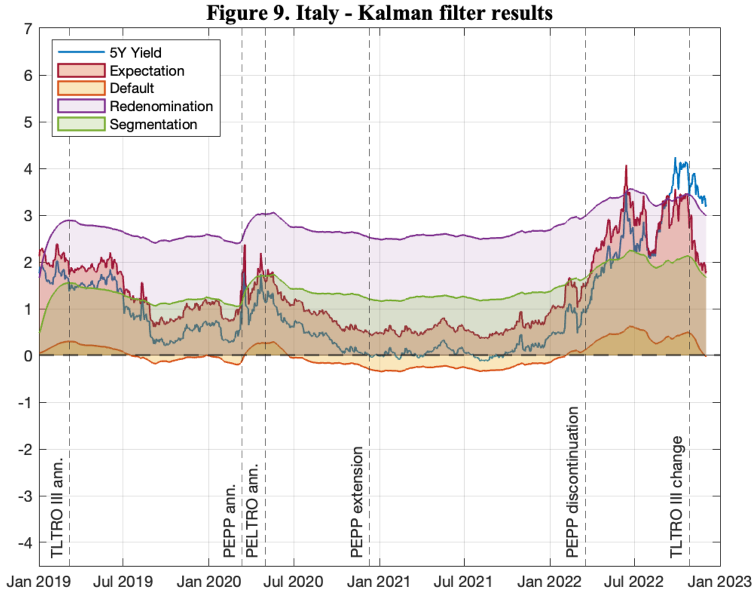
We start by analyzing the results for Italy. In Figures 8 and 9, we have an overview of the different risk premia, respectively before and after applying the Kalman filter on the interested channels (the default, redenomination, and segmentation risk premia). Awe see that the filter cancels out the noise and in the cleaned series we do not observe outliers.

Figure 8. Italian sovereign yield and premia



In figure 9, we thus have a better overview of the channels' sizes. We notice that the size of the redenomination and segmentation channel is higher than that of the other term premia. Instead, the default risk premium has the smallest size, meaning that default concerns were generally low.

Figure 9. Italy - Kalman filter results



In Table 5, we see that overall, the biggest movements following program announcements have been registered in the expectations channel, where on average each measure caused a decrease of -8.48

b.p. However, also the other channels register significant changes oscillating between 1 b.p. and 2 b.p. on average.

Looking at the program level, for TLTRO the default and segmentation channels show significant positive movements: after TLTRO III related announcements the default premium increased by 1 b.p. and the segmentation premium by 1.4 b.p. Looking at the TLTRO dates individually, we see that almost all changes are highly significant with the biggest reactions generally found in the expectation premium. However, it shall be noted that all transmission channels show remarkable reactions to TLTRO announcements with the exception of the redenomination channel, which movements are often non-significant.

Table 5: Event Study Results - Kalman filter

Country	*Program*	*Date*	*Yield*	*Expectation*	*Default*	*Redenomination*	*Segmentation*
Italy	Total	-	-9.8***	-8.48*	1.11**	1.05*	1.74***
	TLTRO	-	-2.46	-1.65	0.94*	0.55	1.36**
		7 Mar 2019	-40.0**	-39.9***	-0.82***	-0.91	-0.88***
		6 Jun 2019	-16.9	-26.1***	-1.11***	-1.54	-1.51***
		29 Jul 2019	4.23	6.32***	0.21***	0.24	0.19***
		12 Sep 2019	-11.4	-6.39***	2.05***	1.62	1.61***
		12 Mar 2020	116***	115***	9.59***	9.45***	16.2***
		30 Apr 2020	-16.6	-13.7***	0.19***	-0.24	-0.18***
		29 Jan 2021	6.13	-0.19***	-0.06***	-0.50	-0.46***
		30 Apr 2021	-3.58	0.02***	0.98***	0.54	0.57***
		27 Oct 2022	-59.9***	-49.6***	-3.27	-3.01***	-3.08***
	PEPP	-	-31.5***	-28.6***	1.61*	2.50**	2.81**
		18 Mar 2020	-51.8***	-52.5***	8.68***	11.9***	12.6***
		4 Jun 2020	-29.2**	-28.3*	-2.76***	-3.07***	-2.84***
		10 Dec 2020	-4.99	-4.69	-1.12***	-1.43***	-1.39***

According to Table 4, the announcement dates with the most significant movements in government bond yields were 7 March 2019, 12 March 2020, and 27 October 2022. In Table 5, on all three dates, the biggest movements were in the expectation premia. On 7 March 2019 also the default and segmentation channels show significant contributions. On 12 March 2020, the second largest changes were in the segmentation risk premium which shows an increase of 16 b.p.

It seems that the results of Table 4 for TLTRO are mainly driven by the reactions to the expectations risk premium with some contributions from the segmentation risk premium.

Regarding PEPP announcements, we can see that, at the aggregate level, the expectation component has the highest average change on announcement dates, which amounts to an average decrease of 29 b.p. In Table 3, the most significant changes in sovereign yield were on 18 March 2020 and 4 June 2020. On the first PEPP announcement are registered large movements for all channels. The expectation premium decreased by around 53 b.p., while default, redenomination, and segmentation increased by 9 b.p., 12 b.p., and 13 b.p. The announcement of the extension on 4 June 2020 also sees the main changes in the expectation premium, followed by considerable movements in the other components.

Overall, the main fluctuations for Italy are found in the expectation channel, but with contributions from the others and in particular from the segmentation component. At the same time, the default channel seems to have played an important role in TLTRO III announcements. The redenomination channel appears to be the one with relatively less significant movements, even though it still played an active role in monetary policy transmission, especially for PEPP.

Spain

Turning to the results for Spain, displayed in Figures 10 and 11 are the risk premia before and after Kalman filtering. Here we observe that while the size of the redenomination channel is still much higher than the rest, that of the segmentation premia is more negative compared to the case of Italy and it follows more closely the path of the default premium. Magnitudes are smaller than what is observed in Italy.

Figure 10. Spanish sovereign yield and premia

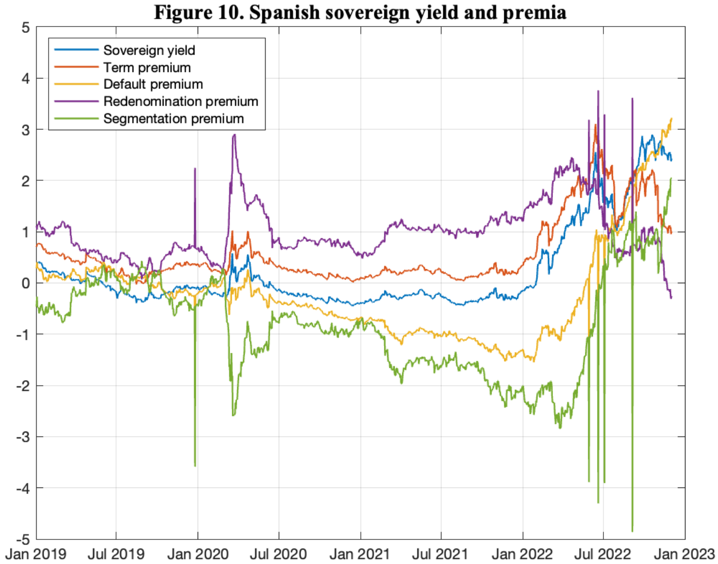
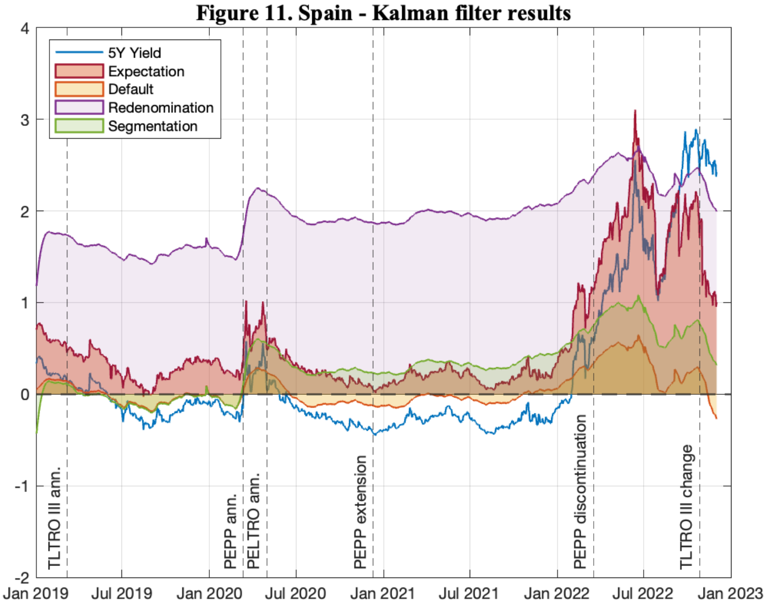


Figure 11. Spain - Kalman filter results



In Table 6, we see from the total overview that significant movements on all announcement dates were found for the redenomination and segmentation components. These averaged to an amount of respectively 1.5 b.p. and 1.4 b.p., similar to what was found for Italy. Differently, though, the expectation channel is notably less significant despite still accounting for the largest average change.

Table 6: Event Study Results - Kalman filter

Country	*Program*	*Date*	*Yield*	*Expectation*	*Default*	*Redenomination*	*Segmentation*
Spain	Total	-	-2.8	-2.96	0.47	1.46**	1.38**
	TLTRO	-	-5.16*	-4.52	0.23	0.70	0.58
		7 Mar 2019	-12.7	-13.8	-1.12	-1.54***	-1.55***
		6 Jun 2019	-3.45	-16.3	-1.92	-2.18***	-2.09***
		29 Jul 2019	-4.85	-2.88	0.15	-0.18***	-0.15***
		12 Sep 2019	12.8	14.7	4.35**	4.35***	4.21***
		12 Mar 2020	37.7***	40.1***	7.87***	14.6***	13.4***
		30 Apr 2020	-36.2***	-36.9***	-2.15	-2.69***	-2.65***
		29 Jan 2021	1-76	1.93	0.48	0.16***	0.19***
		30 Apr 2021	1.55	1.73	0.36	0.05***	0.08***
		27 Oct 2022	-39.5***	-28.7***	-5.94***	-6.26***	-6.29***
	PEPP	-	4.44	1.79	1.17	3.68***	3.72***
		18 Mar 2020	43.7***	14.9	6.79***	14.6***	14.6***
		4 Jun 2020	8.79	-6.68	-2.67	-2.64***	-2.61***
		10 Dec 2020	-1.82	-2.88	-0.63	-0.92***	-0.89***

TLTRO results are non-significant at an aggregate level, however, a big reduction in the expectation component is found (at around 4.5 b.p.). In Table 4, it was shown that the main yield movements happened on 12 March 2020, 30 April 2020, and 27 October 2022. This is confirmed as on these dates most channels show significant and large fluctuations. In particular, sizable changes are registered in the expectation premium which changed by 40 b.p., -37 b.p. and -29 b.p. Redenomination and segmentation channels follow in magnitude these changes (namely recording variations of 15 b.p., -3 b.p., -6 b.p. and 13 b.p., -3 b.p., -6 b.p.). Fluctuations in the default risk premium are of similar magnitudes but are non-significant on 30 April 2020.

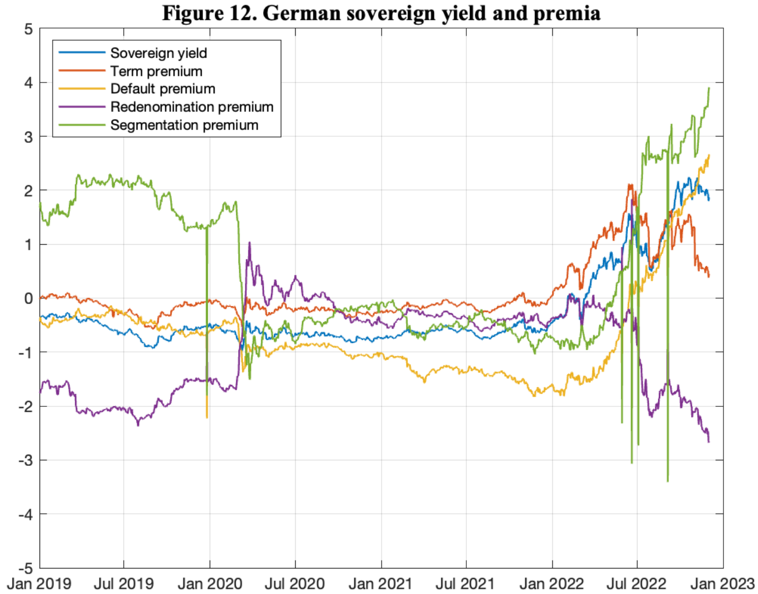
For PEPP dates, redenomination and segmentation changes again appear to be the main ones with the highest and most significant reactions to the announcements, both with an average 4 b.p. increase following event dates. In Table 3, only the first PEPP announcement seems to have caused significant yield changes. This can be confirmed as here most channels saw significant changes, namely the default (7 b.p.), the redenomination, and segmentation channels (both 15 b.p.). The changes caused by the first announcement are also the largest ones.

Overall, the main contributions to Spanish yield reaction from pandemic program announcements come from the redenomination and segmentation channels, followed by the default channel. The expectation risk premium here instead, seems to have played a less significant role. In fact, despite being generally higher than the other channels, it shows significance only on specific announcement dates.

Germany

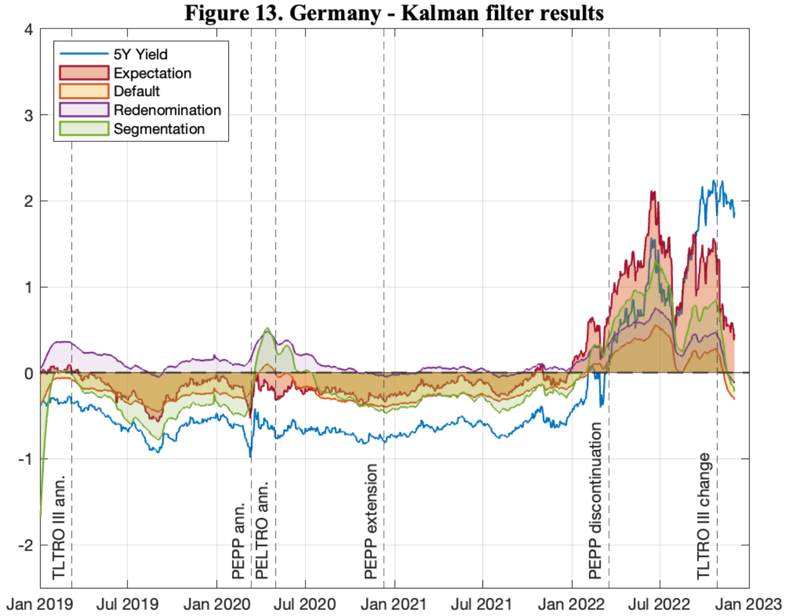
We turn to the results for Germany. We observe that the sizes of the different channels are smaller than those of the other countries (Figure 13). This is expected as it reflects a more stable economy and lower risk profile. The redenomination channel is also smaller than in Italy and Spain.

Figure 12. German sovereign yield and premia



With the exception of the period after the PEPP discontinuation announcement, where the expectation component is dominant, the magnitudes of all channels are quite similar.

Figure 13. Germany - Kalman filter results



In Table 7, we observe the results for Germany. Here the total effect is not significant for any channel. This is in contrast to what was found looking at yield changes (Table 3) and could be due to the fact that it is harder to attribute the changes to specific transmission channels but rather to the interplay among them.

For TLTRO's aggregate results, we also do not observe significant effects at the channel level. Table 4 suggests that 12 September 2019, 12 March 2020, 30 April 2020, and 27 October 2022 triggered the main reactions in yield. In Table 7, on these dates, we find the most significant changes for all components. While for the first two all the risk premia show an increase following the announcements, the last two show a reduction. In all dates, the highest fluctuations are recorded in the expectation risk premium all at around 20 b.p. (increase in the first two dates and decrease in the last two). The segmentation channel records the second-highest movements for these TLTRO dates.

Table 7: Event Study Results - Kalman filter

Country	*Program*	*Date*	*Yield*	*Expectation*	*Default*	*Redenomination*	*Segmentation*
Germany	Total	-	-7.78***	2.39	-0.05	-0.03	0.19
	TLTRO	-	-4.3*	-2.57	-0.29	-0.27	-0.61
		7 Mar 2019	-11.4	-13.3	-1.99	-1.96	-4.43
		6 Jun 2019	0.49	-12.0	-1.68	-1.63	-3.76
		29 Jul 2019	0.49	-2.32	-0.86	-0.88	-2.15
		12 Sep 2019	22.2***	22.0**	4.09**	4.10**	8.18*
		12 Mar 2020	22.7***	23.6**	5.88***	5.94***	14.4***
		30 Apr 2020	20.5***	-22.3**	-4.76**	-4.69**	-9.73**
		29 Jan 2021	-4.02	3.59	0.58	0.55	0.64
		30 Apr 2021	1.39	-0.32	1.22	1.17	1.87
		27 Oct 2022	-23.3	-21.9**	-5.09***	-5.03***	-10.4**
	PEPP	-	11.6***	17.1***	0.69	0.71	2.59
		18 Mar 2020	15.6*	43.0***	6.5***	6.55***	17.2***
		4 Jun 2020	-7.58	9.69	-3.58*	-3.52*	-7.18*
		10 Dec 2020	-3.18	-1.52	-0.54	-0.91	-2.24

PEPP aggregate results are significant only for the expectation channel. The highest average change is in the expectations risk premium (17 b.p.). In Table 3, the announcement on 18 March 2020 recorded a significant change in sovereign yields. This is confirmed in Table 7 as all channels record significant fluctuations. Namely, the expectation channel sees the main increase (43 b.p.), followed by the segmentation (17 b.p.), redenomination (6.5 b.p.), and default (6.5 b.p.) risk premia.

Interestingly, also the announcement on 4 June 2020 shows significant decreases in the default, redenomination, and segmentation channels.

To sum up, for Germany we observe that expectation and segmentation components were the most dominant. For both TLTRO and PEPP, the expectations channel has the largest effect, followed by the segmentation channel.

Conclusion

In this research, we have investigated the question of what channels played the most relevant role in monetary policy transmission during the years following the outbreak of the pandemic. To do so, we have gone through the literature and looked at what models were used to isolate and estimate these channels. We have decided to perform an event study to identify the changes in government bond yields on monetary policy announcement dates and observe their immediate effect on the markets. To be able to study the movements caused by the different risk premia composing the government yields, we made use of the Kalman filter: a method useful to estimate unobservable variables through the use of observable ones. We considered for our analysis Italy, Spain, and Germany.

The results suggest that overall program announcements during the pandemic caused a decrease in government yields in all three countries under our study. In general, the expectation channel was the main driver of these changes. The second most active channel for all economies was the segmentation risk premium. In Spain, the expectation's effect is the largest on specific announcement dates, but generally not significant on other dates. Instead, the most present channel is the redenomination channel, reflecting the higher risk faced by the country. Moreover, it shall be noted that in Italy also the default channel played at times a significant role.

Looking at TLTRO III announcements specifically, these caused a drop in yields for Italy, Spain, and Germany. Reactions related to TLTRO communications were mainly attributable to the expectation premium in all countries. The events causing the most significant reaction in yields were the announcement of easing conditions (12 March 2020) and the final adjustment of TLTRO III interest rate calculation (27 October 2022).

PEPP announcements led to a significant decrease in Italian yields, but a moderate increase in Spanish and German yields. In Spain, the increase was due to redenomination and segmentation components, while in Germany to the expectations channel. This can be explained by the market assumption that the ECB would act by adjusting the policy rate rather than introducing another purchase program. In the case of PEPP, the most significant movement was caused by the first announcement of the introduction of the program (18 March 2020).

We confirm our assumption that certain channels were more strongly involved than others in the transmission of monetary policy, and that their relative importance also differed according to the economy considered. We see that once again expectations were greatly influenced by monetary policy, but from the analysis, we see that market segmentation also played a relevant role in these years. Thus, it appears that on average the risk of default and the risk of redenomination, which are somehow connected, were not the main concern in the pandemic crisis but rather there was more uncertainty about the efficiency and proper functioning of the economy (segmentation channel). This

is true if we generalize the results for the economies we considered, even if Italy and Spain seem to be still somehow exposed to these concerns which are almost absent in Germany.
The results in line with those of Corradin et al. (2021), but we are able to enrich them by analyzing a wider range of announcements related also to TLTROs which were a largely important tool introduced in these years and as we see, it played also a big role in influencing the markets. Through this, we can also group the announcements and find the channels' relative importance per program.
One limitation of our approach, however, is that it does not allow for non-linearity which could be a relevant feature of some channels. Another limitation is that given the turmoiled times considered, the yield and its components may have been influenced by other market events which we do not capture here. For example, some announcements may have been leaked and this could decrease the magnitude of the effect of the announcement itself.

Future research could further enrich this field by possibly extending this estimation to other countries, or maybe even foreign economies (i.e., the US market) to observe how different the reaction to the respective pandemic measures was there. Another point that could be investigated, is that of fiscal policy measures, which we decided to exclude in this study. It could be interesting to observe whether fiscal policy somehow interfered or contributed to influencing market reactions on announcement days, maybe impairing the normal transmission of some channels.

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Summary

Introduction

Our objective is to explain how the ECB's measures taken following the pandemic influenced the yield curve. We look at the effects of the ECB's communication regarding its programs on government bond yields and the transmission channels. We carry an event study and observe whether European economies had different reactions. We consider three major euro area economies: Germany, Italy, and Spain. We analyze which transmission channels played a dominant role in the yield reduction and decompose the sovereign yield into five components: the expectations risk premium, the duration risk premium, the default risk premium, the segmentation risk premium, and the redenomination risk premium. Studying these mechanisms enables to comprehend the dynamics causing movements in the yield curve, but also highlights what the market saw as main concerns and how monetary policy was perceived. Reactions to monetary policy can differ among countries and this is relevant in the euro area where different countries with their own economic and risk profiles are subject to the same central bank measures. It is useful to see how and to what extent common measures can differ in response. We will consider two main program announcements: those related to the Targeted Longer Term Refinancing Operations (TLTRO III) and the Pandemic Emergency Purchase Program (PEPP). We look at the effect caused by the single announcements, but also on the aggregate results per program. We observe that the countries analyzed show results different both in magnitudes and relative importance of the transmission channels.

Literature Review

The asset purchase program (APP) aims at lowering long-term interest rates to ease market conditions. As the ECB buys bonds their demand increases, the price rises, and banks are encouraged to make more loans and lowering bank lending rates. It acts on the long-term side of the curve decreasing the duration risk and credit risk. Government bond yields are affected by different factors and can be thought of as an aggregate of different components hard to disentangle. These are at the root of yield variations and are the term premium, the default risk premium, the duration risk premium, the redenomination risk premium, and the segmentation premium. It is hard to understand which of these makes up most of the currently observed yield as they can have different dominance according to the economic scenario.

The Yield Curve and its Stylized Facts

The yield curve shows the relationship between the interest rate yields on bonds with different maturities but the same risk and liquidity (Mishkin, 1990). Typically, central banks influence short-term rates by adjusting the policy rate. Doing so, they influence various aspects of economic activity. However, also long-term rates play a significant role in influencing the behavior of firms and banks (Geiger, 2011). The difference between long- and short-term yields is called the term spread and is the slope of the yield curve. Normally, it is positive, to reflect compensation of interest rate risk for holding bonds with longer maturities. A theory for the yield curve must address three empirical facts: that interest rates of bonds with different maturities move together, that when short-term rates are low the curve tends to be upward sloping and vice versa, and that the yield curve is generally upward sloping (the term spread is positive). The *Expectations Theory* assumes that investors are risk neutral and indifferent between holding bonds of short- or long-term maturities. Long-term rates are determined by short-term ones: long rates are the weighted average of expected future short rates. Despite being able to explain different features of the term structure, it does not explain why the yield curve is then generally upward sloping: if investors are indifferent between maturities, they will not require a term premium for holding bonds of longer maturities and the term structure of interest rates should be flat (Geiger, 2011). The *Segmented Market Theory* assumes that investors have strong preferences for maturities, to the point that they can be considered as different markets. Investors are risk-averse and will require higher compensation to hold long-term maturity bonds to account for the extra risk. This explains the upward-sloping structure of the yield curve. However, by considering long and short-term yields as independent, this theory does not explain the co-movement between short- and long-term yields. The *Liquidity Premium Theory* agrees with the *Expectations Theory* in stating that long-term rates are determined by short-term ones. However, investors are risk-averse and require a liquidity premium as compensation for the interest rate risk they bear. This theory proves to be the most complete in explaining the movements of the term structure and it shows how monetary policy can influence the yield curve via the transmission channels. Starting from the assumptions of the *Liquidity premium theory*, we disentangle different factors affecting the term premium over time.

The Asset Purchase Program and the Pandemic stimulus package

Quantitative easing is a monetary policy tool meant to promote borrowing and spending in times of crisis. It consists of the large-scale purchase of securities by the central bank. If the policy rate is already close to the zero-lower bound, this tool is useful in sustaining asset prices, and lowering long-term interest rates so that investment and economic activity are sustained. Many central banks have implemented quantitative easing, especially in the aftermath of the GFC. An example is the ECB. The APP is a monetary policy stimulus meant to address deflation risks by easing borrowing to households and firms. At the same time, its purpose is to anchor and support asset prices. Its announcement caused a sharp decline in yields of euro area countries, in particular for those economies with lower credit ratings, such as Italy and Spain (Altavilla, et al., 2021). When the pandemic started, the ECB was then called to act to sustain economic activity. Two types of programs were adopted: lending programs and further asset purchases. The main lending programs that targeted the pandemic crisis were the TLTRO III and the Pandemic Emergency Long Term Refinancing Operations (PELTROs). Both aimed at increasing the supply of liquidity in the market, but the TLTRO-III more directly addressed the risk of a credit crunch (Lane, 2021). On the asset purchase side, the PEPP was announced on March 18th, 2020. It is considered the most substantial measure taken in response to the crisis (European Central Bank, 2021).

Transmission channels

We follow the analysis done by Krishnamurthy et al. (2017) who identify several channels that together contribute to spreading the effect of these policies on interest rates. The first is the *Expectations Channel*. It is related to monetary policy announcements which give a signal to the future path of the ECB stance. Market participants can anticipate a sequence of policy rate changes, letting monetary policy work through these expectations. Then, the yield curve is also a reflection of whether monetary policy is being understood by investors (Geiger, 2011). Another channel is the *Duration Risk Channel*. Long-term rates account for compensation represented by the term premium. Part of this is related to intertemporal return due to the interest rate risk of longer maturity bonds (Krishnamurthy, et al., 2017). The *Default risk premium* is related to the possibility that the issuer of the bond may not be able to meet its contractual obligations at maturity. Credit Default Swap (CDS) rates are a useful proxy to study the magnitude of this channel as used to hedge against the probability of default. Then, we have the *Segmentation* Channel. Segmentation arises when investors have different valuations of a bond, causing constraints in the participation and market price to be different from the actual value as only a subset of investors participates. This is reflected in bond yields. Finally, the *Redenomination* Channel reflects the risk that a currency may default, and the government may redenominate its debt at a depreciated exchange rate (Corradin, et al., 2021). This is similar to the default risk, but redenomination has a direct impact on private borrowers as it reduces their debt obligations in the involved currency.

Previous research

Krishnamurthy and Vissing-Jorgensen (2011) test whether the changes in interest rates on announcement days are different from those occurring on days separate from the announcements using F tests: if we accept the null that the changes are the same, then there is no effect pursuing the announcement that is different from regular rates fluctuations. For the method to work, it is essential that the announcement was not leaked before the official date, and that the price impact is instantaneous. Krishnamurthy et al. (2017) looked at the transmission channels focusing on the ECB's policies in response to the sovereign debt crisis. They looked at the effects of the Securities Market

Programme (SMP), the Outright Monetary Transmission (OMT), and the LTROs in three countries: Italy, Spain, and Portugal. They decompose the government bond yields into a component that is common to all euro-area countries and some country-specific components. The latter consists of the redenomination, segmentation, and default risk channels which are not directly observable. To disentangle their effects, the Kalman filter methodology is used, augmented via VAR to account for some delay in the reaction of asset prices to monetary policy announcements. The Kalman filter method is combined with an event-study approach, using 2-day changes to allow for a delay in price. We will adopt this methodology to evaluate the transmission channels at play throughout the pandemic crisis. We will look at three representative economies to compare the different outcomes.

Empirical Strategy

We use an event study to observe the impact of the ECB's communication on the yield curve. We disentangle the channels through which the pandemic programs operated in the economy. We expect to find that certain channels were more active than others and with differences in their relative importance according to the jurisdictions. We analyze Italy, Spain, and Germany as these were greatly involved in the PEPP program and thus most likely affected by related announcements. They are interesting to look at also because of how their economies compare to each other which could result in differences in transmission channels.

The model

As in Krishnamurthy et al. (2017), we consider four channels. We kept channels that before appeared to be less active in monetary policy propagation as now they might have played a bigger role. Namely, we kept the redenomination risk as for some countries it might have been very relevant now: the economic slowdown could have increased concerns about the strength of the euro. We focus on expectation and duration risk channels (identified together), the default risk channel, the segmentation risk channel, and the redenomination risk channel. We use an event study to document the reduction in government bond yields caused by ECB's policies during the pandemic. This is based on the assumption that market prices are efficient and incorporate all available information: following an announcement, prices adjust to reflect the newly available information. If so, then we can study how announcements impact the term structure of interest rates. We will estimate the following:

$$\Delta {y_t}^c = \alpha_0^c + \alpha_1^c \, \mathbb{I}_{\{monetary\, policy\, announcement\}} + \varepsilon_t^c \quad (1)$$

$\Delta {y_t}^c$ represents the daily change in the 5-year yield. The α_i^c terms with $i = 0,1$ are respectively the constant and slope parameters: α_1^c represents the surprise component of the announcements and α_0^c represents the effect under yield fluctuations on days when no announcement took place. Then, we have the indicator function which is equal to one on the days of the monetary policy statements. To be specific, this will equal 0.5 on the day of, and on the day after the announcement so that the estimate for α is approximately the sum of these two observations (Corradin, et al., 2021). This allows for a delay in price reaction. Then, we turn to the identification of the different term premia that contribute to influencing the yield to quantify to what extent they participated in the transmission of monetary policy to financial markets. The bond yield can be decomposed as follows:

$$\boldsymbol{y_T^C = \frac{1}{T}\int_0^T E[i_t]dt + Duration_T + Default_T^C + Segmentation_T^C + Redenominaiton_T^C} \qquad (2)$$

The first two components, the expectations and duration risk channel, are not country dependent. This means that their estimators will be the same across the euro area. They will be considered together through the euro swap rate. The segmentation and redenomination risk premia are harder to disentangle because not directly observable and because they do not have one specific estimator. For this, we will adopt the Kalman Filter methodology.

The Kalman filter

Kalman filtering is particularly useful when we want to estimate a value that contains measurement errors, high variance, and uncertainty. It is used when estimating the state of a discrete-time controlled process (x) governed by a linear stochastic difference equation. One characteristic of x, the state vector, is that it is not directly observable but can be inferred from other measurable variables (Kleinbauer, 2004). It is the vector of the latent components: in this case, the risk premia. Because x_t is not observable, we will make use of y_t (observable), which is the vector of government bond yields and the other estimators. Below, the components of the two vectors:

$$y_t = \begin{bmatrix} Gov.yield - EUR\ swap \\ US\ Gov.yield - \ USD\ swap \\ Corp.yield - USD\ swap \\ CDS\ swap \end{bmatrix} \qquad x_t = \begin{bmatrix} term\ premium \\ default\ risk\ premium \\ redenomination\ risk\ premium \\ segmentation\ risk\ premium \end{bmatrix}$$

$$x_t = a + Tx_{t-1} + v_t \qquad v_t \sim N(0, H_t) \qquad (3)$$

$$y_t = Zx_t + w_t \qquad w_t \sim N(0, Q) \qquad (4)$$

Thus y_t is a linear combination of x_t. $Z(i,j)$ is the state transition matrix and it is very important for identification. It links elements of the observed asset price y_t (represented by the i rows) and of the latent component x_t (represented by the j columns). For its construction, we will follow the example set by Krishnamurthy et al. (2017). We consider the fact that, while CDS contracts under CR clauses do not comprehend the risk of redenomination, those under the CR14 clause do. Because this applies to all three countries, to estimate the redenomination channel we use the fact that the yield of the corporate foreign-denominated bond (namely, USD-denominated) net of the USD swap rate, captures the default risk. This subtracted from the CDS, will result in the redenomination risk. Thus:

$$Z = \begin{pmatrix} 1 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 \end{pmatrix}$$

Finally, $T = I_4$ where I_4 is a 4 by 4 identity matrix. The filter works through two groups of equations: time update and measurement update equations. Time update equations forecast the current state and are predictor equations: they predict the future state through a dynamic model. Instead, measurement update equations make ex-ante estimates. The state vector can be decomposed into an *a priori* and an *a posteriori* value. Measurement updates incorporate the new observation into the ex-ante estimate for a better ex-post estimate and to minimize the covariance of the estimator (Kleinbauer, 2004).

The data

The expectation and duration component will be found by using the Euro swap rate and will be analyzed together as done by Krishnamurthy et al. (2017). We will use the Euro Overnight Interest Average (EONIA) OIS rate and the Euro Short Term rate (€STR). EONIA swap rates were considered to be the main benchmark for the short end of the term structure, and they represented the most liquid segment of the money market. However, it was discontinued and so for the period following December 31st, 2021 we will use the newly introduced €STR which became the new overnight unsecured benchmark rate for the euro area (Nicoloso & Tsonchev, 2019). To identify the default risk premium component, we will use US government bond yields denominated in dollars. Foreign government bonds can't be redenominated through euro changes and thus they are not affected by redenomination risk. Netting for the US dollar swap rate, representing the expectation and duration component, they should only capture the default risk premium component of sovereign bond yields. Because we consider in all three countries CDS contracts under the CR14 clause, the redenomination risk will be the difference in the yield of the USD-denominated (swap-adjusted) corporate bond net of the corporate CDS rate. For the choice of eligible corporate bonds, we decided to focus on those of safe non-financial companies with the same duration so that they identify solely the riskless interest rate and are not closely associated with the sovereign default risk. Namely, these are ENI S.P.A. for Italy, Telefonica S.A.U. for Spain, and Mercedes for Germany. Finally, the segmentation component is calculated as the residual of the yield, net of the other components. To summarize, the identification would go as follows:

$$\text{Expectation/Duration component} = \text{Euro swap rate}$$

$$\text{Default component} = \text{swap adjusted yield on USD denominated bond}$$

$$\text{Redenomination component} = \text{corporate bond yield} - \text{USD swap rate} - \text{CDS rate}$$

$$\text{Segmentation component} = \text{Yields} - \text{Euro swap rates} - \text{Default} - \text{Redenomination}$$

We focus on 5-year maturity as this reflects the average maturity of euro area sovereign debt among the different countries (Corradin, et al., 2021). We mainly used Bloomberg for bond yields data, Refinitiv for corporate CDSs, and the ECB's Statistical Data Warehouse for the Euro swap rate.

Estimation results

In the table below, is a summary of the event dates we consider with a short description of the content of the announcement. Each date has been linked to a program category (either TLTRO or PEPP).

Program	*Date*	*Description*
TLTRO	7 Mar 2019	Initial announcement
TLTRO	6 Jun 2019	Technical details
TLTRO	29 Jul 2019	Legal acts
TLTRO	12 Sep 2019	Changed interest rate
TLTRO	12 Mar 2020	Easing conditions
TLTRO	30 Apr 2020	Rate reduction
TLTRO	29 Jan 2021	Technical changes
TLTRO	30 Apr 2021	Technical changes
TLTRO	27 Oct 2022	Interest rate recalibration
PEPP	18 Mar 2020	Initial announcement
PEPP	4 Jun 2020	Extension
PEPP	10 Dec 2020	PEPP extension

Firstly, we will conduct an event study to visualize the effect of the program announcements on government bond yields. This gives us an overview of which programs and events had a higher impact. Secondly, we use the Kalman filter to identify the unobservable channels. With the filtered estimates we perform a second event study to find the main channels responsible for yield changes.

Event Study Analysis

We observe the results related to government bond yields broken down by program announcements. This detects the differences in influences on yield movements among countries and programs. The coefficient shows how the announcement affected the government bond yield (in basis points).

Table 2: Event Study Results

Program	α_1^{Spain}	α_1^{Italy}	$\alpha_1^{Germany}$
TLTRO	-5.16*	-2.46	-4.3*
PEPP	4.44	-31.5***	11.6***
Total	-2.8	-9.8***	-7.78***

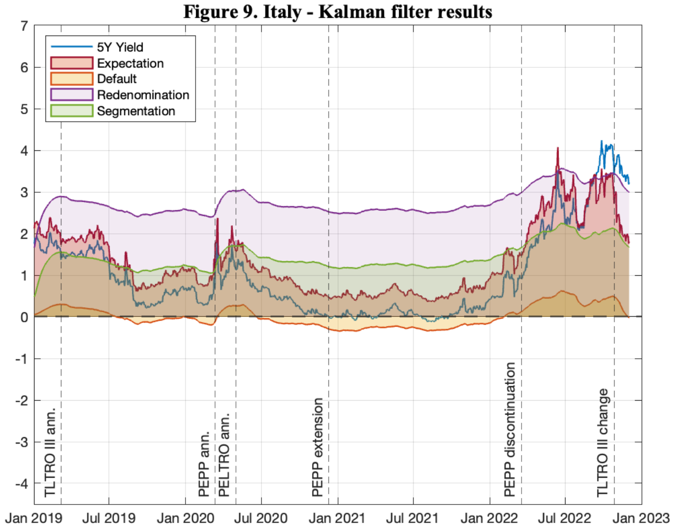
The most significant impact in yield movements caused by program-related announcements (total row) is registered in Italy and Germany. Both register highly significant downward changes on announcement days. PEPP announcements caused significant changes in Germany and Italy but, while for Italy the impact is still negative, for Germany it is positive. This is in line with the findings of Corradin et al. (2021) which explain that market participants might have been expecting a reduction in the deposit facility rate instead of the introduction of another purchase program, causing an increase in expected future rates and the term premium. TLTRO III announcements appear to have had a negative effect in all countries but are non-significant in Italy.

We now break down the yield into the four components that we have decided to analyze: expectation, default, redenomination, and segmentation channels. We calculated estimates for the channels of interest with data on corporate bond yields and CDSs. Then, we filtered out the noise in the estimators via the Kalman filter and, with the cleaned series, we performed again the event study.

Italy

In figure 9, we have an overview of the channels' sizes after applying the Kalman filter. The redenomination and segmentation channels are larger than the other term premia. The default risk premium has the smallest size, meaning that default concerns were generally low.

Figure 9. Italy - Kalman filter results



In Table 5, we see that the biggest movements following program announcements have been registered in the expectations channel. However, also the other channels were significant contributors. At the program level, for TLTRO the default and segmentation channels show significant positive movements. Almost all changes on TLTRO dates are highly significant with the biggest reactions generally found in the expectation premium. All transmission channels show remarkable reactions with the exception of the redenomination channel, which movements are often non-significant. The announcement dates with the most significant movements in government bond yields were 7 March 2019, 12 March 2020, and 27 October 2022. On all three dates, the biggest movements were in the expectation premia. On 7 March 2019, the default and segmentation channels show significant changes. On 12 March 2020, the second largest changes were in the segmentation risk premium. Results for TLTRO in Italy are thus mainly driven by the reactions to the expectations risk premium with contributions from the segmentation risk premium and marginally from the other channels. Regarding PEPP announcements, at the aggregate level, the expectation component has the highest average change on announcement dates. On the first PEPP announcement are registered large movements for all channels. The announcement of the extension on 4 June 2020 sees the main changes in the expectation premium, followed by the other components.

Overall, the main fluctuations for Italy are found in the expectation channel with contributions from the others and particularly from the segmentation component. The default channel seems to have played an important role in TLTRO III announcements. The redenomination channel appears to be the one with less significant movements, even though it still played an active role in monetary policy transmission, especially for PEPP.

Table 5: Event Study Results - Kalman filter

Country	*Program*	*Date*	*Yield*	*Expectation*	*Default*	*Redenomination*	*Segmentation*
Italy	Total	-	-9.8***	-8.48*	1.11**	1.05*	1.74***
	TLTRO	-	-2.46	-1.65	0.94*	0.55	1.36**
		7 Mar 2019	-40.0**	-39.9***	-0.82***	-0.91	-0.88***
		6 Jun 2019	-16.9	-26.1***	-1.11***	-1.54	-1.51***
		29 Jul 2019	4.23	6.32***	0.21***	0.24	0.19***
		12 Sep 2019	-11.4	-6.39***	2.05***	1.62	1.61***
		12 Mar 2020	116***	115***	9.59***	9.45***	16.2***
		30 Apr 2020	-16.6	-13.7***	0.19***	-0.24	-0.18***
		29 Jan 2021	6.13	-0.19***	-0.06***	-0.50	-0.46***
		30 Apr 2021	-3.58	0.02***	0.98***	0.54	0.57***
		27 Oct 2022	-59.9***	-49.6***	-3.27	-3.01***	-3.08***
	PEPP	-	-31.5***	-28.6***	1.61*	2.50**	2.81**
		18 Mar 2020	-51.8***	-52.5***	8.68***	11.9***	12.6***
		4 Jun 2020	-29.2**	-28.3*	-2.76***	-3.07***	-2.84***
		10 Dec 2020	-4.99	-4.69	-1.12***	-1.43***	-1.39***

Spain

In figure 11, we observe that the size of the redenomination channel is considerably higher than the rest. The segmentation premium is smaller compared to Italy and follows closely the default premium. In Table 6, we see from the total overview that significant movements on all announcement dates were found for the redenomination and segmentation components. Differently from Italy, the expectation channel is notably less significant despite still accounting for the largest average change. TLTRO results are non-significant at an aggregate level, however, there was a big reduction in the expectation component. Main yield movements happened on 12 March 2020, 30 April 2020, and 27 October 2022. On these dates, most channels show significant and large fluctuations, in particular the expectation premium.

Figure 11. Spain - Kalman filter results

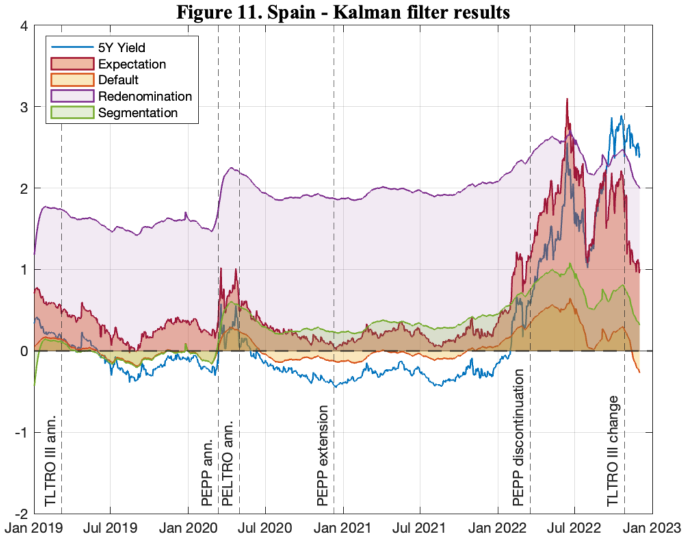


Table 6: Event Study Results - Kalman filter

Country	*Program*	*Date*	*Yield*	*Expectation*	*Default*	*Redenomination*	*Segmentation*
Spain	Total	-	-2.8	-2.96	0.47	1.46**	1.38**
	TLTRO	-	-5.16*	-4.52	0.23	0.70	0.58
		7 Mar 2019	-12.7	-13.8	-1.12	-1.54***	-1.55***
		6 Jun 2019	-3.45	-16.3	-1.92	-2.18***	-2.09***
		29 Jul 2019	-4.85	-2.88	0.15	-0.18***	-0.15***
		12 Sep 2019	12.8	14.7	4.35**	4.35***	4.21***
		12 Mar 2020	37.7***	40.1***	7.87***	14.6***	13.4***
		30 Apr 2020	-36.2***	-36.9***	-2.15	-2.69***	-2.65***
		29 Jan 2021	1-76	1.93	0.48	0.16***	0.19***
		30 Apr 2021	1.55	1.73	0.36	0.05***	0.08***
		27 Oct 2022	-39.5***	-28.7***	-5.94***	-6.26***	-6.29***
	PEPP	-	4.44	1.79	1.17	3.68***	3.72***
		18 Mar 2020	43.7***	14.9	6.79***	14.6***	14.6***
		4 Jun 2020	8.79	-6.68	-2.67	-2.64***	-2.61***
		10 Dec 2020	-1.82	-2.88	-0.63	-0.92***	-0.89***

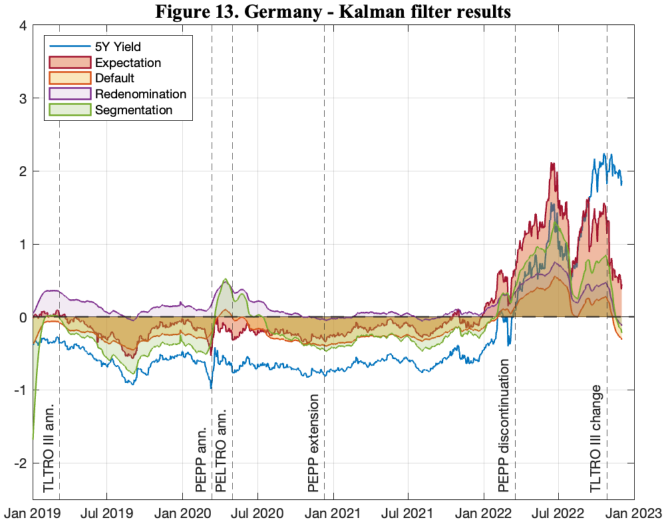
Redenomination and segmentation channels follow these changes. For PEPP dates, redenomination and segmentation changes again appear to be the main ones with the highest and most significant reactions to the announcements. The first PEPP announcement caused the most significant yield changes for the default, redenomination, and segmentation channels. The changes caused by the first announcement are also the largest ones.

For Spain, the main reactions come from the segmentation and the redenomination channel. The expectation risk, despite being generally higher than the other channels, shows significance only following specific announcements.

Germany

In Germany, we observe that the sizes of the channels are smaller than in the other countries (Figure 13). This is expected as it reflects a more stable economy and lower risk profile. The redenomination channel is smaller than in Italy and Spain. With the exception of the period after the PEPP discontinuation announcement, where the expectation component is dominant, the magnitudes of all channels are comparable.

Figure 13. Germany - Kalman filter results



Here the total effect is not significant for any channel (Table 7). This is in contrast to what is found looking at yield level and could be due to the fact that it is harder to attribute the changes to specific transmission channels but rather to the interplay among them. In TLTRO's aggregate results, we do not observe significant effects at the channel level. 12 September 2019, 12 March 2020, 30 April 2020, and 27 October 2022 triggered the main reactions. While for the first two all the risk premia show an increase following the announcements, the last two show a reduction. On all dates, the highest fluctuations are recorded in the expectation risk premium. The segmentation channel records the second-highest movements for these TLTRO dates. PEPP aggregate results are significant only for the expectation channel. The announcement on 18 March 2020 recorded a significant change in sovereign yields and all channels record significant fluctuations. The expectation channel sees the main increase, followed by the segmentation risk premia. Interestingly, also the announcement on 4 June 2020 shows significant decreases in the default, redenomination, and segmentation channels.

In conclusion, for Germany both in TLTRO and PEPP, the expectations channel was dominant, followed by the segmentation channel.

Table 7: Event Study Results - Kalman filter

Country	*Program*	*Date*	*Yield*	*Expectation*	*Default*	*Redenomination*	*Segmentation*
Germany	Total	-	-7.78***	2.39	-0.05	-0.03	0.19
	TLTRO	-	-4.3*	-2.57	-0.29	-0.27	-0.61
		7 Mar 2019	-11.4	-13.3	-1.99	-1.96	-4.43
		6 Jun 2019	0.49	-12.0	-1.68	-1.63	-3.76
		29 Jul 2019	0.49	-2.32	-0.86	-0.88	-2.15
		12 Sep 2019	22.2***	22.0**	4.09**	4.10**	8.18*
		12 Mar 2020	22.7***	23.6**	5.88***	5.94***	14.4***
		30 Apr 2020	20.5***	-22.3**	-4.76**	-4.69**	-9.73**
		29 Jan 2021	-4.02	3.59	0.58	0.55	0.64
		30 Apr 2021	1.39	-0.32	1.22	1.17	1.87
		27 Oct 2022	-23.3	-21.9**	-5.09***	-5.03***	-10.4**
	PEPP	-	11.6***	17.1***	0.69	0.71	2.59
		18 Mar 2020	15.6*	43.0***	6.5***	6.55***	17.2***
		4 Jun 2020	-7.58	9.69	-3.58*	-3.52*	-7.18*
		10 Dec 2020	-3.18	-1.52	-0.54	-0.91	-2.24

Conclusion

We investigated what channels played the most relevant role in monetary policy transmission during the years following the outbreak of the pandemic. We looked at the literature and studied the models used to isolate and estimate these channels. An event study was performed to identify the changes in government bond yields on monetary policy announcement dates and observe their effect on the markets. To analyze the movements caused by the different risk premia composing the government yields, we adopted the Kalman filter, a method to estimate unobservable variables through the use of observable ones. We considered Italy, Spain, and Germany.

The results suggest that overall program announcements during the pandemic caused a decrease in government yields in all three countries. The channels that generally were more reactive to program announcements were the expectation channel and the segmentation channel. The latter can be explained by the market frictions caused by the economic slowdown but are also a result of the increased scarcity of bonds caused by the purchase programs. Default and redenomination risk were not as dominant as in previous research, despite still present respectively in Italy and Spain. Looking at TLTRO III announcements, these caused a drop in yields for Italy, Spain, and Germany. These movements were mainly attributable to the expectation premium in all countries. For TLTRO, the announcements causing the most significant reaction in yields were the announcement of easing conditions (12 March 2020) and the final adjustment of TLTRO III interest rate calculation (27 October 2022). PEPP announcements led to a significant decrease in Italian yields, but a moderate increase in Spanish and German yields. In Spain, the increase was due to redenomination and segmentation components, while in Germany to the expectations channel. The most significant movement for PEPP was caused by the initial announcement (18 March 2020).

From the results, we can confirm our view that certain channels were more strongly involved than others in the transmission of monetary policy, and that their relative importance also differed according to the economy considered. We see that once again expectations were greatly influenced by monetary policy, but from the analysis, we see that market segmentation also played a relevant role in these years. On average, the risks of default and redenomination were not the main concern but rather there was more uncertainty about the efficiency and proper functioning of the economy. This is true if we generalize the results for the economies we considered, even if Italy and Spain seem to be still somehow exposed to these concerns which are almost absent in Germany.