Universitat Autònoma de Barcelona

Essays on Monetary Policy and Digital Currencies

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Supervised by Hugo Rodríguez Mendizábal

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La brevedad es el alma del ingenio (William Shakespeare).

A mis padres, Ana y Eloy,
A mi hermano, Juan,
Y a mis tías, Carmen, Rosa y Pilar,
que han hecho posible
y han sido partícipes de todo lo que he conseguido.

Acknowledgements

Knowledge is in the end based on acknowledgement (Ludwig Wittgenstein).

Trying to reach the dreams of some distant past, I embarked on one of the most feared roller coasters in the world: a Ph.D. The road, hard and full of weeping violins, has been traversed with the invaluable assistance of mentors and friends.

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Chapter 1

Introduction

This thesis consists of one theoretical and two empirical essays about current topics in the monetary economics and digital currencies field. In particular, it studies the relationship between European Central Bank's (ECB) non-standard monetary policies and the Spanish banking sector profitability. Second, it analyses the linkage between an interest-bearing central bank digital currency (CBDC) and financial stability in a modern monetary system where liquidity is created endogenously. Finally, it focuses, first, on whether distrust in the existing financial system is a motive for investing in cryptocurrencies, and second, on the socioeconomics of cryptocurrency investors in the U.S.

Immediately after the Global Financial Crisis (GFC) of 2007-09, nominal interest rates in several advanced economies were reduced to levels close to the zero lower bound.[1] With no room for further rate cuts and as a response to the financial turmoil, in the first half of 2008 the ECB had to put into practice for the first time in its history some non-standard monetary policy measures in order to satisfy urgent liquidity needs of depository institutions (Szczerbowicz, 2015). From one-year long-term refinancing operations (LTROs) to covered bonds purchase programs, from securities markets programs to very long-term refinancing operations, non-standard monetary policies deployed by the ECB resulted in an unprecedented expansion of its balance sheet.

The second chapter of the thesis, *Non-Standard Monetary Policies and Bank Profitability: The Case of Spain*[2], looks at the causal effect of unconventional monetary policies on banking profitability. I focus on Spain since the banking sector is a cornerstone of the Spanish financial system.

From a theoretical perspective, non-standard monetary policies can affect the banking sector through three main channels: the portfolio channel, the liquidity

[1] Technically, nominal interest rates can be below the zero lower bound until the "effective lower bound". However, if they hit the reversal rate, the negative effects on the banking sector and the economy overall will outweigh the positive effects (Brunnermeier and Koby, 2018). The monetary authorities which have led money market rates into negative territory are the Swedish Riksbank, Danmarks Nationalbank, the Swiss National Bank, the European Central Bank, and the Bank of Japan.

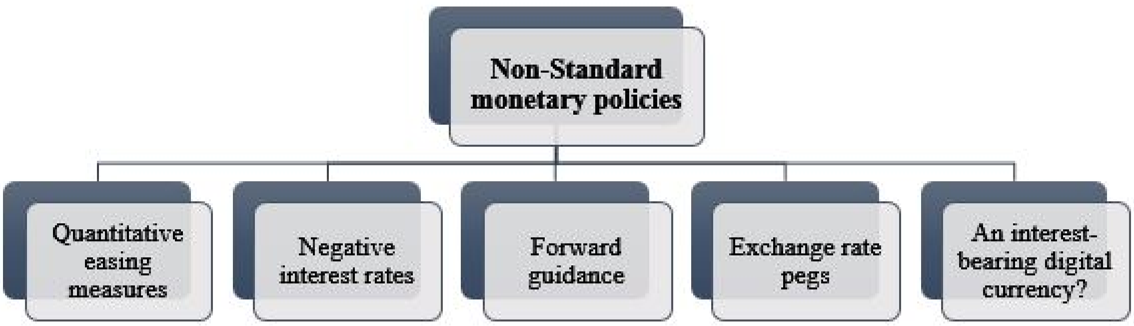
[2] This paper has been published in the *International Journal of Finance and & Economics*. For a full reference, see Tercero-Lucas (2021b).

channel and the signalling channel. Their overall effect on banks' profitability, however, remain unclear. On the one hand, quantitative easing measures may generate capital gains derived from the increase of the valuation of bonds in the banks' portfolio and may improve the macroeconomic outlook, boosting the demand for credit and reducing non-performing loans. On the other hand, they may depress long-term interest rates and flatten the yield curve, which will be translated to a reduction of banks' earnings on maturity transformation activities. Besides, when deposit rates are close to the zero-lower bound, financial institutions are reluctant to pass-through negative rates to commercial deposits (Bowdler and Radia, 2012).

Using individual bank data from several Spanish institutions, and applying different econometric techniques, the results do not show a discernible impact between the Eurosystem's nonstandard monetary policy measures (ECB's total assets, excess reserves and the slope of the yield curve) and bank profitability measured as return on assets, pre-tax operating income and interest margins. These findings are robust to a wide variety of specifications and robustness checks. Apart from contributing to the literature studying the causal effect of non-standard monetary policies on the banking sector, the findings in this chapter are consistent with the work of Altavilla et al. (2018), although they focus more generally in European banks.

Apart from quantitative easing measures, central banks have used other less standard monetary policies such as negatives interest rates and forward guidance. In Figure 1.1 can be appreciated all the existing non-standard monetary policy measures[3] and a new measure which is not a reality nowadays: an interest-bearing digital currency. It is said that central banks are running out of ammunition.[4]

Figure 1.1: Types of non-standard monetary policies



Source: Author's elaboration

After years and years of unprecedented monetary stimulus, both inflation and inflation expectations remained low in the Eurozone and in the US until 2022.

[3] A report of the BIS (2019) classifies non-standard monetary policy measures in four categories: negative interest rate policy, expanded lending operations, asset purchase programmes and forward guidance. Exchange rate pegs cannot be applied to countries with free floating.

[4] Bordo and Levin (2019) argue that both the QE3 program of the Federal Reserve and non-standard monetary policies of the ECB and the Bank of Japan barely had any effect on core inflation.

Policy rates were near to the effective lower bound and decreasing longer-term rates has proven to be an arduous task. Conventional tools have not been able to provide further stimulus to the economy. Developed countries have situated in a quasi-liquidity trap-situation in which central banks have started to considered new instruments. On the one hand, central bankers are assessing whether they should modify their inflation-target approach. On the other hand, they are analysing a completely dissimilar proposal: whether they should issue a public digital currency[5]. The current President of the Dutch central bank (De Nederlandsche Bank), Klass Knot, issued a warning about the use of these non-standard monetary policy tools: "monetary policy may wish to display more inertia, [...] caution or carefulness, in deploying policy instruments on those fronts where our knowledge is less developed" (Knot, 2019, p.5).

The new digital technologies give monetary authorities an opportunity for creating a central bank-issued digital currency and providing access to digital forms of central bank liabilities, an idea originally proposed by James Tobin in the mid-eighties: "[...] the government should make available to the public a medium with the convenience of deposits and the safety of currency, essentially currency on deposit, transferable in any amount by check or other order" (Tobin, 1987, p.172). As Carstens (2019, p-2) argues, "technological innovations have continually reshaped the monetary system, either by changing the nature of money or the workings of the payment system". Issuing a public digital currency will place central banks at the forefront of the digital transformation in an environment where consumers are looking for more convenient payment services and the use of digital payment services is getting larger (BIS, 2018). In some Nordic countries, the demand for cash is declining (Engert et al. (2019)).[6] This has influenced the central bank of Sweden to launch the so-called e-Krona project so as to determine whether it should supply a CBDC to the general population (Riksbank, 2017, 2018).[7]

Given that the topic is utterly new, not all monetary authorities in the world are engaged in central bank digital currency (CBDC) work. According to a survey conducted by the Bank for International Settlements (Barontini and Holden, 2019), 70 percent of the 63 respondents are working on this issue, focusing the majority on a general purpose CBDC or in both retail and wholesale CBDC. From the central banks which are engaging in CBDC, all of them are researching or studying it, 50 percent are dealing with experiments or proof-of-concept, and just a 10 percent are developing the public digital currency or in a pilot phase. It seems clear that monetary authorities that are seriously considering its issuance are in the minority. On the other hand, it is noticeable the increase of banks that are dealing with experiments or proof-of-concept from 2017 (35 percent) to 2018 (almost a 50 percent).

[5]Since this measure has never been implemented, I consider it a non-standard monetary policy tool (see Figure 1.1)

[6]Rogoff (2017) points out that the demand for cash tends to be driven by anonymity and related to criminal activities and tax evasion.

[7]For an analysis of the economics of CBDCs, see Auer and Böhme (2020); Auer et al. (2021); Tercero-Lucas (2021a), among others.

A CBDC raises questions about the role of central bank money, the structure of financial intermediation and the transmission mechanism of monetary policy. In the third chapter of the thesis, entitled *Central Bank Digital Currencies and Financial Stability in a Modern Monetary System*, I evaluate the linkage between an interest-bearing CBDC and financial stability in a modern monetary system where liquidity is created endogenously. In this chapter, a realistic view of the money creation process, a basic feature of a modern monetary system, is taken. Banks play an intermediation role in the process of wage payments between entrepreneurs and workers and money in the form of deposits is created when a bank provides a loan, i.e., endogenous money creation.

Researchers and central banks have expressed concerns about the effects of the introduction of a CBDC on financial stability due to possible outflows from commercial banks to CBDC. Since the topic is relatively new, the literature on the impact of CBDC's introduction on the aggregate variables, monetary policy or financial stability is not very abundant. The third chapter shows that the CBDC interest rate has a direct impact on the commercial bank's loan rate. In addition, central bank can prevent a digital bank run from occurring by imposing a not relatively high interest rate on reserves. However, if the central bank aims at preserving financial stability and having positive a positive net worth, i.e., positive seigniorage revenues, the issuance of a CBDC by the monetary authority imposes an additional constraint. In the event that both objectives cannot be achieved at the same time, the central bank must choose one. A CBDC imposes a lower bound of the reserves interest rate that has relevant implications for financial stability.

Apart from CBDCs, private digital currencies have emerged as an alternative with the potential to enhance efficiency in the provision of digital services. Bitcoin, ether, or solana, as well as most cryptocurrencies, which built upon blockchain technology[8], have become more and more popular over time, and the number of users is increasing. The emergence of these new forms of money and payment systems may alter the architecture of the systems and disrupt the monetary policy mechanism. In fact, private cryptocurrencies have been marketed as alternatives to fiat currencies and commercial and traditional banking. Cryptocurrency proponents argue that key value propositions of the asset class are their asserted resistance to debasement and censorship by national governments or financial institutions over who can transact. In the fourth chapter of this doctoral dissertation, entitled *Distrust or Speculation? The Socioeconomic Drivers of U.S. Cryptocurrency Investments*[9] [10] we use representative U.S. data from the Survey of Consumer Payment Choice provided by the Federal Reserve Bank of Atlanta to analyse whether cryptocurrencies are attractive to retail investors as alternatives to the mainstream financial system.

[8]Blockchain allows that transactions cannot be erased or edited. Their decentralised structure allows transferring private digital currencies without a third financial intermediary intervention, such as a bank.

[9]This chapter is co-authored with Raphael Auer. A previous version of the manuscript was published as a BIS working paper (see Auer and Tercero-Lucas (2021)).

[10]This manuscript has been referenced in two of the most important economics newspapers, such as the Financial Times and The Economist as well as a large number of other outlets (for instance, see The Block).

Employing different econometric techniques, results suggest that compared with the general population, cryptocurrency investors show no differences in their level of security concerns with either cash or commercial banking services. Therefore, we find no evidence to support the hypothesis that cryptocurrencies are sought as alternatives to the mainstream financial system. The chapter also focuses on examining the profile of cryptocurrency investors. Our data shows that cryptocurrency investors tend to be educated, young and male. In addition, people who have experience using digital finance are more likely to invest in cryptocurrencies. Lastly, we disentangle the role of knowledge acquisition and cryptocurrency investment decisions conditional on knowledge and examine the evolution of patterns of cryptocurrency investments across time and cryptocurrencies.

The meteoric increase in the value of bitcoin, ether and related altcoins has positioned cryptocurrencies at the forefront of not only investors' attention but also regulators. Their rapid evolution and international nature raise the potential for regulatory gaps, fragmentation or arbitrage. Therefore, understanding the concerns and sociodemographic features of cryptocurrency owners is crucial to those wanting to gauge the potential of crypto markets and how large this asset class could eventually become in the forthcoming years. One of the last findings of the chapter - that cryptocurrency markets are dominated by young "digital native" investors - indicates substantial growth potential for this industry.

Finally, the fifth and last chapter summarises the main findings, discusses policy implications of the results in the dissimilar chapters of the thesis, and provides new avenues for further research.

Chapter 2

Non-Standard Monetary Policies and Bank Profitability: The Case of Spain*

Abstract

The aim of this study is to examine the effects of non-standard monetary policy measures implemented by the Eurosystem on the Spanish banking sector profitability. To do this, a new database is built merging data from the Spanish Banking Industry Statistical Yearbook and from the Spanish Stock Market Commission. Applying different econometric techniques to a panel of 54 Spanish banks that covers the period 2001-2017 and controlling for bank-specific factors and macroeconomic conditions, no discernible impact is found between the Eurosystem's non-standard monetary policy measures (ECB's total assets, excess reserves and the slope of the yield curve) and bank profitability measured as return on assets, pre-tax operating income and interest margins. This result is robust to different specifications and to different groups of banks.

JEL Classification: E43 E51 E52 E58 G21

Keywords: Non-standard Monetary Policy Measures, Banking Sector, Profitability

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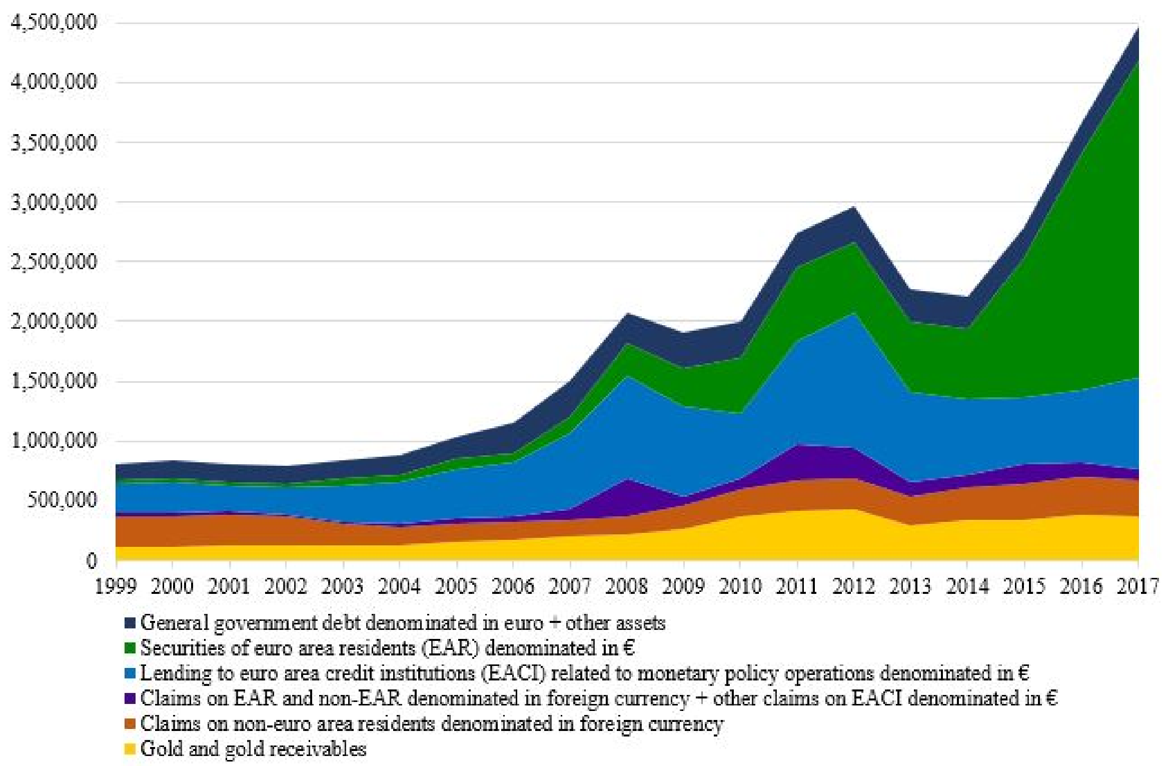
2.1 Introduction

This paper evaluates whether the non-standard monetary policy measures implemented by the Eurosystem have had any effect on the profitability of the Spanish banking sector. Non-standard monetary policy measures commenced in the first half of 2008 as a response to the financial turmoil of the Great Recession. Their first aim was to satisfy the urgent liquidity needs of depository institutions.[1] In 2009 and 2010, the ECB introduced new unconventional measures which were complementary to interest-rate decisions: one-year long-term refinancing operations (LTROs); a covered bonds purchase program; and the first sovereign bond purchase program, the Securities Markets Program (SMP) (Szczerbowicz, 2015). The sovereign debt crisis forced the ECB to activate its SMP again and put in place a second covered bond purchase program. Once there was no more room to cut interest rates, the European monetary authority deployed a package of measures from 2014 onwards, including credit easing measures, a third covered bond purchase program, an asset-backed securities purchase program, a corporate sector purchase program, and new targeted longer-term refinancing operations. Although Eurozone economies started to grow, inflation did not reach the 2 percent target, so the asset purchase program was prolonged several times until the end of 2018 (Hartmann and Smets, 2018). These non-standard monetary policy measures deployed by the ECB resulted in an unprecedented expansion of its balance sheet (see Figure 2.1).

Figure 2.1: Eurosystem total assets (€million)



Source: ECB

[1] There are several types of non-standard monetary policies: quantitative easing programs, negative interest rates, long-term refinancing operations and forward guidance.

Given the scale of the measures, a plethora of studies have tried to identify their effects in the Eurozone on output and inflation (Gambacorta et al., 2014; Peersman, 2011), interest rates (Ambler and Rumler, 2019), bond yields (Abidi and Miquel-Flores, 2018; Blot et al., 2019; Scotti et al., 2014), stock prices and exchange rates (Haitsma et al., 2016; Scotti et al., 2014), financial stability (Heider et al., 2018), wealth distribution of households (De Luigi et al., 2019) and on small and medium-sized enterprises (Ferrando et al., 2019) among others.[2]

Non-standard monetary policies may also have affected the banking sector via three main channels: the portfolio channel, the liquidity channel, and the signalling channel (Bowdler and Radia, 2012). Their effects, however, remain unclear. On the one hand, quantitative easing depresses long-term interest rates and flattens the yield curve, which may reduce bank earnings on maturity transformation activities (negative effect). It also hurts bank profitability when deposit rates are close to the zero-lower bound, since financial institutions are reluctant to pass negative rates through to commercial deposits (negative effect). On the other hand, quantitative easing measures may generate capital gains because of the increased valuation of bonds in bank portfolios and may lower the cost of debt (positive effect). In addition, non-standard monetary policies may improve the macroeconomic outlook, which may boost the demand for credit and reduce non-performing loans and loan loss provisioning (positive effect). Results may depend on the country analysed and the time-period chosen. In the USA, the findings of Montecino and Epstein (2014) suggest that depository institutions that sold Mortgage-Backed Securities (MBS) to the Federal Reserve increased their profits during the 2008-2009 period. Chodorow-Reich (2014) estimates that the introduction of non-standard monetary policies in the US in 2008 had a positive impact on financial institutions, with even bigger effects on life insurance companies. Lambert and Ueda (2014) found that bank profitability and risk-taking in the US banking sector are ambiguously affected by non-standard monetary policies. In a similar vein, Lopez et al. (2018) investigated the effect of negative nominal interest rates on bank profitability using a panel of 5,100 European and Japanese banks, determining that negative nominal interest rates have a small effect on bank profitability. On the contrary, Mamatzakis and Bermpei (2016) estimated that the Federal Reserve's unconventional monetary policies had a negative effect on US bank performance. In the Euro area, Acharya et al. (2019) highlight that the 2012 ECB Outright Monetary Transactions (OMT) program could indirectly recapitalize the European banking sector by influencing the prices of assets held in bank portfolios. In particular, those depository institutions with a significant quantity of bonds issued by Mediterranean European countries benefited the most. Altavilla et al. (2018) studied the impact of both conventional and unconventional Eurozone monetary policies on a sample of more than 50 banks, including eight Spanish banks. They did not find any association between easing of monetary policy and lower bank profits. The main difference between their research and mine is that their data is only from 8

[2]See Dell'Ariccia et al. (2018) for a very-detailed summary of the effects of unconventional monetary policies in the Euro Area, Japan, and the United Kingdom. See Kuttner (2018) for a similar analysis in the United States.

Spanish banks, hence the effects of the ECB's non-standard monetary policies on the profitability of the whole Spanish banking sector are still unknown.

Amongst the different types of bank business models, the traditional financial intermediation model predominates in Spain. Loans to the non-financial private sector and deposits taken by the private sector account for a much higher percentage of Spanish banks' total assets than in other European countries (Maudos and Vives, 2016), so a significant number of households and companies meet their finance needs via direct bank intermediation. The banking sector has always been particularly important to the Spanish economy. In fact, the Spanish banking sector, and the rest of the Eurozone banking system, are cornerstones of the Eurozone's monetary policy. Nowadays, financial institutions complain about the negative effects that some non-standard monetary policies have on their profits. A sound banking sector is crucial for a country like Spain. Spanish banks retain a critical role in direct intermediation and can also be considered managers of financial risk. Effective financial intermediation and sound financial institutions are clearly linked to a sound economy (Camdessus, 1997). The impact of a financial system breakdown would be huge and the associated fiscal costs of bailouts should be considered.

Non-standard monetary policies deployed by the Eurosystem could affect bank profitability and hence financial stability and soundness (Altavilla et al., 2018). Besides, the ability of banks to provide credit to other economic agents could be hindered (Freixas et al., 2015). Therefore, this study tackles an issue hotly debated in the media, trying to shed light on this relationship and offer new insights into the fourth-largest economy of the Eurozone. This paper is a case study which contributes to the literature about the impact of monetary policy actions on bank performance. Understanding the effects of non-standard measures, especially their potential negative impacts, has significant policy implications

The financial crisis hit Spanish commercial and saving banks directly and hard enough that there were not only some bailouts, but also a massive restructuring of the banking sector. On the one hand, some savings banks merged to create new entities (e.g. Bankia, Abanca, Liberbank, or Unicaja). The rest, on the other hand, were absorbed by the main Spanish commercial banks. This fact should be controlled for in my investigation, so this paper differs from the rest of the literature by taking non-consolidated data from 54 commercial banks into account and constructing new 'virtual entities' which capture the Spanish banking sector transformation process and the impact of ECB actions on bank profitability.

Applying different econometric techniques and controlling for bank-specific factors and macroeconomic conditions, no discernible impact is found from the ECB's non-standard monetary policy measures, as proxied by ECB total assets, excess reserves, and the slope of the yield curve, on bank profitability, measured as return on assets (ROA) and pre-tax operating income (PTOIR), over the 2001-2017 period. This result is robust to different specifications and robustness checks. In addition, it may be reasonable because of the effects of non-standard monetary policies on the different components of bank profits. Further analysis shows that the previously not discernible association between non-standard monetary policies and bank profitability does not vary depending on different bank sizes, ratios of loans to total assets, or short-term funding.

The rest of the paper is structured as follows. Section 2 presents an overview of the Spanish banking sector and how non-standard monetary policies could affect bank profitability. Section 3 introduces the data set and variables employed in the analysis. Section 4 discusses the methodology presenting the econometric framework whilst section 5 presents the empirical results. Section 6 stresses the main findings.

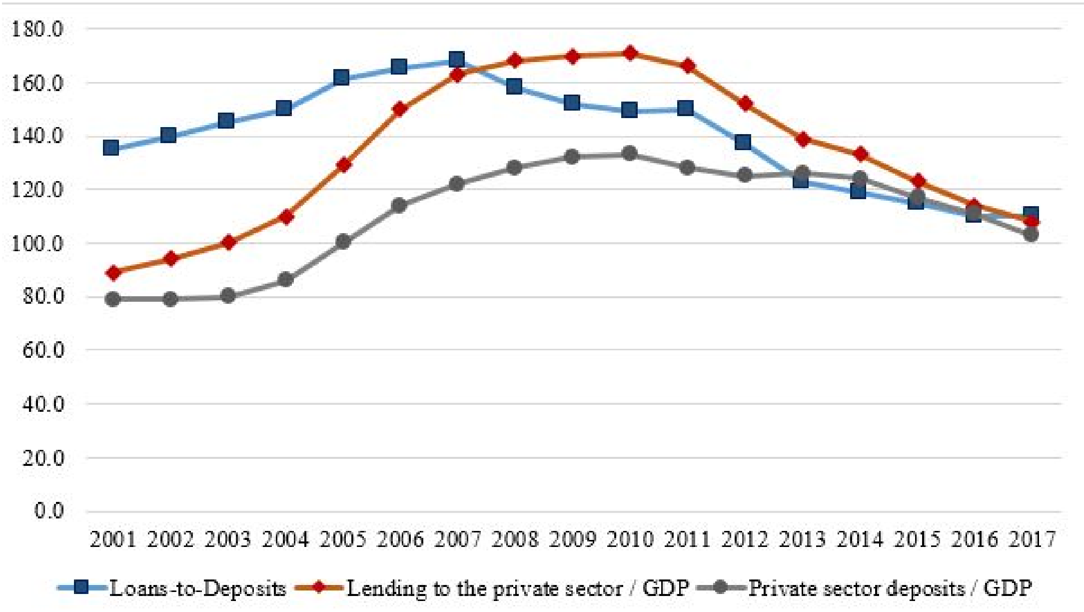
2.2 The banking sector and non-standard monetary policies

2.2.1 The Spanish banking sector: Some facts

Amongst all kinds of bank business models in developed countries, in Spain the traditional financial intermediation model predominates. This is reflected in the percentage of Spanish banks' total assets made up by loans to the non-financial private sector and deposits taken by the private sector, which is more than 10 percent higher than the European average (Maudos and Vives, 2016).Therefore, because an important number of households and firms meet their finance needs through direct bank intermediation, the Spanish banking sector and the whole Eurozone banking system are cornerstones of Eurosystem monetary policy. Before the Great Recession and the sovereign debt crisis, the Spanish banking sector had remarkable weaknesses. Maudos (2012) highlights that the creation of the European Monetary Union led to a low nominal interest rate environment, with negative real interest rates in some countries, which Spanish commercial and saving banks took advantage of. This excessive liquidity was canalized through a significant increase in loans, not only from commercial banks, but especially from savings banks. As Figure 2.2 shows, the ratio of private sector loans to GDP rose from 89 percent in 2001 to 168 percent in 2008, which implies that loans growth was higher than GDP growth. On the other hand, loans grew more than deposits in the first half of the decade. Since 2008, however, they have decreased to a greater extent than deposits. The loans-to-deposits ratio fell from its peak in 2007 of 168 percent to 110 percent in 2017.

Before the real estate bubble burst, Spanish bank profitability, measured as return on assets (ROA) or profits before tax to total assets, had always been, on average, higher than the ROA of other European countries such as France, Germany, and Italy (with a few exceptions). Figure 2.3 shows the quite important fact that, since the recovery of the Spanish economy, bank profitability has never returned to pre-crisis levels (0.8–1.1 percent). Since 2013, the ROA has oscillated between 0.0 percent and 0.4 percent. Figure 2.4 shows that the interest margin of the Spanish banking sector has followed a trend similar to ROA and has not returned to its previous level. The financial crisis eroded bank interest margins and they have not recovered since. Besides, the low nominal interest rate

Figure 2.2: Loan and deposit indicators (in percentage)



Source: BBVA Research

environment before 2007 caused households and non-financial companies to start using leveraging. However, after 2007 some of them started defaulting on their loans. On the contrary, the leveraging ratio of the banking sector remained almost constant from 2001 to 2012, but it has increased from then on.

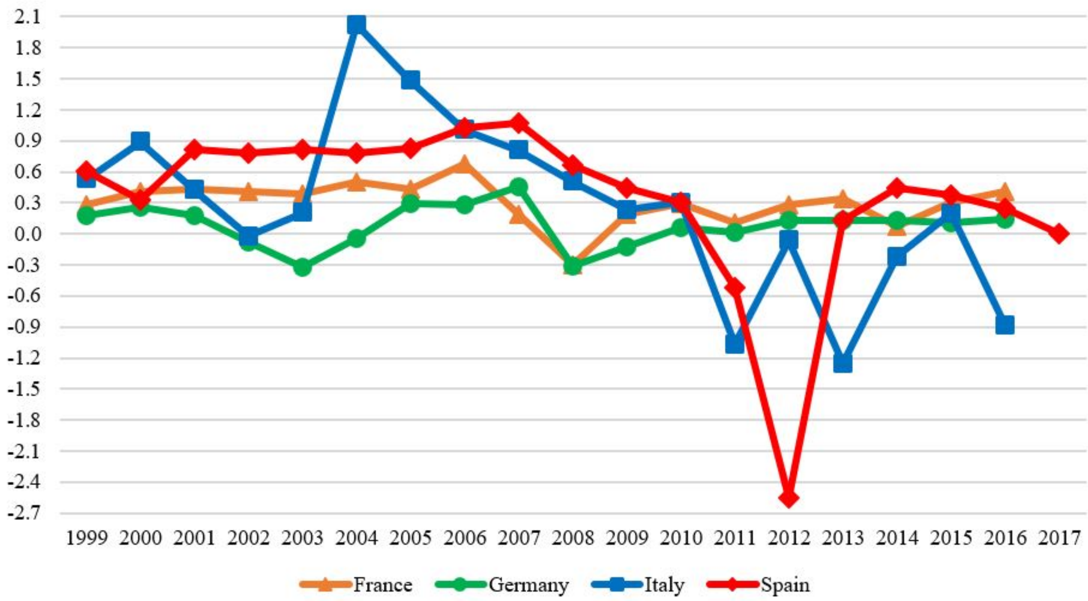
Although the financial crisis affected both commercial and saving banks, the latter almost disappeared. Their reckless behavior, partly explained by the presence of public authorities on their boards of directors, led to excessive risk-taking (García-Marco and Robles-Fernández, 2008). Those which did not go into bankruptcy formed new entities or were absorbed by larger commercial banks. The financial crisis provoked a tremendous consolidation of the Spanish banking sector and the creation of new "super-banks".[3]

2.2.2 Bank profitability and monetary policy in the literature

The relationship between bank profitability and conventional monetary policy has been studied since the 1940s. Samuelson (1945) emphasized that an increase in the interest rate boosts bank profitability via an increase in bank interest margins. An interest rate increase will push up the interest rates of loans to a greater extent than the interest rates paid on bank deposits. The study of Hancock (1985) supports this hypothesis. He estimated that the profit elasticity of loans is larger than the profit elasticity of term deposits. On the contrary, Flannery (1981) found no clear relationship between market interest rate levels and bank profitability, and showed that large banks hedged against interest rate risks. Apart from the impact of monetary policy on interest margins, interest rate changes may also

[3]For instance, the sum of the assets of Banco Santander, BBVA, Banco Sabadell and Bankinter in 2007 accounted for 28.7 percent of Spanish banks' total assets, whereas in 2017 they accounted for 43.0 percent.

Figure 2.3: ROA by country (in percentage)

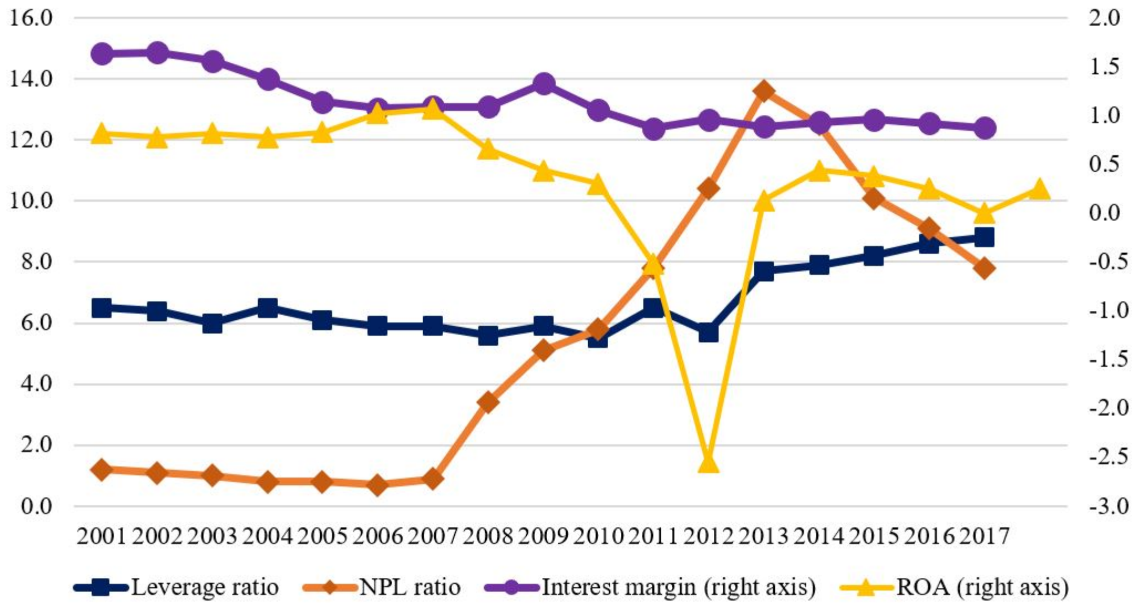


Source: BBVA Research and ECB

affect the term premium, altering the yield curve and thus bank profitability (English, 2002; English et al., 2012). The study by Borio et al. (2017) confirms that the interest rate level has a positive and significant relationship with both bank profitability and the slope of the yield curve. In a similar line, Demirgüç-Kunt and Huizinga (1999) found that an increase in interest rate levels increases interest margins and profitability. However, Lopez et al. (2018) show that, compared to low positive rates, negative nominal interest rates have only a small effect on bank profitability.

On the other hand, the literature has established three different main channels through which non-standard monetary policies – i.e. purchase of government bonds from investors like banks or pension funds – may have an impact on the profitability of the banking sector, especially via their effect on asset prices (Bowdler and Radia, 2012). The first is the so-called "portfolio rebalancing" channel. Tobin (1963, 1969) and Brunner and Meltzer (1972) highlight that central bank asset purchases provide cash to the owners of the assets. Since cash and the assets bought are not perfect substitutes for each other, financial institutions will use that cash to buy closer substitutes for previous assets, rebalancing their portfolios and taking more risks than if they had just held the money. The second channel is the "liquidity channel". Quantitative easing reduces the net supply of longer-term assets which provokes an increase in their prices and a decrease in their yields (Altavilla et al., 2018). The provision of liquidity through asset purchase programs to not only the financial sector, but also the non-financial sector, reduces the liquidity premia associated with times of financial distress (Bowdler and Radia, 2012). Non-standard monetary policies can also affect the banking sector via the "signalling channel". The Global Financial Crisis made forward guidance an essential tool of central bankers (McKay et al., 2016). When the ECB reveals its possible future policy decisions, it signals economic prospects

Figure 2.4: Some bank indicators (in percentage)



Source: BBVA Research

to the market. Maintaining the asset-purchase programs for a long period of time may signal that because the economic situation is still fragile (Mamatzakis and Bermpei, 2016), there is an intention to keep short-term interest rates low for a long period of time (Altavilla et al., 2018) and that long-term interest rates may decrease (Bowdler and Radia, 2012). This mechanism is closely related to the interest rate channel proposed by Samuelson (1945).

Empirical studies trying to disentangle the different effects of non-standard monetary policy on the profitability of the banking sector started with Lambert and Ueda (2014) and Montecino and Epstein (2014). The first study showed that bank profitability and risk-taking in the US banking sector are not really affected by the Fed's unconventional monetary policies (Lambert and Ueda, 2014). The second one showed that depository institutions that sold MBS to the Federal Reserve increased their profitability during the 2008-2009 period (Montecino and Epstein, 2014). Mamatzakis and Bermpei (2016) estimated that the Federal Reserve's unconventional monetary policies had a negative effect on US bank performance. In the Eurozone, citetAltavillaetal2018 did not find any association between monetary policy easing and lower bank profits once they controlled for the endogeneity of the policy.

2.3 Data and variables

I constructed a new database employing annual data from the *Spanish Banking Industry Statistical Yearbook* of the Spanish Banking Association for the period from 1999 to 2017.[4] However, the yearbook does not include all those new entities

[4]In the empirical models, data from 2001 to 2017 will be employed because there is no data prior to 2001 for some country-level variables.

created after 2010, most of which were created by mergers of troubled savings banks. To ensure I included them in the sample, data from the Spanish Stock Market Commission was employed (CNMV).

Some Spanish depository institutions are major global firms which are thus exposed to different markets, not only inside the European Union but also in Latin America and Asia. Since I am only interested in the effects of the ECB's non-standard monetary policies on the outcomes of Spanish banks, non-consolidated data is used. Consolidated data could distort my results because the balance sheets of headquarters and subsidiaries may cancel each other out. The Spanish Banking Association reports both non-consolidated (in Spain only) and consolidated data. The sample is adjusted following Borio et al. (2017). I controlled for 47 mergers and acquisitions over the 1999-2017 period by constructing "new virtual entities" which are derived from adding balance sheets (see Table A1 and A2 in the Appendix A). This is key in the Spanish context because there has been tremendous consolidation in the banking sector since the beginning of the Great Recession. I am, however, conscious that this method reduces the number of banks in the sample.[5]

The frequency is annual and all variables are in thousand euros. The final sample includes 54 commercial banks[6] and a total of 742 observations. Inconsistencies and extreme values (outliers) have also been removed. The number of banks varies year to year from a minimum of 35 to a maximum of 54 (with all new created entities included).

2.3.1 Dependent variables

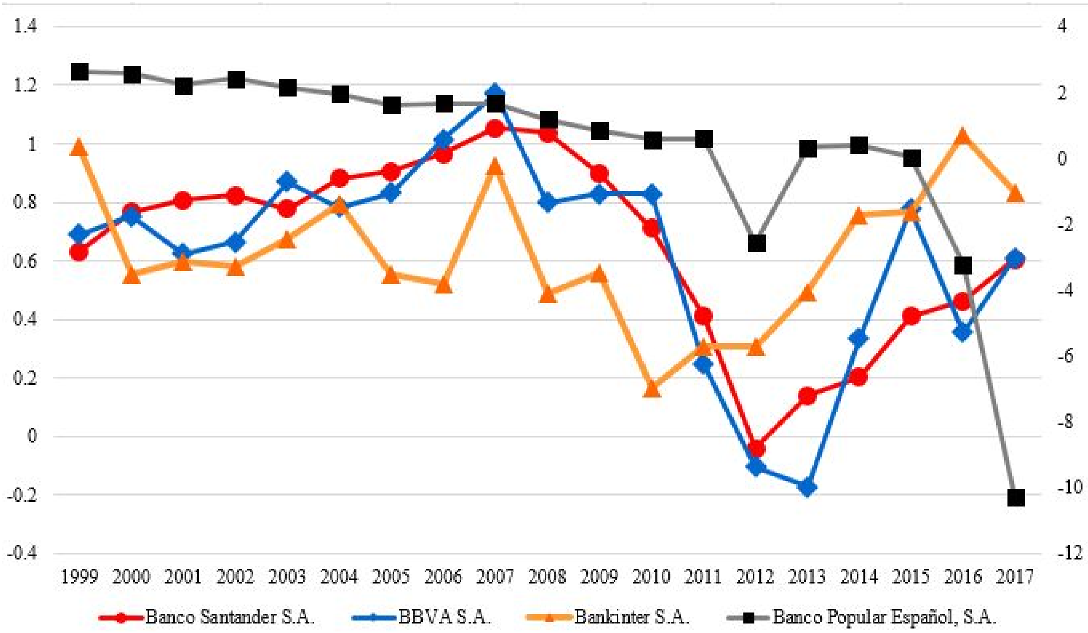
The data provided by the Spanish Banking Association and the Spanish Stock Market Commission allows us to compute different bank profitability measures. The first one is the return on assets (ROA), which is the simplest measure of bank performance. It reflects the ability of a depository institution to obtain profits from its asset management tasks. It is computed as the ratio of total bank profits before taxes over total assets (Mamatzakis and Bermpei, 2016; Pasiouras and Kosmidou, 2007; Trujillo-Ponce, 2013). Profits before taxes are employed to avoid tax system changes. Figure 2.5 shows the evolution of the return on assets of some

[5]I have had to keep track of all changes in banks names during the 1999-2017 period. Table A3 in the Appendix A provides a follow-up on this matter.

[6]Banks in the sample are: A&G Banca Privada, Allfunds Bank, AndBank España, Aresbank, BNP Paribas España, Banca Pueyo, Banco Alcalá, Banco Europeo de Finanzas, Banco Finantia Sofinloc, Banco Inversis, Banco Mediolanum, Banco Pichincha España, Banco de Depósitos, Banco de la Nacion Argentina, Bancofar, Bank Degroof Petercam Spain, Bankoa, Banque Marocaine du commerce exterieur international, Citibank España, Credit Suisse Ag, EBN Banco de Negocios, JP Morgan Chase Bank National Association, Nuevo Micro Bank, Popular Banca Privada, Renta 4 Banco, Self Trade Bank, The Bank of Tokyo Mitsubushi UFJ, UBS Bank, Abanca, BBVA, Banca March, Banco Caixa Geral, Banco Caminos, Banco Cooperativo Español, Banco Pastor, Banco Popular Español, Banco Santander, Banco de Crédito Social Cooperativo, Banco de Sabadell, Bankia, Bankinter, Caixabank, Deutsche Bank, EVO Banco, Ibercaja, Kutxabank, Liberbank, Open Bank, Santander Consumer Finance, Santander Investment, Santander Securities Services, Targobank, Unicaja and Wizink Bank.

of the major Spanish banks. Banco Popular suffered an important crisis in 2016 and 2017 that led to its absorption in 2018 by Banco Santander.

Figure 2.5: ROA of some of the main Spanish banks (Banco Popular right axis)



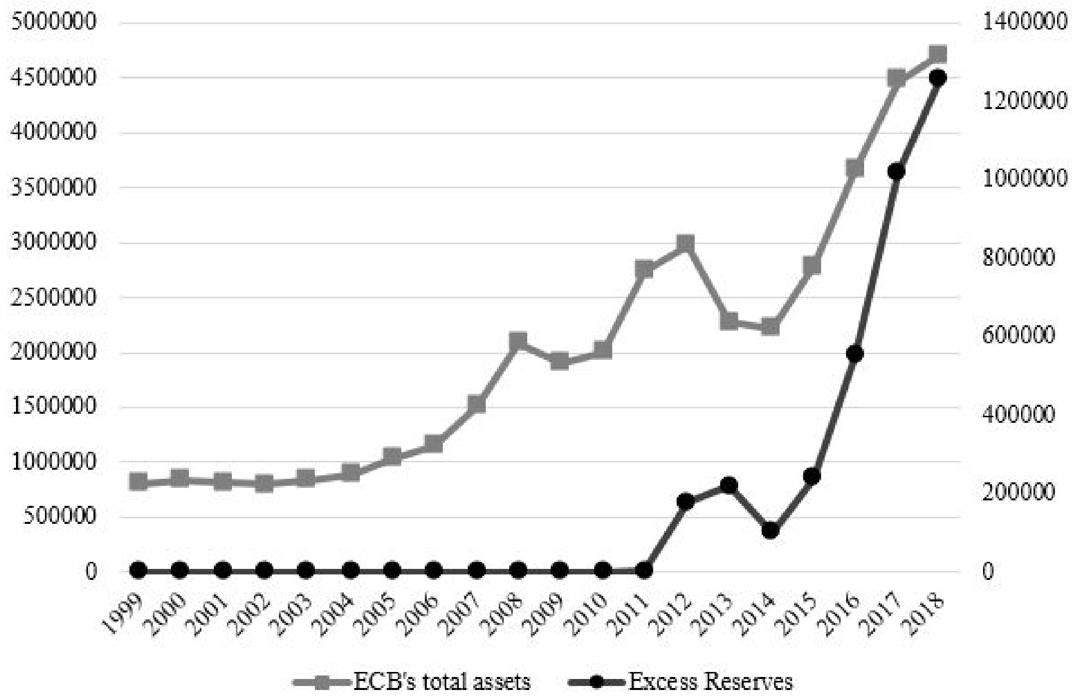
Source: Spanish Banking Association and Spanish Stock Market Commission

The return on equity (ROE) is also another measure of profitability widely used. Nevertheless, neither the Spanish Banking Association nor the Spanish National Stock Market Commission provide me enough information to compute it over the whole period considered. As a complement to ROA, the pre-tax operating income to total assets ratio (PTOIR) will be employed (Mamatzakis and Bermpei, 2016). Additionally, another measure used in the literature is the interest margin because it is a momentous source of bank profitability (Mamatzakis and Bermpei, 2016). The interest margin is the difference between the interest rate of lending and the interest rate of deposits. García-Herrero et al. (2009) highlight that the interest margin is an appropriate measure of profitability if the behavior of banks is the one which determines interest rate revenues and expenses and not government policies. Although in the literature the net interest margin is computed as a percentage of the average earning assets, I will employ the interest margin to total assets ratio (IMR) because of data availability.

2.3.2 Non-standard monetary policy variables

Since the outbreak of the Great Recession, the ECB has notably expanded the size of its balance sheet both in the asset and liability side. In the first place, by providing liquidity to depository institutions. Secondly, by starting asset purchase programs and holding Eurozone securities. The increase in the asset side of the ECB's balance sheet can be appreciated in Figure 2.6. In 2008 the ECB's total assets were €2.075 trillion whereas in 2018, they are €4.702 trillion. Several studies have employed the asset side of the central bank as a measure of non-standard monetary policies to assess its effects on some macroeconomics variables. For instance, Gambacorta et al. (2014) demonstrate that an exogenous increase in the central bank balance sheet increases temporarily output and inflation and Eser and Schwaab (2013) study the impact of the ECB's Securities Markets Programme (2010-2011) on sovereign bond markets. Using also this measure, Chodorow-Reich (2014) proves that the introduction of unconventional monetary policies by the US Federal Reserve benefited banks. However, Lambert and Ueda (2014) find that, in the US, bank profitability and risk taking are vaguely affected by them. On the contrary, Mamatzakis and Bermpei (2016) show that the increase in the asset side of Fed's balance sheet has a negative relationship with bank profitability. Hence, I use the logarithm of ECB's assets as a first measure of non-standard monetary policy measures.

Figure 2.6: ECB total assets and Euro area banks excess reserves (right axis) (€million)



Source: ECB

As in the case of the US (Keister and McAndrews, 2009; Todd, 2013), the non-standard monetary policy measures carried out by the ECB have led to a substantial increase in excess reserves held by Eurozone credit institutions (Darvas and Pichler, 2018): from €0.966 billion in December 2007 to €1.204 trillion in January 2019 (see Figure 2.6). Excess reserves are those reserves held by credit institutions at the central bank account in excess of the amount that the ECB requires. Since the mid-2014, the ECB adopted a negative deposit rate on its deposit facility. As Mamatzakis and Bermpei (2016), I employ the logarithm of excess reserves as a second measure of the ECB's non-standard monetary policy measures.

The ECB's total assets and the Eurosystem's excess reserves, are a proxy of asset purchase programs (quantitative easing). They can proxy liquidity injections as well, as the ECB expanded its balance sheet to provide long-term funding to euro area banks. However, these measures are poorly correlated with forward guidance and negative interest rates. This means that they are capturing the "quantity effect" of non-standard monetary policies, but not the "price effect". This "price effect" can be measured by the slope of the yield curve. As in Altavilla et al. (2018), the slope of the Spanish yield curve will be computed as the difference between the 10-year Spanish bond yield and the 2-year Spanish bond yield.

2.3.3 Bank and country-level data

In the literature several variables have been used as controls. I will split these factors that influence banks' performance in two different categories: bank-specific factors and macroeconomic variables which capture the Spanish economic conditions.

Bank-specific factors

A natural variable to control for existing economies of scale is bank total assets (proxied by bank size). The empirical evidence on the relationship between size and profitability depends on the country and period analyzed. Some authors argue that large banks tend to raise less expensive capital than smaller banks so they can be more profitable (Short, 1979). Others argue that large banks gain from being more diversified (Mester, 1993). On the other hand, large banks can also be negatively affected by bureaucracy and other kinds of rigidities (Athanasoglu et al., 2008; Demirgüç-Kunt and Huizinga, 2000). The natural logarithm of banks' total assets is used. Another relevant variable to account for is the customer loans to total assets ratio (García-Herrero et al., 2009; Mamatzakis and Bermpei, 2016). To capture possible liquidity problems (Petria et al., 2015), the loan to customer deposits ratio is used. Trujillo-Ponce (2013) argues that when there is an extreme competition to capture deposits, depository institutions will increase the interest rate they offer losing revenues. Hence, the annual growth rate of customer deposits will be considered.

An additional control variable to be taken into consideration is market power. The structure–conduct–performance hypothesis states that monopolistic profits are derived from higher levels of market power. In the literature, market power is proxied by taking the share of individual total assets to the whole sector total assets (García-Herrero et al., 2009; Petria et al., 2015). I do the same here.[7]

Macroeconomic conditions

To capture the Spanish economic conditions I employ a set of macroeconomic variables such as real GDP growth, inflation, stock market volatility and ECB's main refinancing operations (MRO) interest rate. A higher economic growth is related to an increase of the demand for loans by households and firms (Petria et al., 2015), which could be translated to a higher bank profitability. Economic

[7] I would have also liked to control for other bank-level variables such as the liquid assets to total assets ratio or a funding costs variable. Unfortunately, such variables are not included in the Spanish Banking Association files.

growth is proxied by the real GDP growth (Bikker and Hu, 2002; García-Herrero et al., 2009; Mamatzakis and Bermpei, 2016; Avalos and Mamatzakis, 2018). An increase in the consumer price index may affect not only wages but also other costs of financial institutions (Revell, 1979). Perry (1992) argues that if depository institutions anticipate inflation their revenues will increase to a greater extent than their costs because they will adjust properly interest rates. The opposite would happen if inflation is not unanticipated, with its negative effects on bank profitability. Therefore, the effects of inflation in bank performance are uncertain.

As in Lambert and Ueda (2014), the volatility of stock price index is used to control for the stress in the stock market. Higher stock market volatility can negatively affect bank performance. Finally, the ECB's MRO interest rate is included to control for the conventional monetary policy of the European monetary authority. A positive relationship is expected on bank profitability (Jimenez et al., 2013), especially on the interest margin variable.

2.3.4 Descriptive statistics

Table 2.2 presents a summary of the descriptive statistics of all variables employed in the analysis.[8] On average, bank profitability measured as ROA is 0.57, as pre-tax operating income it is 0.74 and as interest rate margin it is 1.68. The large standard deviations of the loans to deposits ratio and customer deposits growth are due to the important changes in these magnitudes from some small banks from one period to another.

2.4 Econometric framework

The suitable econometric framework to deal with the data I use is a panel data model. Firstly, a static-panel will be considered. In order to identify whether I should employ a fixed-effects model or a random-effects model, the Hausman (1978) test is performed. In the twelve estimated models, the null hypothesis is rejected. This implies that the fixed effect estimator should be used.[9]

The static-panel model that I employ can be summarised by the following expression:

$$BP_{i,t} = c + \beta(NSMP)_{i,t} + \sum_{j=1}^{n} \gamma_j (BSF^{j}_{i,t}) + \sum_{k=1}^{m} \delta_k (MC^{k}_{t}) + v_i + u_{i,t} \qquad (2.1)$$

In equation 2.1 subscripts i and t index banks and time in years, respectively; $BP_{i,t}$ is the vector of bank-specific measure of the Spanish banks profitability. As stated before, it has been proxied in three different ways: i) the ROA (return of assets), ii) the PTOIR (pre-tax operating income ratio), and iii) the IMR (interest margin ratio). The variable $NSMP_{i,t}$ captures the non-standard monetary policies and is proxied by i) Eurosystem total assets, ii) excess reserves, iii) the slope of the yield curve. The variable $BSP^{j}_{i,t}$ stands for bank-specific factors as described

[8] The correlation matrix is presented in Table B1 in the appendix.
[9] See Table C1 and Table C2 in Appendix C.

Table 2.1: Summary of variables. Definition and sources

Variable	Definition	Statistical Source
Dependent variables		
Return of assets (ROA)	Individual profits before tax per bank over total assets per bank	AEB and CNMV*
Pre-tax operating income ratio (PTOIR)	Pre-tax operating income over total assets	AEB and CNMV
Interest margin ratio (IMR)	Interest margin to total assets ratio	AEB and CNMV
Independent variables		
Eurosystem total assets (ESTA)	Assets that the Eurosystem national central banks and the ECB held at the end of the year with third parties	ECB
Excess reserves (EERR)	Reserves held by credit institutions at the central bank account in excess of the amount that the ECB requires	ECB
Slope of the yield curve (SYC)	Difference between the 10-year Spanish bond yield and the 2-year Spanish bond yield	Bloomberg
Bank size (BS)	Natural logarithm of total assets	AEB and CNMV
Loans to assets ratio (LTA)	Customer loans over total assets	Own calculations
Loans to deposits (LD)	Customer loans over customer deposits	Own calculations
Deposits growth (DG)	Customer deposits growth per year	Own calculations
Market power (MP)	Total assets per bank over the total assets of the whole banking sector	BBVA Research and own calculations
Real GDP growth (RGDP)	Real Gross Domestic Product change per year	Eurostat
Inflation (INF)	Change in the price index	Eurostat
Volatility of stock price index (VSPI)	Natural logarithm of the 360-day standard deviation of the return on the Spanish stock market index	Fed Bank of St. Louis
Main refinancing operations rate (MRO)	Interest rate depository institutions pay when they borrow money from the ECB for one week	ECB

Source: Author's elaboration. *AEB stands for Spanish Banking Association. CNMV stands for Spanish Stock Market Commission.

in Table 2.1 whilst MC_t^k stands for macroeconomic conditions, which do not vary across banks. β, γ_j and δ_k are the rest of the parameters to be estimated. Finally, v_i is the unobserved bank-specific effect and u_i the idiosyncratic error term.

Secondly, I should be aware of the potential econometric issues that data could present. The first one is the possible endogeneity character of the explanatory variables. Bank profitability could have an impact on some of the bank-specific variables as well as on macroeconomic determinants. For instance, some measures adopted by the Eurosystem during the crisis have been partially a response to problems in the banking sector. Hence, they may not be truly independent. The

Table 2.2: Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
Depedent variables				
ROA	0.57	2.50	-32.99	16.81
PTOIR	0.74	2.0	-15.04	16.81
IMR	1.69	1.49	-0.51	10.76
Non standard monetary policy variables				
ESTA	14.44	0.54	13.58	15.31
EERR	9.23	2.89	6.50	13.83
SYC	1.57	0.67	0.19	2.62
Bank-level variables				
BS	8.01	2.40	2.81	13.29
LTA	48.08	29.89	0.01	99.22
LD	327.15	2530.63	0.12	67339.38
DG	144.27	2221.96	-99.02	52310.39
MP	1.48	3.61	0.00	18.67
Country-level variables				
RGDP	1.58	2.48	-3.57	4.11
INF	1.99	1.52	-0.50	4.08
VSPI	3.11	0.31	2.44	3.60
MRO	1.59	1.40	0	4.30

Source: Author's elaboration. The final sample includes 742 observations (the same as in Table 2.5).

second issue is the persistence of bank performance, a well-documented fact in the literature (Knapp et al., 2006). Lastly, unobserved heterogeneity should be taken into account (bank profitability can be affected by some features of depository institutions which are not measurable). The standard methodology to address all my concerns is to apply the generalised method of moments (GMM) dynamic panel estimator, developed for dynamic panel data models by Arellano and Bond (1991) and improved by Arellano and Bover (1995) and Blundell and Bond (1998) which yields consistent and unbiased estimates.[10] Specifically, I apply a two-step GMM system. This method combines the difference equation with a level equation so as to form a system of equations.[11]

The validity of the GMM system estimator approach relies on two different and important assumptions: i) the instruments will be valid only if they are uncorrelated with the error term, and ii) the GMM system estimator requires that the error terms I have estimated are stationary. The first assumption will be tested through the Hansen J-Statistics of over-identifying restrictions. In addition, the difference-in-Hansen test will be performed. It considers whether the difference between the corresponding Hansen statistics is small enough for the null hypothesis not to be rejected. The second assumption implies the absence

[10]Before applying the System-GMM approach, I will perform a dynamic fixed-effects model to check whether the differences between both models are important.

[11]As the estimated asymptotic standard errors of the two-step GMM estimator may be downward biased, I apply the finite sample correction proposed by Windmeijer (2005) to control for this.

of second-order serial correlation in the first difference residual. To test this assumption, I use an statistic developed by Arellano and Bond (1991).

The dynamic panel model that I employ can be summarised in the following expression:

$$BP_{i,t} = c + \alpha(BP_{i,t-1}) + \beta(NSMP)_{i,t} + \sum_{j=1}^{n} \gamma_j(BSF^{j}_{i,t}) + \sum_{k=1}^{m} \delta_k(MC^{k}_{t}) + v_i + u_{i,t} \quad (2.2)$$

In equation 2.2 subscripts i and t index banks and time in years, respectively; $BP_{i,t}$ is the vector of bank-specific measure of the Spanish banks profitability. $BP_{i,t-1}$ denotes the dependent variables lagged one period. α measures the speed of mean reversion. As Trujillo-Ponce (2013) underscores, a value of α between 0 and 1 implies that bank profitability will ultimately come back to the equilibrium level. $NSMP_{i,t}$ is the variable that captures the non-standard monetary policies. The rest remains equal to equation 2.1.[12]

2.5 Empirical results

In this paper, I investigate empirically whether the non-standard monetary policy measures of the Eurosystem have affected bank profitability in Spain with annual panel of 54 banks during the period 2001-2017. Three different measures of bank profitability are employed: ROA, PTOIR and IMR. The results need to be interpreted with caution. Bank profitability may be affected by fiscal and financial factors I have not controlled for.

In section 5.1, I conduct a static fixed-effects regression. In section 5.2, I move from a static context to a dynamic one employing the same methodology as in the previous section. Finally, in section 5.3, I use a system-GMM estimator.

2.5.1 Static fixed-effects estimation

Table 2.3 presents the first set of results of a static fixed-effects regression for the three measures of bank profitability (ROA, PTOIR, and IMR) in Spain. Columns "A" show the results using Eurosystem total assets as a proxy for non-conventional monetary policies. Columns "B" present the outcomes employing excess reserves as proxy. Columns "C" present the results using the slope of the yield curve as proxy. Results for the three measures of bank profitability are presented in staggered fashion. First, I directly regressed my interest variable with the measure of bank profitability. Second, I controlled for bank-specific factors. Third, I also controlled for macroeconomic conditions.

Starting with ROA (Columns 1A-3C) as proxy for bank profitability, none of the coefficients of Eurosystem total assets are statistically significant. The results are similar when using excess reserves or the slope of the yield curve, when I

[12]The endogeneity of instruments have been tested using the Durbin-Wu-Hausman test, resulting negative.

control for bank-specific factors and macroeconomic conditions. Regarding the PTOIR variable (Columns 4A-6C), when I control for bank-specific factors only, a negative and significant association is found between ECB total assets and the slope of the yield curve. Moreover, if macroeconomic conditions are added to the equation, this relationship remains for Eurosystem total assets but changes its sign for the other variables. Nonetheless, excess reserves do not seem to affect bank profitability, measured as PTOIR. In the third set of regressions (Columns 7A-9C), a positive association between excess reserves, the slope of the yield curve, and the interest margin ratio is found after controlling for both bank-specific factors and macroeconomic conditions.

Overall, employing a static-fixed effects methodology I cannot reject the null hypothesis that non-standard monetary policy measures do not have an impact on bank profitability. Although my analysis of the Spanish banking sector is new, Lambert and Ueda (2014) did not find a conclusive association between bank profitability and non-standard monetary policies in the case of the USA.

2.5.2 Dynamic fixed-effects estimation

The main drawback of the static fixed-effects model I employed for the previous section is that the dynamics of bank profitability, which are regarded as quite relevant in the literature, were not taken into consideration (Mamatzakis and Bermpei, 2016; Trujillo-Ponce, 2013).

Table 2.4 reports the empirical estimations including the first lag of the dependent variable (Dep.var_{t-1}). All coefficients of the lagged profitability variables are positive and statistically significant, confirming the dynamic character of the model and the importance of controlling for this. There are only minor changes compared to the static fixed-effects specification. When ROA is proxy for bank profitability (models 10A-12C), neither Eurosystem total assets nor excess reserves have any effect on it, no matter which control variables are in play. Only the slope of the yield curve has a positive effect. In the case of PTOIR (models 13A-15C), outcomes do not differ at all from Table 2.3. Finally, non-standard monetary policies' effects on bank profitability, as proxied by excess reserves, are positive and significant at one percent significance level (model 18B) when bank-specific variables and macroeconomic conditions are included for IMR.

2.5.3 System-GMM estimation

Table 2.5 reports the empirical estimations from equation 2.2, using the system-GMM estimator.[13] In this case, results are not reported in staggered fashion as in the static and dynamic fixed-effects regressions. This is because the number of instruments employed depends on the number of independent variables, so

[13]I am using from the second to the fifth lag as instruments for the difference and the level equation. I am aware that the higher the number of instruments, the lower the validity of the post-estimation diagnostic tests. As rule of thumb, I have limited the number of instruments to the number of groups in the sample.

Table 2.3: Static fixed-effects estimations

Dep. variable: Return on assets (ROA)									
Model	1A	1B	1C	2A	2B	2C	3A	3B	3C
Eurosystem total assets	-0.030			-0.430			-0.209		
	(0.334)			(0.302)			(0.283)		
Excess reserves		-0.005			-0.038			-0.023	
		(0.052)			(0.048)			(0.062)	
Slope of the yield curve			-0.293**			-0.325**			0.386
			(0.133)			(0.127)			(0.261)
Bank factors	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Macro. cond.	No	No	No	No	No	No	Yes	Yes	Yes
Within R^2	0.001	0.001	0.008	0.026	0.021	0.029	0.046	0.046	0.047
F-statistic	0.01	0.01	4.864***	8.641***	9.050***	14.20***	11.47***	11.48***	11.62***
Dep. variable: Pre-tax operating income ratio (PTOIR)									
Model	4A	4B	4C	5A	5B	5C	6A	6B	6C
Eurosystem total assets	-0.280			-0.649***			-0.430**		
	(0.251)			(0.215)			(0.213)		
Excess reserves		-0.031			-0.050			-0.010	
		(0.044)			(0.038)			(0.050)	
Slope of the yield curve			-0.340**			-0.353***			0.621*
			(0.132)			(0.127)			(0.348)
Bank factors	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Macro. cond.	No	No	No	No	No	No	Yes	Yes	Yes
Within R^2	0.008	0.003	0.020	0.050	0.029	0.043	0.072	0.065	0.074
F-statistic	1.241	0.483	6.645**	19.50***	19.74***	24.04***	23.14***	21.77***	23.97***
Dep. variable: Interest margin ratio (IMR)									
Model	7A	7B	7C	8A	8B	8C	9A	9B	9C
Eurosystem total assets	-0.384***			-0.266*			-0.151		
	(0.141)			(0.142)			(0.131)		
Excess reserves		-0.050**			-0.024			0.034**	
		(0.023)			(0.018)			(0.016)	
Slope of the yield curve			-0.094			-0.046			0.372**
			(0.074)			(0.066)			(0.141)
Bank factors	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Macro. cond.	No	No	No	No	No	No	Yes	Yes	Yes
Within R^2	0.070	0.033	0.007	0.098	0.083	0.079	0.119	0.120	0.130
F-statistic	7.42**	4.67*	1.62	10.55***	10.87***	10.32***	8.19***	7.73***	10.09***
Observations	744	744	744	744	744	744	744	744	744
Banks in the sample	54	54	54	54	54	54	54	54	54

Source: Author's elaboration. Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by depository institution. Constant included but not reported.

if I used a different number of instruments for each regression, results would not be comparable. Before commenting the results, the diagnostic test should be analysed. The post-estimation diagnostic tests suggest the following: i) The null hypothesis of the AR(2) test (Arellano and Bond, 1991) is that the errors in the first difference regression exhibit no second-order serial correlation. The null cannot be rejected in any of the models; ii) The Hansen (1982) J test is a test of the

Table 2.4: Dynamic fixed-effects estimations

Dep. variable: Return on assets (ROA)									
Model	10A	10B	10C	11A	11B	11C	12A	12B	12C
ROA_{t-1}	0.317***	0.315***	0.309***	0.299***	0.302***	0.295***	0.288***	0.288***	0.289***
	(0.078)	(0.078)	(0.080)	(0.077)	(0.076)	(0.078)	(0.080)	(0.079)	(0.079)
Eurosystem total assets	-0.100			-0.319			-0.236		
	(0.231)			(0.237)			(0.225)		
Excess reserves		-0.007			-0.022			-0.022	
		(0.037)			(0.035)			(0.054)	
Slope of the yield curve			-0.180*			-0.193*			0.435*
			(0.105)			(0.101)			(0.229)
Bank factors	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Macro. cond.	No	No	No	No	No	No	Yes	Yes	Yes
Within R^2	0.105	0.105	0.108	0.115	0.112	0.115	0.128	0.127	0.129
F-statistic	8.433***	8.194***	13.33***	37.76***	32.94***	33.59***	43.12***	39.60***	46.79***
Dep. variable: Pre-tax operating income ratio (PTOIR)									
Model	13A	13B	13C	14A	14B	14C	15A	15B	15C
$PTOIR_{t-1}$	0.411***	0.412***	0.403***	0.391***	0.402***	0.394***	0.380***	0.384***	0.381***
	(0.087)	(0.084)	(0.087)	(0.086)	(0.081)	(0.083)	(0.090)	(0.088)	(0.090)
Eurosystem total assets	-0.238			-0.412**			-0.333**		
	(0.158)			(0.170)			(0.156)		
Excess reserves		-0.019			-0.022			0.000	
		(0.027)			(0.025)			(0.041)	
Slope of the yield curve			-0.182*			-0.179*			0.541**
			(0.098)			(0.095)			(0.261)
Bank factors	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Macro. cond.	No	No	No	No	No	No	Yes	Yes	Yes
Within R^2	0.213	0.208	0.212	0.225	0.215	0.219	0.234	0.230	0.236
F-statistic	22.11***	13.94***	23.35***	80.76***	68.40***	73.12***	60.53***	57.37***	62.99***
Dep. variable: Interest margin ratio (IMR)									
Model	16A	16B	16C	17A	17B	17C	18A	18B	18C
IMR_{t-1}	0.476***	0.490***	0.500***	0.471***	0.477***	0.478***	0.469***	0.468***	0.459***
	(0.139)	(0.132)	(0.127)	(0.144)	(0.141)	(0.140)	(0.143)	(0.140)	(0.142)
Eurosystem total assets	-0.150			-0.076			0.052		
	(0.119)			(0.098)			(0.099)		
Excess reserves		-0.020			-0.007			0.041***	
		(0.017)			(0.012)			(0.012)	
Slope of the yield curve			-0.047			-0.023			0.155
			(0.046)			(0.038)			(0.119)
Bank factors	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Macro. cond.	No	No	No	No	No	No	Yes	Yes	Yes
Within R^2	0.344	0.340	0.336	0.365	0.363	0.363	0.380	0.387	0.382
F-statistic	24.43***	17.33***	10.64***	8.283***	5.584**	5.281**	12.20***	12.10***	15.03***
Observations	744	744	744	744	744	744	744	744	744
Banks in the sample	54	54	54	54	54	54	54	54	54

Source: Author's elaboration. Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by depository institution. Constant included but not reported.

over-identifying restrictions. Under the null hypothesis, there is no correlation between the instruments and the error term. I cannot reject the null in any of the models. In addition, the difference-in-Hansen test will has been performed. It considers whether the difference between the corresponding Hansen statistics is small enough for the null hypothesis not to be rejected. According to the results, the instruments are valid.

All coefficients of the lagged profitability variables (Dep.var_{t-1}) are positive and highly statistically significant, confirming the findings of the dynamic fixed-effects model. The value of the lagged ROA is close to 0.20, indicating a low persistence in bank profitability, while the value of the lagged PTOIR is almost 0.35, which can be understood as a moderate persistence in bank profitability. In contrast, there is a high persistence in the interest margin ratio variable, whose coefficient is around 0.75. Related papers have found similar results (e.g. Athanasoglu et al. (2008); Trujillo-Ponce (2013)).

Once endogeneity issues have been properly controlled for, no association is found between Spanish bank profitability, as proxied by ROA and PTOIR, and the three measures of non-standard monetary policies (models 19A-21C). All outcomes are in line with the static and the dynamic fixed-effects specifications. It is quite reasonable to believe that the overall effect of non-standard monetary policies on bank profitability is neutral. On the one hand, quantitative easing depresses long-term interest rates and flattens the yield curve, which may reduce bank earnings from maturity transformation activity. This clearly is a negative effect which may also damage bank profitability when deposit rates are close to the zero-lower bound, because depository institutions are reluctant to pass through negative rates to commercial deposits, another negative effect. On the other hand, quantitative easing measures may lower the cost of bank liabilities, not only increasing their net worth but also relaxing their financial constraints. This may generate capital gains because of the increased valuation of bonds in bank portfolios and may lower the cost of debt, both positive effects. Besides, unconventional monetary policies may enhance macroeconomic conditions, boosting the demand for credit and reducing the share of non-performing loans, a positive effect.

Notwithstanding these findings, I found a positive and statistically significant association (model 21B) between IMR and excess reserves. In fact, a one percent increase in excess reserves is associated with a 0.04 percent increase in IMR. Non-standard monetary policies such as quantitative easing flatten the yield curve, which compresses net interest margins. However, non-standard monetary policies mainly affect long-term interest rates, implying that the interest rates on loans decrease more than the interest rates on deposits. In fact, deposit rates may stay unchanged at the zero-lower bound. Because this result is counterintuitive, some robustness checks were performed.

The literature does not provide conclusive evidence about the effects of non-standard monetary policies and bank performance. Whilst Mamatzakis and Bermpei (2016) estimate that the Fed's unconventional monetary policies had a negative effect on US bank performance, Lambert and Ueda (2014) do not find such effects. In the Eurozone, no association has been found between monetary policy easing and lower bank profits (Altavilla et al., 2018). My results follow this trend.

Table 2.5: System GMM estimation

	ROA			PTOIR			IMR		
Model	19A	19B	19C	20A	20B	20C	21A	21B	21C
$Dep.var_{t-1}$	0.191*	0.195*	0.193**	0.346***	0.322***	0.348***	0.768***	0.751***	0.740***
	(0.100)	(0.104)	(0.093)	(0.127)	(0.125)	(0.131)	(0.118)	(0.132)	(0.122)
Eurosystem total assets	0.006			-0.267			0.037		
	(0.422)			(0.257)			(0.077)		
Excess reserves		0.000			-0.002			0.045***	
		(0.066)			(0.046)			(0.013)	
Slope of the yield curve			0.331			0.479			0.130
			(0.276)			(0.313)			(0.099)
Bank factors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Macro. cond.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
AR1 (p-value)	0.056	0.057	0.052	0.027	0.030	0.030	0.001	0.003	0.001
AR2 (p-value)	0.195	0.195	0.180	0.259	0.273	0.258	0.250	0.682	0.344
Hansen (p-val.)	0.608	0.510	0.475	0.296	0.589	0.296	0.412	0.273	0.375
Difference Hansen-test	0.734	0.434	0.491	0.946	0.999	0.845	0.664	0.732	0.723
Wald test	31.59***	41.68***	23.06***	37.77***	47.49***	43.78***	273.8***	248.5***	373.6***
Observations	742	742	742	742	742	742	742	742	742
Banks in the sample	54	54	54	54	54	54	54	54	54

Source: Author's elaboration. Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by depository institution (corrected by the finite sample correction proposed by Windmeijer (2005)). Constant included but not reported. Number of instruments: 56.

2.5.4 Robustness analysis

There may be several reasons to explain the previous findings. It may be an omitted-variable bias. In other words, the model is not properly controlling for bank-specific factors and macroeconomic conditions. A second reason may be that the non-conventional monetary policy measures deployed by the ECB affect each bank in a different way depending on their economies of scale or financial structure. The results could also be driven by the creation of new entities as a consequence of the restructuring process of the Spanish banking sector or by the creation of "new virtual entities". I will try to shed light to these issues in the present section, conducting some robustness checks. Finally, non-standard monetary policies may have both positive and negative effects, compensating each other. Trying to isolate this kind of effects may be quite complicated and it is beyond the scope of this paper.

New control variables

Trying to capture a possible omitted-variable bias, the system-GMM equation is re-estimated. To do this, I add some variables increasing the number of regressors. Firstly, Athanasoglu et al. (2008) and Trujillo-Ponce (2013) highlight that the relationship between size and profitability may be non-linear. Therefore, the natural logarithm of banks' total assets and their square (BS2) is used to control for this fact. On the other hand, the Great Recession was followed by far-reaching normative and policy changes specifically targeting the banking sector, both internationally and at the national level. At international level, for example, the capital conservation buffer is applied from January 1, 2015, in Spain. The range goes from 0 per cent in 1999-2015, to 0.625 percent in 2016 and 1.25 percent in 2017. At national level, the Spanish saving banks were bailed out in 2012. This bailout was accompanied by a Memorandum of Understanding (MoU), which led to more significant provisioning by Spanish banks, a new reform of the saving banks, higher solvency requirements, and the creation of a "bad bank" (the SAREB) (Maudos and Vives, 2016). This will be captured by a dummy variable.

Table 2.6 reports the empirical estimations using the system-GMM estimator. As in the previous section, all post-estimation diagnostic tests (AR(2) test, Hansen test and difference Hansen-test) suggest that the instruments I am using are valid. In this new specification, some of the independent variables have not only the same sign but also the same statistical significance as in Table 2.5.

The coefficients of the non-standard monetary policies are not statistically significant when profitability is defined in terms of ROA and PTOIR. Nevertheless, there is a major change with respect to Table 2.5. When it is controlled for the square of the natural logarithm of banks' total assets and for regulation, there is not a statistically significant association (model 24B) between IMR and excess reserves. This result is in line with the outcomes of Altavilla et al. (2018).

As an additional robustness check, some institutional variables can be controlled for[14]. At firm level, management stability can be proxied by the change in the president of the bank. At national level, in order to control for institutional quality and good governance, two additional variables have been included: a political stability and absence of violence indicator and, a rule of law indicator. Table D1, in the appendix reports the results. They do not differ from those presented in Table 2.5.

Heterogeneous effects

The non-conventional monetary policy measures deployed by the ECB may affect each bank in a heterogeneous way depending on their economies of scale, financial structure, or funding. So as to deal with this, I will perform some regressions taking into account these characteristics.

First, banks will be classified into three different categories with respect to the level of total assets (bank size): depository institutions in the fourth quartile or "small banks" (4^{th}q.BS), banks in the third and the second quartile or "middle size banks" (med.BS), and banks in the first quartile or "big banks" (1^{st}q.BS). As an arbitrary measure to classify banks, the year 2015 will be used, a year in which the maximum number of banks are present in the sample. A dummy variable will

[14]I would like to thank the anonymous referee for this suggestion.

Table 2.6: System GMM with new regressors

	ROA			PTOIR			IMR		
Model	22A	22B	22C	23A	23B	23C	24A	24B	24C
Dep.var_{t-1}	0.202* (0.109)	0.196* (0.114)	0.203** (0.096)	0.345*** (0.123)	0.327*** (0.115)	0.350*** (0.122)	0.772*** (0.124)	0.771*** (0.125)	0.763*** (0.125)
Eurosystem total assets	-0.079 (0.348)			-0.491 (0.330)			-0.001 (0.129)		
Excess reserves		0.159 (0.288)			0.090 (0.214)			0.019 (0.086)	
Slope of the yield curve			0.312 (0.286)			0.488* (0.266)			0.089 (0.113)
Bank factors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Macro. cond.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
AR1 (p-value)	0.055	0.056	0.052	0.025	0.025	0.026	0.001	0.001	0.001
AR2 (p-value)	0.210	0.236	0.190	0.262	0.307	0.261	0.370	0.428	0.497
Hansen (p-val.)	0.862	0.825	0.938	0.708	0.856	0.756	0.764	0.691	0.744
Difference Hansen-test	0.988	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Wald test	50.82***	50.21***	36.30***	82.63***	108.3***	64.93***	550.5***	464.2***	498.7***
Observations	742	742	742	742	742	742	742	742	742
Banks in the sample	54	54	54	54	54	54	54	54	54

Source: Author's elaboration. Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by depository institution (corrected by the finite sample correction proposed by Windmeijer (2005)). Constant included but not reported. Number of instruments: 67.

be created for the small[15], the big banks group[16], and the middle size group.[17] Then, I will interact the non-standard monetary policy variables with the dummy variable of each group. Table 2.7 reports the empirical estimations (the square of the logarithm of total assets and financial regulation variables have not been included[18]). The post-estimation diagnostic tests suggest that the instruments employed are valid.

Some interesting facts arise. The coefficients of the interaction between non-standard monetary policies measured as Eurosystem total assets (ESTA) and all groups and bank profitability are not statistically significant. This implies that no association has been found when non-standard monetary policies are captured by the Eurosystem total assets. In the same way, when they are captured by the slope of the yield curve (SYC), no effect is found with respect to ROA and IMR. On the

[15]The "small banks" group is composed by the following 13 banks: A&G Banca Privada, AndBank España, BNP Paribas España, Banco Alcalá, Banco Europeo de Finanzas, Banco Finantia Sofinloc, Banco Pichincha España, Banco de Depósitos, Banco de la Nacion Argentina, Bank Degroof Petercam Spain, Banque Marocaine du commerce exterieur international, Citibank España and Self Trade Bank.

[16]The "big banks" group is composed by the following 14 banks: Abanca, BBVA, Banco Cooperativo Español, Banco Popular Español, Banco Santander, Banco de Sabadell, Bankia, Bankinter, Caixabank, Ibercaja, Liberbank, Santander Consumer Finance and Unicaja.

[17]The "middle size banks" group is composed by the rest of the depository institutions.

[18]If they are included, all variables of interest are not statistically significant, confirming the main results.

Table 2.7: System GMM estimation based on total assets classification

	ROA			PTOIR			IMR		
Model	25A	25B	25C	26A	26B	26C	27A	27B	27C
$Dep.var_{t-1}$	0.233**	0.199*	0.196**	0.369***	0.348***	0.333***	0.793***	0.796***	0.740***
	(0.106)	(0.105)	(0.096)	(0.117)	(0.124)	(0.119)	(0.097)	(0.123)	(0.121)
ESTA $\times$ 4^{th}q.BS	-0.149			-0.279			0.054		
	(0.280)			(0.238)			(0.112)		
ESTA $\times$ med.BS	-0.269			-0.402			0.019		
	(0.323)			(0.264)			(0.143)		
ESTA $\times$ 1^{st}q.BS	-0.351			-0.435			0.032		
	(0.418)			(0.340)			(0.191)		
EERR $\times$ 4^{th}q.BS		0.004			-0.023			0.039*	
		(0.073)			(0.053)			(0.024)	
EERR $\times$ med.BS		0.003			0.005			0.028*	
		(0.076)			(0.068)			(0.017)	
EERR $\times$ 1^{st}q.BS		-0.075			-0.022			0.053*	
		(0.104)			(0.115)			(0.031)	
SYC $\times$ 4^{st}q.BS			0.730			0.642			0.197
			(0.478)			(0.430)			(0.192)
SYC $\times$ med.BS			0.314			0.531**			0.146
			(0.269)			(0.270)			(0.177)
SYC $\times$ 1^{st}q.BS			0.238			0.407*			0.095
			(0.245)			(0.238)			(0.108)
Bank factors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Macro. cond.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
AR1 (p-value)	0.050	0.053	0.052	0.025	0.023	0.027	0.001	0.001	0.001
AR2 (p-value)	0.165	0.184	0.170	0.245	0.259	0.262	0.380	0.601	0.429
Hansen (p-val.)	0.926	0.892	0.943	0.815	0.697	0.756	0.773	0.755	0.643
Difference Hansen-test	0.998	1.000	1.000	1.000	1.0000	1.000	1.000	1.000	0.934
Wald test	46.80***	41.88***	31.18***	40.00***	72.04***	55.07***	448.6***	314.1***	293.4***
Observations	742	742	742	742	742	742	742	742	742
Banks in the sample	54	54	54	54	54	54	54	54	54

Source: Author's elaboration. Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by depository institution (corrected by the finite sample correction proposed by Windmeijer (2005)). Constant included but not reported. Number of instruments: 66.

contrary, non-standard monetary policies proxied by the excess reserves seems to affect negatively at 10 percent significance level bank profitability captured through IMR. Nonetheless, it is not enough evidence to claim that there is any effect. Hence, I should rule out that the previous findings are driven by the chosen year to classify depository institutions. Therefore, I re-estimate the baseline equation taking into account the quartile distribution in 2014 and 2016. Although some banks move from one group to another, the results presented in Table 2.7 are completely robust: no evidence is found about the relationship between non-standard monetary policies and Spanish banking sector profitability when it is captured through ROA or PTOIR. Results concerning interest margin are also robust.[19]

[19] Results are available upon request.

In Spain, a huge number of households and companies meet their financing needs through direct bank intermediation. Therefore, loans tend to be an important part of the assets of Spanish banks and a remarkable source of revenues (Maudos and Vives, 2016). Depository institutions will be classified into the same categories as before but depending on the level of their loan to total assets ratio (LTA): depository institutions in the fourth quartile or "low level of loans to total assets group" (4^{th}q.LTA), banks in the third and the second quartile (med.LTA), and banks in the first quartile or "high level of loans to total assets group" (1^{st}q.LTA). The year 2015 is taken to classify banks. A dummy variable will be created for the low level of loans to total assets group[20], for the high level of loans to total assets group[21] and the remaining depository institutions belong to the middle level of loans to total assets group.

Table 2.8 reports the empirical estimations. In models 28A, 28C, 29A, 29B, 30A and 30C, no evidence is found of heterogeneous effects of non-standard monetary policies on bank profitability as a function of loan to total assets ratio. Instead, the coefficient of non-standard monetary policies captured through excess reserves and the IMR of depository institutions in the second and third and the first quartile is positive and statistically significant at 10 and 1 percent respectively. The coefficient of unconventional monetary policies captured through the slope of the yield curve and PTOIR of depository institutions in the fourth, and second and third quartiles is positive and statistically significant at 10 and 5 percent respectively. This is not enough evidence to claim that there is a strong relationship between non-standard monetary policies and bank profitability of the Spanish banking sector. Once I re-estimate the baseline equation to discard that results are driven by the chosen year, the outcomes remain without changes.[22]

Third, the funding structure of Spanish banks can be a relevant determinant. Demirgüç-Kunt and Huizinga (2010) argue that those depository institutions which rely more on short-term funding -deposits- tend to suffer less from the risks derived from liquidity problems. Hence, depository institutions will be classified into the same categories as before but depending on the level of their deposits to total assets ratio (DTA). The year 2015 is taken to classify banks. A dummy variable will be created for the low level of deposits to total assets group

[20] The low level of loans to total assets group is composed by the following 13 banks: Allfunds Bank, Banco Cooperativo Español, Banco Europeo de Finanzas, Banco Finantia Sofinloc, Banco Mediolanum, Banco de Crédito Social Cooperativo, Banco de la Nación Argentina, Citibank, EBN Banco de Negocios, Open Bank, Popular Banca Privada, Santander Securities Services and Self Trade Bank.

[21] The high level of loans to total assets group is composed by the following 13 banks: A&G Banca Privada, BNP Paribas, Banco Cetelem, Banco de Sabadell, Bancofar, Bankinter, Bankia, Caixabank, Deutsche Bank, Kutxabank, Nuevo Micro Bank, Gargobank and The Bank of Tokyo Mitsubushi UFJ.

[22] Results are available upon request.

Table 2.8: System GMM estimation based on loan to total assets classification

	ROA			PTOIR			IMR		
Model	28A	28B	28C	29A	29B	29C	30A	30B	30C
Dep.var_{t-1}	0.181**	0.164	0.188*	0.319***	0.320***	0.336***	0.743***	0.756***	0.721***
	(0.092)	(0.109)	(0.098)	(0.106)	(0.121)	(0.123)	(0.114)	(0.133)	(0.125)
ESTA × 4^{th}q.LTA	0.091			-0.137			0.082		
	(0.444)			(0.262)			(0.085)		
ESTA × med.LTA	-0.018			-0.205			0.055		
	(0.444)			(0.250)			(0.085)		
ESTA × 1^{st}q.LTA	-0.056			-0.248			0.050		
		(0.457)			(0.256)			(0.082)	
EERR × 4^{th}q.LTA		0.145			0.134			0.062*	
		(0.116)			(0.099)			(0.028)	
EERR × med.LTA		0.017			0.023			0.043***	
		(0.069)			(0.055)			(0.016)	
EERR × 1^{st}q.LTA		-			-0.073			0.021	
		0.091*							
		(0.053)			(0.046)			(0.019)	
SYC × 4^{st}q.LTA			1.178			1.046*			0.259
			(0.634)			(0.480)			(0.172)
SYC × med.LTA			0.284			0.471**			0.097
			(0.287)			(0.232)			(0.141)
SYC × 1^{st}q.LTA			0.274			0.160			0.127
			(0.373)			(0.290)			(0.133)
Bank factors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Macro. cond.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
AR1 (p-value)	0.062	0.066	0.059	0.031	0.032	0.035	0.002	0.004	0.002
AR2 (p-value)	0.207	0.229	0.205	0.244	0.260	0.278	0.492	0.702	0.530
Hansen (p-val.)	0.938	0.946	0.854	0.876	0.823	0.676	0.751	0.731	0.676
Difference Hansen-test	1.000	1.000	0.970	1.000	1.000	0.999	0.999	0.997	0.998
Wald test	34.88***	40.88***	39.07***	78.97***	90.24***	44.08***	310.3***	460.2***	392.9***
Observations	742	742	742	742	742	742	742	742	742
Banks in the sample	54	54	54	54	54	54	54	54	54

Source: Author's elaboration. Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by depository institution (corrected by the finite sample correction proposed by Windmeijer (2005)). Constant included but not reported. Number of instruments: 66.

(4^{th}q.DTA)[23], for the high level of deposits to total assets group (1^{st}q.DTA)[24], and for the medium level (med.DTA).[25]

Table 2.9 shows the results. Non-standard monetary policies captured through

[23]The low level of deposits to total assets group is composed by the following 13 banks: Allfunds Bank, Aresbank, Banco Cetelem, Banco Europeo de Finanzas, Banco de Crédito Social Cooperativo, Banco de la Nación Argentina, Banque Marocaine du commerce exterieur international, Citibank España, EBN Banco de Negocios, JP Morgan Chase Bank National Association, Nuevo Micro Bank, Santander Consumer Finance and The Bank of Tokyo Mitsubushi UFJ LTD.

[24]The high level of deposits to total assets group is composed by the following 14 banks: Banca March, Banca Pueyo, Banco Inversis, Banco Mediolanum, Banco Pastor, Banco Pichincha España, Bankia, Liberbank, Open Bank, Popular Banca Privada, Santander Securities Services, Self Trade Bank, Targobank and Unicaja.

[25]The medium level of deposits to total assets group is composed by the rest of the depository institutions.

the Eurosystem total assets do not seem to affect any of the bank profitability measures. When non-standard monetary policy measures are proxied by excess reserves, a 5 percent statistically significance association is found between them and IMR for those banks which belong to the medium level of deposits to total assets (second and third quartile) group. When they are proxied by the slope of the yield curve, a 10 percent statistically significance association is found between them and ROA and PTOIR for the fourth quartile group of banks. Nevertheless, these relationships vanish if the chosen year changes.[26] Therefore, none of the standard monetary policy measures are statistically significant.

Table 2.9: System GMM Estimation based on deposits to total assets classification

	ROA			**PTOIR**			**IMR**		
Model	31A	31B	31C	32A	32B	32C	33A	33B	33C
Dep.var_{t-1}	0.207**	0.194**	0.196**	0.331***	0.311**	0.307**	0.757***	0.755***	0.735***
	(0.091)	(0.097)	(0.093)	(0.127)	(0.123)	(0.121)	(0.110)	(0.128)	(0.109)
$\text{ESTA} \times 4^{th}$q.DTA	0.057			-0.052			-0.053		
	(0.179)			(0.112)			(0.040)		
$\text{ESTA} \times$ med.DTA	-0.062			-0.127			-0.068		
	(0.194)			(0.106)			(0.041)		
$\text{ESTA} \times 1^{st}$q.DTA	-0.076			-0.126			-0.068		
	(0.180)			(0.098)			(0.044)		
$\text{EERR} \times 4^{th}$q.DTA		0.132			0.104			0.039	
		(0.108)			(0.083)			(0.027)	
$\text{EERR} \times$ med.DTA		-0.055			-0.053			0.041**	
		(0.061)			(0.051)			(0.018)	
$\text{EERR} \times 1^{st}$q.DTA		-0.038			-0.033			0.030	
		(0.067)			(0.056)			(0.020)	
$\text{SYC} \times 4^{st}$q.DTA			0.850*			0.820*			0.295**
			(0.458)			(0.420)			(0.141)
$\text{SYC} \times$ med.DTA			-0.020			0.141			0.138
			(0.239)			(0.239)			(0.114)
$\text{SYC} \times 1^{st}$q.DTA			0.289			0.497*			0.016
			(0.289)			(0.293)			(0.143)
Bank factors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Macro. cond.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
AR1 (p-value)	0.048	0.051	0.045	0.029	0.033	0.029	0.001	0.002	0.001
AR2 (p-value)	0.163	0.181	0.160	0.251	0.267	0.284	0.283	0.554	0.303
Hansen (p-val.)	0.948	0.773	0.931	0.758	0.873	0.768	0.695	0.641	0.811
Difference Hansen-test	1.000	0.991	1.000	1.000	1.000	1.000	0.922	0.996	1.000
Wald test	58.47***	50.21***	44.16***	66.89***	201.9***	69.81***	293.7***	312.6***	417.3***
Observations	742	742	742	742	742	742	742	742	742
Banks in the sample	54	54	54	54	54	54	54	54	54

Source: Author's elaboration. Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by depository institution (corrected by the finite sample correction proposed by Windmeijer (2005)). Constant included but not reported. Number of instruments: 66.

[26]Results available upon request.

Without new entities

In order to avoid that the results are driven by the creation of new entities as a consequence of the restructuring process of the Spanish banking sector, I exclude the following banks from the sample: Abanca (2011), Banco de Crédito Social Cooperativo (2014), Bankia (2011), Caixabank (2010), Ibercaja (2011), Kutxabank (2012), Liberbank (2011), Unicaja (2011). All of the previous banks were created merging savings banks in different regions of the Spanish geography. Table 2.10 reports the empirical estimations for this new sample using the system-GMM estimator. The main results do not differ from those reported in Table 2.5. The first lag of all profitability variables is statistically significant and non-standard monetary policies do not seem to have any effect on bank profitability when it is proxied by ROA, PTOIR or the interest margin.

Table 2.10: Excluding new entities. System GMM estimation

	ROA			PTOIR			IMR		
Model	34A	34B	34C	35A	35B	35C	36A	36B	36C
BP_{t-1}	0.210**	0.211*	0.211*	0.397***	0.412***	0.403***	0.780***	0.793***	0.775***
	(0.107)	(0.111)	(0.115)	(0.124)	(0.131)	(0.120)	(0.120)	(0.110)	(0.113)
Eurosystem Total Assets	0.106			-0.184			-0.067		
	(0.404)			(0.241)			(0.112)		
Excess Reserves		0.258			0.239			0.011	
		(0.324)			(0.254)			(0.099)	
Slope of the yield curve			0.067			0.200			0.115
			(0.269)			(0.208)			(0.121)
Bank factors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Macro. cond.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
AR1 (p-value)	0.076	0.077	0.076	0.058	0.055	0.056	0.001	0.001	0.001
AR2 (p-value)	0.203	0.214	0.209	0.194	0.205	0.193	0.186	0.184	0.189
Hansen (p-val.)	0.961	0.952	0.991	0.897	0.918	0.805	0.893	0.857	0.925
Difference Hansen-test	0.998	0.993	1.000	1.000	1.000	1.000	0.909	0.947	0.999
Wald test	48.15***	60.48***	60.67***	116.7***	119.3***	103.3***	426.5***	380.3***	343.2***
Observations	659	659	659	659	659	659	659	659	659
Banks in the sample	46	46	46	46	46	46	46	46	46

Source: Author's elaboration. Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by depository institution (corrected by the finite sample correction proposed by Windmeijer (2005). Constant included but not reported. Number of instruments: 56.

Finally, a two-stage panel least square instrumental variable approach is employed. The main results are robust to this specification (see Appendix E).

2.6 Conclusion

The traditional financial intermediation model predominates in Spain. This feature makes the Spanish banking sector, along with the rest of the Euro area banking system, cornerstones of the Eurosystem monetary policy. However, although the financial crisis eroded Spanish bank profitability, it has not recovered, on average, since then. Financial institutions attribute this to negative effects that some non-standard monetary policies may have on their profits. A sound banking sector is crucial for a developed economy. In fact, effective financial intermediation and sound financial institutions are clearly linked to a healthy economy (Camdessus, 1997). Hence, this paper empirically investigates whether the non-standard monetary policy measures implemented by the Eurosystem have affected the profitability of the Spanish banking sector. Understanding these effects, especially their potential negative impact, has important policy implications.

Controlling for bank-specific factors and macroeconomic conditions, no effect of non-standard monetary policy measures on bank profitability is found through Eurosystem total assets, excess reserves, or the yield curve slope. This can be explained by the different positive and negative impacts of non-standard monetary policies on bank profitability. Quantitative easing measures lower the cost of bank liabilities, not only increasing their net worth but also relaxing their financial constraints. In addition, capital gains may be generated by the increased valuation of bonds in bank portfolios, which may lower the cost of debt and improve the macroeconomic outlook, which may boost the demand for credit and reduce non-performing loans and loan loss provisioning (positive effects). Nonetheless, quantitative easing depresses long-term interest rates and flattens the yield curve, reducing bank earnings from maturity transformation activity. It can also damage bank profitability when deposit rates are near the zero-lower bound, because financial institutions may be reluctant to pass through negative rates to commercial deposits, at least in Spain. The neutral result is robust to different specifications and robustness checks and is in line with the results of Altavilla et al. (2018).

The literature has established three different channels through which non-standard monetary policies might have an impact on the banking sector: the portfolio rebalancing channel, the liquidity channel, and the signalling channel. It is likely that some effects just offset each other. Disentangling these effects is an avenue for further research.

2.7 Appendix

This appendix provides additional tables and figures that are also discussed in the paper.

Appendix A. Data cleaning

In this section I will explain how the database has been built. Two main statistical sources have been employed: the Spanish Banking Association and the Spanish Stock Market Commission (CNMV). From the Spanish Banking Association I have gathered annual data from the Spanish Banking Industry Statistical Yearbook (SBISY) for a period that goes from 1999 to 2017. Since the SBISY does not include those new entities created after 2010, data from the CNMV is employed. This data is collected from the audits of each bank that were presented to the CNMV each year. An important feature of this data is that it is presented in both consolidated and non-consolidated data. Given that some Spanish depository institutions are major global firms (e.g. Banco Santander or BBVA) and they are therefore exposed to different markets, non-consolidated data is preferred.

The economic and financial crisis led to a massive restructuring process of the Spanish banking sector. Some saving banks in trouble were merged to each other in order to create new entities (e.g. Bankia (merging Caja Madrid, Bancaja, Caja de Canarias, Caja de Ávila, Caixa Laietana, Caja Segovia and Caja Rioja), Abanca (merging Caixa Galicia and Caixanova), Liberbank (merging Cajastur, Caja de Extremadura, Caja de Castilla-La Mancha and Caja de Cantabria), Kutxabank (Bilbao Bizkaia Kutxa, Caja Vital and Kutxa).). The rest were absorbed by the main Spanish commercial banks (Banco Santander, Banco Popular, BBVA and Banco Sabadell). Hence, new "virtual-entities" have been constructed adding balance sheets over the 1999-2017 period in order to control for mergers and acquisitions. Tables A1 and A2 shows this process in detail. All banks which declared bankruptcy before 2017 have been removed from the sample.

Table A1: Mergers and acquisitions

Main bank	**Absorbed/acquired bank**	**Year**
Banco Santander	Banco de Desarrollo Económico Español	2003
	Banco de Vitoria	2004
	Banco Banif	2013
	Banco Español de Crédito (BANESTO)	2013
Banco Popular	Banco de Castilla	2008
	Banco de Crédito Balear	2008
	Banco de Galicia	2008
	Banco de Vasconia	2008
	Banco de Andalucía	2009
BBVA	BBVA Privanzabanco	2003
	Banco de Crédito Local de España	2009
	Finanzia, Banco de Crédito	2011
	Unoe Bank S.A.	2016
	Banco Depositario BBVA	2016

Source: Spanish Banking Industry Statistical 2017 Yearbook.

Besides, I have had to keep track of all changes in bank names during the 1999-2017 period. Table A3 show the changes in bank names.

Table A2: Mergers and acquisitions (Continuation)

Main bank	**Absorbed/acquired bank**	**Year**
Banco Caixa Geral	Banco Extremadura	2001
	Banco Simeón	2002
Banco Inversis	Bancoval Securities Services	2017
Banco Sabadell	Soldbank	2001
	Banco Herrero	2002
	Activobank	2003
	Banco de Asturias	2003
	Banco Atlántico	2004
	Banco Urquijo	2006
	Banco CAM	2012*
Caixabank	Microbank de la Caixa	2011
	Banca Cívica	2012
	Banco de la Pequeña y la Mediana Empresa	2012
	Banco de Valencia	2013
	Barclays Bank	2015
Bankia	Caja Madrid	2010*
	Bancaja	2010*
	Caja de Canarias	2010*
	Caja de Ávila	2010*
	Caixa Laietana	2010*
	Caja Segovia	2010*
	Caja Rioja	2010*
Liberbank	Cajastur	2011*
	Caja de Extremadura	2011*
	Caja de Castilla-La Mancha	2011*
	Caja de Cantabria	2011*
Abanca	Caixa Galicia	2011*
	Caixanova	2011*
Kutxabank	Bilbao Bizkaia Kutxa	2011*
	Caja Vital	2011*
	Kutxa	2011*

Source: Spanish Banking Industry Statistical 2017 Yearbook. *Data retrieved from the Spanish Stock Market Commission.

Table A3: Changes in bank names

Current name	**Previous name**	**Year***
Allfunds Bank	Banco de Sevilla	2000
Aresbank	Banco Árabe Español	2008
Banco Caixa Geral	Banco Luso Español	2002
Banco Bilbao Vizcaya Argentaria (BBVA)	Banco Bilbao Vizcaya	2000
Banco Cetelem	Banco Fimestic	2002
Banco Finantia Sofinloc	Banco Esfinge	2002
Banco Inversis	Banco Inversis Net	2008
Banco Mediolanum	Banco de Finanzas e Inversiones (FIBANC)	2012
Banco Santander	Banco Santander Central Hispano	2007
Bank Degroof Petercam Spain	Privat Bank	2008
Credit Suisse AG	Credit Suisse	2009
EBN Banco de Negocios	Sociedad Española de la Banca de Negocios	2001
Open Bank	Patagon Internet Bank and Patagon Bank	2002 and 2005
Renta 4 Banco	Banco Alicantino de Comercio	2011
Santander Consumer Finance	HBF Banco Financiero	2002
Santander Securities Services S.A.U.	Banesto Banco de Emisiones and Santander Banco de Emisiones	2012 and 2013
Santander Investment	Santander Central Hispano Investment and Santander Investment Services	2004 and 2006
Targobank	Banco Popular Hipotecario	2011
Wizink Bank	Bancopopular-e	2016

Source: Spanish Banking Industry Statistical 2017 Yearbook. *Year the name was changed.

Appendix B. Descriptive statistics

Table B1 shows the correlation matrix among all both dependent and independent variables employed in the model.

Table B1: Correlation matrix

Var.	ROA	PTOIR	IMR	ESTA	EERR	SYC	BS	LTA	LD	DG	MP	RGDP	INF	VSPI	MRO
ROA	1.00														
PTOIR	0.86	1.00													
IMR	0.14	0.23	1.00												
ESTA	0.03	-0.03	-0.17	1.00											
EERR	0.02	-0.02	-0.12	0.82	1.00										
SYC	-0.04	-0.07	-0.03	0.41	0.50	1.00									
BS	-0.06	-0.07	-0.15	0.11	0.08	0.02	1.00								
LTA	-0.02	-0.01	0.33	-0.07	-0.09	-0.05	0.30	1.00							
LD	0.03	0.04	0.04	-0.05	-0.03	-0.02	-0.02	0.12	1.00						
DG	-0.00	-0.01	-0.01	0.00	-0.04	0.04	-0.01	-0.02	-0.01	1.00					
MPI	-0.02	-0.02	-0.10	0.02	0.03	-0.00	0.70	0.11	-0.03	0.02	1.00				
RGDP	0.03	0.07	-0.01	-0.37	-0.12	-0.69	-0.04	-0.01	0.03	-0.08	0.01	1.00			
INF	-0.05	-0.01	0.11	-0.55	-0.63	-0.51	-0.06	0.07	0.04	-0.03	-0.00	0.21	1.00		
VSPI	-0.10	-0.09	0.05	0.20	0.09	0.62	-0.01	0.00	0.03	0.07	-0.00	-0.64	-0.21	1.00	
MRO	-0.02	0.04	0.15	-0.74	-0.81	-0.73	-0.07	0.08	0.07	0.00	-0.00	0.30	0.76	-0.18	1.00

Source: Author's elaboration. Number of observations: 742. Variables → ROA: Return of assets, PTOIR: Pre-tax operating income ratio, IMR: Interest margin to total assets ratio, ESTA: Eurosystem total assets, EERR: Excess reserves, SYC: Slope of the yield curve, BS: Bank size, LTA: Loans to assets ratio, LD: Loans to deposits, DG: Deposits growth, MP: Market power index, RGDP: Real GDP growth, INF: Inflation, VSPI: Volatility of stock price index, MRO: ECB's Main refinancing operations rate.

Appendix C. Hausman specification test

So as to choose what model fits better with our data, I will apply the Hausman (1978) specification test. Under the null hypothesis, the Balestra-Nerlove estimator is consistent and efficient but even though the within-groups estimator is consistent, it is not efficient (Baltagi, 2008). Therefore, if I do not reject the null hypothesis, the random effects model will be chosen. On the other hand, under the alternative hypothesis, the Balestra-Nerlove estimator is inconsistent and the within-groups estimator is consistent so I will have to employ a fixed effects model. The Hausman (1978) test computes the difference between the two estimators, weighted by the inverse of the differences of the variance-covariance matrices of both estimators. It seems remarkable that the variance-covariance matrices of both estimators should be positive definite.

As the difference between the variance-covariance matrix of both estimators is not positive definite in all cases, I will base both variance-covariance matrices on disturbance variance estimate from the Balestra-Nerlove (efficient) estimator.

Table C1 shows the results of the Hausman (1978) test for the static model with all bank-specific variables and macroeconomic conditions. The fixed effect (within-groups) estimator should be used in all models.

Table C1: Hausman specification test

	ROA			PTOIR			IMR		
Model	3A	3B	3C	6A	6B	6C	9A	9B	9C
$\chi^2(8)$*	37.57	37.55	40.52	47.27	43.01	49.84	15.94	17.18	15.41
Prob > χ^2	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.03	0.05

Source: Author's elaboration. *Degrees of freedom.

Table C2 shows the results of the Hausman (1978) test for the dynamic model. Again, the fixed effect (within-groups) estimator should be used in all models.

Table C2: Hausman specification test

	ROA			PTOIR			IMR		
Model	12A	12B	12C	15A	15B	15C	18A	18B	18C
$\chi^2(9)$*	83.88	83.33	84.15	96.59	93.82	97.34	207.38	202.44	208.95
Prob > χ^2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: Author's elaboration. *Degrees of freedom.

Appendix D. Additional regressions

Table D1 reports the regressions of estimating equation 2.2 including not only the new regressors incorporated in Table 2.6 (the square of the natural logarithm of banks' total assets, the capital conservation buffer and the banking reform) but also three institutional variables. At firm level, management stability has been included. It captures whether the president of the bank has changed or not in a given year. This data has been obtained from the Spanish Banking Association.

At national level, to control for institutional quality and good governance, a political stability and absence of violence indicator and, a rule of law indicator have been incorporated. According to Kaufmann et al. (2009), the political stability and absence of violence variable measures "perceptions of the likelihood of political instability and/or politically-motivated violence, including terrorism". The rule of law indicator reflects "perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence". Both variables have been retrieved from the Worldwide Governance Indicators of the World Bank. The correlation between them is -0.12.

Results are completely robust to the inclusion of these institutional variables and do not differ from those presented in Table 2.5.

Table D1: System GMM with institutional variables

	ROA			PTOIR			IMR		
Model	A1A	A1B	A1C	A2A	A2B	A2C	A3A	A3B	A3C
Dep.var_{t-1}	0.254**	0.244**	0.239**	0.337***	0.323**	0.312**	0.688***	0.699***	0.696***
	(0.109)	(0.099)	(0.100)	(0.129)	(0.136)	(0.131)	(0.129)	(0.133)	(0.125)
Eurosystem total assets	-0.079			-0.286			0.110		
	(0.309)			(0.298)			(0.110)		
Excess reserves		0.332			0.243			-0.005	
		(0.283)			(0.255)			(0.083)	
Slope of the yield curve			0.054			0.156			-0.066
			(0.244)			(0.222)			(0.121)
Bank factors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Macro. cond.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
AR1 (p-value)	0.053	0.053	0.055	0.037	0.048	0.050	0.001	0.002	0.001
AR2 (p-value)	0.184	0.199	0.188	0.328	0.400	0.342	0.706	0.703	0.869
Hansen (p-val.)	0.992	0.997	0.994	0.979	0.979	0.978	0.998	0.997	0.996
Difference Hansen-test	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Wald test	44.26***	58.30***	54.39***	79.43***	71.05***	87.98***	684.1***	616.4***	570.8***
Observations	742	742	742	742	742	742	742	742	742
Banks in the sample	54	54	54	54	54	54	54	54	54

Source: Author's elaboration. Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by depository institution (corrected by the finite sample correction proposed by Windmeijer (2005)). Constant included but not reported. Number of instruments: 82.

Appendix E. Instrumental variable estimation

In this section, a two-stage least square instrumental variable approach is employed as a final robustness check.

The instrumental variable employed has been the consumer confidence indicator (CCI), computed by the OECD for Spain.[27] It provides an indicator of the expectations of consumption and savings of households. The connection between non-standard monetary policies and the consumer confidence indicator is straightforward. Central banks tend to start deploying measures when they observe a sign of economic weaknesses in order to stop a possible recession.

As Table E1 shows, the CCI satisfies all the tests performed when the "endogenous" regressor is the Eurosystem total assets and the slope of the yield curve. When the endogenous regressor is excess reserves, the Cragg-Donald Wald F statistic does not satisfy the 10% Stock-Yogo weak ID test critical value (which is 16.38). However, it does satisfy the 15% Stock-Yogo weak ID test critical value (8.96). On the other hand, the Kleibergen-Paap rk Wald F statistic is higher than all the Stock-Yogo weak ID critical values.

All in all, the 2SLS-IV approach confirms the main results of the paper. Non-

[27] The regression includes all variables presented in the robustness check (i.e., banks' total assets and their square, the capital conservation buffer, and the MoU indicator).

standard monetary policy measures during do not seem to affect Spanish banks' profitability.

Table E1: 2SLS-IV estimation

	ROA			PTOIR			IMR		
Model	A4A	A4B	A4C	A5A	A5B	A5C	A6A	A6B	A6C
Eurosystem total assets	0.529 (0.641)			-0.368 (0.447)			-0.880 (0.92)		
Excess reserves		1.49 (1.820)			-1.55 (1.336)			-2.35 (2.220)	
Slope of the yield curve			-0.494 (0.600)			0.344 (0.417)			0.817 (0.900)
Kleibergen-Paap rk LM statistic.	82.27***	19.22***	107.2***	81.52***	47.2***	106.44***	78.58***	18.4***	102.66***
Cragg-Donald Wald F statistic.	182.8***	13.39*	231.0***	183.9***	16.55*	231.61***	182.12***	12.92*	229.46***
Kleibergen-Paap rk Wald F statistic	248.6***	23.56***	361.8***	247.4***	18.5***	361.16***	238.66***	22.43***	348.82***
Observations	742	742	742	742	742	742	742	742	742
Banks in the sample	54	54	54	54	54	54	54	54	54

Source: Author's elaboration. Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by depository institution. The Cragg-Donald Wald F statistic and the Kleibergen-Paap rk Wald F statistic are compared in each case with the Stock-Yogo weak ID test critical values.

Chapter 3

Central Bank Digital Currencies and Financial Stability in a Modern Monetary System.*

Abstract

The aim of this study is to disentangle the effects of introducing an interest-bearing central bank digital currency (CBDC) for financial stability using a Diamond and Dybvig (1983) model in which (i) both CBDC and private bank deposits can be used in exchange and (ii) liquidity is created endogenously. Agents have direct access to a CBDC via deposits at the central bank. They use both sight deposits and CBDC deposits to buy goods and commercial banks borrow reserves to cover liquidity needs. The introduction of an interest-bearing CBDC has direct implications on the sight deposits rate and on the loan rate of banks. Besides, if the central bank aims at having a positive net worth and the absence of bank runs, a high supply of a CBDC is a necessary condition to achieve both objectives. If this is not provided, it will endanger financial stability.

JEL Classification: E42 E58 G21

Keywords: CBDC, banking sector, financial stability, bank runs

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"Today, probably more than at any other time in our history, innovation has the potential to profoundly alter banking activities. It is no longer just about transforming our payment systems, it is our very currency that is at stake" (Villeroy de Galhau, 2019, p.4).

3.1 Introduction

Traditional means of payment are progressively being replaced by retail payment innovations and electronic payment instruments. This fact combined with the fear of using cash because of the pandemic caused by the Coronavirus disease (COVID-19) (ECB, 2020), suggest an evolution toward a cashless society in payments.[1] As a response, central banks are carefully analysing the possibility of issuing digital forms of money for general use (Boar and Wehrli, 2021; Náñez Alonso et al., 2021), that is, central bank digital currencies (CBDCs). Their ever-mounting attention and the hope they become the means of payment of the future, have led to their interest skyrocketing among not only central bankers but also policymakers, lobbyists and financial services companies.

Although in early stages, many jurisdictions are already focusing on the possible CBDC design (Auer et al., 2020). The CBDC could be universally accessible - retail CBDC - or being restricted to a particular group or agents - wholesale CBDC.[2] It may bear interest - interest-bearing CBDC - or not, similar to cash or private cryptocurrencies. Besides, the monetary authority could put into practice caps to holdings of the digital currency to prevent undesirable consequences (BIS, 2018). Anonymity vis-à-vis the central bank is another feature. The CBDC may be token-based, in a similar way to private digital tokens, or account-based.[3,4]

The rise of CBDCs – with two countries and one monetary union that have already issued a public money in digital form[5] – demands a finicky investigation of its implications for monetary policy, financial stability and payment systems.[6]

[1] While cash is being substituted as a means of payment, the demand for banknotes has constantly increased. This is known as the *cash paradox* (Jiang and Shao, 2020).

[2] Auer and Böhme (2020) analyse some of the technical design choices for retail CBDCs and their possible trade-offs. For a detailed discussion regarding the differences between a wholesale CBDC and a retail CBDC, see Pfister (2019).

[3] The main difference between token and account-based CBDCs is that they have a dissimilar form of verification when they are exchanged (Kahn and Roberds, 2009).

[4] For a comparison of a CBDC with cash, reserves and private digital currencies, see Table A1 in Appendix A.

[5] In October 2020, the Central Bank of the Bahamas issued the first retail CBDC in the world, the Sand Dollar. That announcement was followed, in March 2021, by the Eastern Caribbean Central Bank (ECCB). The ECCB deployed its DCash, becoming the first monetary union in launching a CBDC project. Finally, Nigeria's CBDC, the eNaira, was issued in October 2021.

[6] CBDCs may also have an impact in other areas. Lagarde (2018) remarks that the growth of CBDCs can increase financial inclusion since they will reach people and enterprises in remote zones. In a similar line, Mancini-Griffoli et al. (2018) highlight that a CBDC could encourage financial inclusion and minimize some of the costs and risks associated to the payment system,

What impact will the introduction of a retail CBDC have in the financial system? Will an interest-bearing retail CBDC make digital bank runs more likely, destabilising the financial system? Is financial stability compatible with other objectives of the central bank? The goal of this chapter is to formally disentangle the effects of introducing an interest-bearing central bank-issued digital currency on financial stability and financial fragility in a modern monetary system.

I develop a tractable model based on the seminal paper of Diamond and Dybvig (1983) with nominal bank contracts (Skeie, 2008; Allen et al., 2014) and the features of a modern monetary system described in Rivero Leiva and Rodríguez Mendizábal (2019), in an environment where both public digital money and private bank deposits are used in exchange and money is created endogenously.[7] Entrepreneurs need to borrow money from commercial banks to pay their workers. Lending to them, commercial banks create inside money (deposits). When they receive their salary, workers save their money in sight deposits that will be remunerated at the end of the period. The following period, they have the chance to transfer money from their commercial bank account to the central bank, at a cost. As Meaning et al. (2018) underscore, commercial banks may react to the competition from central bank deposits by making it more costly to allocate funds out of the bank, that is, establishing or increasing fees. Households – formed by an entrepreneur and a worker – may use both commercial and central bank liabilities (deposits) as means of payment to buy goods and services. At the end of the final period, they must repay the loan to commercial banks.

Unlike the previous literature, one particular feature of the model is that there is no cash.[8] Therefore, a widely accessible CBDC that replaces cash is introduced into this economy. Contrary to the paper by Rivero Leiva and Rodríguez Mendizábal (2019), everyone can open an account at the central bank free of charge.[9] In addition, the central bank has the possibility of remunerating its deposits at a variable rate. Besides being a tool for improving the transmission of monetary policy – aspect beyond the scope of this paper – an interest-bearing CBDC can be used for financial stability reasons and to prevent the monetary authority becoming a significant financial middleman if the CBDC converts into a large-scale store of value. Niepelt (2020) adds that the introduction of a CBDC in combination with the refinancing operations rate may increase transparency, improving public scrutiny of central bank policies and reducing the influence of well-organised lobbies.

reduce informality, tax evasion and illegal activities (Rogoff, 2017) and create a more efficient electronic payment system (Marcel, 2019). There are also short-term economic gains derived from the creation of a public digital currency: fees from withdrawing money from the ATM or insurance, storage and transportation costs. Central banks could save printing and coining costs as well. Notwithstanding, apart from perks, concerns and costs may also arise. Marcel (2019) warns about the need to improve cybersecurity of central banks to prevent ciberattacks and potential frauds.

[7] Deleidi and Fontana (2019) have empirically proved the validity of the endogenous money theory in the Eurozone for the 1999–2016 period.

[8] Engert et al. (2018) find that the disruptions that could be associated to a cashless society are not important and will not cause material and system-wide problems.

[9] This may result in social savings if there are gains produced by economies of scale, as Eichengreen (2019) stresses.

My main results are as follows. First, the model allows us to scrutiny how issuing an interest-bearing CBDC affects the interest rates managed by commercial banks. It is shown that the interest rate of deposits offered by commercial banks will react directly depending on the CBDC interest rate. A higher CBDC interest rate set by the central bank will force commercial banks to improve the attractiveness of sight deposits through a higher interest rate.

In addition, the interest rate and the supply of a CBDC have an impact on the loan rate. Imposing a higher CBDC interest rate will force commercial banks to pay a higher interest rate on sight deposits. As the funding costs are going to increase, they will also have to impose a higher loan rate in order to be solvent in the last period. A higher supply of a CBDC will push the banks to establish a higher loan rate depending on the difference between both the refinancing interest rate of the central bank and the interest rate of the CBDC deposits.

Second, the model is also a useful framework to analyse the possibility of digital bank runs. Weidmann (2018, p.4) remarks: "in a digital bank run, all it takes is a few mouse clicks to transfer savings out of the private financial system and into a central bank account. Customers are less likely to think twice about doing that". A digital run may befall for two reasons: either because households have a strong preference for retail CBDC deposits or fear bank failure. Nevertheless, it may be the case households think that commercial banks will become insolvent. If that occurs, they will not be able to retrieve their funds. Trying to anticipate this situation, they will be part of a massive withdrawal of deposits from the commercial bank. In this paper, I prove that the central bank can prevent a coordinated digital bank run from occurring by imposing a not relatively high interest rate on the refinancing operations. In other words, the opportunity of a run only becomes visible at moderately high interest rates on the refinancing rate of the central bank. This reinforces the role of the central bank as lender of last resort with the aim of stopping a liquidity crisis from turning into a solvency crisis.

Third, I analyse under which conditions the central bank can guarantee financial stability and aiming at having seigniorage revenues. If the supply of a CBDC is high enough and the interest rate of the open market operations is higher than the interest rate of the CBDC deposits, the economy will be in a situation where financial stability and seigniorage revenues can coexist. Nevertheless, I prove that aiming at having seigniorage revenues, the issuance of a CBDC by the central bank imposes a lower bound. The substitution of sight deposits by CBDC deposits forces banks to charge a higher interest rate of loans to avoid being insolvent because of the increase of deposit funding.

In this paper, I abstract from many important issues. The central bank could implement other strategies to stop the possibility of a bank run. First, it can restrict the decline in bank deposits and lending by setting limits on individual CBDC holdings. Second, it can discourage - through fees or other instruments - convertibility from bank deposits to retail CBDC deposits. Both may be avenues for future research. In addition, the model is developed to allow for a representation of outside money in the form of a CBDC and inside money in the form of commercial bank deposits and loans. It can be extended by incorporating a private digital currency which competes with both sight and CBDC deposits.

This research is closely related to the very recent literature analysing the impact of issuing a retail CBDC in the banking system. Based on the "new monetarism" approach of Lagos and Wright (2005) and Rocheteau and Wright (2005), Chiu et al. (2019) assess the general equilibrium effects of introducing a CBDC and find that it cannot only improve bank intermediation efficiency but also increase lending – even if the usage of a CBDC is low. In an environment where both CBDC and private bank deposits can be employed in exchange, Keister and Sanches (2019) find that although CBDC promote efficiency in exchange and raises welfare, it may also crowd out bank deposits, lowering investment. Combining the overlapping generations (OLG) framework of Diamond (1965) and the banking models of Klein (1971) and Monti (1972), Andolfatto (2021) examines the consequences of introducing a CBDC on a monopolistic banking sector and interest rates. He underlines that the introduction of an interest-bearing CBDC increases financial inclusion and may affect the equilibrium interest rate on deposits, but not the interest rate on bank lending or the level of investment. Built in the standard neoclassical growth model, Piazzesi and Schneider (2020) show that the competition between private sight deposits and CBDC deposits will endanger the supply of deposits of commercial banks, which may provoke that credit lines become more expensive. Instead, using a new Keynesian dynamic stochastic general equilibrium (NK-DSGE) model, Gross and Schiller (2021) show that although a CDBC may crowd out bank deposits, this effect can be alleviated if the monetary authority tries to disincentive CBDC holdings or provides central bank funds.

This paper relates also to the strand of the literature that focuses on the effects in financial stability and financial fragility. Kim and Kwon (2019) base their analysis in the OLG framework of Champ et al. (1996) and find that the introduction of a public digital currency decreases private credit supply and increases the nominal interest rate, which may translate to a raise in the likelihood of bank-runs, undermining financial stability. Extending the bank run model of Gertler and Kiyotaki (2015), Bitter (2020) finds that while a CBDC decreases net worth in the banking industry in non-crisis times, it may lessen the risk of a bank run in turmoil periods. In a similar line – but employing a Diamond and Dybvig (1983) model – Fernández-Villaverde et al. (2021) show that although the central bank may dissuade digital bank runs, it can also jeopardize maturity transformation since it will arise as a deposit monopolist. In a different study, Fernández-Villaverde et al. (2020) present an impossibility result, also known as the CBDC trilemma. The central bank can only achieve at the same time two of the following objectives: efficiency, financial stability (i.e., absence of runs), and price stability. After studying how a CBDC would facilitate runs out of bank deposits into a CBDC in financial upheaval situations, Bindseil (2020) explores possible solutions to the problem. Böser and Gersbach (2020) add that central banks can use monetary policy with tight collateral requirements to prevent the possibility of bank runs. Nevertheless, after certain periods, such policy will make banking activities unviable. Finally, Berentsen and Schär (2018) argue that a retail CBDC will increase the stability of the financial system because it would have a disciplining effect on commercial banks. Despite the significant contribution of all these papers, the role that outside money plays is not the one it actually does in the current monetary system. Therefore, this paper is the first attempt to combine a realistic view of money creation with the issuance of a retail interest-bearing CBDC.

Policymakers and central bankers are in need of new insights about retail-issued CBDCs. A challenge that they have faced over these first years of researching about public digital currencies is finding a consensus of their theoretical effects. My findings not only provide new insights into the CBDC and financial stability literature. They also matter for the future design of a CBDC. In a landscape where cash is disappearing, and electronic payments are rising, central banks should be placed at the forefront of the digital transformation.

The paper is structured as follows. Section 2 describes the theoretical model and characterises the equilibrium with both valued sight and CBDC deposits. Section 3 presents under which conditions digital bank runs may happen and when financial stability and seigniorage revenues may coexist. Finally, section 4 concludes.

3.2 A model of banking with CBDC

The economy represents a geoid whose measure is assumed to be 1. In this geoid, there are three dates: period 0, 1 and 2. Locations are continuously distributed over the geoid and on each location there is a continuum of identical risk averse households and a continuum of banks, both with measure 1. Each household is composed by a worker and an entrepreneur. There is also a central bank, a centralized goods market and a centralized labour market.[10] Both workers and entrepreneurs can access the banking system without incurring in a cost. Doing so, the households can earn an interest rate i^s on sight deposits held in the bank (private bank deposits) and i^d on deposits held in the central bank (digital currency deposits).

3.2.1 Households

Households are composed of a worker and an entrepreneur. The household's objective is to choose a path for consumption to maximize the sum of utilities where $U(\cdot)$ is bounded, continuously differentiable, strictly increasing, strictly concave, satisfy Inada conditions, and have a coefficient of relative risk aversion

$$-c \cdot \frac{U''(c)}{U'(c)} > 1. \tag{3.1}$$

[10]Workers supply labour inelastically.

Households face uncertainty about future liquidity needs in period $t = 0$. With probability λ, household becomes impatient ($h = 1$) and prefers to consume in period $t = 1$, while with probability $(1 - \lambda)$ the household is impatient ($h = 2$) and consumes at $t = 2$. Households observe types at the beginning of period 1 (once the idiosyncratic liquidity shock is realised).

Entrepreneurs

Entrepreneurs hire labour at $t = 0$. This labour is can be used in two risk-free productive technologies: long and short. They employ a fraction α of labour in the short technology and the remaining $1 - \alpha$ in the long technology.

The long technology needs two periods to produce goods. At $t = 0$, the long productive technology starts producing. As a result, it gives $\rho_2 > 1$ units of the good at $t = 2$. If a fraction $y \in [0, 1]$ of the long productive technology is interrupted at $t = 1$, it will produce $\rho_1 \cdot y$ units of the good (with $0 \leq \rho_1 \leq 1$). The remaining fraction left until maturity of the production process will yield $\rho_2(1 - y)$ in period $t = 2$.

The short productive technology produces each period and gives 1 unit of the good as return. The goods produced are sold either at $t = 1$ or $t = 2$. At $t = 1$, if not consumed, the goods can be stored.

When workers are hired, at time $t = 0$, entrepreneurs lack the credibility to convince those workers they will get paid in that period. Besides, assume entrepreneurs cannot use the worker in their household and need to hire them from other households in a competitive labour market. Then, given that entrepreneurs enter in $t = 0$ with no resources, they need to borrow inside money from a bank located in the same location they live in.

Workers

At $t = 0$, each worker is endowed with a unit of time. They work for an entrepreneur who is not in their same household in exchange for an income W. This income is a wage received as a sight deposit. At $t = 1$, the deposit interest rate (i_1^s) is paid by the financial institution to the deposit account holder. Furthermore, they have the responsibility of buying consumption goods for the household at period 1 or 2, depending on whether the household is impatient or patient.

At $t = 1$, impatient households purchase goods transferring part of their liquid funds (sight deposits) to entrepreneurs of different households in exchange for goods produced. Hence, they are subject to a money in advance (MIA) constraint

$$P_1 \cdot c^1 \leq (1 + i_1^s) \cdot W, \tag{3.2}$$

with c^1 (c^2) the consumption of impatient (patient) agents, and P_1 (P_2) the nominal price of the consumption good in period 1 (period 2). After goods purchases, the household has to make a portfolio choice allocating the resources that are left plus the revenues from selling goods[11] at $t = 1$ into either public digital currency or sight deposits. Households face two different portfolio constraints depending on whether they are impatient or patient:

$$(1+\psi)\cdot D_2^1 + S_2^1 \leq (1+i_1^s)\cdot W - P_1\cdot c^1 + P_1\cdot q_1^1 \tag{3.3}$$

if the household is impatient and

$$(1+\psi)\cdot D_2^2 + S_2^2 \leq (1+i_1^s)\cdot W + P_1\cdot q_1^2 \tag{3.4}$$

if the household is patient. Variables q_1^1 and q_1^2 are the amount of goods sold by the entrepreneur of a household of type 1 and 2 respectively. D_2^1 (D_2^2) is the public digital currency holdings of impatient (patient) agents, and S_2^1 (S_2^2) is the sight deposits of impatient (patient) agents. Meaning et al. (2018) highlight that banks may respond to the competition from a CBDC by making it more costly to transfer funds out of the bank. This feature is captured in my model by the term ψ, which is a commission charged by the bank.

The amount of goods sold by the entrepreneur has to satisfy the following resource constraint:

$$q_1^1 \leq \alpha + \rho_1\cdot y^1 \tag{3.5}$$

if the household is impatient, and

$$q_1^2 \leq \alpha + \rho_1\cdot y^2 \tag{3.6}$$

if the household is patient. The production of impatient or patient households coming from the short productive technology (α) and the interrupted fraction of the long productive technology ($\rho_1\cdot y^h$) has to be equal or higher than the total amount of goods sold in the first period (q_1^h).[12]

At $t = 2$, since patient households are the only ones who consume goods, they face a MIA constraint of the form:

$$P_2\cdot c^2 \leq (1+i_2^d)\cdot D_2^2 + (1+i_2^s)\cdot S_2^2 + P_2\cdot(\alpha + \rho_1\cdot y^2 - q_1^2). \tag{3.7}$$

The left hand-side of equation (3.7) represents the value of the goods consumed. The right hand-side expresses the return on both sight and digital currency deposits and the goods stored in the previous period, that can be consumed today.

After goods are consumed, the household has to pay back the original loan taken by the entrepreneur and the interest rate associated to it (i^l). If the household is impatient, the total amount of available resources has to be equal or higher than the loan and its interest rate:

$$(1+i^l)\cdot W \leq (1+i_2^d)\cdot D_2^1 + (1+i_2^s)\cdot S_2^1 + P_2\cdot\left[(1-\alpha-y^1)\cdot\rho_2 + \alpha + \rho_1\cdot y^1 - q_1^1\right]. \tag{3.8}$$

[11] The revenues will come from the short technology and from the liquidation of the long technology.

[12] With $h = 1$ if the household is impatient and $h = 2$ if the household is patient.

The right hand-side of equation (3.8) encompasses the income from both the sight and digital currency deposits and the sale of the remaining produced goods. If the household is patient, its loan repayment equation takes the following form:

$$(1+i^l)\cdot W \leq (1+i_2^d)\cdot D_2^2 + (1+i_2^s)\cdot S_2^2 + P_2\cdot\Big[(1-\alpha-y^2)\cdot\rho_2+\alpha+\rho_1\cdot y^2 - q_1^2\Big] - P_2c^2. \quad (3.9)$$

3.2.2 Banks

The role of banks is needed to solve the commitment problem between entrepreneurs and workers (Rivero Leiva and Rodríguez Mendizábal, 2019). Banks located in the same location as entrepreneurs lend them inside money to pay their workers. Banks directly deposit the amount of inside money in the worker's account. The account is shared both by the worker and the entrepreneur who belong to the same household. This action produces a double entry in the balance sheet of the bank, allowing us to introduce endogenous liquidity creation as in reality. McLeay et al. (2014, p.14) highlight that "whenever a bank makes a loan, it simultaneously creates a matching deposit in the borrower's bank account, thereby creating new money". Most of money in reality is created by commercial banks making loans.

At $t = 1$, the bank has to demand reserves to avoid possible liquidity shortages that it may have. I assume that banks do not need collateral to borrow money from the monetary authority. The interest rate that the central bank charges for refinancing commercial banks is i^R. The main purpose of banks in this economy is to maximize their net worth at $t = 2$, being solvent at $t = 1$ (i.e. positive net worth). In the first period, the net worth of the commercial bank (NW_1^B) is equal to the assets it has, i.e. the amount of money lent to the entrepreneurs (W), minus their liabilities, which correspond to the deposits in the commercial bank (S_2^1) and the money that has been transferred to digital currency accounts at the central bank (D_2^1). In addition, the bank also charges a fee (ψ) from transferring the money to a non-commercial bank account. The equation of the net worth in the first period takes the following form:

$$NW_1^B = W - [\lambda(D_2^1 + S_2^1 - \psi D_2^1) + (1-\lambda)(D_2^2 + S_2^2 - \psi D_2^2)]. \quad (3.10)$$

In the second period, $t = 2$, banks receive the interest rate from the loan (asset side) and pay an interest rate on sight deposits to the household and an interest rate on the reserves borrowed to the central bank (liabilities). The rest of the liability part refers to the amount of goods sold by both types of households in the second period ($P_2[\lambda q_2^1 + (1-\lambda)q_2^2]$) minus the use of sight deposits for consumption by patient households ($(1-\lambda)P_2c^2$). Therefore, the net worth will be in the second period will be:

$$\begin{aligned} NW_2^B = (1+i^l)W - (1+i_2^s)[\lambda S_2^1 + (1-\lambda)S_2^2] + (1-\lambda)P_2c^2 \\ -P_2[\lambda q_2^1 + (1-\lambda)q_2^2] - (1+i^R)[\lambda D_2^1 + (1-\lambda)D_2^2]. \end{aligned} \quad (3.11)$$

I assume that there is perfect competition in the banking sector. Commercial banks will make decisions to maximize their net worth in the second period conditioned on the net worth in $t = 1$ being non-negative.

3.2.3 Central bank

In this economy, the central bank has three monetary policy instruments: the interest rate of the refinancing operations (i^R), the interest rate of the CBDC deposits (i^d) and the supply of CBDC deposits (D_2^h).[13] At the beginning of period $t = 0$, the central bank chooses both interest rates and the supply of CBDC conditioned on the monetary policy objectives it may have, that is, preserving financial stability and having non-negative net worth (non-negative seigniorage revenues).

In period $t = 1$, the net worth of the central bank is composed by the loans it has granted to the banks and the digital currency deposits it holds:

$$NW_1^{CB} = [\lambda D_2^1 + (1-\lambda)D_2^2] - \lambda D_2^1 - (1-\lambda)D_2^2 = 0. \tag{3.12}$$

In period $t = 2$, the central bank receives its income from the reserves lent to commercial banks and has to pay the CBDC remuneration:

$$\begin{aligned} NW_2^{CB} = (1+i^R)[\lambda D_2^1 + (1-\lambda)D_2^2] - (1+i_2^d)(1-\lambda)D_2^2 - (1+i_2^d)\lambda D_2^1 \\ = (i^R - i_2^d)[\lambda D_2^1 + (1-\lambda)D_2^2]. \end{aligned} \tag{3.13}$$

It is clear that the level of seigniorage revenues (i.e. $NW_2^{CB} > 0$) that the central bank will have depends on the difference between the refinancing rate (i^R) and the CBDC interest rate (i^d), as long as it has established a positive supply of the CBDC.

Figure 3.1 presents a simple illustration of the model and how all the agents interact among them.

3.2.4 CBDC, sight deposits and fiat reserves

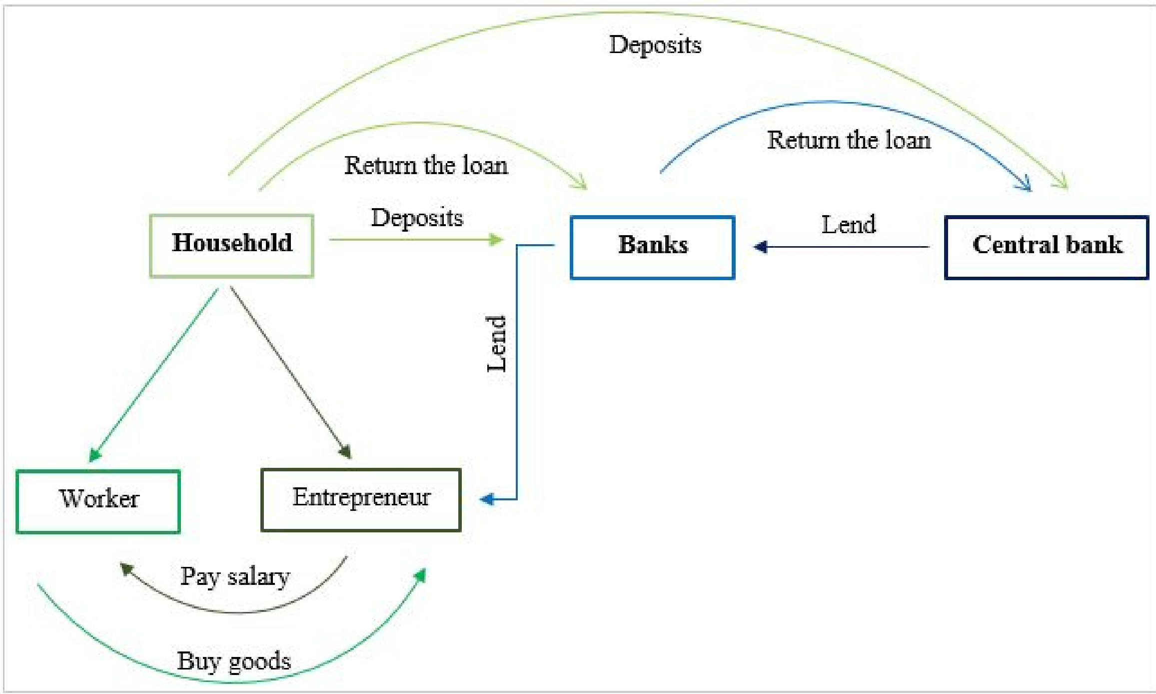
In this economy, cash has been completely replaced by a CBDC issued by the central bank. Thus, the CBDC is a direct claim on the monetary institution. The CBDC is a complete safe and liquid asset, universally accessible (retail CBDC), i.e. it can be held by all types of households without any restriction in an account at the central bank. It implies it can be held by households in unlimited quantities. As in reality, I assume the central bank cannot lend to households.

On the other hand, CBDC and sight deposits are used by households to acquire consumption goods. Both pay an interest rate in each period (i_2^d, i_1^s and i_2^s respectively). The demand of the public digital currency will depend on how desirable it is in comparison with other means of payment, i.e., private sight deposits.

Although both the CBDC and fiat reserves are liabilities to the central bank, they present some differences. First, the CBDC can be held by households in the

[13] There may be the case in which the supply of CBDC is completely elastic to the interest rate of CBDC deposits, i^d. This is not explored in this paper and leaves an avenue for further research.

Figure 3.1: Representation of the model



Source: Author's elaboration

form of accounts at the central bank and outside the banking system. On the contrary, reserves can only be held by banks. Second, the CBDC is used to make payments and offset liquidity risk in the household payment system and reserves are used to offset liquidity risk and service payment orders in the banking system. The supply for CBDC has implications on the demand for reserves because it forces banks to demand reserves when sight deposits are converted into a CBDC.

Table 3.1: Glosary

Variable	Description	Variable	Description
c	consumption	ρ	fraction of the production
y	long productive technology	q	amount of goods sold by the entrepreneur
s	sight deposits	d	CBDC deposits
i^d	CBDC interest rate	ψ	bank commission
i^s	sight deposits interest rate	i^l	loan interest rate
α	fraction of labour used at time $t = 0$ by the household in the short technology	λ	share of impatient agents

3.2.5 Household problem

Households choose consumption (c^h) in period $t = h$, with $h = 1$ for impatient households and $h = 2$ for patient households, liquidation of the long productive technology (y^h) and the portfolio allocation at $t = 1$, between digital currency holdings (D_2^h) and sight deposits holdings (S_2^h), to maximize her utility. As the problem is neutral with respect to the loan, W, everything is normalised by it. Hence, lower case letters of prices, digital currency holdings and sight deposit holdings imply that they have been divided by W.

Let $v^1(\alpha)$ be the maximum level of utility that the impatient household is going to obtain as a function of the technology portfolio, with α being a fraction of the hired labour in the short technology. The optimization problem is as follows:

$$v^1(\alpha) = \max\left\{U(c^1)\right\} \tag{3.14}$$

subject to the money in advance constraint:

$$p_1 \cdot c^1 \leq 1 + i_1^s; \ (\eta_1) \tag{3.15}$$

to the portfolio constraint:

$$d_2^1(1+\psi) + s_2^1 \leq 1 + i_1^s - p_1 \cdot c^1 + p_1 \cdot q_1^1; \ (\kappa_1) \tag{3.16}$$

to the resource constraints:

$$0 \leq q_1^1; \ (\tau_1) \tag{3.17}$$

$$q_1^1 \leq \alpha + \rho_1 \cdot y^1; \ (\varphi_1) \tag{3.18}$$

and to the loan repayment equation:

$$\begin{aligned} 1 + i^l \leq p_2 \cdot [(1 - \alpha - y^1)\rho_2 + \alpha + \rho_1 \cdot y^1 - q_1^1] \\ +(1 + i_2^d)d_2^1 + (1 + i_2^s) \cdot s_2^1; \ (\Xi_1). \end{aligned} \tag{3.19}$$

In parenthesis at the end of each equation is the corresponding Lagrange multiplier.

For the patient household, let $v^2(\alpha)$ be the maximum level of utility that the she is going to obtain as a function of the technology portfolio, with α being a fraction of the hired labour in the short technology. The optimization problem is as follows:

$$v^2(\alpha) = \max\left\{U(c^2)\right\} \tag{3.20}$$

subject to the portfolio constraint:

$$(1+\psi)d_2^2 + s_2^2 \leq 1 + i_1^s + p_1 \cdot q_1^2; \ (\kappa_2) \tag{3.21}$$

to the resource constraints:

$$0 \leq q_1^2; \ (\tau_2) \tag{3.22}$$

$$q_1^2 \leq \alpha + \rho_1 \cdot y^2; \ (\varphi_2) \tag{3.23}$$

to the money in advance constraint:

$$p_2 \cdot c^2 \leq (1 + i_2^d)d_2^2 + (1 + i_2^2)s_2^2 + p_2(\alpha + \rho_1 \cdot y^2 - q_1^2); \ (\eta_2) \tag{3.24}$$

and to the loan repayment equation:

$$1 + i^l \leq (1 + i_2^d)d_2^2 + (1 + i_2^2)s_2^2$$
$$+p_2(\alpha + \rho_1 \cdot y^2 - q_1^2) - p_2 c^2 + p_2(1 - \alpha - y^2)\rho_2; \ (\Xi_2). \tag{3.25}$$

The first order conditions and the household-labour-technology problem are characterised in Appendix B.

3.2.6 Equilibrium with valued both sight and CBDC deposits

Definition 1. An equilibrium is a collection of allocations $\{\alpha, y^h, c^h, q_1^h, s_2^h$ and $d_2^h\}$ for $h \in \{1, 2\}$ and prices $\{p_1, p_2, i_1^s, i_2^s,$ and $i^l\}$ such that:

1. given prices, allocations solve individual problems of both households and commercial banks, and,
2. prices are such that goods market clear for $t = 1$ and $t = 2$.

Let us characterise the equilibrium with both CBDC and sight deposits.

Definition 2. *An equilibrium with valued both sight deposits and central bank digital currency deposits is an equilibrium in which* $s_2^1 > 0$, $s_2^2 > 0$, $d_2^1 > 0$, $d_2^2 > 0$.

Proposition 1. *There exists a unique equilibrium with valued both sight deposits and central bank digital currency deposits in which*:

- *the equilibrium value of the consumption basket for impatient households is 1, i.e.,* $c^1 = 1$,
- *the equilibrium value of the consumption basket for patient households is* ρ_2*, i.e.,* $c^2 = \rho_2$,
- *production decisions satisfy:* $y^1 = y^2 = 0$, $\alpha = \lambda$,
- *the amount of goods sold by the entrepreneur satisfies:* $q_1^1 = q_1^2 = \alpha$, $q_2^1 = q_2^2 = (1 - \alpha)\rho_2$,
- *the price in period 1 is equal to:* $p_1 = 1 + 2\psi[\lambda d_2^1 + (1 - \lambda)d_2^2]$,
- and *interest rates are*:

$$i_1^s = 2\psi[\lambda d_2^1 + (1 - \lambda)d_2^2]; \tag{3.26}$$

$$(1 + \psi)(1 + i_2^s) = (1 + i_2^d) = \rho_2 \cdot \frac{p_2}{p_1}; \tag{3.27}$$

$$i^l = \left(i^R - \frac{(1 - \psi)i_2^d - 2\psi}{1 + \psi}\right)[\lambda d_2^1 + (1 - \lambda)d_2^2] + \frac{i_2^d - \psi}{1 + \psi}. \tag{3.28}$$

Proof. See Appendix C.

Discussion. The nominal interest rate for both CBDCs $(1 + i_2^d)$ and sight deposits $(1 + i_2^s)$, together with the interest rate of sight deposits in period 1 (i_1^s), the price level for the second period (p_2), and the interest rate of the loans (i^l), are not determined individually. The real variables are determined.

From the sight deposits-CBDC interest rate condition (equation (3.27)), it can be drawn that the relative attractiveness of central bank money relative to bank deposits will rest on the interest rate of both competing means of payment and the fee established by commercial banks. In equilibrium, households will be indifferent to hold commercial bank money or central bank money. Besides, if banks make free to transfer funds out of their institution ($\psi = 0$), in equilibrium, the interest rate of sight deposits and CBDCs deposits in the second period will be the same, i.e., neither sight deposits nor CBDC deposits will dominate in rate of return to each other.

The interest rate of sight deposits in the first period will depend on the commission and the amount of central bank digital currency supplied by the central bank. This has two main implications. First, as there is no aggregate uncertainty, i.e, banks behave under perfect foresight in aggregate, the bank will anticipate the revenues it will have in the first period as a consequence of the conversion of sight-deposits to a CBDC. The competition in the banking sector forces it to remunerate deposits in period $t = 1$. Again, if banks make free to transfer funds out of their institution (ψ =0), in equilibrium, the interest rate of sight deposits in period $t = 1$ will be zero. These levels ensure that the net worth of banks is zero in the first period. Second, the central bank may affect - through monetary policy, i.e. changes in the amount of the CBDC supplied - both interest rates and prices.

These interest rate levels ensure that the net worth of banks is zero in both the first and the second period. Thus, banks are solvent in the second period and no runs will happen. This means that maintaining sight deposits in commercial banks as well as CBDC deposits at the central bank is an equilibrium outcome.

Implications on the loan rate. Until now, I have characterised the equilibrium conditions with valued both sight and CBDC deposits. Let us determine how the interest rate on loans vary depending on the different monetary policy instruments (equation (3.28)):

- The higher the refinancing rate of the central bank is, the higher the lending rate in equilibrium will be. In particular:

$$\frac{\partial i^l}{\partial i^R} = (\lambda d_2^1 + (1 - \lambda) d_2^2) \geq 0 \tag{3.29}$$

  Higher refinancing rates imply an increase of the costs of commercial banks. To compensate this, they need to increase their revenues through a higher loan interest rate.

In addition, the impact of the interest rate of the refinancing operations will be even higher the higher the supply of the CBDC is. The mechanism is straightforward. A higher amount of CBDC deposits will imply that the commercial bank should refinance that amount, borrowing more reserves from the central bank. However, the interest rate i^R would have no effect if the central bank chooses to not supply CBDC.

- The impact of choosing a high CBDC interest rate on the loan rate will depend on the amount of the CBDC offered - weighted by their respective types of agents:

$$\frac{\partial i^l}{\partial i^d} = \frac{1}{1+\psi} - \frac{1-\psi}{1+\psi}(\lambda d_2^1 + (1-\lambda)d_2^2). \tag{3.30}$$

The only case where the derivative is zero happens when:

$$\lambda d_2^1 + (1-\lambda)d_2^2 = \frac{1}{1-\psi}.$$

In this economy, the amount of CBDC will always be lower than the threshold, $\frac{1}{1-\psi}$. Hence, an increase of the CBDC interest rate would make the commercial bank to increase the loan rate:

$$\frac{\partial i^l}{\partial i_2^d} > 0. \tag{3.31}$$

The intuition is as follows. Higher CBDC interest rates will increase the cost of deposit funding for commercial banks, which will directly lead to higher lending rates.

- The impact of choosing a high CBDC supply on the loan rate will depend on the difference between the refinancing rate of the central bank, the CBDC sight deposits interest rate and the fee:

$$\frac{\partial i^l}{\partial(\lambda d_2^1 + (1-\lambda)d_2^2)} = i^R - \frac{(1-\psi)i_2^d - 2\psi}{1+\psi}. \tag{3.32}$$

In the case where $\psi = 0$, if the refinancing rate is higher than the interest rate of the CBDC, a higher supply of a CBDC will be compensated with a higher loan interest rate. As the commercial bank will need to finance at a higher interest rate than the rate it had to pay to the sight deposits, it will need higher revenues from loans.

The central bank's policy through its digital currency has implications not only for prices in the economy but also for how expensive borrowing is.

3.3 Financial stability, digital bank runs and monetary policy with a CBDC

3.3.1 Digital bank run

It may be the case that households have concerns of the solvency of their bank. Both impatient and patient households need their funds at the financial institution to repay the loan in $t = 2$. If some customers of the banking system withdraw their funds of one bank or of a set of banks with mass zero, the probability of default by banks increases. I assume that in $t = 1$, some households decide to withdraw their sight deposits[14], that is, agents cause a coordinated digital bank run. This would occur immediately.

It will take for households a few seconds - through an electronic device - to transfer savings out of some commercial banks and into their central bank account. Since there is no cash in this economy, households can put their funds into a CBDC deposits at the central bank, goods stored or deposits in other commercial banks.

To make our analysis comparable to the one in Diamond and Dybvig (1983) and Rivero Leiva and Rodríguez Mendizábal (2019), I assume that the coordinated digital bank run happens when the liquidity preference shock has already been realised, at the beginning of period 1. This also means that the loan rate and the interest rate of the sight deposits in period $t = 1$ have already been established. However, households have not been able to purchase goods yet.

Proposition 2. *The possibility of a digital run will become reality if the following condition is fulfilled*:

$$i^R > i^l. \tag{3.33}$$

Proof. See the first part of Appendix D.

Discussion. A self-fulfilling digital bank run will occur in equilibrium if the refinancing rate established by the central bank is high enough. Households will evaluate this condition ex-ante and will run on their bank because that banks will not be solvent in the second period.

In times of economic turmoil, issuance of a retail CBDC could endanger financial stability by transferring funds from bank deposits to a CBDC deposits at the central bank. Conversely to condition (3.33), as long as the refinancing rate of the central bank is not really high (equation (3.33) is not satisfied), there will not be a digital bank run. That implies the following:

$$i^R \leq i^l.$$

[14] A bank run on a group of banks with positive mass or a systemic digital bank run are not evaluated in this paper.

As in equilibrium, $i^l = \left(i^R - \frac{(1-\psi)i_2^d - 2\psi}{1+\psi}\right)[\lambda d_2^1 + (1-\lambda)d_2^2] + \frac{i_2^d - \psi}{1+\psi}$, I use expression (3.33) to determine when a self-fulling digital bank will not be triggered.

In particular, a self-fulling digital bank run will not be triggered in equilibrium as long as[15]

$$i^R \leq \frac{i_2^d - \psi - ((1-\psi)i_2^d - 2\psi)[\lambda d_2^1 + (1-\lambda)d_2^2]}{(1+\psi)(1-\lambda d_2^1 - (1-\lambda)d_2^2)}. \tag{3.34}$$

3.3.2 Monetary policy

The issuance of a retail CBDC may have important monetary policy considerations. In particular, an interest-bearing CBDCs would give the monetary authority two additional instruments: the interest rate of the CBDC deposits (i^d) and the supply of CBDC deposits. Those instruments and the interest rate of the refinancing operations (i^R), are the central bank's tools for achieving its monetary policy objectives: financial stability and aiming non-negative net worth.[16]

However, for each i^R, i^d, and the supply of a CBDC, there will be an equilibrium where the net worth of both commercial banks and the central bank and the likelihood of a digital bank run will be different.

If the objective of the monetary policy of the central bank is to ensure that:

- the net worth of commercial banks is positive, i.e., $nw_2^B > 0$,
- the net worth of the central bank is positive, i.e., $nw_2^{CB} > 0$,
- and there is an absence of digital bank run, then,

it must be the case that the refinancing rate of the central bank is bounded. To avoid a digital bank run, that interest rate has an upper-bound (equation (3.34)). To avoid central bank losses, the refinancing rate has a lower-bound, that is:

$$i^R > i_2^d.$$

Thus, the refinancing rate of the central bank has both a lower and a upper bound:

$$i^R \in \left[i_2^d, \frac{i_2^d - \psi - ((1-\psi)i_2^d - 2\psi)[\lambda d_2^1 + (1-\lambda)d_2^2]}{(1+\psi)(1-\lambda d_2^1 - (1-\lambda)d_2^2)}\right]. \tag{3.35}$$

[15]See the second part of Appendix D.

[16]Note that under this framework, the central bank cannot perform its monetary policy aiming at improving the welfare of households. Monetary policy does not affect consumption levels, i.e., it is not possible to characterise the welfare-maximizing monetary policy with respect to consumption. Other papers have shown that a CBDC can impact consumption. For instance, Davoodalhosseini (2021) computes the benefits of a public digital currency to be around 0.16 percent of total consumption.

I have to determine under which conditions there is a range of values of the interest rate of a CBDC deposits and the CBDC supply that allow the net worth of the central bank and commercial banks to be positive and avoid a digital bank run. Thus, is must be the case that:

$$i_2^d < \frac{i_2^d - \psi - ((1-\psi)i_2^d - 2\psi)[\lambda d_2^1 + (1-\lambda)d_2^2]}{(1+\psi)(1-\lambda d_2^1 - (1-\lambda)d_2^2)}.$$

Proposition 3. *The central bank will achieve financial stability and will be solvent - i.e, will have seigniorage revenues, at the same time, for any reasonable value of i_2^d, where $i_2^d < i^R$, as long as*:

$$\lambda d_2^1 + (1-\lambda)d_2^2 > 0.5. \tag{3.36}$$

Proof. See Appendix E.

Notice this result is independent on the value of the fee established by commercial banks.

Discussion. Introducing an interest-bearing retail CBDC is often seen as an additional instrument of monetary policy. Nevertheless, issuing a CBDC imposes an additional constraint. This happens because the interest rate on the CBDC deposits cannot be independent from the refinancing rate. The connection between the two arises from the competition between means of payment, private deposits and CBDC by agents, together with the solvency bounds of commercial banks and the required seigniorage revenues of the central bank.

If the supply of a CBDC is high enough, the economy will be in a situation where financial stability and seigniorage revenues can coexist. Aiming at having a positive net worth, i.e., positive seigniorage revenues, the issuance of a CBDC by the central bank imposes an additional constraint. The lower bound of the refinancing interest rate has relevant implications for financial stability since the remuneration of central bank digital currency deposits has direct impact on the lending rate. Establishing a relatively high CBDC interest rate will force the central bank to set also a high refinancing rate if it aims at positive seigniorage revenues. As a result, there will be an upward pressure on the loan rate of commercial banks. At the same time, the opportunity of a coordinated digital bank run only becomes visible at moderately high interest rates on the CBDC deposits.

Financial stability and positive seigniorage revenues can coexist as long as the supply of the CBDC is large enough. In this economy, the higher the supply of the CBDC is, the higher the loan rate will be. Such supply affects the loan rate through two different channels. First, directly, depending on the difference between the refinancing rate of the central bank and the CBDC interest rate (equation 3.32). Second, indirectly, through the refinancing rate (equation 3.29). When the supply of the CBDC is higher than the deposits provided by commercial banks in the economy, that is, when $d_2^1 + (1-\lambda)d_2^2 > 0.5$, the loan interest rate will be higher than the refinancing rate of the central bank. Hence, a high supply of the CBDC does not endanger financial stability as long as the refinancing rate is not high enough. The substitution of sight deposits by CBDC deposits, however, will force banks to charge a higher interest rate of loans to avoid being insolvent.

However, if the monetary authority supplies an amount of CBDC:

$$\lambda d_2^1 + (1 - \lambda) d_2^2 < 0.5,$$

and the open market operations interest rate is higher than the CBDC interest rate (positive seigniorage revenues), in equilibrium, the lending rate established by commercial bank would be lower than the refinancing rate of the central bank. Therefore, a self-fulfilling digital bank run would be triggered.

If we are in a situation where $d_2^1 + (1 - \lambda) d_2^2 > 0.5$ but the interest rate of CBDC deposits is higher than the interest rate of the open market operations, the central bank will have losses, i,e., a negative net worth. But, the reader may be wondering whether there is a need of having seigniorage revenues. The objective of the central bank usually is far beyond being profitable. It is not a profit-maximising enterprise. In fact, having negative net wealth is not uncommon, specially in developing countries. For instance, Stella and Lonnberg (2008) show that at least 15 Latin American central banks had losses for five or more years between 1987 and 2005. As long as an automated and fully credible rule of re-capitalisation by the government of the monetary authority in case of negative worth is implemented (Bindseil et al., 2004), losses do not necessarily jeopardise the central banks' monetary policy targets. In this paper, both having monetary losses and preserving financial stability may coexist. However, in practice, central banks are more likely to report slightly positive profits than negative ones (Goncharov et al., 2020). Goncharov et al. (2020) highlight that the political environment - fear to operational independence - and behavioural and agency frictions are related to loss avoidance.

3.4 Conclusion

Innovation in the payments arena is rapidly evolving and modifying the current monetary landscape. This digital shift has reached central banks and monetary institutions resulting in a race to develop and issue a new form of digital money: a central bank digital currency. In this paper, I have offered an examination of the effects of introducing an interest-bearing central bank-issued digital currency on financial stability in a modern monetary system where both public digital money and private bank deposits can be used interchangeably. To do so, I employ a Diamond and Dybvig (1983) model with nominal bank contracts (Skeie, 2008; Allen et al., 2014) and the features of a modern monetary system (McLeay et al., 2014; Rivero Leiva and Rodríguez Mendizábal, 2019).

In equilibrium with both valued sight and CBDC deposits, agents are indifferent to hold commercial bank money or central bank money. The relative attractiveness of central bank money relative to bank deposits will mainly rest on the interest rate of both competing means of payment and the fee established by commercial banks. Examining the impact of introducing an interest-bearing

CBDC is of interest from a variety of policy perspectives. I show that the central bank's policy through its digital currency has implications not only for prices in the economy but also for how expensive borrowing is. A higher CBDC interest rate will force commercial banks to impose a higher lending rate in order to compensate the increase of deposit funding. I also find that, conditioning on allowing a high supply of the CBDC, the central bank can guarantee both financial stability and seigniorage revenues. The second target, however, imposes a lower bound on the refinancing rate of the central bank that may endanger financial stability.

In this paper, for the sake of simplicity, I abstract from many relevant issues. Suppose that the banking system is not permitted to borrow all the reserves they want. This imposes an additional constraint on the bank's constrained maximization problem. How is this new equilibrium different from the equilibrium in which there are no reserve requirements? Moreover, I assume that the central bank sets both prices and quantities of the CBDC. Setting the quantities of the CBDC can be seen as a strategy to stop the possibility of a bank run because the monetary authority is restricting the decline in bank deposits allowing limits on CBDC holdings. But what if the supply of CBDC is completely elastic to the interest rate of CBDC deposits? This would have important implications for financial stability and is an avenue for future research. In addition, the model is developed to allow for a representation of outside money in the form of a CBDC and inside money in the form of commercial bank deposits and loans. In the reality, in economies prone to currency crises, private digital currencies are also surging as an alternative store of value. The model could be extended by incorporating a private digital currency which competes with both sight and CBDC deposits. Finally, another limitation of my model is that it has been set in the context of a closed economy. Bank runs of the previous decades and centuries have befallen in an open environment. Households may have the chance to migrate their deposits from their local bank to a foreign bank or to an external central bank – if that is permitted. In fact, the current financial and payments systems share widespread cross-border linkages. It may be the case that a poorly designed retail CBDC issued in one country endangers the stability of the financial system of other countries. This leaves another avenue to further investigation.

3.5 Appendix

Appendix A. Design alternatives for a CBDC

Table A1 provides a classification of the different types of money and the features they share.

Table A1: Classification of money*

	Universally accessible	Electronic	Central bank issued	Interest bearing	Caps
Cash	✓	✗	✓	✗	✗
Reserves	✗	✓	✓	✓	✗
Private digital currencies	✓	✓	✗	✗	✗
Wholesale CBDC	✗	✓	✓	✓	✓
Retail CBDC	✓	✓	✓	✓	✓

Source: Author's elaboration based on the classification of Bech and Garratt (2017) and BIS (2018).
*A check mark means that it is possible to implement the feature.

Bordo and Levin (2018) highlight that a CBDC would fulfill all the fundamental tenets of currencies established by Jevons (1875) a century and half ago. It can perfectly be a unit of account, a medium of exchange with no cost, a secure store of value (Bordo and Levin, 2018) and a standard of deferred payment (Shirai, 2019).

Appendix B. First order conditions

Solving the maximization problem, the first order conditions for consumption, central bank digital currencies, sight deposits, the amount of goods sold by the entrepreneur of a household of type 1 and 2 and the long technology are:

Consumption:

$[c^1] : U'(c^1) = p_1 \cdot (\eta_1 + \kappa_1).$
$[c^2] : U'(c^2) = p_2 \cdot (\eta_2 + \Xi_2).$

CBDC deposits:

$[d_2^1] : d_2^1 \cdot [\Xi_1(1 + i_2^d) - \kappa_1(1 + \psi)] = 0.$
$[d_2^2] : d_2^2 \cdot [\Xi_2(1 + i_2^d) + \eta_2(1 + i_2^d) - \kappa_2(1 + \psi)] = 0.$

Sight deposits:

$[s_2^1] : s_2^1 \cdot [\Xi_1(1 + i_2^s) - \kappa_1] = 0.$
$[s_2^2] : s_2^2 \cdot [(\Xi_2 + \eta_2)(1 + i_2^s) - \kappa_2] = 0.$

Amount of goods sold by the entrepreneur:

$[q_1^1] : q_1^1 \cdot [\tau_1 - \varphi_1 - p_2\Xi_1 + p_1\kappa_1] = 0.$
$[q_1^2] : q_1^2 \cdot [\tau_2 - \varphi_2 - p_2(\eta_2 + \Xi_2) + p_1\kappa_2] = 0.$

together with the slackness conditions:

$\tau_1 \cdot q_1^1 = 0.$
$\tau_2 \cdot q_1^2 = 0.$
$\varphi_1(\alpha + \rho_1 \cdot y^1 - q_1^1) = 0.$
$\varphi_2(\alpha + \rho_2 \cdot y^2 - q_1^2) = 0.$

Long productive technology:

$[y^1] : [\varphi_1\rho_1 + \Xi_1 p_2(\rho_2 - \rho_1)]y^1 = 0.$
$[y^2] : [\varphi_2\rho_1 + \Xi_2 p_2(\rho_2 - \rho_1) + p_2\rho_1\eta_2]y^2 = 0.$

There are also the envelope conditions with respect to α:

$\frac{dv^1(\alpha)}{d\alpha} = \varphi_1 + \Xi_1 p_2(1 - \rho_2).$

$\frac{dv^2(\alpha)}{d\alpha} = \varphi_2 + p_2\eta_2 + p_2\Xi_2(1 - \rho_2).$

Besides, on period $t = 0$, the household chooses the split of hired labour between both the short and long technology to solve the problem:

$$v(\alpha) = \max\left\{\lambda v^1(\alpha) + (1 - \alpha)v^2(\alpha)\right\} \tag{3.37}$$

subject to

$$0 \leq \alpha \leq 1. \tag{3.38}$$

Thus, the first order condition is:

$$\lambda\frac{dv^1(\alpha)}{d\alpha} + (1 - \lambda)\frac{dv^2(\alpha)}{d\alpha} + \beta_0 - \beta_1 = 0, \tag{3.39}$$

with β_0 and β_1 the Lagrange multipliers associated to left-hand side and right-side of the constraint (equation (3.38)) respectively.

Appendix C. Equilibrium with valued both sight and CBDC deposits. Proof of proposition 1

I prove that there exists a unique equilibrium with valued both sight deposits and central bank digital currency deposits. To do that, I obtain the interest rate conditions, the consumption levels and the production decisions, given the size of the short term technology, α, chosen by the entrepreneurs.

Let us obtain the equilibrium values of the consumption baskets and the production decisions:

Assuming that the amount of goods sold by the entrepreneur is positive in the first ($q_1^1 > 0$) and the second period ($q_1^2 > 0$)[17]:

[17] $q_1^1 = 0$ and $q_1^2 = 0$ cannot be a equilibrium because impatient households consume in period 1.

$$\tau_1 - \varphi_1 = p_2\Xi_1 - p_1\kappa_1. \tag{3.40}$$

$$\tau_2 - \varphi_2 = p_2(\eta_2 + \Xi_2) - p_1\kappa_2. \tag{3.41}$$

Using equations (3.40) and (3.50):

$$\frac{p_1}{p_2}\frac{(1+i_2^d)}{(1+\psi)} = 1 + \frac{\varphi_1 - \tau_1}{p_2\Xi_1}. \tag{3.42}$$

Employing equations (3.41) and (3.51):

$$\frac{p_1}{p_2}\frac{(1+i_2^d)}{(1+\psi)} = 1 + \frac{\varphi_2 - \tau_2}{p_2(\Xi_2 + \eta_2)}. \tag{3.43}$$

From equations (3.42) and (3.43), two possibilities arise:

i) If $\varphi_1 = \varphi_2 = 0$ and $\tau_1 = \tau_2 = 0$, then:

$$p_1\frac{(1+i_2^d)}{(1+\psi)} = p_2. \tag{3.44}$$

This would imply that $q_1^1 > \alpha$, $y^1 = 0$, $q_1^2 > \alpha$, $y^2 = 0$.

ii) If $\varphi_1 > 0, \varphi_2 > 0$ and $\tau_1 = \tau_2 = 0$, then, the following two options may happen:

$$p_1\frac{(1+i_2^d)}{(1+\psi)} = p_2 + \frac{\varphi_1}{\Xi_1}.$$

$$p_1\frac{(1+i_2^d)}{(1+\psi)} = p_2 + \frac{\varphi_2}{\Xi_2 + \eta_2}.$$

Therefore, they both may be summarized in:

$$p_1\frac{(1+i_2^d)}{(1+\psi)} > p_2 \tag{3.45}$$

This would imply that $q_1^1 = \alpha + \rho_1 y^1$, and $q_1^2 = \alpha + \rho_1 y^2$.

One of the two possibilities should be rule out. Using the envelope conditions, if $\alpha \in (0,1)$[18] and $\beta_0 = \beta_1 = 0$, then:

$$\varphi_1 - p_2\Xi_1(\rho_2 - 1) = 0.$$

$$\varphi_2 - p_2\Xi_2(\rho_2 - 1) + p_2\eta_2 = 0.$$

Solving them for the expression in the right side of equations (3.42) and (3.43) respectively (knowing that $\tau_1 = \tau_2 = 0$):

[18]First, it is assumed that α is an interior solution. But α can also be a corner solution. This will be ruled out later.

$$1 + \frac{\varphi_1}{p_2 \Xi_1} = \rho_2.$$

$$1 + \frac{\varphi_2}{p_2(\Xi_2 + \eta_2)} = \rho_2 \cdot \frac{\Xi_2}{(\Xi_2 + \eta_2)}.$$

Plugging them in equations (3.42) and (3.43) respectively:

$$\frac{p_1}{p_2} \frac{(1 + i_2^d)}{(1 + \psi)} = \rho_2.$$

$$\frac{p_1}{p_2} \frac{(1 + i_2^d)}{(1 + \psi)} = \rho_2 \cdot \frac{\Xi_2}{(\Xi_2 + \eta_2)}$$

To hold, it must be the case that **the cash-in advance constraint of patient households at $t = 2$ is slack**. In other words, $\eta_2 = 0$. Hence, the **interest rate condition** in period 2 is:

$$(1 + i_2^d) = \rho_2 \cdot \frac{p_2}{p_1}(1 + \psi). \tag{3.46}$$

Assume now that $y^1 = y^2 = 0$. This would imply the following conditions:

$$\varphi_1 \rho_1 > \Xi_1 p_2 (\rho_1 - \rho_2).$$

$$\Xi_2 p_2 (\rho_2 - \rho_1) + \rho_1 p_2 \eta_2 > \varphi_2 \rho_1.$$

Using the loan repayment equation (budget constraint) for both agents at $t = 2$ (equations (3.19) and (3.25)) and knowing that $\Xi_1 > 0$, $\Xi_2 > 0$, $y^1 = y^2 = 0$, and $q_1^1 = q_1^2 = \alpha$, I get:

$$1 + i^l = p_2 \cdot (1 - \alpha)\rho_2 + (1 + i_2^d) d_2^1 + (1 + i_2^s) \cdot s_2^1.$$

$$1 + i^l = (1 + i_2^d) d_2^2 + (1 + i_2^2) s_2^2 - p_2 c^2 + p_2 (1 - \alpha)\rho_2.$$

Equating both expressions:

$$(1 + i_2^d) d_2^1 + (1 + i_2^s) \cdot s_2^1 = (1 + i_2^d) d_2^2 + (1 + i_2^2) s_2^2 - p_2 c^2.$$

Making use of equations (3.16) and (3.21):

$$(1 + i_2^d)(d_2^1 - d_2^2) - (1 + i_2^s) p_1 c^1 = (1 + i_2^s)(1 + \psi)(d_2^1 - d_2^2) - p_2 c^2.$$

As $(1 + i_2^s) = \rho_2 \cdot \frac{p_2}{p_1}$, then:

$$[(1 + i_2^d) - (1 + i_2^s)(1 + \psi)](d_2^1 - d_2^2) + p_2 c^2 = \rho_2 p_2 c^1. \tag{3.47}$$

From the market clearing, it is known that:

$$\lambda c^1 = \lambda q_1^1 + (1-\lambda) q_1^2.$$

$$\lambda c^1 = \lambda \alpha + (1-\lambda)\alpha; c^1 = 1.$$

The **equilibrium value of the consumption basket for impatient households** is 1.

Now, I obtain the sight deposits-CBDC interest rate equivalence. From the first order conditions of sight deposits and CBDC deposits:

$$\Xi_1(1+i_2^s) - \kappa_1 = 0. \tag{3.48}$$

$$(\Xi_2 + \eta_2)(1+i_2^s) - \kappa_2 = 0. \tag{3.49}$$

$$\Xi_1(1+i_2^d) - \kappa_1(1+\psi) = 0. \tag{3.50}$$

$$\Xi_2(1+i_2^d) + \eta_2(1+i_2^d) - \kappa_2(1+\psi) = 0. \tag{3.51}$$

Combining both equations (3.48) and (3.50), I obtain the following condition:

$$(1+\psi)(1+i_2^s) = (1+i_2^d).$$

The previous expression is the **sight deposits-CBDC interest rate condition** of the impatient agents.

Using equations (3.49) and (3.51), let us now prove that the same expression is achieved for the patient agents.

Remember the first order conditions of CBDC and sight deposits of the patient agent:

$$(\Xi_2 + \eta_2)(1+i_2^s) - \kappa_2 = 0.$$

$$\Xi_2(1+i_2^d) + \eta_2(1+i_2^d) - \kappa_2(1+\psi) = 0.$$

Combining both, I get:

$$(\Xi_2 + \eta_2)(1+i_2^s)(1+\psi) = (\Xi_2 + \eta_2)(1+i_2^d).$$

Simplifying:

$$(1+i_2^s)(1+\psi) = (1+i_2^d),$$

which is exactly the same as the sight deposits-CBDC interest rate equivalence of the impatient agents.

If I plug the sight deposits-CBDC interest rate condition (equation (3.27)) in equation (3.47), it is obtained the **equilibrium value of the consumption basket for patient households**:

$$c^2 = \rho_2 \cdot c^1 = \rho_2.$$

The interior solution implies $y^1 = y^2 = 0$, $\alpha = \lambda$, $c^1 = 1$, $c^2 = \rho_2$ together with the interest rate conditions:

$$(1 + i_2^s) = \frac{(1 + i_2^d)}{(1 + \psi)} = \rho_2 \cdot \frac{p_2}{p_1}. \tag{3.52}$$

However, apart from the previous interior solution, equation (3.39) could also hold if:

$$\varphi_1 - \Xi_1 p_2(\rho_2 - 1) > 0 > \varphi_2 - \Xi_2 p_2(\rho_2 - 1) - p_2\eta_2$$

In this case, if

$$\varphi_1 > \Xi_1 p_2(\rho_2 - 1) > 0,$$

by possibility (ii), it should be the case that $q_1^h = \alpha + \rho_1 y^h$ for both types of households.

Solving equation (3.42) for φ_1 and plugging it in the previous expression:

$$\frac{p_1}{p_2}(1 + i_2^d) > \rho_2.$$

The other case is:

$$\varphi_2 < \Xi_2 p_2(\rho_2 - 1) + p_2\eta_2.$$

Solving equation (3.43) for φ_2 and plugging it in the previous expression:

$$\frac{p_1}{p_2}\frac{\Xi_2 + \eta_2}{\Xi_2}(1 + i_2^d) < \rho_2.$$

If the MIA constraint of patient households is slack, I am under a contradiction. Consequently, this interior solution is ruled out.

Moreover, equation (3.39) could also hold if:

$$\varphi_1 \Xi_1 p_2(\rho_2 - 1) < 0 < \varphi_2 - \Xi_2 p_2(\rho_2 - 1) - p_2\eta_2.$$

Following the same procedure as in the previous case, I obtain that:

$$\frac{p_1}{p_2}(1 + i_2^d) < \rho_2.$$

$$\frac{p_1}{p_2}\frac{\Xi_2+\eta_2}{\Xi_2}(1+i_2^d) > \rho_2.$$

If the MIA constraint of patient households is slack, I am under a contradiction again.

Notwithstanding, if $\eta_2 \neq 0$, the previous interior solutions may hold. Following Rivero Leiva and Rodríguez Mendizábal (2019, p.28), it can be easily shown that this is not a possible solution.

In addition, α could also be a corner solution either at $\alpha = 0$ or $\alpha = 1$. Both are ruled out and cannot be an equilibrium solution.[19]

All in all, the only solution with both valued sigh deposits and CBDCs holdings involves $\alpha = \lambda, c^1 = 1, c^2 = \rho_2, y^1 = y^2$ and the interest rates obey equation (3.52).

Let us compute now the equilibrium interest rates:

Equating to zero the net worth of a bank at period 1:

$$nw_1^B = 1 - \lambda(d_2^1 + s_2^1 - \psi d_2^1) - (1-\lambda)(d_2^2 + s_2^2 - \psi d_2^2) = 0. \tag{3.53}$$

Substituting equation (3.16) and equation (3.21):

$$\begin{aligned} nw_1^B = 1 - \lambda(d_2^1 - \psi d_2^1 + i_1^s - p_1 \cdot c^1 + p_1 \cdot q_1^1 - (1+\psi)d_2^1) \\ -(1-\lambda)(d_2^2 - \psi d_2^2 + 1 + i_1^s + p_1 \cdot q_1^2 - (1+\psi)d_2^2) = 0; \end{aligned}$$

$$nw_1^B = -i_1^s + 2\psi\lambda d_2^1 + (1-\lambda)2\psi d_2^2 = 0;$$

$$i_1^s = 2\psi[\lambda d_2^1 + (1-\lambda)d_2^2]. \tag{3.54}$$

The interest rate of sight deposits in the first period will depend on the commission and the amount of central bank digital currency deposits demanded.

Finally, I can get the price in period 1. The budget constraint of impatient agents was binding. Hence, since consumption of the impatient agents was 1, price in the first period will be higher than 1 - as long as the fee and the supply of the CBDC are both positive - and equal to:

$$p_1 = 1 + i_1^s = 1 + 2\psi[\lambda d_2^1 + (1-\lambda)d_2^2]$$

Equating to zero the net worth of a bank at period 2.

[19]See Rivero Leiva and Rodríguez Mendizábal (2019, p.29).

$$nw_2^B = (1+i^l) - (1+i_2^s)[\lambda s_2^1 + (1-\lambda)s_2^2] + (1-\lambda)p_2 c^2 \\ -p_2[\lambda q_2^1 + (1-\lambda)q_2^2] - (1+i^R)[\lambda d_2^1 + (1-\lambda)d_2^2]. \tag{3.55}$$

Substituting both MIA constraints:

$$nw_2^B = (1+i^l) - (1+i_2^s)[\lambda(1+i_1^s - p_1 c^1 + p_1 q_1^1 - (1+\psi)d_2^1) + \\ (1-\lambda)(1+i_1^s + p_1 q_1^2 - (1+\psi)d_2^2)] + (1-\lambda)p_2 c^2 - p_2[\lambda q_2^1 + \\ (1-\lambda)q_2^2] - (1+i^R)[\lambda d_2^1 + (1-\lambda)d_2^2].$$

After some simplifications:

$$nw_2^B = 1 + i^l + (1+i_2^s)(1+\psi)[\lambda d_2^1 + (1-\lambda)d_2^2] - (1+i_2^s)(1+i_1^s) \\ -(1+i^R)[\lambda d_2^1 + (1-\lambda)d_2^2].$$

Since:

$$(1+i_2^s) = \frac{1+i_2^d}{1+\psi}.$$

I obtain the following:

$$nw_2^B = 1 + i^l + (1+i_2^d)[\lambda d_2^1 + (1-\lambda)d_2^2] - 1 - i_1^s - i_2^s - i_1^s \cdot i_2^s - (1+i^R)[\lambda d_2^1 + (1-\lambda)d_2^2].$$

Rearranging some terms

$$nw_2^B = i^l + (i_2^d - i^R)[\lambda d_2^1 + (1-\lambda)d_2^2] - i_1^s - i_2^s - i_1^s \cdot i_2^s,$$

and plugging Equation (3.54), I obtain the following expression:

$$nw_2^B = i^l + (i_2^d - i^R)[\lambda d_2^1 + (1-\lambda)d_2^2] - 2\psi[\lambda d_2^1 + (1-\lambda)d_2^2] - i_2^s - i_2^s \cdot 2\psi[\lambda d_2^1 + (1-\lambda)d_2^2];$$

$$nw_2^B = i^l + (i_2^d - i^R)[\lambda d_2^1 + (1-\lambda)d_2^2] - \frac{i_2^d - \psi}{1+\psi} - \frac{2\psi}{1+\psi} \cdot (1+i_2^d) \cdot [\lambda d_2^1 + (1-\lambda)d_2^2];$$

$$nw_2^B = i^l + (i_2^d - i^R - \frac{2\psi \cdot (1+i_2^d)}{1+\psi})[\lambda d_2^1 + (1-\lambda)d_2^2] - \frac{i_2^d - \psi}{1+\psi}.$$

Simplifying:

$$nw_2^B = i^l + \left(\frac{(1-\psi)i_2^d - 2\psi}{1+\psi} - i^R\right)[\lambda d_2^1 + (1-\lambda)d_2^2] - \frac{i_2^d - \psi}{1+\psi}.$$

In equilibrium, the loan rate of commercial banks would be adjusted to fulfill the following condition:

$$i^l = \left(i^R - \frac{(1-\psi)i_2^d - 2\psi}{1+\psi}\right)[\lambda d_2^1 + (1-\lambda)d_2^2] + \frac{i_2^d - \psi}{1+\psi}. \tag{3.56}$$

Appendix D. Digital bank run. Proof of proposition 2

If there is a digital bank run, commercial banks will not have to pay interest rate on sight deposits. Household will value whether the net worth of the commercial bank in the second period is positive or negative, i.e., whether the bank is solvent. The net worth of a commercial bank in the second period is:

$$nw_2^B = (1+i^l) + (1-\lambda)p_2c^2 - p_2[\lambda q_2^1 + (1-\lambda)q_2^2] \\ -(1+i^R)[\lambda d_2^1 + (1-\lambda)d_2^2].$$

Rearranging some terms:

$$nw_2^B = (1+i^l) - [(1+i^R)][\lambda d_2^1 + (1-\lambda)d_2^2] + (1-\lambda)p_2c^2 - p_2[\lambda q_2^1 + (1-\lambda)q_2^2];$$

$$nw_2^B = (1+i^l) - [(1+i^R)][\lambda d_2^1 + (1-\lambda)d_2^2].$$

As I am evaluating a situation in which all funds are withdrawn, it means that:

$$\lambda d_2^1 + (1-\lambda)d_2^2 = 1.$$

Therefore:

$$nw_2^B = (1+i^l) - (1+i^R).$$

A commercial bank will remain solvent as long as:

$$nw_2^B = (1+i^l) - (1+i^R) \geq 0.$$

Analogously:

$$i^l \geq i^R. \tag{3.57}$$

As long as the refinancing rate of the central bank is lower than the loan rate established by commercial banks, there will not be a digital bank run.

Households will not coordinate in a run in their bank, given that the rest of the banks are solvent, triggering a digital bank run, as long as the refinancing rate of the central bank is not particularly high. In particular, as long as

$$i^R \leq \left(i^R - \frac{(1-\psi)i_2^d - 2\psi}{1+\psi}\right)[\lambda d_2^1 + (1-\lambda)d_2^2] + \frac{i_2^d - \psi}{1+\psi};$$

$$i^R - i^R[\lambda d_2^1 + (1-\lambda)d_2^2] \leq \left(-\frac{(1-\psi)i_2^d - 2\psi}{1+\psi}\right)[\lambda d_2^1 + (1-\lambda)d_2^2] + \frac{i_2^d - \psi}{1+\psi};$$

$$(1 - \lambda d_2^1 - (1-\lambda)d_2^2)\cdot i^R \leq \frac{i_2^d - \psi}{1+\psi} - \frac{(1-\psi)i_2^d - 2\psi}{1+\psi}[\lambda d_2^1 + (1-\lambda)d_2^2];$$

$$i^R \leq \frac{\frac{i_2^d-\psi}{1+\psi} - \frac{(1-\psi)i_2^d-2\psi}{1+\psi}[\lambda d_2^1+(1-\lambda)d_2^2]}{(1-\lambda d_2^1-(1-\lambda)d_2^2)};$$

$$i^R \leq \frac{i_2^d-\psi-((1-\psi)i_2^d-2\psi)[\lambda d_2^1+(1-\lambda)d_2^2]}{(1+\psi)(1-\lambda d_2^1-(1-\lambda)d_2^2)}.$$

This condition must be satisfied. Otherwise, a self-fulling digital bank run will occur in equilibrium.

Appendix E. Monetary policy. Proof of proposition 3

I should determine under which conditions, i_2^d will allow that the net worth of the central bank and commercial banks is positive and there is an absence of a digital bank run. To do show, I know that:

$$i_2^d < \frac{i_2^d-\psi-((1-\psi)i_2^d-2\psi)[\lambda d_2^1+(1-\lambda)d_2^2]}{(1+\psi)(1-\lambda d_2^1-(1-\lambda)d_2^2)};$$

$$i_2^d(1+\psi)(1-\lambda d_2^1-(1-\lambda)d_2^2) < i_2^d-\psi-((1-\psi)i_2^d-2\psi)[\lambda d_2^1+(1-\lambda)d_2^2];$$

$$i_2^d(1+\psi)(1-\lambda d_2^1-(1-\lambda)d_2^2) < i_2^d-\psi-(1-\psi)i_2^d[\lambda d_2^1+(1-\lambda)d_2^2]+2\psi[\lambda d_2^1+(1-\lambda)d_2^2];$$

$$i_2^d(1+\psi)(1-\lambda d_2^1-(1-\lambda)d_2^2)-i_2^d+(1-\psi)i_2^d[\lambda d_2^1+(1-\lambda)d_2^2] < -\psi+2\psi[\lambda d_2^1+(1-\lambda)d_2^2];$$

$$[(1+\psi)(1-\lambda d_2^1-(1-\lambda)d_2^2)+(1-\psi)[\lambda d_2^1+(1-\lambda)d_2^2]-1]\cdot i_2^d < 2\psi[\lambda d_2^1+(1-\lambda)d_2^2]-\psi;$$

$$(\psi-2\psi[\lambda d_2^1+(1-\lambda)d_2^2)\cdot i_2^d < 2\psi[\lambda d_2^1+(1-\lambda)d_2^2]-\psi;$$

$$(1-2[\lambda d_2^1+(1-\lambda)d_2^2)\cdot i_2^d < 2[\lambda d_2^1+(1-\lambda)d_2^2]-1.$$

The previous inequality will be fulfilled in the following situations:

- $\lambda d_2^1+(1-\lambda)d_2^2 > 0.5$, for all values of i_2^d, as long as, $i_2^d > -1$.
- $i_2^d < -1$, for all values of the supply of the CBDC, i.e., $\lambda d_2^1+(1-\lambda)d_2^2$. This is not realistic situation. The central bank will not establish a CBDC deposits interest rate of -100%.

Chapter 4

Distrust or Speculation? The Socioeconomic Drivers of U.S. Cryptocurrency Investments.*

Abstract

Employing representative data from the U.S. Survey of Consumer Payment Choice, we find no evidence that cryptocurrency investors are motivated by distrust in fiat currencies or regulated finance. Compared with the general population, investors show no differences in their level of security concerns with either cash or commercial banking services. We find that cryptocurrency investors tend to be educated, young and digital natives. In recent years, a gap in ownership of cryptocurrencies across genders has emerged. We examine how investor characteristics vary across cryptocurrencies and show that owners of cryptocurrencies increasingly tend to hold their investment for longer periods.

JEL Classification: D14 D91 E42 G11 G12 G28 O33

Keywords: digital currencies, cryptocurrencies, distributed ledger technology, blockchain, payments, digitalisation, banking, household finance, money

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4.1 Introduction

The rise and fall of bitcoin, ether, and related cryptocurrencies – with market capitalisations (see Figure 4.1a) at times rivalling that of silver, the world's major financial companies, and even the stock markets of large advanced economies[1] – warrants a close examination of investor motivations and levels of sophistication.

One aspect of particular relevance is that the purported motivation for the creation of these cryptocurrencies has been to design an alternative to fiat money and commercial banking, with the goal of creating a new form of exchange that is resistant to debasement and censorship by governments and financial institutions. As put by Nakamoto (2008, p.1):[2]

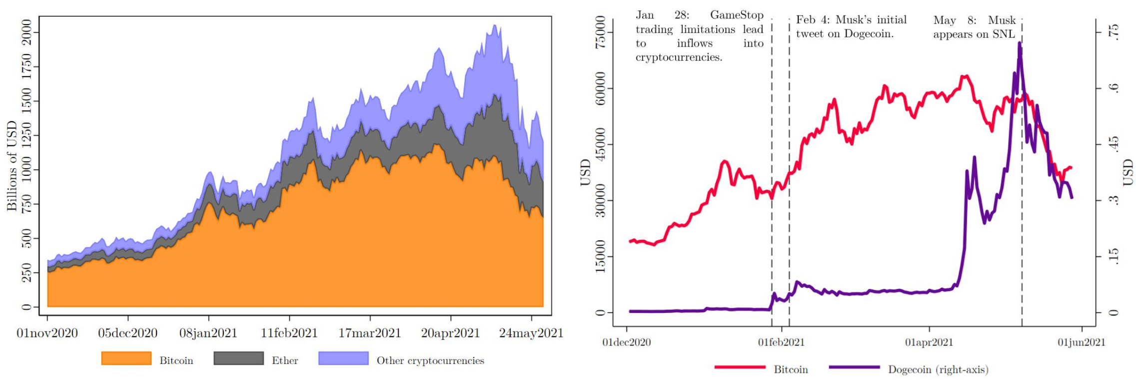
"What is needed is an electronic payment system based on cryptographic proof instead of trust, allowing any two willing parties to transact directly with each other without the need for a trusted third party".

This narrative is also relied upon frequently by the proponents of this asset class. One noteworthy episode is the trading suspension of GameStop shares on the app Robinhood that occurred in early 2021. The suspension was – incorrectly – interpreted as censorship and market manipulation in favour of large hedge funds (see Ossinger and Hunter (2021) and Appendix A). Due to ensuing media coverage, a substantial inflow of funds into cryptocurrencies resulted.

Figure 4.1: Market valuations have reached new records.

(a) Market capitalisations*

(b) Bitcoin and dogecoin prices



Source: CoinMarketCap (Panel (a)) and Coindesk.com (Panel (b)). **Other cryptocurrencies* include the sum of the market capitalization of the biggest cryptocurrencies (excluding stablecoins) after bitcoin and ether.

[1] As of 26 May 2021, silver had a market capitalization of around $1.51 trillion, gold's market capitalization was $12.04, JPMorgan Chase was $497.38 billion and Bank of America was $365.75 billion (CompaniesMarketCap, 2021). In comparison, at that day, total market capitalisation of cryptocurrencies was $1.72 trillion. As of 8 May 2021, total market capitalisation of cryptocurrencies (including stablecoins) reached its peak at $2.42 trillion, doubling the combined market capitalisation of all companies included in the German DAX 30 index (CoinMarketCap, 2021).

[2] For example, Vitalik Buterin, considered "non-discrimination and non-censorship" one of the key principles behind the design of Ethereum (Buterin, 2013)

In the subsequent hype, the price of bitcoin continued surging, exceeding $50,000 soon after the trading suspension, and peaking at over $63,000 several weeks later (see Figure 4.1b). Brought to the attention of many via widely read tweets by Elon Musk, the cryptocurrency Dogecoin saw an almost ten-fold price increase during this episode (Ossinger and Hunter, 2021). However, cryptocurrency prices collapsed during mid-May 2021, after renewed statements by Mr Musk and the announcement of a ban for financial institutions and payment companies from providing cryptocurrency services in China.[3]

As the end of the GameStop episode exemplifies, the narrative of cryptocurrencies as a censorship-resistant asset class does not always square with reality.[4] Cryptocurrencies are rife with fraud and theft (Auer and Claessens, 2019; Foley et al., 2019; Twomey and Mann, 2020),[5] mostly due to the fact that coins are held in the custody of unregulated middlemen (Kharif, 2020). Cryptocurrencies such as bitcoin that are sustained by costly computing ("proof-of-work") tend to be centralised (Huang, 2020) and their basic security model might not be sustainable (Auer, 2019a).[6] There is ample debate on the censorship-resistance, decentralisation, and legal nature of other cryptocurrencies, as well (Fröwis and Böhme, 2017; Walch, 2019; SEC, 2020).[7]

Amidst a discrepancy between sociological narrative and factual evidence, it is important to understand who the retail investors in cryptocurrencies are, what their level of trust and knowledge is, and how they interact with the mainstream financial system. The objective of this paper is hence threefold. We start by examining the hypothesis that cryptocurrencies are sought out of distrust in fiat currencies or regulated finance. Second, we study the broader socioeconomic characteristics of U.S. retail consumers and disentangle the role of knowledge acquisition and investment decisions conditional on knowledge. Third, we examine the evolution of patterns of cryptocurrency investments across time and cryptocurrencies.

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[3]See BBC (2021). Dogecoin has been subject to even higher volatility during May. Its price dropped by around 30% on May 9, the day of the appearance of Elon Musk on the TV show "Saturday Night Live".

[4]The emergence of cryptocurrencies has also led to the development of stablecoins, such as the Facebook's Diem project. For an analysis of this and other global stablecoins, see Arner et al. (2020), Frost et al. (2020), Melachrinos and Pfister (2020) and Tercero-Lucas (2020).

[5]There have been many cases of fraud in the industry. One example is the project PlusToken, which turned out to be a cryptocurrency Ponzi scheme that attracted millions of people with promises of high returns on investment. The operators were taken to court and found guilty of defrauding investors of almost $2.3 billion (Akhtar, 2021). Investors are also subject to cyber attacks that have affected both open source distributed ledgers (e.g., in February, 2020, the IOTA Foundation had to temporarily shut down the IOTA network after suffering an attack on its wallet app (Pan, 2020)) and cryptocurrencies exchange markets (e.g., in the first quarter of 2020, Altsbit, an Italian cryptocurrency exchange, had to close because the majority of user funds were stolen in a cyber attack (Partz, 2020)).

[6]Also, the environmental impact must not be forgotten. Bitcoin's energy consumption is exceeding that of entire countries (see Carstens (2018a) and De Vries (2018)).

[7]They are further used for illegal activities, including money laundering and the financing of terrorism. See e.g., Fanusie and Robinson (2018). Foley et al. (2019) estimate that around one quarter of bitcoin users were involved in illegal activity in the pre-2018 period, which translated to $76 billion per year.

We employ the Survey of Consumer Payment Choice (SCPC), a representative micro-level dataset provided by the Federal Reserve Bank of Atlanta. The survey covers the 2014-19 period and is representative of the US population. Using a variety of econometric specifications, we first find no evidence about the hypothesis that cryptocurrencies are sought as an alternative to fiat currencies or regulated finance in the US. Compared with the general population, cryptocurrency investors show no differences in their level of security concerns with either cash or commercial banking services. We do, however, find that those who are concerned with the security of cash or bank accounts tend to acquire information about cryptocurrencies.[8] Moreover, those being aware of or investing in cryptocurrencies find traditional banking less convenient that the rest of the respondents. It may be the case that this segment of the population has had less positive experience with their traditional banks. As a result, their levels of dissatisfaction may be higher than the levels of the rest of the population. On the contrary, the same dissatisfaction does not appear regarding cash.

Our second set of results regards the broader sociodemographics of cryptocurrency investors. Higher educational attainment is associated with more knowledge about and likelihood of owning a cryptocurrency. Male gender is associated with a 2 to 2.2 percentage points higher likelihood of owning at least one cryptocurrency. The probability of knowing at least one cryptocurrency is higher for men and for those individuals with higher levels of both income and an education.

We provide some evidence that the impact of gender and age on cryptocurrency investment is unrelated to differences in knowledge about the underlying technology. Despite converging knowledge levels about cryptocurrencies, a gender gap in terms of ownership has emerged.[9] In the same vein, although age has no effect on knowledge about cryptocurrencies, it does have a strong effect on investment decisions.

Our last set of results regards the evolution of these patterns of cryptocurrency investments across time and cryptocurrencies. Owners of ether and xrp are the most educated in our sample, followed by bitcoin cash and bitcoin users. Conversely, those owning litecoin are the least educated. We document trends in knowledge and ownership, and develop an empirical test for so called "hodling"- a term in the cryptocurrency community that refers to buying and holding a cryptocurrency over the long-term.[10] Specifically, we estimate that owning a cryptocurrency in one year increases the probability, on average, of owning a cryptocurrency in the following year by 50%.

[8]Our findings also suggest that experience with digital finance, captured through having a debit card, and using a mobile payment app, increases the probability of investing in cryptocurrencies.

[9]This is in contrast to the finding of a survey discussed in Baker (2019), which found that "67 percent of women felt their lack of familiarity with bitcoin stopped them from investing in it, compared to 48 percent of men".

[10]For a further explanation of the origin of the term, see StormGain (2020).

Overall, our paper contributes to several literatures spanning the fields of sociology, economics, financial stability, and computer science. Our focus on the sophistication of retail cryptocurrency investors and on whether the demand for cryptocurrencies is driven by distrust in fiat money and/or the commercial financial industry contributes to the literature of the sociology of financial markets (Pixley, 2004; Knorr Cetina and Preda, 2005; Preda, 2007; Knorr Cetina and Preda, 2012). Lack of trust has been shown to be a main driver of investment decisions and limited stock market participation (see Guiso et al. (2008); Georgarakos and Pasini (2011); Balloch et al. (2015)).[11] Given the paramount importance of trust for the monetary and financial system (see Carstens (2018b, 2019); Borio (2019)), the persistent rise of cryptocurrencies could potentially evidence rising distrust in today's arrangements.[12] In that light, our key finding alleviates these concerns: cryptocurrency investors do not present differences in their level of security concerns with mainstream payment options, i.e., trust in cash or the banking deposits.

From a policy angle, one of the main takeaways is that as the goals of investors are the same as those for other asset classes, so should be the regulation. A clarifying regulatory and supervisory framework for cryptocurrency markets may be useful for the industry. In fact, regulatory announcements have had a strong impact on cryptocurrency prices and transaction volumes (Auer and Claessens, 2019, 2020), and those pointing to the establishment of specific regulations tailored to cryptocurrencies and initial coin offerings are strongly correlated with relevant market gains. Here, one important consideration regards how one could apply technology-neutral regulation, while at the same time harnessing the potential of the technology itself in the supervision process. One option for such a framework is "embedded supervision", developed in Auer (2019b). This means implementing a supervisory framework for cryptocurrencies that allows for compliance to be automatically monitored by reading the market's ledger. The goal is low-cost supervision of decentralised markets, which may be particularly relevant amidst recent deliberations of the need for adequate prudential oversight of the cryptocurrency industry (Basel Committee, 2019, 2021).

We are also interested in the prevention of consumer fraud in the cryptocurrency industry, and in particular, whether cryptocurrencies in general, or specific projects, target poor and uneducated or rather the sophisticated and wealthy investor class who can afford to experiment. Several consumer agencies have warned against cryptocurrency scams. Policymakers have also shown their

[11] Employing data from all Bitnodes operating worldwide between 2014 and 2018, (Saiedi et al., 2020) argue that low trust in the financial system has contributed to the spread of Bitcoin infrastructure. In addition, they show that Bitcoin's support is higher in cities with well-developed banking services. Beyond trust, (De Bondt, 2005) finds that self-confidence and financial sophistication are important determinants of the perceived attractiveness of different asset classes and investment strategies. Analysing a survey of more than 3,100 European investors, he also documents differences in values and beliefs by age, health status, religious affiliation, and gender. As he highlights, people's values and beliefs are highly correlated with investment behaviour.

[12] The level of trust is also determined by other factors such as differences in educational attainment (Guiso et al., 2004) or in religious upbringing (Guiso et al., 2003).

concern about the increasing adoption of cryptocurrencies.[13] Our results – which show that cryptocurrency investors tend to be educated – to some extent imply that a majority of cryptocurrency investors may well be aware of the inherent risks. Our findings also suggest that being young increases the likelihood of owning cryptocurrencies. Since older people are at greater risk of both consumer and financial fraud (Temple, 2007; DeLiema et al., 2020), young people stand a better chance of avoiding them. This part of the analysis is closely related to recent literature analysing the profile and behaviour of cryptocurrency users.[14]

Our analysis is also related to the literature examining gender gaps in finance.[15] Women tend to be more risk-averse than men when it comes to holding risky assets (Jianakoplos and Bernasek, 1998; Borghans et al., 2009; Arano et al., 2010), and there are significant differences across genders in the use of FinTech (Chen et al., 2021).

Further, understanding the concerns and sociodemographic characteristics of cryptocurrency owners is crucial to those wanting to gauge the potential of cryptocurrency markets and estimate how large this asset class could eventually become. We find that cryptocurrencies, at least at current, remain niche markets dominated by young male investors, while other parts of the population acquire information about this asset class, but ultimately do not invest in it. However, a feature pertinent to analysing the potential of the cryptocurrency market is the phenomenon of *hodling*. Our results suggest that it is a persistent trait among cryptocurrency investors.

In addition, our findings may be informative for the likely user sophistication of future digital currencies,[16] including stablecoins or central bank digital currencies. Understanding the socioeconomic characteristics of cryptocurrency investors can be a first step in forecasting who the initial adopters of such future digital currencies may be.[17]

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[13]For instance, a member of the US Federal Reserve Board, Lael Brainard, stated that "cryptocurrencies may raise important investor and consumer protection issues. The lack of strong governance and questions about the applicable legal framework for some cryptocurrencies may make consumers vulnerable to mistakes, thefts, and security breaches without much, or any, recourse" (Brainard, 2018).

[14]Almost all previous studies focus solely on Bitcoin and do not tackle the security and convenience aspects of cryptocurrencies. In this respect, Bohr and Bashir (2014) show that age, mining status, time of initial use, engaging in online discourse, geographical location, and political orientation are relevant factors to use bitcoin. Henry et al. (2018) estimate that being a man and having a higher level of education increases the probability of knowing bitcoin in Canada. Moreover, bitcoin awareness is more common among unemployed individuals. Using a survey among Austrian households, Stix (2019) argues that potential adopters of cryptocurrencies are younger and are more willing to accept financial risk. Fujiki (2020) finds that Japanese crypto-asset owners are more likely to be men, young, have a high pre-tax income, hold graduate degrees, and have a high level of financial literacy.

[15]Employing U.S. data, Bannier et al. (2019) find that men have greater knowledge regarding the features of bitcoin than women.

[16]Voskobojnikov et al. (2020) find that the type of cryptocurrency and its area of application are critical to determining which risks and mitigation strategies the user employs.

[17]In particular, the degree of user sophistication may be key to the adoption of a token-based CBDC that requires the handling of digital signatures and allows for anonymity. Auer and Böhme

The remainder of this paper is structured as follows. Section 2 describes the data used. Section 3 outlines the empirical strategy used to identify the effects of interest. Section 4 provides an overview of the main results and presents some robustness checks. Section 5 documents some trends. Section 6 concludes.

4.2 Data

In this paper, we use data from the Survey of Consumer Payment Choice (SCPC). The SCPC is a representative micro-level data set provided by the Federal Reserve Bank of Atlanta since 2009. It provides an overview of the payment behaviour of US consumers. The SCPC[18] comprises information from the Diary of Consumer Payment Choice (DCPC). In the DCPC, consumers record details of specific payment transactions and choices (Foster et al., 2009). The SCPC does not have a perfect longitudinal design, meaning that if a person is selected in a given wave, that person does not always continue as a sample member in the subsequent editions.[19]

Each annual wave contains information about US consumers' payment behaviour regarding the use of cash, electronic payments and cryptocurrencies, as well as the number of transactions made via these means of payment. A crucial feature of the SCPC for this analysis is that it makes information for every respondent on whether that person is aware of one or more cryptocurrencies and whether that person owns any cryptocurrencies. In addition, the data include such socioeconomic characteristics as age, gender, race, region, education level, marital status, household income level and the number of people living in the same household.

4.2.1 The Estimation sample

The main analysis uses the 2019 wave, completed by a total of 3,372 individuals.[20] As an additional analysis, we use the 2014-19 waves. In Figure 4.2a, it is shown that the 2014, 2015, 2016, 2017 and 2018 samples contain 1,238, 1,429, 3,404, 3,099 and 3,153 individuals respectively. From the data, 1,264 individuals participated in just one wave and 3,876 participated in more than one wave. From them, 470 participated in the six waves of the survey (Figure 4.2b). Although respondents of the survey are selected randomly, they can refuse to participate on it.

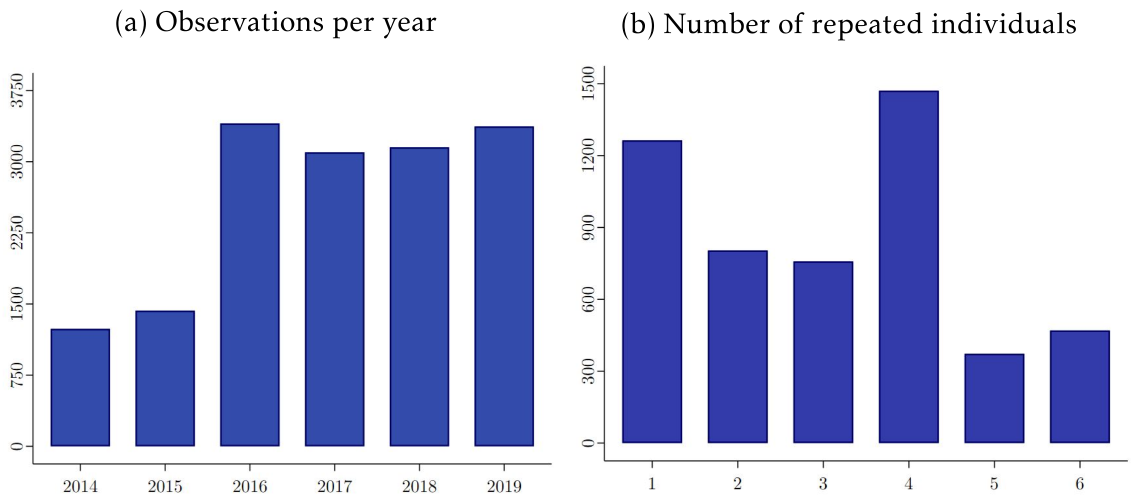
(2020) analyse the technical design choices for retail CBDCs and their trade-offs, while Auer et al. (2020) take stock of approaches around the world.

[18]For detailed analysis on each version of the SCPC, see Foster et al. (2009, 2011, 2013), Schuh and Stavins (2014, 2015), Greene et al. (2017), Greene and Schuh (2017), and Foster et al. (2020).

[19]For instance, since 2014 (N=1238), only 470 individuals have remained in the sample in the subsequent editions until 2019 (Figure 4.2b).

[20]In the 2019 survey, respondents participate in September (SCPC) and October (DCPC) (Foster et al., 2020).

Figure 4.2: Observations and repeated individuals.



Source: 2014-19 SCPC.

4.2.2 Descriptive statistics

Table A1 presents the main descriptive statistics for the 2019 wave.[21] We use four main outcome variables: ownership; ownership number; knowledge; and knowledge number. Ownership (knowledge) captures whether an individual owns (recognises or knows of) at least one of the following cryptocurrencies: bitcoin, xrp, litecoin, ether, bitcoin cash, stellar, eos, or any other cryptocurrency. Ownership number (knowledge number) stands for the number of different cryptocurrencies that a person owns (recognises or knows of). Of the people who responded to the survey, 73% knew of at least one cryptocurrency. However, only 1.4% owned a cryptocurrency in 2019.[22]

It is likely that those individuals with a higher level of digital skills know and own more cryptocurrencies rather than those with a lower level. The level of digitalisation is captured through three different variables: i) whether a person has a debit card, ii) whether a person has used a mobile app to pay in the past 12 months, iii) and whether a person has used PayPal to make a purchase or pay another person.[23] In 2019, more than 81% of the survey respondents have a debit card, 25.4% have used a mobile app to pay and almost 40% have used at least once PayPal to make an online purchase in the past 12 months.

Digitalisation has led to a proliferation of cashless or contactless payment methods driven by consumers and companies, both of whom want to be able to make payments quickly and safely and transfer funds around the world at no cost. Hence, the decision to invest in cryptocurrencies may be driven by consumer perception of other means of payments. These variables allow us to test whether the demand for cryptocurrencies is indeed driven by distrust in

[21] Table B1, in the Appendix, presents the main descriptive statistics with weights.

[22] There are no cryptocurrency owners who state that they do not know about cryptocurrencies.

[23] PayPal launched its own cryptocurrency service, allowing people to buy, hold and sell cryptocurrencies on its site and applications (BBC, 2020).

Table A1: Descriptive statistics (2019 wave)

Variable	Mean	Std. Dev.	Min.	Max.
Main outcome variables				
Ownership	0.014	0.118	0	1
Ownership-number	0.031	0.315	0	7
Knowledge	0.730	0.444	0	1
Knowledge-number	1.281	1.250	0	8
Digitalisation variables				
Having a debit card	0.815	0.388	0	1
Mobile app for payments	0.254	0.435	0	1
Usage of PayPal	0.391	0.488	0	1
Secur. and conv. variables				
Convenience of cash	3.994	1.140	1	5
Security of cash	2.685	1.551	1	5
Conv. of bank acc. number paym.	3.234	1.183	1	5
Sec. of bank acc. number paym.	2.828	1.283	1	5
Conv. of on. bank. bill payments	3.926	1.074	1	5
Security of on. bank. bill paym.	3.260	1.211	1	5
Sociodemographic variables				
Income	11.320	3.929	1	16
Education	3.407	1.119	1	5
Married	0.695	0.461	0	1
Age	52.981	15.298	18	109
Retired	0.255	0.436	0	1
Male	0.436	0.496	0	1
White	0.839	0.368	0	1

The final sample includes 3235 observations. Descriptive statistics are computed without using weights. Ownership (knowledge) captures whether an individual owns (recognises or knows) at least one of the following cryptocurrencies: Bitcoin, xrp, litecoin, ether, bitcoin cash, stellar, eos, or any other different cryptocurrency. Ownership-number (knowledge-number) stands for the number of different cryptocurrencies that a person owns (recognises or knows).

cash or the financial industry. In the SCPC, respondents classify the security and convenience of cash, bank account number payments and online banking bill payments into five categories respectively: 1 – very inconvenient/risky, 2 – inconvenient/risky, 3 – neither inconvenient nor convenient/risky nor secure, 4 – convenient/secure, 5 – very convenient/secure. In all cases, the average ranges from around 2.7 to 4.

Regarding the socioeconomic indicators included in the analysis, the average income category is 11.3. Household income is divided into sixteen categories (see Table C1 in the Appendix). Category 11 corresponds to a level of household income between $40,000 and $49,999. The average educational attainment of the 2019 sample is 3.4. Educational attainment was divided into 16 categories in the 2018 and 2019 survey waves. However, since it was divided into just five categories in the 2014–17 waves, we transform the 16 categories into five (see Table C2). The variable "married" represents current marital status. It takes a value of 1 if the respondent is married and a value of 0 if the respondent is separated, divorced or widowed or never married. In the sample, 43.6% of individuals are men; the average age is close to 53; 25.6% are retired; and 83.8% are white.

4.3 Methodology

In order to corroborate or disprove the hypothesis that cryptocurrencies are sought after as an alternative to fiat currencies or regulated finance, as well as to study the socioeconomic characteristics of US retail cryptocurrency investors, we employ the standard linear probability model (LPM):

$$Y_{i,t} = \beta_0 + \beta_1 D_{i,t} + \beta_2 S_{i,t} + \beta_3 X_{i,t} + \epsilon_{i,t} \tag{4.1}$$

where $Y_{i,t}$ is a categorical variable that takes the value 1 if individual i owns (recognises) at least one cryptocurrency in the year t, and 0 otherwise. $D_{i,t}$ is a vector of digitalisation variables at individual level in year t. $S_{i,t}$ is a vector of security and convenience variables at individual level in year t. $X_{i,t}$ is a vector of socioeconomic variables at the individual level that includes gender, age, level of education, income, race and marital status in year t. Finally, standard errors are clustered by individual.

In the cases in which the outcome of interest is a count variable that takes nonnegative integer values 0, 1, 2, 3, ..., i.e., the number of known or owned cryptocurrencies, a standard count model is applied.

Since the outcome of interest is nonnegative, we need to specify our object of interest, $E(Y_{i,t}|W_{i,t})$, by means of a function that guarantees nonnegative values.[24] The simplest model in this context is the Poisson model, which models the conditional mean through the exponential function. However, once the goodness-of-fit chi-squared test is estimated[25], we conclude that the data do not fit the model well. Therefore, a negative binomial model is estimated.[26] The main difference between both models is that the negative binomial model relaxes the assumption of the equality of the conditional mean and the conditional variance. Let us consider the following specification for the conditional mean:

$$E(Y_{i,t}|W_{i,t}) = exp(\beta_0 + \beta_1 D_{i,t} + \beta_2 S_{i,t} + \beta_3 X_{i,t}) = exp(W_i'\beta) \tag{4.2}$$

The conditional variance is modelled as follows:

[24] Assume for simplicity that $W_{i,t} = \beta_0 + \beta_1 D_{i,t} + \beta_2 S_{i,t} + \beta_3 X_{i,t}$.

[25] The results of this test are available upon request.

[26] We have also performed a likelihood-ratio test comparing the Poisson model with the negative binomial model and, in all the cases, we reject the null hypothesis that states that there is no overdispersion.

$$V(Y_{i,t}|W_{i,t}) = exp(W_i'\beta) * (1 + \alpha \cdot exp(W_i'\beta)) \quad (4.3)$$

where α is the overdispersion parameter. The negative binomial model is estimated by maximum likelihood (ML) and average marginal effects are computed.

4.4 Empirical results

The main purpose of this paper is to analyse whether the demand for cryptocurrencies is indeed driven by distrust in cash or the financial industry, and to develop a socioeconomic profile of US retail cryptocurrency investors. The next sections aim at answering these research questions

4.4.1 LPM results

Initial results

Tables A2 and A3 show the econometric results of estimating Equation (4.1). In each column, we estimate the relationship between each independent variable and the main outcome variable (i.e., owning or recognising at least one cryptocurrency). Weights are included in all regressions.[27]

The first set of initial results (Table A2, upper rows) show that all the digitalisation variables have a positive impact on the likelihood of owning at least one cryptocurrency. Having a debit card, using a mobile app for payments and using PayPal increase the probability of investing into cryptocurrencies by 1.9, 3.5 and 2 percentage points, respectively. The findings also show that the demand for cryptocurrencies is not driven by distrust in cash or the financial industry, given that there are no differences in the perceived security of cash and offline and online banking. We can thus preliminarily argue that there is no evidence about the hypothesis that cryptocurrencies are sought as an alternative to fiat currencies or regulated finance. However, compared with non-owners, cryptocurrency owners tend to find both cash and traditional banking services less convenient, although this is not the case for online banking.[28]

We also show the correlation between payment experience and level of knowledge about cryptocurrencies. We find that the level of digitalisation increases knowledge about cryptocurrencies by around 16–17 percentage points. Those who recognise at least one cryptocurrency find cash less secure. In other words, ceteris paribus, if a consumer considers cash to be one step higher in terms of the security scale, the probability of that consumer knowing about at least one cryptocurrency is 3.5 percentage points lower. That same consumer is also likely to consider paying bills via online banking more secure and paying bills via

[27]Survey weights are provided by the SCPC to generate population estimates.

[28]In order to purchase cryptocurrencies, investors need a mean of payment such as a debit or a credit card. In Appendix D, we restrict the sample to those individuals who are: (i) debit card adopters, and (ii) credit card adopters. Replicating columns 4-9 of Table A3, results are completely robust.

Table A2: Payment behaviour, cryptocurrency ownership and knowledge

	Debit	Mobile	PayPal	Cash		Trad. Bank.		Online Bank.	
				Conv.	Sec.	Conv.	Sec.	Conv.	Sec.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Owner.	0.019***	0.035***	0.019**	-0.007*	-0.001	-0.008***	-0.002	-0.001	-0.001
	(0.005)	(0.011)	(0.009)	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
R^2	0.003	0.015	0.005	0.004	0.000	0.006	0.000	0.000	0.000
Know.	0.158***	0.171***	0.171***	-0.007	-0.035***	-0.042***	-0.010	0.035***	0.024**
	(0.033)	(0.023)	(0.022)	(0.010)	(0.007)	(0.009)	(0.009)	(0.011)	(0.010)
R^2	0.017	0.030	0.034	0.000	0.014	0.012	0.001	0.007	0.004
Weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	3,235	3,235	3,235	3,235	3,235	3,235	3,235	3,235	3,235

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual. Constant included but not reported. Owner. (know.) captures whether an individual owns (knows or recognises) at least one cryptocurrency. Debit stands for having a debit card; Mobile: Using of mobile app for payments. Trad. Bank.: bank account number payments; Online Bank.: online banking bill payments. Conv. and Sec. stand for convenience and security respectively.

online banking more convenient.[29] These patterns are consistent with those observed among people who have security concerns around fiat money and so acquire information about cryptocurrencies, but ultimately decide not to invest in them.

Of course, broader socioeconomic characteristics matter as well when it comes to knowledge acquisition and investment decisions around cryptocurrencies. From Table A3, it can be derived that education, income, being a man and being married positively influence both knowing about and owning a cryptocurrency. However, being one year older (or being retired) has a negative significant effect only on owning a cryptocurrency. Race is uncorrelated with cryptocurrency ownership.

Payment behaviour and sociodemographics: joint regressions

Table A4 presents a new set of regressions that examine the partial effect of payment behaviour and broader sociodemographics. It shows the econometric results of estimating Equation (4.1) when the main outcome variable is owning at least one cryptocurrency. Since education and income are jointly influenced by an unmeasured third variable (latent variable), they are included separately in each regression. This is a way of dealing with the possible endogeneity problem.[30] In

[29] Krombholz et al. (2017) present one of the first studies analysing how bitcoin users assess the bitcoin ecosystem in terms of privacy, anonymity and security.

[30] Table E1 presents the results of estimating Equation (4.1) with both income and education included at the same time. Results do not differ from those presented in Table A4.

Table A3: Sociodemographics and cryptocurrency ownership and knowledge

	Education (1)	Income (2)	Age (3)	Retired (4)	Married (5)	Male (6)	White (7)
Owner.	0.009***	0.002**	-0.001***	-0.020***	0.017***	0.023***	0.002
	(0.003)	(0.001)	(0.000)	(0.005)	(0.007)	(0.008)	(0.009)
R^2	0.007	0.004	0.010	0.004	0.004	0.008	0.000
Know.	0.110***	0.031***	-0.001	0.007	0.056**	0.114***	0.086**
	(0.010)	(0.003)	(0.001)	(0.027)	(0.025)	(0.023)	(0.029)
R^2	0.086	0.080	0.001	0.000	0.003	0.016	0.007
Weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	3,235	3,235	3,235	3,235	3,235	3,235	3,235

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual. Constant included but not reported. Owner. (know.) captures whether an individual owns (knows or recognises) at least one cryptocurrency.

addition, weights are included. Columns 1 and 2 present the main results excluding the payment behaviour indicators. Columns 3-4 and 5-6 present the outcomes including the digitalisation variables (i.e., having a debit card, usage of mobile app payments, and usage of PayPal) and the convenience and security variables respectively. Finally, columns 7 and 8 present the results with all variables included at the same time.[31]

Security concerns have no impact on cryptocurrency investments also conditioned on sociodemographic indicators. This highlights that the demand for cryptocurrencies is not driven by distrust in cash, traditional banking payments or online banking payments. Both having a debit card and having used a mobile app to make a payment in the last 12 months increase the probability of owning a cryptocurrency by 0.9 and 2.4-2.7 percentage points, respectively. Compared with non-owners, cryptocurrency investors tend to find traditional banking services less convenient. There are no differences with respect to cash and online banking payments.

[31] In order to test multicollinearity, we compute the Variable Inflation Factor (VIF) for the regressors in columns 7 and 8. The values of all variables lie in the (1, 2) interval.

Table A4: Ownership – payment behavior and sociodemographics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digitalisation variables								
Debit			0.009***	0.009**			0.010**	0.009**
card			(0.003)	(0.004)			(0.004)	(0.004)
Mobile			0.029***	0.026**			0.027***	0.024**
app			(0.010)	(0.010)			(0.010)	(0.010)
PayPal			0.007	0.009			0.007	0.008
			(0.008)	(0.008)			(0.008)	(0.008)
Convenience variables								
Cash					-0.006	-0.006	-0.005	-0.005
					(0.004)	(0.004)	(0.004)	(0.004)
Trad.					-	-0.006*	-0.006*	-0.006*
Banking					0.007**			
					(0.004)	(0.004)	(0.004)	(0.004)
Online					0.002	0.002	0.000	0.001
Banking					(0.004)	(0.004)	(0.004)	(0.004)
Security variables								
Cash					-0.000	0.000	0.000	0.000
					(0.003)	(0.003)	(0.003)	(0.003)
Trad.					0.001	0.000	0.001	0.001
banking					(0.005)	(0.005)	(0.005)	(0.005)
Online					-0.002	-0.000	-0.002	-0.001
Banking					(0.005)	(0.005)	(0.005)	(0.005)
Sociodemographic variables								
Educ.	0.009***		0.006*		0.008**		0.005*	
	(0.004)		(0.003)		(0.004)		(0.003)	
Income		0.002*		0.000		0.001		0.001
		(0.001)		(0.001)		(0.001)		(0.001)
Age		-		-		-		-
		0.001***		0.001***		0.001***		0.001**
		(0.000)		(0.000)		(0.000)		(0.000)
Married	0.014**	0.011	0.013**	0.012*	0.013**	0.010	0.012**	0.011*
	(0.006)	(0.007)	(0.006)	(0.007)	(0.006)	(0.007)	(0.006)	(0.007)
Male	0.022***	0.020***	0.022***	0.021***	0.022***	0.020***	0.022***	0.021***
	(0.008)	(0.007)	(0.008)	(0.007)	(0.008)	(0.007)	(0.008)	(0.007)
White	-0.000	-0.002	-0.001	-0.001	-0.001	-0.002	-0.001	-0.002
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.018	0.022	0.031	0.032	0.025	0.028	0.036	0.037
Obs.	3,235	3,235	3,235	3,235	3,235	3,235	3,235	3,235

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual. Constant included but not reported. Trad. Banking: bank account number payments. Online Banking: online banking bill payments.

Income level does not affect the main outcome variable of this specification. Each additional year of age reduces, on average, the probability of owning a cryptocurrency by 0.1 percentage points. In order to corroborate this result, Table F1, in Appendix F, reproduces Table A4, but instead of using the variable "age" it uses the variable "retired". "Retired" captures whether a person has withdrawn from active working life or not. Results show that being retired reduces the probability of owning a cryptocurrency, on average, by between 1 and 1.7 percentage points. Albert and Duffy (2012) show that older adults are more risk-averse than younger adults, having a lower expected utility from future income. The studies of Stix (2019) and Hundtofte et al. (2019) also support this finding. They argue that potential adopters of cryptocurrencies are younger and are more willing to accept financial risks. Analysing mortality beliefs, Heimer et al. (2019) estimate that older individuals place more weight on natural ageing, overestimating long-run survival rates. This reduces consumption and investment during retirement, in line with our results.

Being a man in the US increases, on average, the likelihood of owning at least one cryptocurrency by 2 to 2.2 percentage points.[32] As Jianakoplos and Bernasek (1998) document, there are gender differences in financial risk-taking. When it comes to holding risky assets, women tend to be more risk-averse than men and therefore are unlikely to trust digital currencies that are volatile. Related research by Borghans et al. (2009) and Arano et al. (2010) also support this finding. Gender differences also extend to a sector closely related to the cryptocurrency industry: the FinTech industry. Chen et al. (2021) find that men are more likely to use Fintech products and services than women. Being married seems to increase the likelihood of investing in cryptocurrencies as well.[33] On the contrary, race does not affect the probability of owning a cryptocurrency.

In contrast, the higher the educational attainment achieved by the individual, the more likely it is that that individual owns a cryptocurrency. This result is consistent with the findings of Black et al. (2018). They show that an extra year of education increases participation in financial markets, and therefore risk-taking, by 2 percentage points.

Drivers of knowledge acquisition: joint regressions

For the purpose of this study, it is essential to understand the impact of payment behaviour variables and socioeconomic characteristics on information and knowledge about cryptocurrencies. Table A5 shows the results of estimating Equation (4.1) when the main outcome variable is knowing about at least one cryptocurrency.

In this case, we find that all the digitalisation indicators are statistically significant, i.e. the digitalisation level increases the knowledge about

[32] This can be interpreted as the difference between 0.7% of female respondents and 2.9% of male respondents in the survey (Figure 4.8a).

[33] Although the relationship between risk aversion and marriage is not clear in the literature (see Outreville (2014)), the link between cryptocurrency ownership and being married deserves a further investigation with a richer sample.

cryptocurrencies. Those who recognise at least one cryptocurrency also find traditional banking payments less convenient and online banking bill payments more convenient than those who do not. While they also find cash less secure, there is no discernible effect found regarding their opinion of the safety of either traditional or online banking.

Moving from a lower category of education to a higher one increases the probability, on average, of recognising at least one cryptocurrency by around 8.7 to 11.1 percentage points.[34] Similarly, the higher the income level, the higher is the probability (from 2.3 percentage points to 3.1) of knowing about at least one cryptocurrency. On the other hand, current marital status (being married, separated, divorced or widowed or never having married) is not statistically significantly related to the dependent variable. Being a man in the US increases, on average, the probability of knowing about at least one cryptocurrency by between 9.6 and 12.1 percentage points. This result is in line with the study of Bannier et al. (2019). They highlight that men have a higher degree of knowledge regarding bitcoin than women. Age, however, is not a relevant factor in terms of knowing about at least one cryptocurrency. If "retired" is incorporated into the model instead of age, results coincide with the ones in the main regression (Table F2 in Appendix F).

Ownership conditioned on knowing about cryptocurrencies

Table A6 presents the results when we restrict the sample to those individuals that know about at least one cryptocurrency. The hypothesis that the demand for cryptocurrencies is driven by distrust in cash or the financial sector cannot be corroborated. Security concerns have no impact on cryptocurrency investment conditioned on knowing about cryptocurrencies. Education increases the likelihood of owning a cryptocurrency conditioned on knowing about at least one cryptocurrency. Nonetheless, becoming one year older decreases, on average, the likelihood of owning a cryptocurrency by 0.1 percentage points. These results are consistent with those presented in Table A4.

[34]The magnitude of the coefficients is generally larger in this section because of the percentage of individuals who know about cryptocurrencies is much larger than the percentage of owners.

Table A5: Knowledge – payment behavior and sociodemographics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digitalisation variables								
Debit card			0.079**	0.058*			0.075**	0.056*
			(0.032)	(0.032)			(0.031)	(0.032)
Mobile app			0.086***	0.095***			0.078***	0.087***
			(0.023)	(0.025)			(0.023)	(0.024)
PayPal			0.085***	0.098***			0.074***	0.084***
			(0.021)	(0.022)			(0.021)	(0.021)
Convenience variables								
Cash					0.010	0.003	0.016*	0.008
					(0.009)	(0.009)	(0.009)	(0.009)
Trad. banking					-0.044***	-0.052***	-0.040***	-0.049***
					(0.009)	(0.009)	(0.009)	(0.009)
Online Banking					0.040***	0.041***	0.032***	0.034***
					(0.011)	(0.011)	(0.011)	(0.011)
Security variables								
Cash					-0.026***	-0.024***	-0.023***	-0.022***
					(0.007)	(0.007)	(0.007)	(0.007)
Trad. banking					-0.008	-0.015	-0.006	-0.011
					(0.010)	(0.010)	(0.010)	(0.010)
Online Banking					0.017	0.019*	0.013	0.014
					(0.011)	(0.011)	(0.011)	(0.011)
Sociodemographic variables								
Educ.	0.111***		0.092***		0.101***		0.087***	
	(0.009)		(0.010)		(0.009)		(0.010)	
Income		0.031***		0.025***		0.028***		0.023***
		(0.003)		(0.003)		(0.003)		(0.003)
Age		-0.001		0.000		-0.000		0.001
		(0.001)		(0.001)		(0.001)		(0.001)
Married	0.022	-0.041	0.013	-0.036	0.016	-0.044*	0.009	-0.039*
	(0.024)	(0.025)	(0.023)	(0.024)	(0.023)	(0.024)	(0.023)	(0.023)
Male	0.117***	0.096***	0.121***	0.104***	0.118***	0.099***	0.120***	0.105***
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.021)	(0.022)
White	0.080***	0.038	0.074***	0.039	0.074***	0.034	0.068**	0.034
	(0.028)	(0.028)	(0.027)	(0.027)	(0.027)	(0.027)	(0.026)	(0.026)
Weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.111	0.094	0.136	0.120	0.136	0.124	0.156	0.143
Obs.	3,235	3,235	3,235	3,235	3,235	3,235	3,235	3,235

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual. Constant included but not reported. Trad. Banking: bank account number payments. Online Banking: online banking bill payments.

Table A6: Ownership conditional on knowing at least one cryptocurrency

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digitalisation variables								
Debit			0.015***	0.011**			0.015***	0.011**
card			(0.005)	(0.005)			(0.006)	(0.005)
Mobile			0.034***	0.029**			0.032***	0.027**
app			(0.013)	(0.013)			(0.012)	(0.012)
PayPal			0.010	0.012			0.010	0.011
			(0.010)	(0.010)			(0.010)	(0.010)
Convenience variables								
Cash					-0.008	-0.008	-0.006	-0.006
					(0.006)	(0.006)	(0.005)	(0.005)
Trad.					-0.009*	-0.008*	-0.008*	-0.007
Banking					(0.005)	(0.005)	(0.005)	(0.005)
Online					0.002	0.002	0.000	0.001
Banking					(0.005)	(0.005)	(0.005)	(0.005)
Security variables								
Cash					0.000	0.000	0.000	0.000
					(0.003)	(0.003)	(0.003)	(0.003)
Trad.					0.002	0.001	0.002	0.001
banking					(0.007)	(0.007)	(0.007)	(0.007)
Online					-0.003	-0.001	-0.003	-0.002
Banking					(0.006)	(0.006)	(0.007)	(0.006)
Sociodemographic variables								
Educ.	0.011**		0.007*		0.010*		0.006	
	(0.005)		(0.004)		(0.005)		(0.005)	
Income		0.001		0.000		0.001		0.000
		(0.002)		(0.002)		(0.002)		(0.002)
Age		-		-		-		-
		0.001***		0.001***		0.001***		0.001**
		(0.000)		(0.000)		(0.000)		(0.000)
Married	0.020**	0.020*	0.020**	0.022**	0.019**	0.019*	0.019**	0.020**
	(0.009)	(0.011)	(0.009)	(0.011)	(0.008)	(0.010)	(0.008)	(0.010)
Male	0.028***	0.025***	0.029***	0.028***	0.028***	0.026***	0.029***	0.027***
	(0.011)	(0.010)	(0.011)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
White	-0.002	-0.002	-0.001	-0.001	-0.001	-0.001	-0.000	-0.000
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.018	0.022	0.031	0.032	0.025	0.028	0.036	0.037
Obs.	2283	2283	2283	2283	2283	2283	2283	2283

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual. Constant included but not reported. Trad. Banking: bank account number payments. Online Banking: online banking bill payments.

4.4.2 Negative binomial model results

Tables A7 and A8 show the results of estimating Equation (4.2), when the main outcome variable is the number of cryptocurrencies owned and the number of cryptocurrencies known.

Table A7 reveals that, compared with non-owners, cryptocurrency investors show no differences in their level of security concerns with either cash or commercial banking services. These investors do find traditional banking services less convenient, results that are consistent through the whole study. Nevertheless, educational attainment does not play a role here and income level is not statistically significant when the digitalisation variables are included in the model. With each increasing year of age, the difference in the logs of expected counts would be expected to decrease by 0.002–0.003 units, while holding the other variables in the model constant. This result is in line with the estimates of Stix (2019). The difference in the logs of expected counts is expected to be 0.068–0.106 units higher for males compared with females, while holding the other variables constant in the model. Gender differences in financial risk-taking (Jianakoplos and Bernasek, 1998; Borghans et al., 2009; Arano et al., 2010; Chen et al., 2021) are also present in this case. Being married compared with being single, divorced or widowed also positively affects the main variable of interest.

Table A8 exhibits results in line with the outcomes presented in Table A5. Its interpretation is as follows: if an individual had achieved one extra level of education, the difference in the logs of expected counts would be expected to increase by around 0.22–0.29 units, while holding the other variables in the model constant. Moreover, being in a higher category of income increases the difference in the logs of expected counts by 0.05–0.07 units. The relationship between the number of known cryptocurrencies and age is negative. The difference in the logs of expected counts is expected to be 0.49–0.56 units higher for males compared with females, while holding the other variables constant in the model. Marital status and race are not relevant factors.

Table A7: Number of owned cryptocurrencies (negative binomial model)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digitalisation variables								
Debit card			0.106*	0.078			0.100	0.070
			(0.057)	(0.051)			(0.062)	(0.057)
Mobile app			0.066**	0.050*			0.065**	0.052**
			(0.029)	(0.028)			(0.028)	(0.023)
PayPal			0.054	0.050*			0.057	0.047*
			(0.035)	(0.028)			(0.038)	(0.028)
Convenience variables								
Cash					-0.017**	-0.017*	-0.012	-0.013
					(0.008)	(0.008)	(0.008)	(0.008)
Trad. banking					-0.021***	-0.016**	-0.022**	-0.017**
					(0.008)	(0.008)	(0.010)	(0.009)
Online Banking					0.006	0.007	0.003	0.005
					(0.012)	(0.010)	(0.012)	(0.011)
Security variables								
Cash					0.010	0.010	0.011	0.011
					(0.008)	(0.009)	(0.010)	(0.010)
Trad. banking					0.010	0.012	0.008	0.010
					(0.010)	(0.010)	(0.010)	(0.010)
Online Banking					-0.004	-0.006	-0.008	-0.008
					(0.008)	(0.009)	(0.011)	(0.010)
Sociodemographic variables								
Educ.	0.021*		0.005		0.027**		0.013*	
	(0.011)		(0.012)		(0.013)		(0.009)	
Income		0.007**		0.002		0.009*		0.005
		(0.003)		(0.003)		(0.005)		(0.004)
Age		-0.003***		-0.002**		-0.003***		-0.002**
		(0.001)		(0.001)		(0.001)		(0.001)
Married	0.058**	0.067**	0.066**	0.072**	0.052***	0.060**	0.062**	0.066**
	(0.023)	(0.027)	(0.030)	(0.031)	(0.020)	(0.024)	(0.028)	(0.027)
Male	0.068**	0.072**	0.098**	0.090**	0.079**	0.085***	0.106**	0.100***
	(0.031)	(0.031)	(0.041)	(0.035)	(0.038)	(0.033)	(0.043)	(0.038)
White	0.007	0.009	0.022	0.025	0.003	0.001	0.018	0.016
	(0.018)	(0.020)	(0.022)	(0.023)	(0.020)	(0.021)	(0.022)	(0.021)
Weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo-R^2	0.053	0.086	0.101	0.116	0.077	0.106	0.117	0.131
Obs.	3,235	3,235	3,235	3,235	3,235	3,235	3,235	3,235

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual. Constant included but not reported. Trad. Banking: bank account number payments. Online Banking: online banking bill payments.

Table A8: Number of known cryptocurrencies (negative binomial model)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digitalisation variables								
Debit card			0.245**	0.191*			0.243**	0.189*
			(0.116)	(0.111)			(0.112)	(0.108)
Mobile app			0.388***	0.352***			0.374***	0.341***
			(0.077)	(0.079)			(0.077)	(0.079)
PayPal			0.229***	0.260***			0.205***	0.233***
			(0.070)	(0.071)			(0.071)	(0.073)
Convenience variables								
Cash					-0.007	-0.015	0.018	0.005
					(0.029)	(0.029)	(0.028)	(0.029)
Trad. banking					-0.113***	-0.114***	-0.097***	-0.104***
					(0.031)	(0.031)	(0.032)	(0.032)
Online Banking					0.075**	0.077**	0.051	0.057*
					(0.034)	(0.034)	(0.034)	(0.034)
Security variables								
Cash					-0.083***	-0.075***	-0.077***	-0.073***
					(0.021)	(0.022)	(0.021)	(0.021)
Trad. banking					0.005	-0.020	0.011	-0.011
					(0.037)	(0.036)	(0.036)	(0.036)
Online Banking					0.020	0.038	0.010	0.023
					(0.040)	(0.039)	(0.040)	(0.040)
Sociodemographic variables								
Educ.	0.293***		0.225***		0.271***		0.215***	
	(0.031)		(0.030)		(0.033)		(0.031)	
Income		0.073***		0.051***		0.067***		0.049***
		(0.014)		(0.013)		(0.014)		(0.013)
Age		-0.012***		-0.008***		-0.011***		-0.006***
		(0.002)		(0.002)		(0.002)		(0.002)
Married	-0.004	-0.119	-0.022	-0.101	-0.024	-0.136	-0.033	-0.115
	(0.077)	(0.088)	(0.074)	(0.086)	(0.075)	(0.087)	(0.073)	(0.085)
Male	0.555***	0.494***	0.556***	0.513***	0.559***	0.503***	0.557***	0.518***
	(0.076)	(0.073)	(0.073)	(0.071)	(0.075)	(0.072)	(0.072)	(0.071)
White	0.066	-0.016	0.056	-0.008	0.053	-0.024	0.042	-0.020
	(0.088)	(0.087)	(0.086)	(0.086)	(0.087)	(0.086)	(0.086)	(0.086)
Weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo-R^2	0.038	0.035	0.052	0.047	0.045	0.042	0.058	0.053
Obs.	3,235	3,235	3,235	3,235	3,235	3,235	3,235	3,235

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual. Constant included but not reported. Trad. Banking: bank account number payments. Online Banking: online banking bill payments.

4.4.3 Robustness checks

In the baseline specification (Equation (4.1)), a LPM was employed. One limitation of the LPM is that it does not impose any restriction on the probability. The inability to impose restrictions on the values of the regressors or the parameters means we could obtain estimated probabilities outside the unit interval. The logit model overcomes this limitation by modelling the probability as a cumulative distribution function that always lies in the [0,1] interval. Tables A9 and A10 reports the estimations using a logit model. As marginal effects are not constant, the average marginal effects are computed.

The main results are completely robust to the use of a logit model.[35] Overall, the findings in Table A9 suggest that we do not find evidence about that cryptocurrencies are sought as an alternative to fiat currencies or regulated banking. Cryptocurrency investors show no differences in their level of security concerns with either cash or commercial banking services. They also consider traditional banking services less convenient. Results highlight that being a digital native boosts the usage of cryptocurrencies. Education and being a man increase, on average, the probability of owning at least one cryptocurrency by 0.5 and 1 percentage points, respectively. On the contrary, becoming one year older decreases, on average, the likelihood of owning at least one cryptocurrency by 0.1 percentage points. Results in Table A10 are in line with those in Table A5.

4.4.4 Differences across cryptocurrencies

Are there differences in investor characteristics across groups of cryptocurrencies? This section starts by introducing the best-known cryptocurrencies. As Figure 4.3a shows, the most widely known cryptocurrency is bitcoin, followed by bitcoin cash and ether. Figure 4.3b depicts the percentage of owners classified by each kind of cryptocurrency in 2019. Bitcoin is the most widely owned cryptocurrency, with twice as many investors as is the case for ether. After ether, litecoin is the third most owned cryptocurrency.

So far, we have treated the owners of cryptocurrencies as if they were a uniform and homogeneous group of investors who share the same sociodemographic profile. Investor characteristics may, however, vary across groups of cryptocurrencies. Figure 4.3c shows that cryptocurrency owners are generally more educated than the average. Among the various cryptocurrencies, owners of xrp and ether are the most educated, while those owning litecoin are the least educated, with bitcoin owners ranking in the middle. Cryptocurrency owners have a household income level higher than the average, with owners of xrp, ether and stellar being the wealthiest (Figure 4.3d).

[35]In Appendix G, we control for potential rare event bias in the logit model. The sign and significance of the main variables of the logistic rare event regression à la King and Zeng (2001) are completely robust.

Table A9: Ownership - payment behaviour and sociodemographics (logit model)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digitalisation variables								
Debit card			0.031**	0.026*			0.031**	0.026*
			(0.015)	(0.015)			(0.015)	(0.015)
Mobile app			0.023***	0.019**			0.021**	0.017**
			(0.009)	(0.008)			(0.008)	(0.007)
PayPal			0.008	0.009			0.009	0.009
			(0.007)	(0.007)			(0.008)	(0.007)
Convenience variables								
Cash					-0.005*	-0.005	-0.004	-0.003
					(0.003)	(0.003)	(0.003)	(0.003)
Trad. banking					-0.007**	-0.006*	-0.006**	-0.006*
					(0.003)	(0.003)	(0.003)	(0.004)
Online Banking					0.002	0.002	0.000	0.000
					(0.003)	(0.003)	(0.003)	(0.003)
Security variables								
Cash					-0.001	-0.000	-0.001	-0.001
					(0.003)	(0.002)	(0.002)	(0.002)
Trad. banking					0.001	0.001	0.001	0.001
					(0.004)	(0.004)	(0.004)	(0.004)
Online Banking					-0.002	-0.002	-0.002	-0.001
					(0.004)	(0.004)	(0.004)	(0.004)
Sociodemographic variables								
Educ.	0.010**		0.006*		0.009**		0.005*	
	(0.004)		(0.004)		(0.004)		(0.004)	
Income		0.002		0.001		0.002		0.002
		(0.002)		(0.002)		(0.002)		(0.001)
Age		-0.001***		-0.001**		-0.001**		-0.001**
		(0.000)		(0.000)		(0.000)		(0.000)
Married	0.020*	0.024*	0.020*	0.024**	0.020*	0.023*	0.020*	0.023**
	(0.012)	(0.013)	(0.011)	(0.012)	(0.012)	(0.013)	(0.011)	(0.012)
Male	0.025**	0.025**	0.025**	0.025**	0.025**	0.024**	0.024***	0.024***
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.009)	(0.009)
White	-0.000	-0.003	0.001	-0.003	-0.000	-0.003	0.001	-0.002
	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)	(0.009)
Weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo-R^2	0.110	0.168	0.184	0.217	0.151	0.197	0.213	0.238
Obs.	3,235	3,235	3,235	3,235	3,235	3,235	3,235	3,235

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual. Constant included but not reported. Trad. Banking: bank account number payments. Online Banking: online banking bill payments.

Table A10: Knowledge - payment behaviour and sociodemographics (logit model)

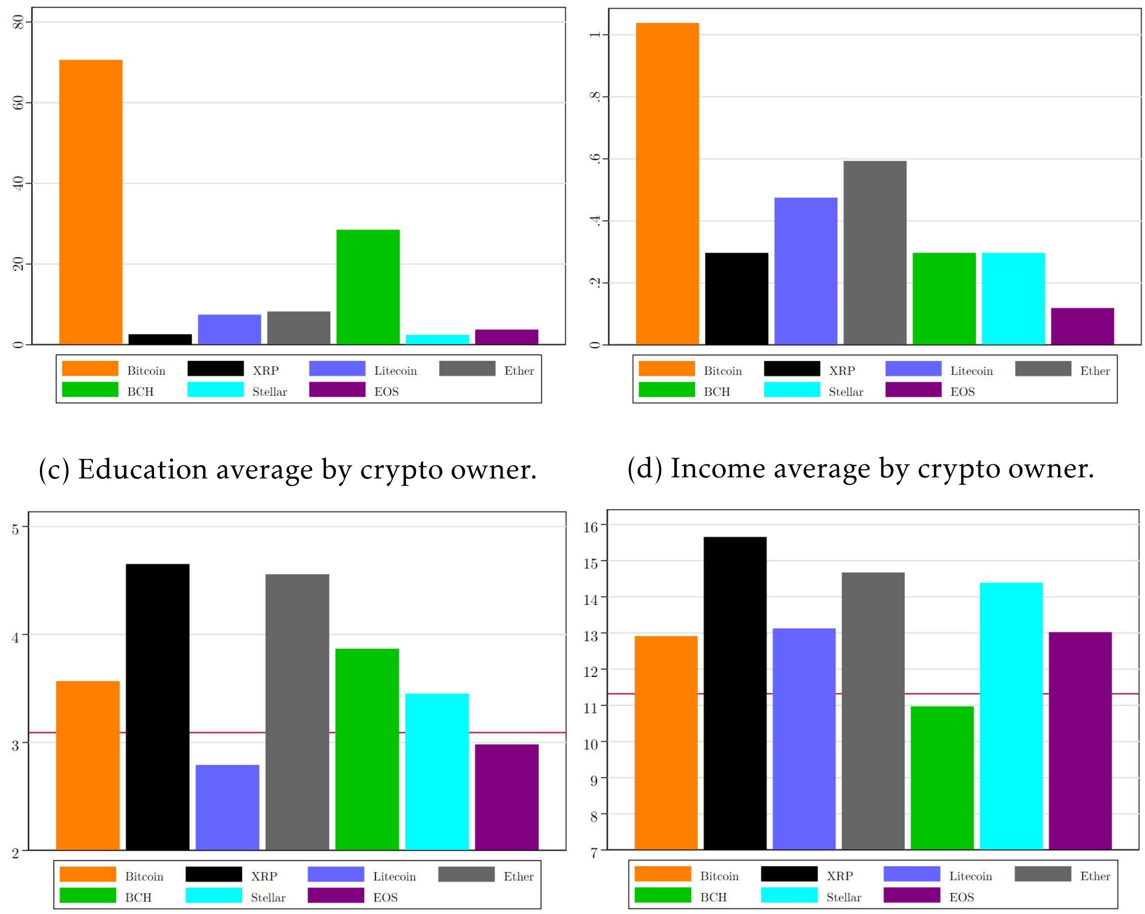
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digitalisation variables								
Debit card			0.066**	0.050*			0.064**	0.048*
			(0.027)	(0.028)			(0.026)	(0.027)
Mobile app			0.098***	0.107***			0.086***	0.094***
			(0.026)	(0.028)			(0.025)	(0.027)
PayPal			0.089***	0.102***			0.076***	0.087***
			(0.023)	(0.023)			(0.023)	(0.023)
Convenience variables								
Cash					0.010	0.002	0.015	0.007
					(0.009)	(0.009)	(0.009)	(0.009)
Trad. banking					-0.045***	-0.053***	-0.041***	-0.049***
					(0.010)	(0.010)	(0.009)	(0.010)
Online Banking					0.039***	0.040***	0.028***	0.032***
					(0.011)	(0.011)	(0.011)	(0.011)
Security variables								
Cash					-0.024***	-0.024***	-0.022***	-0.021***
					(0.007)	(0.007)	(0.007)	(0.007)
Trad. banking					-0.011	-0.017	-0.008	-0.013
					(0.011)	(0.010)	(0.011)	(0.010)
Online Banking					0.020*	0.022*	0.015	0.016
					(0.011)	(0.012)	(0.011)	(0.011)
Sociodemographic variables								
Educ.	0.110***		0.090***		0.098***		0.084***	
	(0.009)		(0.009)		(0.009)		(0.009)	
Income		0.028***		0.021***		0.025***		0.020***
		(0.002)		(0.003)		(0.002)		(0.003)
Age		-0.001		0.000		-0.000		0.001
		(0.001)		(0.001)		(0.001)		(0.001)
Married	0.023	-0.037	0.011	-0.035	0.016	-0.040*	0.006	-0.038*
	(0.023)	(0.024)	(0.022)	(0.023)	(0.022)	(0.023)	(0.022)	(0.023)
Male	0.118***	0.095***	0.122***	0.104***	0.118***	0.100***	0.120***	0.105***
	(0.022)	(0.022)	(0.021)	(0.022)	(0.021)	(0.022)	(0.021)	(0.021)
White	0.076***	0.035	0.066***	0.034	0.069***	0.030	0.060**	0.029
	(0.026)	(0.026)	(0.025)	(0.026)	(0.025)	(0.025)	(0.025)	(0.025)
Weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pseudo-R^2	0.097	0.077	0.121	0.102	0.121	0.104	0.139	0.124
Obs.	3,235	3,235	3,235	3,235	3,235	3,235	3,235	3,235

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual. Constant included but not reported. Trad. Banking: bank account number payments. Online Banking: online banking bill payments.

Figure 4.3: Knowledge and owners by group of crypto (2019).

(a) Recognising crypto (in %). (b) Cryptocurrency owners (in %).

(c) Education average by crypto owner. (d) Income average by crypto owner.



Source: 2019 SCPC.
Note. In panels (c) and (d), the brown line represents the average income and education for all individuals (see Appendix C, Tables C1 and C2 for the household income and educational attainment classifications respectively). Survey weights are included.

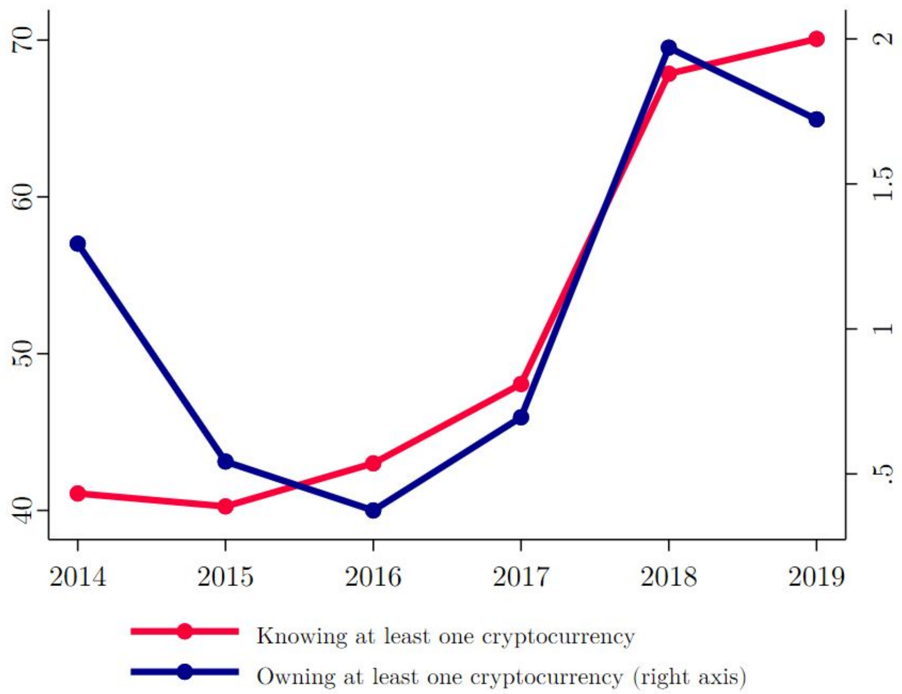
4.5 Trends in and outlook for the cryptocurrency industry

What do the findings of this study imply for the future of the cryptocurrency industry? We discuss whether cryptocurrencies are likely to attract new investors in the future and whether they may retain their existing ones. We also discuss trends in the socioeconomic characteristics of cryptocurrency investors.

4.5.1 Attracting new investors

While knowledge about cryptocurrencies is becoming pervasive, ownership remains limited to a niche population. In 2014 only some 40% of US citizens were aware of at least one cryptocurrency (mainly bitcoin). This percentage increased to almost 70% in 2019 (see Figure 4.4). If the trend continues, in one or two years the entire US population will recognise at least one cryptocurrency. The acceptance and usage of cryptocurrencies are nonetheless not high. Only 1.4% of the US population owned at least one cryptocurrency in 2019.[36] The fraction of crypto-owners experienced a positive trend since 2016 with a slight decline in 2019.

Figure 4.4: Cryptocurrency facts



Source: SCPC.
Note. Survey weights are included.

Since knowledge about cryptocurrencies is already pervasive, it is not likely that significant numbers of new investors will be won over to the asset class via the route of new people learning about the topic. Figure 4.5 shows the amount of new weekly Twitter followers of some of the major cryptocurrency exchanges, such as Binance or Coinbase. There was a significant increase of Twitter followers at the end of the first bitcoin rush.[37] By the end of 2020, cryptocurrency exchanges were gaining some new followers, but not as much as during the last quarter of 2017 or the first quarter of 2018. It is likely that once a person follows one of these accounts, she is much more likely to show interest in a cryptocurrency and to invest in the future. Shen et al. (2019) show that the number of tweets concerning bitcoin can predict the next day's trading volume and volatility.

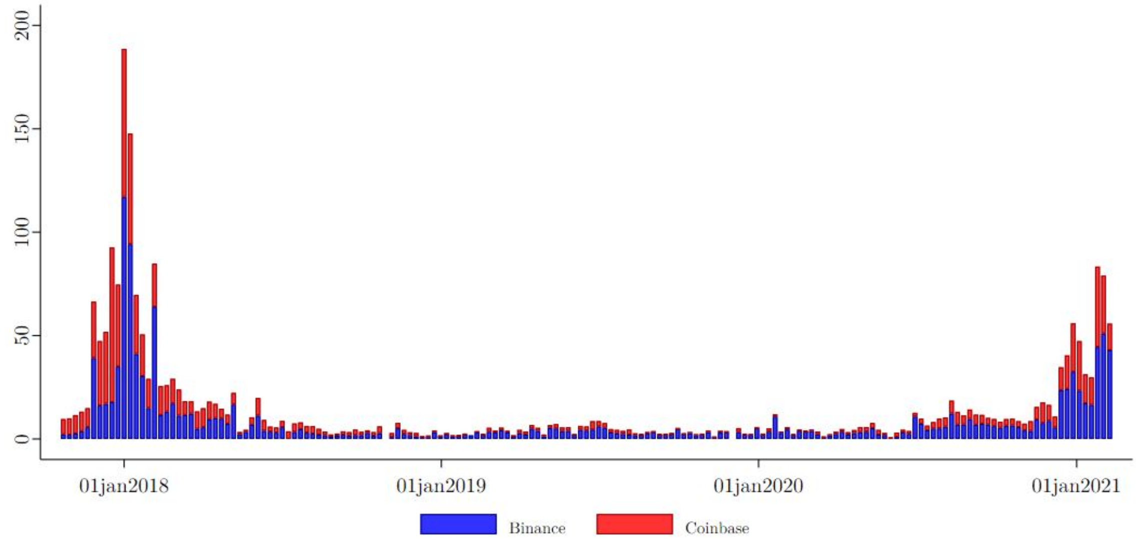
At the end of 2017, LendEDU launched two surveys[38] asking about bitcoin as an investment option. At the time, over 80% of respondents believed that bitcoin would be the largest cryptocurrency in terms of market capitalisation in five years (Figure 4.6a). Asked whether they would like to own bitcoin through futures

[36] This percentage is in line with that of other countries. For instance, Stix (2019) shows that about 1.5% of Austrians own crypto-assets.

[37] Note that it is possible to game this statistic by buying Twitter followers.

[38] Both surveys were answered by the same people, i.e., 564 Americans. See Gitlen (2017) for further details about the methodology of the survey.

Figure 4.5: New Weekly Twitter Followers of Cryptocurrency Exchanges



Source: Socialblade (retrieved from The Block).

contracts if that were possible, more than 40% of the respondents answered affirmatively, while around 34% were not sure (Figure 4.6b). As a result of the high volatility of bitcoin and other cryptocurrencies, the market for cryptocurrency futures contracts grew during 2020 as cryptocurrency investors started to make agreements to buy or sell a cryptocurrency at a later date for a fixed price. Concurrently, some regulatory agencies banned the sale of cryptocurrency derivatives and exchange-traded notes, arguing that these products pose harm and so are ill-suited for the average investor. The UK Financial Conduct Authority (FCA), for example, was the first agency to take such a step, banning the sale of cryptocurrency derivatives and exchange-traded notes.[39]

4.5.2 Retaining existing investors

One of the main features of the cryptocurrency market is its volatility. The price of cryptocurrencies can rise and fall dramatically in the course of a single day. Recognising that the market is prone to such swings, as well as manipulation, the "holding strategy" has evolved. Hodling means to buy a cryptocurrency and hold onto it for a prolonged time without any selling or trading activity. But what is the probability of hodling in the population we examine? To answer this question, we compute the likelihood that an individual that has a cryptocurrency one year continues being an owner the following year.[40] To do so, we estimate Equation (1) maintaining just those individuals that are repeated each two years in the SCPC.[41]

Figure 4.7 presents the estimated coefficients for the variable of owning at

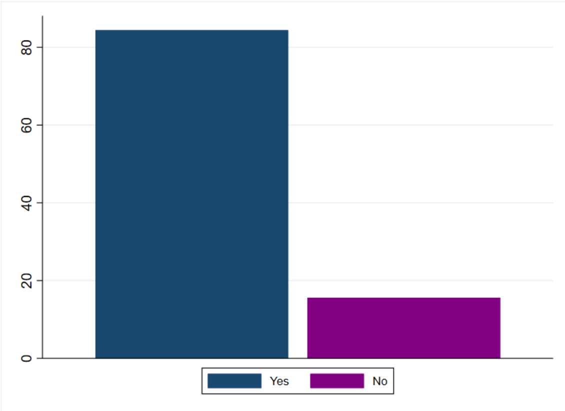
[39] For further information, see FCA (2020).

[40] This measure only captures one dimension of *hodling*. Investors might also increase or reduce the size of their position.

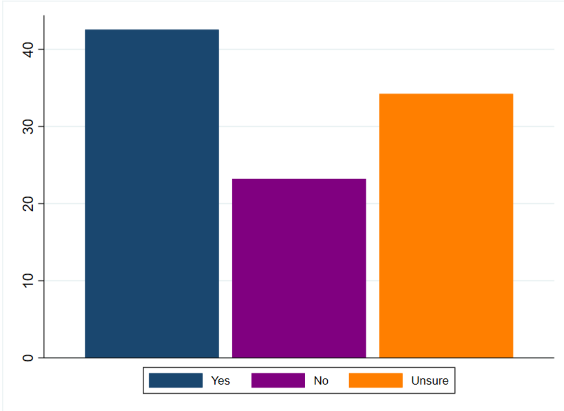
[41] For instance, if an individual responded to the 2014 survey but did not answer the 2015 wave, this observation is deleted.

Figure 4.6: Bitcoin's prospects

(a) In 5 years, will Bitcoin be the largest crypto in terms of market capitalization? (in %).



(b) If possible, would you rather own Bitcoin through futures contracts? (in %).



Source: Gitlen (2017).
Note: These questions belong to Part #2 of the survey conducted in November 2017, and correspond to questions 4 and 3, respectively.

least one cryptocurrency in the previous year.[42] Five regressions are performed. Results are as follows. The likelihood of owning a cryptocurrency in 2015 and 2016 is not affected by owning a cryptocurrency in 2014 and 2015 respectively.

Notwithstanding, owning a cryptocurrency in 2016, 2017 and 2018 increases the probability, on average, of owning a cryptocurrency in 2017, 2018 and 2019 by 61, 56 and 55 percentage points, respectively. In other words, those who invested in cryptocurrencies in the past are likely to remain invested.

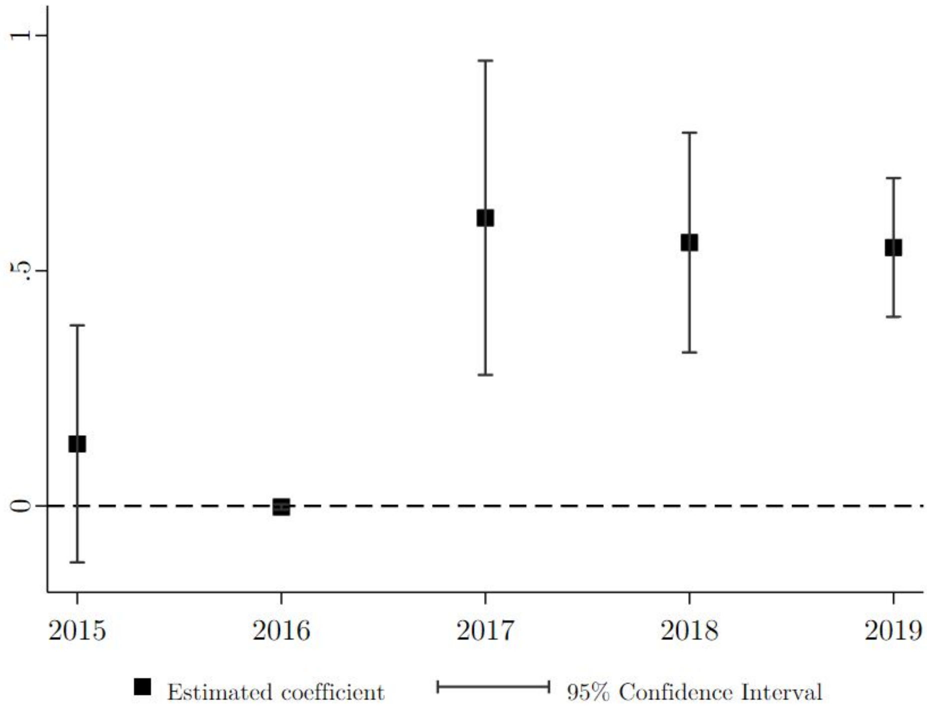
If this finding – that *hodling* has become more pervasive, remains constant in years to come, it may indicate a certain stabilisation in cryptocurrency markets since investors may be using this asset as a store of value rather than a speculative asset. This confirms concurrent work in the field of computer science Abramova et al. (2021), which identifies that the population of cryptocurrency users has grown out of the original group of tech-savvy "cypherpunks" into a heterogeneous community of individuals, including both professional and amateur investors (called "hodlers" and "rookies", respectively).

4.5.3 Trends in the gender and age gap

The impact of characteristics such as gender and age on cryptocurrency investments may be driven by preferences rather than differences in knowledge about the underlying technology. In terms of gender, the knowledge gap has decreased over time. In 2014 only 30% of women had knowledge of at least one cryptocurrency (the percentage was 50% for men), while in 2019 almost 65% of women (and 75% of men) recognised at least one cryptocurrency (Figure 4.8b).

[42]Figure H1 in the Appendix H shows the estimated coefficients and standard errors presented in Figure 7.

Figure 4.7: Estimated coefficients (LPM)



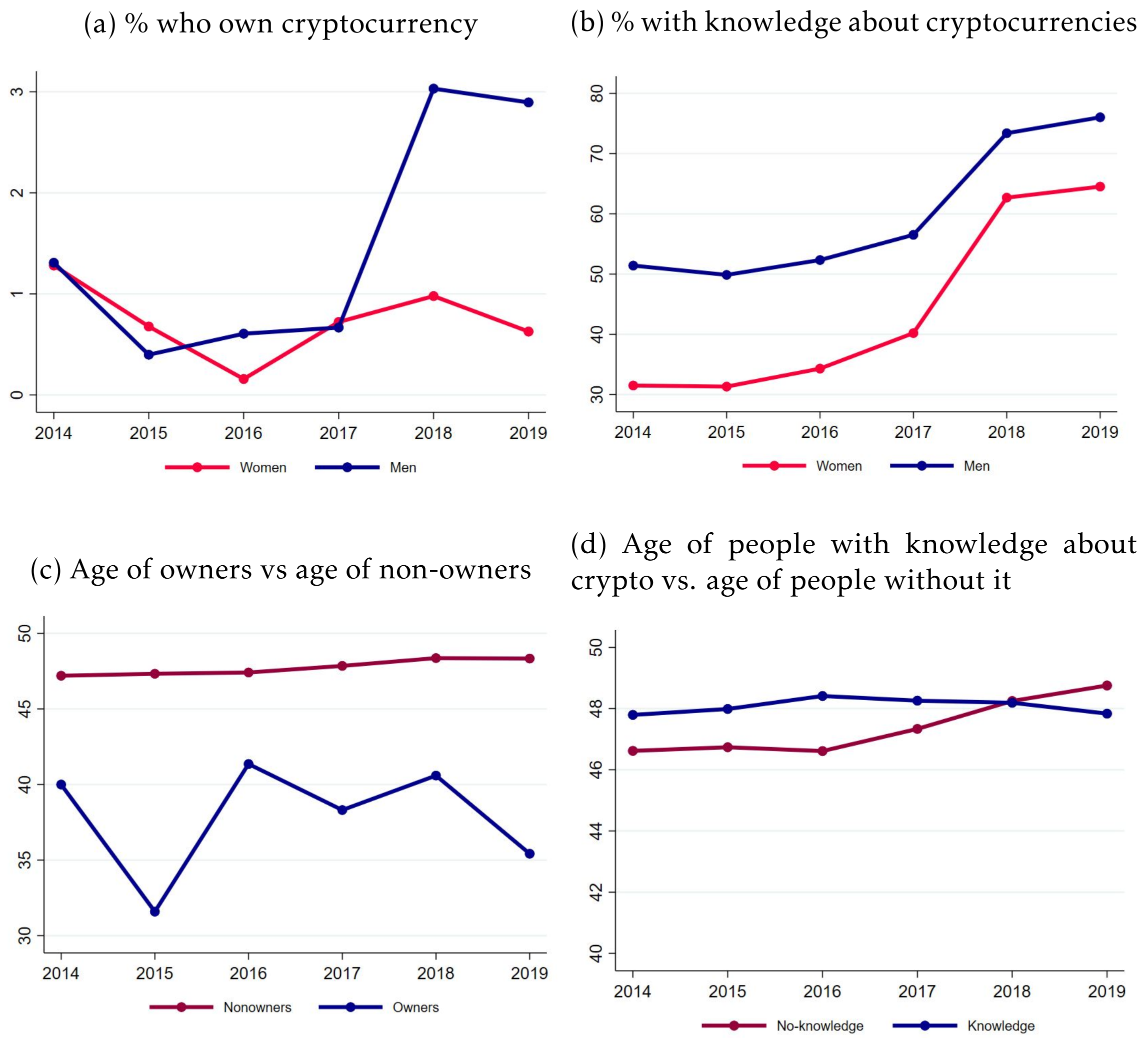
Source: Authors' elaboration.
Note: The regression of the 2014-2015 waves contains 900 repeated individuals. The 2015-2016, 2016-2017, 2017-2018 and 2018-2019 waves have 1013, 2575, 2526, 2652 repeated individuals respectively.

However, during that time, an ownership gap actually emerged, evidencing that preferences matter. As Figure 4.8a shows, whilst the percentage of male and female owners was pretty similar from 2014 to 2017, in 2018 a gender gap emerged.[43]

At the same time, Figure 4.8c presents the age profile of cryptocurrency users. Owners are younger, on average, than non-owners of cryptocurrencies. This has a strong effect on investment decisions. On the other hand, the age profile of those who recognise at least one cryptocurrency is similar to those who have not (Figure 4.8d). This evidences that differences in ownership across age are not driven by knowledge, but rather by preferences

[43]The gender gap is present not only in the cryptocurrency industry but also in the FinTech industry. Chen et al. (2021) find that only 21% of women use fintech products and services while 29% of men do.

Figure 4.8: Cryptocurrency trends (2014-19).



Source: 2019 SCPC.
Note. Survey weights are included.

4.6 Conclusion and policy implications

Providing an in-depth exploration of representative data on cryptocurrency owners, we do not find evidence about that cryptocurrencies are sought as an alternative to fiat currencies or regulated finance: compared with the general population, US cryptocurrency investors show no differences in their level of security concerns with either cash or commercial banking services. Nevertheless, we find that the segment of the population that is aware of or invests in cryptocurrencies finds traditional banking less convenient. This is in contrast with the difference among the levels of convenience of cash.

We also examine the underlying socioeconomic correlates of cryptocurrency investing. We find that men tend to invest more in cryptocurrencies than women. Furthermore, higher levels of income and education, and having digital financial experience (captured through having a debit card and using a mobile app to pay for products and/or services) increase the likelihood of recognising at least one cryptocurrency.

We show that these patterns are driven by the impact of socioeconomic features on knowledge about cryptocurrencies, but also on investment decisions conditional on knowledge about this asset class. Among the various cryptocurrencies, owners of ether and xrp have the highest income and educational levels, while those owning litecoin are the least educated. Last, we document that owning a cryptocurrency increases the probability, on average, of owning a cryptocurrency in one's portfolio the following year by more than 50%.

Finally, we provide some evidence that the impact of gender and age on cryptocurrency investment is unrelated to differences in knowledge about the underlying technology. For example, while knowledge levels have converged over the sample we observe, a gender gap in terms of ownership has emerged.

From a policy perspective, the overall takeaway of our analysis is that as the objectives of investors are the same as those for other asset classes, so should be the regulation.[44] Cryptocurrencies are not sought as an alternative to fiat currencies or regulated finance, but instead are a niche digital speculation object. A clarifying regulatory and supervisory framework for cryptocurrency markets may be beneficial for the industry. In fact, regulatory announcements have had a strong impact on cryptocurrency prices and transaction volumes (Auer and Claessens, 2019, 2020), and those pointing to the establishment of specific regulations tailored to cryptocurrencies and initial coin offerings are strongly correlated with relevant market gains.

Better regulation may also be beneficial – quintessential in fact – for the industry when it comes to the basic security model of many cryptocurrencies. This is so as the long-term viability of cryptocurrencies based on proof-of-work is questionable. Auer (2019a) shows that proof-of-work can only achieve payment security (i.e., finality) if the income of miners is high,[45] and it is questionable whether transaction fees will always be high enough to generate an adequate level of income to guarantee save transactions and rule out majority attacks. In the particular for the case of Bitcoin, the security of payments will decrease each time the "block subsidy" declines (Auer, 2020). Potential solutions[46] often involve

[44]Bouri et al. (2017) stress that although bitcoin was a poor hedge in the 2011-2015 period, it may be suitable for diversification purposes. In the same spirit, Corbet et al. (2018) find that cryptocurrencies may serve as diversification assets for investors in the short-term. Bonaparte (2021) argues that cryptocurrency investors consider cryptocurrencies as a portfolio diversification vehicle.

[45]See also Chiu and Koeppl (2017) and Budish (2018) for related arguments of the cost of decentralised trust, and Leshno and Strack (2020) for a generalization.

[46]Hasu et al. (2019) and Moroz et al. (2020) propose protocol-level changes, among others by increasing miner income or implementing double-spend counter-attacks. Other important platforms in the crypto sphere have already moved or are planning to move to proof-of-stake (Kim, 2021). One of the drawbacks of proof-of-stake is however that so called "long-run" attacks may occur.

some degree of institutionalisation, which in the long-run may require regulation or supervision. Unlike other financial assets, cryptocurrencies pose a significant risk as regards their potential use for money-laundering and terrorist-financing purposes. This may be due to the possibility of holding and transferring funds in a decentralized and anonymous manner. Although authorities globally have made significant progress incorporating anti-money-laundering (AML) and Countering Financing of Terrorism (CFT) rules with respect to cryptocurrencies in national legislations, further steps should be taken to close existing gaps in the regulation (FATF, 2014, 2020, 2021).[47]

In the light of these considerations, an important point regards how one could apply technology-neutral regulation to this asset class, while at the same time harnessing the potential of the technology itself in the supervision process. In this regard, one promising option that supervisory and regulatory agencies could pursue is "embedded supervision" (Auer, 2019b). By this, we understand implementing a supervisory framework for cryptocurrencies that allows for compliance to be automatically monitored by reading the market's ledger. The main aim is low-cost supervision of decentralised markets, which may be particularly relevant amidst recent deliberations of the need for adequate prudential oversight of the cryptocurrency industry (Basel Committee, 2019, 2021).

4.7 Appendix

This Appendix provides additional explanations, tables and figures that are also discussed in the paper.

Appendix A. Social networks move markets

A rumour that professional money managers and some hedge funds were shorting GameStop's shares spread on the forum Reddit in the mid of January 2021. Boosted by comments on WallStreetBets, a subreddit page where users discuss stock trading, a large number of online traders – and some hedge funds[48] – started to buy shares and stock options, increasing the price of GameStop's shares. GameStop's market capitalisation increased to over $22.6 billion from $5 billion, with the stock opening on 27 January at $354.83 a share. Many retail investors were using the American financial services firm Robinhood, which is used to trade stocks and exchange-traded funds through a mobile app. Robinhood, however, had to cease trading of GameStop's shares, as it was facing a $3 billion security demand by its clearing house NSCC amid a massive spike of trading activity and heightened price volatility (Kelly et al., 2021).[49]

[47] Coelho et al. (2021) map out regulatory approaches followed around the world in this respect.

[48] Some hedge funds have made profits of more than $700 million. See Chung (2021).

[49] See Jasinski (2021) for further details about all of the factors that led to Robinhood having to cease trading GameStop shares.

Appendix B. Descriptive statistics

Table B1 presents the main descriptive statistics with weights. In the SCPC, respondents were assigned post-stratified survey weights designed to align as much as possible the composition of the SCPC sample with that of the Current Population Study (CPS) (Foster et al., 2020).

Table B1: Weighted Descriptive statistics

Variable	Mean	Std. Dev.	Min.	Max.
Main outcome variables				
Ownership	0.017	0.131	0	1
Ownership-number	0.04	0.356	0	7
Knowledge	0.709	0.454	0	1
Knowledge-number	1.327	1.382	0	8
Digitalisation variables				
Having a debit card	0.826	0.379	0	1
Mobile app for payments	0.301	0.459	0	1
Usage of PayPal	0.379	0.485	0	1
Secur. and conv. variables				
Convenience of cash	3.945	1.172	1	5
Security of cash	2.733	1.554	1	5
Conv. of bank acc. number paym.	3.213	1.198	1	5
Sec. of bank acc. number paym.	2.836	1.304	1	5
Conv. of on. bank. bill payments	3.909	1.084	1	5
Security of on. bank. bill paym.	3.244	1.214	1	5
Sociodemographic variables				
Income	11.386	4.083	1	16
Education	3.111	1.209	1	5
Married	0.666	0.472	0	1
Age	48.218	16.824	18	109
Retired	0.195	0.396	0	1
Male	0.482	0.5	0	1
White	0.732	0.443	0	1

The final sample includes 3235 observations. Ownership (knowledge) captures whether an individual owns (recognises or knows) at least one of the following cryptocurrencies: Bitcoin, xrp, litecoin, ether, bitcoin cash, stellar, eos, or any other different cryptocurrency. Ownership-number (knowledge-number) stands for the number of different cryptocurrencies that a person owns (recognises or knows).

Appendix C. Income and education

Table C1 shows the household income classification. Table C2 depicts the educational attainment classification. Education was divided into 16 categories in the 2018 and 2019 waves. However, since it was divided into just five categories in the 2014–17 waves, we reduced it to five.

Table C1: Household income classification

Category	**Interval**	**Category**	**Interval**
1	Less than 5,000.	9	30,000 to 34,999.
2	5,000 to 7,499.	10	35,000 to 39,999.
3	7,500 to 9,999.	11	40,000 to 49,999.
4	10,000 to 12,499.	12	50,000 to 59,999.
5	12,500 to 14,999.	13	60,000 to 74,999.
6	15,000 to 19,999.	14	75,000 to 99,999.
7	20,000 to 24,999.	15	100,000 to 149,999.
8	25,000 to 29,999.	16	150,000 or more.

Source: 2014-19 SCPC.

Table C2: Educational attainment classification

Category	**Education level**
1	12th grade (no diploma) or less.
2	High school graduate - high school diploma or the equivalent.
3	Some college but no degree.
4	Associate degree in college (occupational/vocational program or) academic program or bachelors degree.
5	Master's degree, professional school degree or Doctorate degree.

Source: 2014-19 SCPC.

Appendix D. Ownership conditioned on having a debit - credit card

The most common and accepted payment methods to buy cryptocurrencies include debit cards, credit cards and bank transfers. As the SCPC allows us to restrict the sample to those individuals that are (i) debit card adopters and (ii) credit card adopters, we replicate columns 4–9 of Table A3 to assess whether our results are robust.

As Table D1 shows, compared with the general public, cryptocurrency owners show no differences in their level of security concerns with either cash or commercial banking services. Cryptocurrency investors find cash and traditional banking services less convenient. These results are consistent with those presented in Table A3 although the coefficients of cash convenience and traditional banking payments convenience are higher in magnitude.

Table D1: Ownership conditional on being a debit/credit card adopter

	Cash		Trad. Banking		Online Banking	
	Conv.	Sec.	Conv.	Sec.	Conv.	Sec.
	(1)	(2)	(3)	(4)	(5)	(6)
Debit card adopter						
Owner.	-0.008*	-0.001	-0.010***	-0.003	-0.003	-0.001
	(0.005)	(0.003)	(0.004)	(0.004)	(0.005)	(0.005)
R^2	0.005	0.000	0.007	0.001	0.000	0.000
Credit card adopter						
Owner.	-0.009*	-0.002	-0.011***	-0.002	-0.004	-0.001
	(0.005)	(0.003)	(0.004)	(0.005)	(0.005)	(0.005)
R^2	0.005	0.001	0.008	0.000	0.001	0.000
Weights	Yes	Yes	Yes	Yes	Yes	Yes
Obs.	2,636	2,636	2,636	2,636	2,636	2,636

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual. Constant included but not reported. Owner. captures whether an individual owns at least one cryptocurrency. Trad. Banking: bank account number payments; Online Banking: online banking bill payments. Conv. and Sec. stand for convenience and security respectively.

Appendix E. LPM with income and education

Table E1 and E2 present the results of the LPM with both income and education included at the same time. If these results are compared with those in Tables A4 and A5, they do not differ.

Table E1: LPM (ownership) with income and education

	(1)	(2)	(3)	(4)
Digitalisation variables				
Debit card		0.009**		0.009**
		(0.004)		(0.004)
Mobile app		0.024**		0.023**
		(0.010)		(0.009)
PayPal		0.007		0.006
		(0.008)		(0.008)
Convenience variables				
Cash			-0.005	-0.004
			(0.004)	(0.004)
Trad. Banking			-0.006*	-0.005*
			(0.004)	(0.004)
Online Banking			0.001	0.000
			(0.004)	(0.004)
Security variables				
Cash			0.000	0.000
			(0.003)	(0.003)
Trad. banking			0.001	0.001
			(0.005)	(0.005)
Online Banking			-0.001	-0.002
			(0.005)	(0.005)
Sociodemographic variables				
Education	0.008***	0.007**	0.007**	0.006*
	(0.003)	(0.003)	(0.003)	(0.003)
Income	0.000	-0.001	0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Age	-0.001***	-0.001***	-0.001***	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
Married	0.014*	0.014**	0.012*	0.013*
	(0.007)	(0.007)	(0.007)	(0.007)
Male	0.021***	0.022***	0.021***	0.021***
	(0.008)	(0.008)	(0.008)	(0.008)
White	-0.000	0.000	-0.000	-0.000
	(0.009)	(0.008)	(0.009)	(0.008)
Weights	Yes	Yes	Yes	Yes
R^2	0.015	0.029	0.023	0.034
Observations	3,235	3,235	3,235	3,235

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual. Trad. Banking: bank account number payments. Online Banking: online banking bill payments.

Table E2: LPM (knowledge) with income and education

	(1)	(2)	(3)	(4)
Digitalisation variables				
Debit card		0.054*		0.053*
		(0.032)		(0.031)
Mobile app		0.080***		0.075***
		(0.025)		(0.024)
PayPal		0.077***		0.068***
		(0.022)		(0.021)
Convenience variables				
Cash			0.010	0.014
			(0.009)	(0.009)
Trad. Banking			-0.046***	-0.044***
			(0.009)	(0.009)
Online Banking			0.035***	0.029***
			(0.011)	(0.011)
Security variables				
Cash			-0.023***	-0.021***
			(0.007)	(0.007)
Trad. banking			-0.008	-0.005
			(0.010)	(0.010)
Online Banking			0.014	0.010
			(0.011)	(0.011)
Sociodemographic variables				
Education	0.082***	0.073***	0.075***	0.068***
	(0.011)	(0.011)	(0.011)	(0.011)
Income	0.019***	0.015***	0.018***	0.014***
	(0.003)	(0.003)	(0.003)	(0.003)
Age	-0.001	0.000	-0.000	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Married	-0.019	-0.018	-0.023	-0.021
	(0.024)	(0.024)	(0.024)	(0.023)
Male	0.107***	0.113***	0.108***	0.112***
	(0.022)	(0.022)	(0.022)	(0.021)
White	0.056**	0.055**	0.050*	0.049*
	(0.027)	(0.027)	(0.027)	(0.027)
Weights	Yes	Yes	Yes	Yes
R^2	0.130	0.147	0.153	0.167
Observations	3,235	3,235	3,235	3,235

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual. Trad. Banking: bank account number payments. Online Banking: online banking bill payments.

Appendix F. Retired population

Table F1 estimates Equation (4.1). It reproduces Table A4 but instead of using the variable "age", it uses the variable "retired". "Retired" captures whether a person has withdrawn from active working life or not.

Results show that being retired reduces the likelihood of owning at least one cryptocurrency, on average, between 1 and 1.7 percentage points. The rest of the results are completely in line with those in Section 4.4.1.

Table F2 estimates Equation (4.1). As in the previous case, it reproduces Table A5 but instead of using the variable "age", it uses the variable "retired".

Results show that being retired does not affect the probability of recognising at least one cryptocurrency. The rest of the results are consistent with those presented in Section 4.4.1.

Appendix G. Logistic rare event regression.

Table G1 presents the outcomes of the logistic regression controlling for rare events à la King and Zeng (2001). The sign and significance of the main variables are completely consistent with those of the logistic regressions without applying the rare events correction.

Table F1: Owning at least one cryptocurrency

	(1)	(2)	(3)	(4)
Digitalisation variables				
Debit card		0.010**		0.010**
		(0.004)		(0.004)
Mobile app		0.029***		0.027***
		(0.011)		(0.010)
PayPal		0.009		0.008
		(0.008)		(0.008)
Convenience variables				
Cash			-0.006	-0.005
			(0.004)	(0.004)
Trad. Banking			-0.008**	-0.006*
			(0.004)	(0.003)
Online Banking			0.002	0.001
			(0.004)	(0.004)
Security variables				
Cash			-0.000	0.000
			(0.003)	(0.003)
Trad. banking			0.000	0.001
			(0.005)	(0.005)
Online Banking			-0.001	-0.002
			(0.005)	(0.005)
Sociodemographic variables				
Income	0.001	0.000	0.001	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Being retired	-0.018***	-0.010***	-0.015***	-0.008***
	(0.004)	(0.003)	(0.004)	(0.003)
Married	0.011	0.012*	0.010	0.011
	(0.007)	(0.007)	(0.007)	(0.007)
Male	0.020***	0.022***	0.020***	0.021***
	(0.007)	(0.007)	(0.008)	(0.008)
White	-0.002	-0.001	-0.002	-0.001
	(0.009)	(0.009)	(0.009)	(0.009)
Weights	Yes	Yes	Yes	Yes
R^2	0.015	0.029	0.023	0.034
Observations	3,235	3,235	3,235	3,235

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual. Trad. Banking: bank account number payments. Online Banking: online banking bill payments.

Table F2: Knowing at least one cryptocurrency

	(1)	(2)	(3)	(4)
Digitalisation variables				
Debit card		0.060*		0.058*
		(0.032)		(0.031)
Mobile app		0.100***		0.089***
		(0.024)		(0.023)
PayPal		0.099***		0.085***
		(0.022)		(0.021)
Convenience variables				
Cash			0.002	0.009
			(0.009)	(0.009)
Trad. Banking			-0.054***	-0.049***
			(0.009)	(0.009)
Online Banking			0.041***	0.033***
			(0.011)	(0.011)
Security variables				
Cash			-0.024***	-0.023***
			(0.007)	(0.007)
Trad. banking			-0.015	-0.011
			(0.010)	(0.010)
Online Banking			0.018	0.013
			(0.011)	(0.011)
Sociodemographic variables				
Income	0.031***	0.025***	0.028***	0.023***
	(0.003)	(0.003)	(0.003)	(0.003)
Being retired	0.009	0.045*	0.024	0.055**
	(0.026)	(0.026)	(0.025)	(0.026)
Married	-0.041	-0.035	-0.043*	-0.038
	(0.025)	(0.024)	(0.024)	(0.023)
Male	0.097***	0.105***	0.100***	0.106***
	(0.022)	(0.022)	(0.022)	(0.022)
White	0.037	0.037	0.032	0.031
	(0.028)	(0.027)	(0.027)	(0.026)
Weights	Yes	Yes	Yes	Yes
R^2	0.093	0.121	0.124	0.145
Observations	3,235	3,235	3,235	3,235

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual. Trad. Banking: bank account number payments. Online Banking: online banking bill payments.

Table G1: Ownership - Logistic rare events regression

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Digitalisation variables								
Debit card			1.361*	1.079			1.376*	1.110
			(0.761)	(0.828)			(0.779)	(0.824)
Mobile app			1.409***	1.167***			1.262***	1.031**
			(0.424)	(0.439)			(0.401)	(0.402)
PayPal			0.489	0.549			0.524	0.567
			(0.444)	(0.427)			(0.471)	(0.460)
Convenience variables								
Cash					-0.319*	-0.284	-0.220	-0.198
					(0.178)	(0.187)	(0.170)	(0.173)
Trad. Banking					-0.449**	-0.396**	-0.401**	-0.351
					(0.188)	(0.201)	(0.194)	(0.217)
Online Banking					0.089	0.099	0.008	0.009
					(0.192)	(0.189)	(0.189)	(0.193)
Security variables								
Cash					-0.049	-0.024	-0.040	-0.034
					(0.153)	(0.154)	(0.146)	(0.146)
Trad. banking					0.081	0.055	0.082	0.063
					(0.260)	(0.239)	(0.236)	(0.226)
Online Banking					-0.139	-0.111	-0.129	-0.092
					(0.266)	(0.256)	(0.251)	(0.239)
Sociodemographic variables								
Educ.	0.584***		0.375*		0.516**		0.330*	
	(0.195)		(0.202)		(0.204)		(0.208)	
Income		0.134		0.068		0.144*		0.087
		(0.093)		(0.095)		(0.087)		(0.085)
Age		-0.079***		-0.064***		-0.070***		-0.056***
		(0.020)		(0.021)		(0.020)		(0.021)
Married	1.106*	1.397*	1.153*	1.438**	1.149	1.316*	1.182*	1.366**
	(0.669)	(0.736)	(0.658)	(0.698)	(0.707)	(0.732)	(0.684)	(0.686)
Male	1.455***	1.486***	1.491***	1.531***	1.493***	1.459***	1.478***	1.466***
	(0.539)	(0.549)	(0.523)	(0.537)	(0.503)	(0.520)	(0.481)	(0.495)
White	-0.047	-0.221	0.028	-0.180	-0.028	-0.188	0.018	-0.148
	(0.553)	(0.561)	(0.552)	(0.554)	(0.535)	(0.536)	(0.534)	(0.547)
Weights	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual. Constant included but not reported. Trad. Banking: bank account number payments. Online Banking: online banking bill payments.

Appendix H. Owners over time

Table H1 shows the estimated coefficients and standard errors presented in Figure 4.7.

Table H1: Owners over time

	2015	2016	2017	2018	2019
Estimated coefficient	0.132	-0.002	0.612***	0.556***	0.549***
	(0.128)	(0.003)	(0.170)	(0.119)	(0.075)
R^2	0.039	0.014	0.169	0.142	0.418
Observations	900	1,013	2,575	2,526	2,652

Notes: ***, ** and * indicate 1%, 5% and 10% significance levels respectively. In parentheses are presented robust standard errors clustered by individual.

Chapter 5

Conclusions

This Ph.D. thesis studies three relevant topics in the current international financial context: the impact of non-standard monetary policies in banks' profitability, the effects of issuing an interest-bearing CBDC on financial stability and financial fragility and the purported motivation to invest in crypto-assets as well as the socioeconomic profile of cryptocurrency investors.

Related to nonstandard monetary policies, the aim is to understand whether the unprecedented measures carried out by the ECB have been harmful or beneficial to banks' profitability. The second chapter of the manuscript focuses on this issue employing data from Spanish commercial banks. Spain is highly dependent of its traditional financial intermediation system. Using a wide variety of econometric techniques and controlling for individual-specific factors and macroeconomic conditions, no effect of unconventional monetary policy measures deployed by the ECB on Spanish banks' profitability is found. This suggestive evidence may be explained by the different negative and positive contributions of these measures.

The major challenge that policymakers and academic scholars have faced over the years is to find a consensus of which non-standard monetary policy measures promote growth and foster inflation without damaging the banking sector. The second chapter of this thesis has contributed to the debate. The neutral result found is in line with previous related literature (see Altavilla et al. (2018)). In addition, unconventional monetary policies are expected to be utilized in the near future so understanding their impact in all the economic agents and sectors seems to be fundamental issue.

The introduction of a CBDC will be a disruption in the current monetary landscape. It will imply, among other things, that central banks have to extend their role far beyond its present functions. The third chapter of this doctoral dissertation studies the effects of introducing an interest-bearing CBDC on financial stability. To look at this, I develop a tractable Diamond and Dybvig (1983) model with the features of a modern monetary system. The results show the interest rate of deposits offered by commercial banks will react directly depending on the CBDC interest rate. In addition, the interest rate and the supply of a CBDC have an impact on the loan rate. Also, it is shown that allowing a high supply of CBDC is a necessary condition to achieve both financial stability and seigniorage revenues. Hence, issuing a CBDC imposes an additional constraint that may endanger financial stability.

The results are meaningful. First, to the best of my knowledge, no research article has analysed how introducing a central bank-issued digital currency will affect financial stability and financial fragility in an environment where both public digital money and private bank deposits are used in exchange and money is created endogenously. Capturing the real features of a modern monetary system seems extremely important. Second, I have shown that allowing a high supply of CBDC is a necessary condition to achieve both financial stability and seigniorage revenues.

At the time of writing these lines, only two countries and one monetary union have officially issued a sort of CBDC: The Bahamas, the Eastern Caribbean Currency Union and Nigeria. However, there is no public data about the current effects of the CBDC in the financial and banking sectors. Once enough data is available, an empirical exercise can be performed in order to partially test the results of chapter 3. It is, therefore, an avenue for further research.

The fourth chapter of the thesis explores whether cryptocurrency investors are motivated by distrust in fiat currencies or regulated finance. Trust is at the heart of the financial system (Carstens, 2018b), and lack of trust has been associated with limited stock-market participation (Guiso et al., 2008). It is hence crucial to understand whether the continued rise of cryptocurrencies could indicate rising distrust in today's regulated financial markets and monetary arrangements.

Bitcoin and altcoins have become more and more popular over time, with a growing number of users in the recent years. In fact, their quicksilver nature has not prevented possible users from showing interest. Investor interest, both institutional and retail, has risen in last years despite the dizzying price swings. Using data from the Survey of Consumer Payment Choice provided by the Federal Reserve Bank of Atlanta, we find that investors show no differences from the general population in their level of security concerns about either cash or commercial banking services. Cryptocurrencies have not succeeded as a mean of payment yet. Instead, they have been kept by users as a speculative asset in search for yield.

We also report that cryptocurrencies remain niche markets dominated by young male educated investors. In fact, one of the main socioeconomic determinants of US cryptocurrency investors is educational attainment. While other segments of the population get information about this asset class, they do not ultimately invest in it in the same proportion as young male educated users. We also disentangle the role of knowledge acquisition and cryptocurrency investment decisions conditional on knowledge. Finally, we examine the evolution of patterns of cryptocurrency investments across time and cryptocurrencies.

The popularity of cryptocurrencies have led to the creation of many alternatives that allow users to use their cryptocurrencies easily and freely. This chapter may help the society to better understand the profile of the average cryptocurrency user and observe the changes in the consumption habits of the new generation that will lead the financial revolution. However, some questions remain unanswered. Traditional and superficial data of cryptoassets suggest that they are growing very rapidly. This exponential growth may pose financial stability risks in a largely unregulated space. Nevertheless, to what extent can trust these numbers? Do we really know the economic significance of cryptocurrencies? There are ample doubts that actual public trading numbers can be trusted. This leaves an avenue open for further research. Better understanding of the real significance of cryptocurrencies may be quintessential for the industry in general, and for users in particular.

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