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by Edoardo Rainone

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CURRENCY DEMAND AT NEGATIVE POLICY RATES

by Edoardo Rainone*

Abstract

Following the implementation of negative policy rates, interest rates on bank deposits reached historic lows, with values close or equal to zero. This paper investigates the implications of this new environment for currency demand. We find evidence of a structural break in demand for currency when rates on deposits fall below 0.1 per cent. Exploiting time, bank and banknote denomination variations, as well as exogenous reforms that affected currency payments and holdings, our analysis finds that the increase of currency in circulation appears to be mostly driven by transactions rather than by store-of-value demand.

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1 Introduction[1]

After decades of decline following the end of World War II, the recent increase in the demand for currency in many advanced economies is puzzling economists, especially in light of the parallel spread of digital payments.[2] One potential explanation is the lowest level ever reached by short term nominal interest rates, which turned negative in some countries.[3]

Since currency pays a zero nominal gross return, economists have long assumed that nominal interest rates on other reserves of value have a zero lower bound (ZLB, Hicks, 1937). Taking into account also the costs associated with holding currency, its net return is slightly negative, and instead of talking of ZLB today central banks refer to the effective lower bound (ELB) on nominal interest rates. Indeed, the central banks of Switzerland, Denmark, Sweden and the Eurosystem adopted negative policy rates in recent years, showing that the negative interest rate policy (NIRP) could be part of the standard toolkit of central banks (Cœuré, 2016; Mersch, 2019).[4]

Despite the relevance of estimating the effect of NIRP on currency demand, formal empirical analysis is still scant. The reason is twofold. First, there are few monetary systems that adopted negative interest rates in a relatively short observation period. Second, currency demand is difficult to measure at a frequent and disaggregated level.

This paper contributes in this direction by studying how the demand for currency reacts

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[2]See Jobst and Stix (2017) and Ashworth and Goodhart (2020) for studies on the recent trends of currency demand across advanced economies and Bech et al. (2018) for a cross-country comparison of the demand for currency and cashless payments. Remarkable exceptions are Sweden and Norway, where currency in circulation is still declining.

[3]See Del Negro et al. (2019) for a study on the global trends in interest rates.

[4]See Rognlie (2016) for a theoretical model of optimal monetary policy under negative interest rate for currency and Witmer and Yang (2015) for an estimate of the negative rate of currency in Canada. A non exhaustive list of papers that look at what kind of policies may overcome the lower bound problem include Krugman et al. (1998), Eggertsson and Woodford (2003) Buiter (2009), Goodfriend (2000), Buiter and Panigirtzoglou (2003), Mankiw (2009), Rogoff (2015), Rognlie (2016).

to the introduction of negative policy rates. Specifically, we want to answer the following questions. Is the renewed demand for currency driven by the unprecedented low level of interest rates? During the last decade, nominal rates reached their historic lows, and banks set deposit rates at or very close to zero. Have the public reacted differently to changes in interest rates in this new domain, holding more currency? Is there a structural break in the demand for currency when policy rates approach or break the ZLB? A significant shift from commercial bank deposits to central bank liabilities can have financial stability implications. On the one hand, it could impact retail funding and profitability of commercial banks, and potentially interest rates on bank loans and credit to the real economy. On the other hand, higher demand for currency changes the composition of the central bank's liabilities, eventually increasing their size, which in turn affects the asset side and its risk exposure. Studying currency demand in this new domain is useful for understanding what the limit may be below which the costs in terms of financial stability may become too high and the effectiveness of conventional monetary policy significantly reduced. Given that the amount of deposits used for transactions is different from the amount used for storing value, the decrease of deposits can vary significantly depending on which type of deposit is converted in currency. Understanding whether the demand features a structural change and if it is driven mostly by transactions or store-of-value purposes is key to evaluate the amount of deposits that is at risk when policy rates approach the ELB, but how can we assess these two different types of demand?

To answer these questions, we study the demand for currency in Italy, a country that is particularly well suited for the task. The use of currency for payments is intense and comparable to other developed countries, like Germany and Japan,[5] and, as part of the Eurosystem, negative policy rates were introduced in 2014.[6] To measure currency demand and understand its nature we use unique hard granular data on shipments of banknotes between the central bank and commercial banks. Differently from other available measurements, this granular information allows us to observe high frequency data on currency operations

[5]Currency usage in Italy is higher than US, UK and the majority of other European countries, see Esselink and Hernández (2017) for a study on the use of currency across Eurosystem countries.

[6]In June 2014 the overnight rate on reserves was set to -0.1, to then sequentially move to -0.2, -0.3 and -0.4 respectively in September 2014, December 2015 and March 2016.

by banknote denomination for each commercial bank. Combined with monthly information on variation of deposit rates across commercial banks over time, it proves fundamental to estimate the impact of NIRP on currency holdings and its drivers.

We find evidence of a discontinuity in the relationship between rates and currency holdings when the ELB is approached. More specifically, net withdrawals increase by about ten times when deposit rates fall below 0.10 per cent. Despite the significant increase in the marginal effect, when this threshold is crossed, the amount of additional currency issued remains limited. On average a reduction of 5 basis points in deposits rates of a bank from 0.15 to 0.10 implies that 0.16 per cent of its deposits are converted in currency. A reduction of 5 basis points from 0.05 to 0 implies a 1.7 per cent conversion.

To assess the role of store-of-value and transactions demand, we exploit variation in the holdings for different banknote denominations and two reforms that affected in different periods respectively the store-of-value and the transactions demand for currency, after the introduction of NIRP. In the first reform in 2015, the Italian government gave additional tools to the tax revenue agency. It allowed the agency to get detailed data on balances of bank accounts. After the reform, bank deposits thus became less appealing (for example for privacy and tax evasion reasons) than currency. Plausibly, this reform had a more prominent effect on the store-of-value demand. The second reform in 2016 increased the threshold for legal payments in currency from 1000 to 3000 euro. By directly changing the threshold for currency payments, it impacted mainly the transactions demand. We use the variation of net withdrawals by depositors of different banks before and after the two reforms to test whether transactions (or store-of-value) demand was higher for clients exposed to lower interest rates. We find that the higher demand below the estimated threshold is driven mostly by the demand of small banknotes, that are generally used for transactions and less efficient to store value. In addition, currency holdings increased significantly more for clients of banks with lower rates after the second reform, but not after the first. Taken together, our evidences suggest that transactions demand prevails over store-of-value demand, which reconciles with the relatively small increase of currency holdings observed.[7]

[7]We abstract from the distinction between pure transactions and precautionary demand, which is the holding of transaction funds for use if unexpected needs for immediate expenditure occur (see Alvarez and

The result can be rationalized by the behavior of agents stopping actively minimizing their currency inventory when rates are no longer significantly different from zero (Baumol, 1952; Tobin, 1956).[8] In the Tobin-Baumol model, transactions balances become more interest-elastic when rates increase. It means that when rates are higher agents optimize more intensively their currency inventory, which in turn decreases on average over time, *ceteris paribus*. On the contrary, when rates are low enough, the loss due to higher non-interest bearing inventory become negligible, eventually disappearing if rates are equal to zero. This mechanism could help explain the so-called *paradox of currency* whereby, even if the volume of transactions decreases, currency balances increase.[9]

From the policy maker's perspective, if data on deposits' rates and currency operations of commercial banks is readily available, the approach proposed here can be used as a tool to evaluate almost in real-time the effects of monetary policy (even in jurisdictions that did not implement NIRP), in particular how much the deposit facility rate can be lowered and its distance from the ELB.

This study complements the macro finance literature exploring cash holdings (including currency and deposits),[10] and informs the literature that studies the effects of low interest rates on banks' lending and profitability,[11] in particular that concerned with reversal rates and the retail deposit channel, by providing evidences and drivers of acceleration of currency conversion that reflects symmetrically on banks' deposits. In addition, it presents useful information for the literature related to the 'war on cash' and the policy debate on potential limitations of currency,[12] in particular the one arguing that the use of cash should be

Argente, 2021; Alvarez and Lippi, 2009, 2017; Frenkel and Jovanovic, 1980, among others).

[8]We refer to the transactions demand as defined in the Tobin-Baumol model, using deposit rates as in Alvarez and Lippi (2009). Our results, in line with the simple observation of currency in circulation in countries where interest rates are equal to zero, reject the assumption that currency demand goes to infinity when rates goes to zero.

[9]See for example Jiang and Shao (2020) for a discussion.

[10]See among others Gao et al. (2021), Azar et al. (2016), Mulligan (1997), Bover and Watson (2005) and Meltzer (1963) for a studies of corporate demand, and Mulligan and Sala-i Martin (2000), Attanasio et al. (2002) and Alvarez and Lippi (2009) for households demand.

[11]See Heider et al. (2019), Brunnermeier and Koby (2018), Eggertsson et al. (2017), Altavilla et al. (2021), Bottero et al. (2020), Bittner et al. (2020), Ulate (2019), Sims and Wu (2021), Repullo et al. (2020) and Lopez et al. (2020) among others.

[12]See Rogoff (2015), Rogoff and Rogoff (2017), Buiter and Panigirtzoglou (2003), Buiter (2009), Goodfriend (2000), Humphrey (2016), McAndrews (2020), Lastrapes (2018) and Garín et al. (2021) among others.

disincentivized so that central banks can set negative interest rates.

The rest of the paper is organized as follows. Section 2 provides some descriptive evidence on currency demand and interest rates in Italy. Section 3 details the setup of our econometric analysis. Section 4 describes the results for currency demand, while Section 5 reports our analysis on the transactions vs store-of-value demand. Section 6 concludes.

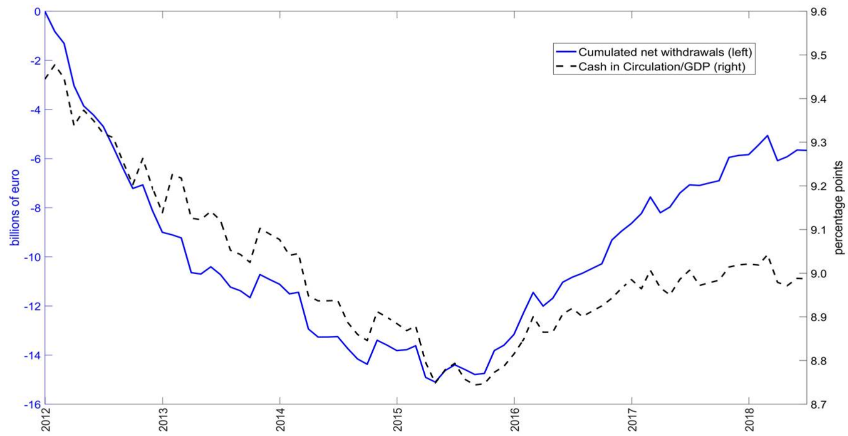
2 Descriptive Evidence

From 2012 to 2015 almost 15 billion euro of notes were deposited at the central bank while from the beginning of 2015 to June 2018 the Italian central bank issued about 10 billion euro of currency (Figure 1).[13] The change in the trend is dramatic and deserves investigation. A simplified counterfactual, which assumes that the trend until 2015 remained stable until 2018, tells us that an additional amount of currency of almost 30 billion euro, about 3 per cent of deposits, was withdrawn in these three years.[14]

[13] See Baldo et al. (2021) for a wide view on the main drivers of banknote circulation in Italy over the last decades.

[14] The time series in Figure 1 represents the value of banknotes issued by the Italian central bank. It is computed as the value of banknotes issued minus the value of banknotes deposited. It is slightly different from the stock reported in the central bank's balance sheet, which is adjusted by the capital key. The increase after 2015 was not driven by an increase of deposits. In Figure A.1 in the Appendix the ratio between currency and deposits is reported, it shows that banknotes holdings increased significantly also as a share of deposits.

Figure 1: Currency Demand - Aggregate Time Series



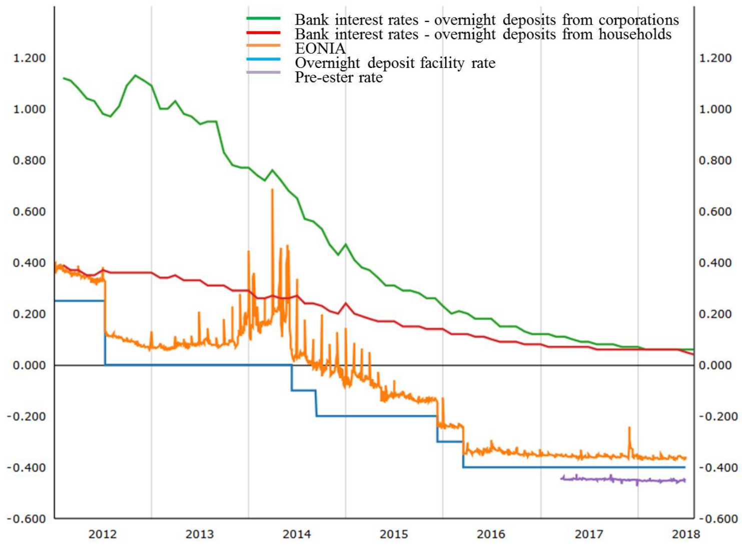
Notes. Monthly data. Blue line: moving average (5 observations) of cumulated net withdrawals from January 2012 to June 2018, expressed in billions of euro. Net withdrawals are calculated as the sum of gross currency withdrawals of all Italian commercial banks minus the sum of gross currency deposits. Source: Bank of Italy Currency Management Department. Black line: currency in circulation over GDP. The starting point for currency in circulation is taken from the Italian central bank balance sheet, page 237 of this document `https://www.bancaditalia.it/pubblicazioni/relazione-annuale/2011/en_rel_2011.pdf?language_id=1`. The other values are derived adding monthly effective net withdrawals, as measured by the blue line. The GDP is taken from ISTAT quarterly estimates at current prices (`http://dati.istat.it/Index.aspx?lang=en&SubSessionId=dbf6fee1-a2c2-4893-9f6b-9f5cb93a34ae`) and is multiplied by four to have a comparable percentage with year GDP.

In the same time span, the overnight interest rates reached their absolute minima since the beginning of the euro (Figure 2). At the beginning of 2015 the EONIA, the euro unsecured overnight interbank rate, broke the ZLB, following the overnight deposit facility rate and remained constantly negative thereafter.[15] The average overnight bank interest rates on deposits of non-financial firms and households followed the other rates. Banks did not pass negative rates on their depositors and thus deposit rates reached their minima from the beginning of the single currency just slightly above zero.[16]

[15]For the most recent period we also reported the PRE-ESTER rate, which was planned to substitute the EONIA.

[16]Mersch (2019) argued that this is a warning sign for central banks of how people may react if attempts were made to extend the lower bound of rates downwards by replacing currency with some form of remunerated digital currency. See Heider et al. (2019) for a study on banks behavior below zero policy rates.

Figure 2: Interest Rates on Deposits



Notes. monthly data. Source: ECB statistical data warehouse (SDW). Overnight bank interest rates for corporations (non-financial firms) and households are taken from the MIR.M.IT.B.L21.A.R.A.2250.EUR.N and MIR.M.IT.B.L21.A.R.A.2240.EUR.N series. The deposit facility rate is from the FM.D.U2.EUR.4F.KR.DFR.LEV series. The EONIA overnight interbank rate is from the EON.D.EONIA_TO.RATE series. The pre-ester rate is from MMSR.B.U2._X.U.S12.BO.WT.D76.MA.EUR. Details on the construction of these variables can be found in the SDW website `https://sdw.ecb.europa.eu/home.do`. Observation period: Jan 2012 - Jun 2018

Starting from these evidences, one may wonder whether the extraordinary low level of the interest rates contributed to the unexpected increased demand for currency. In this paper we focus on the relationship between currency demand and rates on overnight bank deposits, which are the most direct substitute of currency. This is the most liquid interest-bearing asset available for households and non-financial firms and can be used as a mean of payment. The reason to prefer it instead of other types of assets to study the relationship of interest rates with currency demand is threefold. First, deposits are required by law to be converted at sight at par in currency. Second, policy rates are applied on reserves, which are accessible only to commercial banks not to the public. Rates on deposits offered by commercial banks adjust rapidly when policy rates decrease, and the public is exposed to them directly. Third, rates on bonds or other assets accessible to the public imply a longer maturity or higher risk taking (than currency or deposits) and cannot be used as means of payments.[17]

[17] Other interest rates for longer maturity assets may also reflect changes of the term structure that we do not want to pick up. In the next section we describe how we control for changes of the term structure over time.

3 Setup of the Econometric Analysis

Given our interest in assessing whether the introduction of NIRP structurally changed the demand for currency, we focus on a relatively narrow time interval, w.r.t. the long periods considered in the literature estimating the demand for money with low interest rates (see Benati et al., 2021, among others). Another important difference is that we are not interested in estimating money demand in the form of M1, but rather the substitution between deposits and currency within M1.

As currency is exchanged against deposits for the public and has no interest rate, we can consider a measure of net withdrawals as the dependent and rates on the deposits as the main regressor, following a standard approach conceptually similar to those of Mulligan and Sala-i Martin (2000), Attanasio et al. (2002), Lippi and Secchi (2009) and Briglevics and Schuh (2014) among the others, which estimate a within-country panel data model. In this way, we can isolate time-country-specific factors, such us monetary and fiscal policy and other important confounders (see Appendix A.2), that can not be accounted for using cross-country panel data.

A straightforward way to proceed is to use cross-sectional dispersion of interest rates and currency demand at the bank level.[18] Bank usually offer different interest rates in the same time period or similar rates in different periods, for reasons different from their clients' contingent currency demand, like the cost of funding in interbank markets. While bank-level data on interest rates for overnight deposits is available, granular measurement of currency demand is difficult to get and may constitute an obstacle to this type of analysis. The reason lies in one of the unique features of currency, its untraceability, which makes its holding and use not directly measurable.

Potential Data Sources. Researchers have used different methods to measure currency holdings at a disaggregated level.

Household survey data is probably the most popular, because it allows to know the

[18]It could be useful to note that the variation in currency holdings is only demand-driven, as the central bank provides always the amount of currency that is demanded by the public without any limit or price adjustment. This is why we can use variations in currency holdings as a proxy for its demand.

amounts withdrawn from ATMs, received and held by demographic characteristics. For example, the Survey of Consumer Payment Choice (SCPC) is an ongoing research program initiated by the Federal Reserve Bank of Boston in 2003.[19] The issue with survey data is that (i) it is not always available, (ii) it is not frequent (usually yearly or less) and is only available for limited periods, (iii) it does not include firms. In Italy, the survey of household income and wealth (SHIW) has only one question related to currency, and it is about its use for purchases, not holdings, which makes it inappropriate for our investigation.[20]

Payment diary surveys are also a popular way to track currency and other payment instruments usage, diaries include shopping and payment decisions, tracking consumer payment transactions and preferences. They compare currency with other payment instruments, such as debit and credit cards, checks, and electronic options. Diary participants usually report the amount of currency on-hand after each survey day, as well as any currency deposits or withdrawals conducted throughout the day. The detail of the stock and flow of currency at an individual level provides insight into how consumers use currency. In order to better understand the current developments in currency usage, the Eurosystem agreed in 2014 to conduct surveys on the use of currency by households (SUCH) in all euro area countries, except in Germany and the Netherlands, where the corresponding central banks have been carrying out similar surveys since 2008 and 2007, respectively (see Esselink and Hernández, 2017). The SUCH survey was conducted from October to November 2015 and from January to July 2016.[21]

Although useful for the study of currency usage compared with other means of payment for different demographic groups, the survey has a very limited time span and is not linkable with longitudinal data on interest rates, so it is not suited for our purposes.

An additional possibility to measure currency demand is the information from ATMs. ATM information has the advantage of being linkable with longitudinal data on interest rates, but the issues are: (i) it is not the exclusive source from which currency can be

[19]See Schuh and Stavins (2010) for more information and references about the SCPC.

[20]The full dataset is publicly available (with documentation in English) at the Bank of Italy's website, see `https://www.bancaditalia.it/pubblicazioni/indagine-famiglie/index.html`.

[21]It involved 65,281 respondents who kept a diary to write down all the payments and currency withdrawals or replenishments that they carried out during the course of a single day.

obtained; (ii) the ATMs rarely allow to return currency, so it does not provide a full picture about holdings; (iii) often high denomination notes are not distributed through the ATM network (like in Italy and other European countries), so the picture is even more partial.

To overcome the limits of these data sources, we propose an alternative, but pretty natural, strategy to measure variations of currency holdings at a disaggregated level that can be easily matched with bank-specific data on deposits' interest rates. We decompose the total currency net issuance of the central bank (i.e. the blue line in Figure 1) by receiving commercial bank. The main drawback of this data is that, oppositely to survey data, it does not provide information on operations made by banks' clients, their operations are aggregated at the bank-level. Although, it would give us more insights, the absence of this information is not key for our strategy, because we need bank-time variation.

Selected Measurement of Currency Demand. At the aggregate level, the public can obtain additional currency only against deposits at commercial banks, using the ATM or at the bank teller. The only way commercial banks can obtain banknotes is from the central bank. Banknotes are issued by the central bank only against reserves. Figure A.2 depicts a graphical example of such operation. From a balance sheet perspective, depositor i converts deposits at a commercial bank A in currency at par, changing her most-liquid assets composition. Bank A decreases both assets and liabilities by the same amount as the banknotes have to be exchanged against reserves, which thus decrease by the same amount of deposits. The central bank changes its liabilities composition, decreasing reserves and increasing currency. Figure A.3 shows this mechanism. The opposite happens if the depositor returns currency to its bank to obtain deposits.

It follows that, by subtracting the amount of currency returned to that withdrawn, we can approximate the variation of currency holdings of all bank's depositors with these operations.[22] According to Figure A.2, the central bank can keep track of them from both the reserves exchanges (settled in the real-time gross settlement system, the RTGS) or from the banknotes shipments. Given that banks can also hoard currency for themselves,

[22]In principle, the single commercial bank may also obtain notes from other banks, instead of going to the central bank. This practice was not diffused in Italy at the time of this study.

we need to know the stock of banknotes that they have in their caveau. Figure A.4 shows that, Italian banks, despite the negative interest rates on the deposit facility, did not hoard additional currency when rates on reserves turned negative.[23] Oppositely, Italian banks kept their caveau flat at the minimum level, returning the notes in excess or withdrawing them when depositors demand increased. For this reason, we can use net withdrawals as a good proxy for currency holdings of their clients.[24] Figure A.5 shows the amount of banknotes quarterly issued by and returned to the Bank of Italy over time by denomination. The number of notes issued and returned is quite high, revealing a very active caveau management, despite the low or negative interest rate paid on reserves. We can also see that there is some heterogeneity across banknote denominations, that can be exploited to assess transactions vs store-of-value demand for currency (as we do in Section 5). A nice feature of this data is that it reconstructs exactly the aggregate numbers showed in Figure 1. As a consequence we do not rely on a sample that approximate total currency variation, but rather on the population of banknotes issued by the central bank. As Italy is in a monetary union, currency can move easily and be used across European countries, the additional demand for banknotes can thus also be satisfied by cross-border shipments. In particular, given that Italy is a major touristic destination, people from other euro countries can bring banknotes to spend them during their journey. Figure A.4 in the Appendix shows why this aspect is not problematic in our analysis. If the additional notes issued by the central bank were reflecting a lower provision from the borders, we should have observed a decrease of tourists inflows from 2015, while this is not the case. Banknotes can also be demanded in Italy and moved outside the country, for touristic reasons as well for example. Even though Italy has a large positive net position for tourism in the balance of payments, more currency withdrawals could also serve higher touristic demand. From Figure A.3 we can see that touristic outflows did not change dramatically as well as touristic inflows to and from Europe and the rest of the world in the period under analysis. In our regression analysis, we use time fixed effects to control even for small changes of touristic flows and

[23]In other countries, like Germany, banks did it, see the "The demand for euro banknotes at the Bundesbank" in the Economic Bulletin of March 2018 (Bundesbank, 2018).

[24]In the opposite case, if we know the amount of currency held by banks, we just need to subtract its value.

more generally aggregate demand of currency.

Interest Rates. Once we collected data on currency operations by bank, we can match them with data on customer deposits rates. The aggregated time series on bank interest rates on households' and non-financial firms' deposits showed in Figure 2 are available at the bank level.[25] The data contains information about annualized rates on overnight deposits from Italian credit institutions both for new and outstanding amounts.[26] We describe in more detail the dynamics and dispersion of rates in Section A.1.1. Given that this data is monthly, we aggregate currency operations by the same frequency.

Baseline Specification. We estimate the demand for currency with panel data using an approach conceptually similar to those of Mulligan and Sala-i Martin (2000), Attanasio et al. (2002), Lippi and Secchi (2009) and Briglevics and Schuh (2014). These papers use households survey data to estimate currency demand functions, focusing on important factors such as transaction and financial technologies. The main difference with these approaches is in the cross-sectional dimension, which is banks for us instead of individuals. This dissimilarity reflects the different research question, as explained above. Having a panel containing data on rates and currency demand allows us to control for a series of confounding factors like the ones listed in Section A.2. Given that some of them are not observable and taking advantage of the disaggregated dataset constructed, our strategy is to use fixed effects to control for observable and unobservable factors impacting both interest rates and currency demand. In general terms, our baseline econometric model takes the following standard form:

$$c_{t,b} = \alpha + \beta r_{t-1,b} + \eta_t + \mu_b + \epsilon_{t,b}, \tag{1}$$

[25]The two series are identified respectively by the two following codes of the Statistical Data Warehouse of the Eurosystem: MIR.M.IT.B.L21.A.R.A.2250.EUR.N and MIR.M.IT.B.L21.A.R.A.2240.EUR.N. The Italian sample contains about 70 banks, which cover more than 85 per cent of the deposits of the Italian banking system. It follows that some banks are excluded from our analysis, thus we can not exactly reconstruct the aggregate numbers showed in Figure 1.

[26]Unfortunately this information is not available for the postal saving system, which is then excluded from the analysis.

where $c_{t,b}$ is the measure of currency demand at time t for bank b, $r_{t,b}$ is the interest rate on deposits applied by bank b at time (month) t. In what follows our primary measure is $\Delta C_{t,b}$, the net currency withdrawal (gross currency withdrawals minus gross currency deposits) of bank b at time t.[27] η_t are time fixed effects, μ_b are bank fixed effects, $\epsilon_{t,b}$ is a normal random error with mean equal to zero and variance σ_ϵ. Time fixed effects capture macro factors and shocks (like the ones listed in Section A.2) and other time-specific unobservables. Bank fixed effects capture average preferences and heterogeneous composition of their depositors, the bank's role in the ATM network, bank's presence in the territory (branches diffusion), other bank's business model features. These assumptions are quite standard and discussed in Section A.2. Our interest is in estimating β, which is the parameter that captures the effect of the interest rate on the demand for currency. Below we list the main assumptions that allow for the identification of β in this simple model, and the additional exercises done to test the robustness of our results.

4 Currency Demand

Baseline Results. Let us start describing our baseline results. The time span considered in our regression analysis is from January 2010 to June 2018 with monthly frequency data. Table 1 reports the estimates of β in model (1). The dependent variable is the net currency withdrawal (gross currency withdrawals minus gross currency deposits) of bank b at time t. The interest rate is the weighted average annualized rate on overnight deposits of bank b at time $t-1$. The average marginal effect of the interest rate is negative and significant, as expected. The effect is above 30 million euro when we control for time and bank fixed effects. Observe that with this specification we have a non linear relationship between the levels of rates and currency in circulation, which is standard in the literature. Appendix A.3 reports the estimates of β using different functional forms for the relationship between rates and currency, which are also used in the literature, and discusses the optimality

[27] This is the outcome variable we will always refer, to unless differently specified. In Appendix A.3 also alternative dependent variables and functional forms are explored. Appendix A.5 reports all the estimated equations.

of our specification given the data at hand.[28] The results are unchanged if we instead use a contemporaneous instead of a lagged relationship between currency and interest rates. Next, we report the results from a instrumental variable (IV) approach, from a model augmented with bank-year fixed effects to control for unobservable idiosyncratic time-varying factors affecting both rates and currency withdrawals, and from a series of additional robustness exercises. All the robustness checks confirm our main results.

IV estimates. To check the robustness of our results, we use also an instrumental variable approach based on time-varying banks characteristics that affect the interest rate set by the bank but do not directly influence the demand for currency of its clients. In bank's optimization problem, interest rates on deposits are set depending on the composition of assets and liabilities, which can be thus a relevant instrument. For example, the bank can set its interest rates higher to raise funds (liabilities) if it is not able or willing to get enough funding on the interbank market. On the other hand, it may decrease rates if it wants to expand its assets by lending to firms, households or in the interbank market. In addition, if we have dynamic data on balance sheet composition, the explanatory power of the instrument can be quite high. Furthermore, reinforcing the exclusion restriction, banks' balance sheet data is publicly available only with a lag of 3/4 months, in the best case. So, even if depositors would really react to these variables not through interest rates when they set their optimal currency holdings, they cannot see changes in the monthly balance sheet composition of their bank, because they do not see it. It is also not clear why depositors should internalize variations of these items when choosing the optimal amount of deposits to convert in currency, a part from bank's default risk which is discussed below. Below we report the equation estimated in the first step,

$$r_{t,b} = \mu + BS_{t,b}\theta\rho + \eta_t + \mu_b + \epsilon_{t,b},$$

where $BS_{t,b} = [A_{t,b}, L_{t,b}]$, $A_{t,b} = [DS_{t,b}, IL_{t,b}, TL_{t,b}, BL_{t,b}]$ and $A_{t,b} = [IB_{t,b}, T1_{t,b}]$. $DS_{t,b}$ is the amount of domestic securities holdings, $IL_{t,b}$ is the outstanding amount lent in

[28] Appendix A.5 contains the relative formulas (i.e. from model [A.1] on).

Table 1: Demand for Currency - Baseline Results

Dependent variable: currency demand in mln euro		
Interest rate	-40.391 ***	-32.538 ***
	(4,630)	(4,335)
Bank FE	N	Y
Year-Month FE	N	Y
$\bar{R}^2$	0.018	0.722
Observations	6,420	6,420

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The columns contain estimates for equations [A.1] and [A.2] respectively. Appendix A.5 contains the relative formulas. Weighted average of interest rates on overnight deposit accounts for household and firms in percentage points. The dependent is the value in million of euro of the net monthly currency withdrawals of each commercial bank. Net currency withdrawals are measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn by each commercial bank from/to the central bank. Observation period: Jan 2010 - Jun 2018.

the interbank market, $TL_{t,b}$ is the outstanding amount of loans to the private sector and government, $BL_{t,b}$ is the outstanding amount of bad loans, $IB_{t,b}$ is the outstanding amount borrowed in the interbank market, $T1_{t,b}$ is the outstanding amount of Tier1 for bank b at time t. All are expressed as a percentage of total assets. Table 2 reports the results from the first step. The Table confirms the relevance of our IVs, The F-stat is about 20. Unsurprisingly, banks borrowing less in the interbank market pay higher interest on deposits. Rates are on average higher also for banks that lend more both to other banks and to non-financial entities.

Table 3 compares our baseline results in the full sample (from Table A.1), with the same regressions run on the subsample of banks for which we have currency operations, rates and balance sheet data available and the IV estimate for this subsample.[29] We report in Table

[29]The data on balance sheets is from supervisory reports. See Albertazzi et al. (2014) for a detailed description of the dataset used here. The sets of banks for which we have data on currency operations, rates and supervisory reports are not identical, thus we consider the subsample of banks for which all the data is available.

Table 2: Instrumental Variable Estimation
- First Steps -

Dependent variable: interest rate	
Domestic securities	4.2187 ***
	(0.2935)
Interbank borrowing	-1.6793 ***
	(0.2265)
Interbank lending	2.8058 ***
	(0.3386)
NPL	0.0551
	(0.6303)
Tier 1	0.0118
	(0.0308)
Loans	1.4614 ***
	(0.3122)
Bank FE	Y
Year-Month FE	Y
F stat	19,394
Observations	2.887

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. Rates on overnight deposit accounts in percentage points for household and firms. Weighted average rates on overnight deposit accounts in percentage points for household and firms. Assets and liabilities are expressed as a percentage of total assets. Observation period: Jan 2010 - Jun 2018.

A.4 and A.5 the results also for the log and linear specifications in Table A.2. We can see that the effect of rates is always significant and negative, with marginal effects close to the baseline.

Bank-year Fixed Effects. The robustness of our results could be also prone to the existence of some bank-specific dynamic unobservables. For example, given that banks cannot lower rates on deposits below the zero or at least they do not do it in practice, they may charge negative rates indirectly through fees (or other fixed costs) yearly. Another possibility is that depositors of small banks located in different regions are exposed to different economic trends impacting both currency withdrawals and deposit rates. To check whether our result may be affected by this type of issues, we can include bank-year fixed effects. These controls capture any differential evolution featuring banks on a yearly basis. In the last column of Table 4 we report the results and compare them with a model with bank and year fixed effects and without fixed effects. We can see that the magnitude of the effect is stable and significantly different from zero, even when a lot of variation is captured by very granular fixed effects.

Other Robustness Exercises. Even controlling for yearly bank-time fixed effects could not be enough if higher frequency time varying-bank specific unobservables impact both currency withdrawals and lagged rates. Such a situation could materialize when there is a bank run or a idiosyncratic distress event, and the bank start to increase rates to contain depositors' withdrawals. Observe that this mechanism works against the results: higher expected withdrawals should induce a bank to raise interest rates to secure its liquidity. This would result in a positive rather than a negative coefficient. In order to verify this possibility, we check whether there are distress episodes in our sample. Even though there is no bank run in our sample, there are some idiosyncratic distress episodes that generated moderate and temporary deposits' outflows, which in turn may have brought some banks to raise interest rates to retain depositors running away. These episodes are detected using the estimation procedure in Rainone (2021). In Appendix A.1 we provide evidence that distressed banks did not increase deposit rates.[30] This result is in line with Iyer et al. (2016), and supports our identification strategy.

[30] In Figure A.12 in the Appendix we show the evolution of the spread from the average market rate for distressed banks' rates on overnight deposit of household and firms. The spread is divided by the standard deviation of the rate distribution for each month, in order to compare periods with different dispersion. The time series are centered on the month in which the shock hit the bank (the vertical blue line) with an interval of 30 months.

Table 3: Instrumental Variable Estimation

Dependent variable: currency demand in mln of euro

	Full sample	Subsample	IV
Interest rate	-32.538 ***	-46.197 ***	-65.547 *
	(4.335)	(7.454)	(36.984)
Bank FE	Y	Y	Y
Year-Month FE	Y	Y	Y
F stat			19.394
Observations	6,420	2,887	2,887

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. Weighted average rates on overnight deposit accounts in percentage points for household and firms. The dependent is the value in million of euro of the net monthly currency withdrawals of each commercial bank. The IV estimates are performed using the instruments listed in Table A.5. Observation period: Jan 2010 - Jun 2018.

Table 4: Controlling for Bank-year Fixed Effects

Dependent variable: currency demand in mln of euro

Interest rate	-40.391 ***	-32.538 ***	-26.180 ***
	(4.630)	(4.335)	(9.764)
Bank FE	N	Y	N
Time FE	N	Y	Y
Bank-Year FE	N	N	Y
$\bar{R}^2$	0.018	0.728	0.728
Observations	6,420	6,420	6,420

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The columns contain estimates for equations [A.1], [A.2] and [A.29] respectively. Appendix A.5 contains the relative formulas. Rates on current accounts in percentage points. The dependent is the cumulated value in euro of the net monthly currency withdrawals of each commercial bank. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. Observation period: Jan 2010 - Jun 2018.

In Section A.4.2 we also report the results of our main specification augmented with time-varying balance sheet structure of the bank. This robustness check could be useful to control for the possibility that the balance sheet structure of the bank matters for both the pass-through to deposit rates (as shown by Altavilla et al., 2021) and banknotes withdrawals, on a monthly basis. Our main results are still robust also to this specification.

A necessary condition to estimate the parameter of interest is that there is enough variation in deposit rates. At each time, banks' rates are dispersed enough and some banks vary their rates over time. We can check if there is enough variation in deposits' rates. The sequential decrease in the first moment of rates' distribution, witnessed in Figure 2, may also come together with a dramatic decrease of the second moment, not providing enough variation across rates in the cross section for the last months. In Appendix A.1.1 we provide some descriptive statistics, showing that dispersion in interest rates does not drop dramatically in our sample. Implicitly, we are assuming that depositors mainly use interbank transfers to switch bank. Evidences supporting this assumption are provided in Appendix A.4.3. In Appendix A.4 we provide other robustness checks. Overall the ample set of robustness exercises confirms the absence of relevant endogeneity issues in this type of estimation (see also Briglevics and Schuh, 2014; Lippi and Secchi, 2009).

Structural Break in Currency Demand. The period analyzed is the first in history in which nominal rates were so low, and many banks set their deposit rates equal to or very close to zero, thus one may wonder whether depositors reacted differently to changes in the interest rate in this new domain. The public may start perceiving that after a certain point (rate) money on deposits earn nothing and stop trying to store as much as they can on their interest bearing banking account instead of keeping currency. Such possibility is supported by the visual inspection of the relationship between rates and the demand for currency. To check whether there are structural changes in the relationship between currency demand and interest rates, we can use the Bai and Perron (1998, 2003) test for endogenous break points. There are several reasons why this test is particularly appropriate for our research questions: (i) it allows for multiple breakpoints, (ii) we do not have to set *a priori* where the potential breakpoints are, (iii) it provides confidence intervals for the point estimates.

These are appropriate features in our case because thresholds after which interest rates are perceived as not significantly different from zero might be heterogeneous across depositors and we do not have any prior about how many and where they are.[31] Observe that we are not interested in break dates here, our research question is about "break rates" at which currency demand changes. A break rate can be observed in multiple points in time, and it is an interest rate after which the demand of currency changes structurally, independently from the time at which it is observed. Indeed the fact that the same interest rate can be paid by different banks in different time observations allows us to identify the break points along the rate spectrum instead of along the time dimension. Following this procedure we estimate the existence of one breakpoint in the relationship, slightly below 0.1 per cent. Table 5 reports also the confidence interval, the residual sum of squares (RSS) and the Bayesian information criterion (BIC) for up to five breaks.

Panel (a) of Figure A.6 reports graphically the RSS and BIC for different breakpoints; panel (b) depicts the predicted $c_{t,b}$ over the rate dominion. From this figure we can see that the increase of currency withdrawals is pretty dramatic when the estimated threshold is passed.[32] In Table 6 we report the estimated coefficients above and below the threshold. The marginal effect of rates below the threshold is more than ten times higher than above, when we also include bank and time fixed effects. On average a reduction of 5 basis points in deposits rates of a bank from 0.15 to 0.10 implies that 0.16 per cent of its deposits are converted in currency. A reduction of 5 basis points from 0.05 to 0 implies a 1.70 per cent conversion.[33] This threshold may be interpreted as the point after which bank deposits are perceived by the public to pay almost nothing, as currency. It is different from (and higher than) the ELB, which is slightly negative given the storage and other costs related

[31] See Perron et al. (2006) and Andreou and Ghysels (2009) for a review of methods used for detecting structural breaks. Other type of tests can be used, we opted for Bai and Perron (1998) because of its popularity.

[32] We also ran the test with one break including the dummies for the shocks on the demand for currency described in the following section -i.e. the "transaction" and the "store-of-value" shock-. These shocks created a discontinuity in the demand at certain points in time (and thus at certain average market rates), as detailed below. We obtain a point estimate of 0.735, with a similar confidence interval, meaning that the estimated breakpoint does not spuriously pick other discontinuities up. If we run the test on the levels ($C^S_{t,b}$), the point estimate for the break is 0.0757, which is included in the estimated confidence interval of the break estimated for $\Delta C_{t,b}$ and very close to the point estimate.

[33] For this calculation we divided the net currency withdrawals implied by coefficients in the second column of Table 6 by the mean amount of deposits of banks in our sample at the end of 2017.

Table 5: Endogenous Structural Breaks in the Relationship between Currency and Rates

		Estimated breaks				
		Number	5%	Expected Value	95%	
		1	0.0740	0.0741	0.0811	
	Number of breaks					
	0	1	2	3	4	5
BIC	2.5927E+05	2.5914E+05	2.5914E+05	2.5915E+05	2.5918E+05	2.5920E+05
RSS	1.2952E+20	1.2637E+20	1.2588E+20	1.2561E+20	1.2555E+20	1.2553E+20

Notes. Breaks in the relationship between monthly bank-specific net currency withdrawals and the deposit rates. Weighted average of rates on overnight deposit accounts for household and firms in percentage points. The dependent is the value in euro of the net monthly currency withdrawals of each commercial bank. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. Observation period: Jan 2010 - Jun 2018. See Zeileis et al. (2001) for more details on the implementation of the Bai and Perron (1998) test for multiple endogenous break points.

to currency. In addition, the ELB is usually referred to policy rates, while our threshold is estimated for interest rates on deposits. In our sample the threshold maps with a deposit facility rate equal to -0.4. From this standpoint, we can interpret our break rate (κ) as a pre-ELB that marks an area after which agents change their currency demand because rates on deposits are not perceived as significantly higher than zero anymore. In what follows we investigate the role of transactions and store-of-value demand, to enrich the interpretation of this threshold.

Table 6: Estimated Effects above and below the Threshold

Dependent variable: currency demand in mln of euro		
Rates		
Above κ	-60.929 ***	-28.754 ***
	(5.037)	(4.312)
Below κ	-1,511.561 ***	-313.031 ***
	(194.668)	(137.030)
Bank FE	N	Y
Time FE	N	Y
$\bar{R}^2$	0.035	0.728
Observations	6,420	6,420

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. The threshold is the value estimated in Table 5. The columns contain estimates of β_1 and β_2 for equations [A.19] and [A.20] respectively. Appendix A.5 contains the relative formulas. Weighted average of rates on overnight deposit accounts for household and firms in percentage points. The dependent is the value in euro of the net monthly currency withdrawals of each commercial bank. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. Observation period: Jan 2010 - Jun 2018.

5 Transactions vs Store-of-value Demand

At this point we may ask why currency holdings changed significantly when interest rates approached zero. In principle currency has a negative rate (Rognlie, 2016; Rogoff, 2015), because of storing costs for example (Witmer and Yang, 2015), so people should not save in currency if rates are at least equal to zero. On the other hand, currency might be preferable for transactions (for example for evading taxes, see Fedeli and Forte, 1999; Gordon and Li, 2009; Immordino and Russo, 2018; Rainone, 2019) and the losses implied by holding more currency are null without interest rates paid on deposits.

The demand for currency has different purposes, here we divide it in two main components: transactions and store-of-value demand. With transactions demand we mean the balances of currency held to settle expected and unexpected transactions. We abstract here from the distinction between pure transactions and precautionary demand, which is the holding of transaction funds for use if unexpected needs for immediate expenditure occur (see Alvarez and Argente, 2021; Alvarez and Lippi, 2009, 2017; Frenkel and Jovanovic, 1980). We are not interested here in distinguishing between the two so we group them together as both are held to exploit the function of mean of payment of currency. In addition, our measure of currency holdings include both households and firms, so it is more appropriate to include the precautionary demand (Miller and Orr, 1966) in the transactions one. The store-of-value demand includes speculative and portfolio motives (following Keynes and Tobin taxonomy), that are not dictated by real transactions but arise from holding currency as part of a portfolio of assets held as investments. It is worth noting that the exact empirical distinction of these two demand is not possible, as agents do not segregate overnight deposits and currency holdings according to them. It follows that our analysis tries to assess the role of the two indirectly, by exploiting variations and reactions of aggregate currency holdings. It could be argued that our measure of currency holdings is less meaningful than currency transactions to study the transactions demand. Nevertheless, here we are interested in explaining the variation of holdings instead of the volume of transactions, and we want to consider also the store-of-value demand. If we are able to use shocks that are transactions-specific, then variations of holdings can by very powerful and inform directly our object of interest, currency in circulation. In addition, given the unobservable nature of cash transactions, there are no measures with the same cross section and time granular detail of our data that can be used to complement the analysis.

Given that the amount of deposits used for transactions is different from the amount used for storing value, the decrease of deposits can vary significantly depending on which type of deposit is converted in currency. Understanding whether the demand is mainly driven by transactions or store-of-value function is key to evaluate the amount of deposits that is at risk when policy rates approach the ELB, but how can we assess these two different types of demand?

5.1 Empirical Strategy

Our strategy to answer these questions consists in exploiting two sources of variation. First, banknotes are produced in different denominations. Small notes are generally more used to settle transactions (Esselink and Hernández, 2017) and are available at the ATM (in Italy up to the 50 euro banknote). Big notes instead are more efficient to store value, less used and obtainable only at the bank teller. Second, the transactions demand is based on an inventory problem (how to keep optimum amount of currency for a given stream of expenditures), which is different from a short-term most-liquid asset allocation problem, which underlies the store-of-value motive of currency demand. If we have relevant shocks that changed the settings of these problems, we can assess which motive was predominant in determining higher observed currency holdings. In what follows we also use interest rates for households and firms, to see whether they have different effects on currency holdings.[34] Rates on households' deposits are usually lower and less dispersed (see Figure 2 and A.9). All the results hold if we use pooled average rates, weighted for the amounts of deposits of households and firms.

5.2 Banknotes Heterogeneity

In this section, we exploit the fact that euro notes are distributed in seven denominations: 5, 10, 20, 50, 100, 200 and 500.[35] If the demand for the different types of banknotes is observable, we can better understand the main purposes behind the additional demand. We define as small the notes below or equal 50 euro. The reason is twofold. First, they are better suited for low-value transactions. Second, they are available at the ATM in Italy, thus they are often used for common purchases. Bigger notes, 100, 200 and 500, are only available at the bank teller and are of course more appropriate to store value. The strong differences across these notes is clearly visible when the total currency net withdrawals in Figure 1 are disaggregated by denomination. Figure A.7 reports the time series. We can appreciate how the 50 and 20, the most available at the ATM, are also the most issued

[34] Unfortunately we can not split currency holdings between firms and households, thus we must use the aggregate amounts.

[35] The 500 was still distributed at the time this article was written. We exclude coins from the analysis.

and are characterized by strong seasonality, supporting the fact that they are largely used for common transactions. These banknotes are in high demand during Christmas, Easter, summer, in the weekend and in general when people have more leisure time and/or consume more. The big notes are on average more deposited than issued in Italy, and their trend is very smooth as their demand is not much linked with common people purchases. As detailed data on the denomination of shipments of banknotes for each commercial bank is available, we can exploit this information to understand whether banks with lower interest rates experienced higher withdrawals of small or big notes below and above the estimated break point.

Table 7 reports the results for the demand for small and big notes above and below the threshold estimated in Section 4. The acceleration of currency withdrawals below the threshold is significant and substantial only for small notes. The effect is more than ten times greater below the threshold, a proportion slightly higher that the one reported in Table 6.[36]

From these results it seems that the additional currency withdrawals are driven mostly by the demand for small notes. Nevertheless, the aggregation by size may hide important differences. To dig deeper into our data, we can also analyze the demand for each single denomination. Table 8 reports the results. We can see that the increase below the threshold is mostly driven by the 5, 10 and 50 notes, among the small notes, but interestingly also the 100 euro shows a significant increase.[37] More results on banknotes heterogeneity are reported in Sections A.4.4. Even though these evidences seem to support the transactions demand as the main driver, we cannot a priori discard the hypothesis that more currency was used for storing value, especially for the demand for 100 euro banknotes. If we could have a shock that exogenously impacts the store-of-value demand for currency (ideally at the denomination level), we might better assess whether it played a role or not. Complementary, a shock to the transactions demand would help confirming the results on small banknotes

[36]Similar results are obtained if we sum the different denominations.

[37]The 20, 200 and 500 note present positive coefficients above or below the threshold. This may be due to technical features of the supply side. For example, the 200 is the most scarce banknote with a number of bills about 10 times smaller than the 100 (in 2018). Results are robust to a seemingly unrelated regression specification as in Kohli (1988).

Table 7: Estimated Effects above and below the Threshold
-Big and Small Notes-

Dependent variable:		
currency demand in mln of euro		
	Banknotes	
Interest rate	Big	Small
Above κ	-1.271 ***	-6.361 ***
	(0.350)	(1.353)
Below κ	-5.027	-78.302 **
	(11.083)	(39.048)
Bank FE	Y	Y
Year-Month FE	Y	Y
Denomination FE	Y	Y
$\bar{R}^2$	0.58	0.28
Observations	18.466	25.122

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The estimated model in is square brackets. Rates on bank overnight deposit accounts in percentage points. The dependent is the value in million euro of the net monthly currency withdrawals of each commercial bank. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. Observation period: Jan 2010 - Jun 2018.

and reconcile the prominent role of the 100, which is less likely to have a strong transactions demand, at least for comment exchanges.

5.3 A Shock to the Store-of-value Demand

A reform that shocked the store-of-value demand for currency took place in Italy after, and independently to, the introduction of negative policy rates. Compliance with tax payments is a duty of the tax revenue agency, Ω*Agenzia delle Entrate**'.' By law the government can provide the agency with powers of different degrees. Tax evasion in Italy is a big issue and it is estimated to be 12.4 per cent of the GDP in 2016 (according to the Italian national institute of statistics, ISTAT). About half of it is generated by under reporting, which is widespread in almost all the sectors of the economy.[38] To fight tax evasion more effectively the Italian government gave additional tools to the agency in the "2015 Stability Law". More precisely it allowed the agency to get more detailed data on balances of bank accounts.[39] Given that the agency has also information on declared income and wealth, inconsistency can be more easily spotted having banking data. If taxpayers had something to hide, then bank deposits became less appealing and a more valuable and immediate alternative to store value is inevitably currency. Indeed, as detailed in Rainone (2019), this law had a strong effect on the demand for currency. The effect of this shock on different notes can inform us about preferences towards denominations used to store value. Rainone (2019) shows that only the demand for 500 banknotes increased significantly after the shock. The other notes were not impacted at all. The reason is that 500 is the most efficient banknote to store value in terms of needed space, that is a key factor given that the most secure way for depositors to store currency (and other valuables) is using safes at home or at the bank, and the cost of additional space is very expensive especially for the latter. As the depositor has to go to the bank teller to get notes bigger than 50, one may also wonder whether this outcome was generated by a choice of the bank (from the supply side) and not by a choice of the depositor (from the demand side). In other words, it could be that the bank decides to give the 500 banknote instead of the 200 or 100 banknotes. In the next Section, we show that 100 and 200 notes were not limited by the supply side,

[38]See `https://www.istat.it/it/archivio/222223` for more details on the weight of each sector.

[39]It is important to note that the agency received this power, but did not even start implementing the infraBelow κture needed to collect and use the data at that time. The news got very popular on newspapers, so the effect comes from the announcement of this new policy.

Table 8: Demand for Single Denominations

Dependent variable: net monthly currency withdrawals in mln euro

	5	10	20	50	100	200	500
Interest rate							
Above κ	-0.239 ***	0.053	-5.102 ***	-19.876 ***	-2.927 ***	0.037	-0.852 **
	(0.041)	(0.143)	(1.023)	(2.976)	(0.450)	(0.071)	(0.401)
Below κ	-12.739 ***	-11.100 ***	42.774	-233.703 ***	-27.921 **	-1.199	14.717
	(1.304)	(4.549)	(32.542)	(94.405)	(14.252)	(2.248)	(12.620)
Bank FE	Y	Y	Y	Y	Y	Y	Y
Time FE	Y	Y	Y	Y	Y	Y	Y
$\bar{R}^2$	0.66	0.93	0.79	0.74	0.87	0.87	0.83
Observations	6,154	6,268	6,333	6,367	6,284	5,998	6,184

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The estimated model in is square brackets. Rates on current accounts in percentage points. The dependent is the value in euro of the net monthly currency withdrawals of each commercial bank for each denomination. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. Observation period: Jan 2010 - Jun 2018.

because they were available in correspondence of a different shock.[40]

Given that at the time of this shock the rates on deposits already reached their minima but there was variation across banks' deposit rates (as shown in Figures A.9 and A.8), we can test whether depositors more exposed to lower interest rates at the time of the shock withdrew more 500 notes (as they faced lower marginal costs of converting part of their deposits in currency). We estimate the following model to test this hypothesis,

$$c_{t,b,500} = \alpha + \beta_1 r_{t-1,b} + \beta_{Store} r_{t-1,b} * I(t > S_{Store}) + \eta_t + \mu_b + \epsilon_{t,b,500},$$

where $I(.)$ is a indicator function and S_{Store} is the month in which the shock on the store-of-value demand hit, in January 2015.[41] Our results are reported in Table 9. We can see that neither the rates per se or interacted with the shock have significant effects on the demand of 500 euro using both households or firms rates. This evidence does not point toward an

[40]The 50 are the most diffused and not in short supply.
[41]The not interacted dummies are absorbed by time fixed effects.

important role played by the store-of-value function of currency even when interest rates are close or equal to zero.[42] In appendix A.4.5 the store of value shock is also considered for the other big denominations and considering separately interest rates for households and firms.

5.4 A Shock to the Transactions Demand

With the current evidences we may be inclined to attribute a minor role to the store-of-value demand in explaining the additional currency holdings at lower interest rates. To find additional evidences on the role played by the transactions demand for currency, even for big notes,[43] we can exploit a second shock that occurred after the introduction of negative policy rates.

In what follows we refer to the transactions demand as defined in the Tobin-Baumol model, with the reference asset for interest rates being deposits instead of bonds, as in Lippi and Secchi (2009) and Alvarez and Lippi (2009) among the others.[44] In the Tobin-Baumol model, transactions balances become more interest-elastic when rates increase. It means that when rates are higher agents optimize more intensively their currency inventory, which in turn decreases on average over time. On the contrary, when rates are low enough, the loss due to higher non-interest bearing inventory become negligible, eventually disappearing if rates are equal to zero.[45] Differently from Lippi and Secchi (2009), we do not have

[42]We refer to its role when interacted with the interest rate, which does not exclude its importance per se.

[43]The demand for 100 notes was not impacted by the store-of-value shock described in the previous section, but it showed a high elasticity to lower interest rates.

[44]Nowadays, it is more realistic to consider deposits as the asset used to get currency. In the Tobin-Baumol model, bonds can not be used for payments. Even if deposits can be used for payments instead of currency, the main mechanism that the Tobin-Baumol model captures still applies. Given that we have also firms in our sample, another reference model is Miller and Orr (1966). In their model firms receive currency following a stochastic process and decide whether to convert it or hold for future expenditures. Se also Frenkel and Jovanovic (1980) for a model that distinguishes pure transactions versus precautionary demand. For our purposes, the fact that currency is more withdrawn or less deposited, does not matter given that we look at net withdrawals as a proxy for currency holdings. Our measure, which exploits operations between the central bank and commercial banks, does not allow to measure precisely gross withdrawals and deposits operations of commercial banks' clients.

[45]Observe that in the Tobin-Baumol model currency demand goes to infinity when interest rates are equal to zero, which we (and others) already show not to be the case. This is because the ELB is actually below zero, see our discussion in the Introduction. Even if its functional form could be revised, the model still captures the main opportunity-cost mechanism we are interested in.

Table 9: Currency Demand - Evidence from the Store-of-value Shock

Dependent variable: currency demand in mln of euro

	500	
Interest rate	-0.819 **	-0.823 **
	(0.399)	(0.399)
Store-of-value shock * interest rate		0.541
		(1.032)
Bank FE	Y	Y
Time FE	Y	Y
$\bar{R}^2$	0.83	0.83
Observations	6,184	6,184

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The columns contain estimates for equations [A.4] and [A.25] respectively. Appendix A.5 contains the relative formulas. Rates on current accounts in percentage points. The dependent is the value in euro of the net monthly currency withdrawals of each commercial bank. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. The variable "Store-of-value shock" is a dummy that switches to one when the store-of-value shock hit on January 2015. Observation period: Jan 2010 - Jun 2018.

information on cash transactions, nevertheless our measure effectively approximate currency inventory which is our ultimate object of interest here.

The shock was generated by a change in the legal threshold for currency payments, which directly impact the transactions demand and consequently inventory. The government can impose a limit to currency payments. Not all jurisdictions in the Eurozone limit currency payments by law, but many do. In Figure A.13 we report a map that represents the existence of currency payment limits across European countries. When the government increases the limit for example, the possibility of paying higher amounts in currency can impact positively transactions demand. Such impact can vary depending on the interest rate, according to the Tobin-Baumol model. When the currency payment limit is binding, increasing it has a positive effect on their currency disbursements, T in Baumol (1952), having a positive effect on the demand of currency for transaction purposes (see Russo, 2020), the one we want to isolate.

In Italy there have been several changes to this limit in the last decade. In particular, it was increased from 1000 to 3000 in 2016 by the "2016 Stability Law", after the introduction of NIRP. Rainone (2019) showed that this change impacted the demand for 100 and 200 bills, but had no effects on other denominations.[46] This fact constitutes *per se* an evidence against the argument that the supply of larger notes was limited and that the demand for 500 discussed in the previous section was not generated by the demand side.

If the 1000 euro limit on currency payments was binding (as shown in Russo, 2020), we expect the relaxation of such limit to generate higher demand for 100 and 200 from depositors with lower interest rates on their accounts, because they face lower costs of holding more currency (the range of interest rates for households was wider than 1 percentage point in January 2016, see Figure A.9). In order to check this hypothesis we estimate the following model,

$$c_{t,b,100/200} = \alpha + \beta_1 r_{t-1,b} + \beta_{Trans} r_{t-1,b} * I(t > S_{Trans}) + \eta_t + \mu_b + \epsilon_{t,b,100/200},$$

where $I(.)$ is a indicator function and S_{Trans} is the month in which the shock on the transactions demand hit -i.e. January 2016, when the currency payment limit was changed from 1000 to 3000-.[47] We estimate the model for 100 and 200 notes separately. Table 10 reports our results. We can see that lower rates generated higher withdrawals when the "transactions shock" hit. The coefficient of the interaction term is even higher than the baseline marginal effect. This results supports the idea that the higher demand for 100 banknotes observed at lower rates had a transactions motive. Interestingly, even the demand for the 200 banknotes, which seemed one of the less elastic, was significantly higher for depositors exposed to lower rates when the currency payment limit increased.

In Table A.11 we also show the results when we exploit other changes in the currency

[46]Perhaps these big notes are the most efficient to settle transactions between 1000 and 3000. Indeed, the difference between a threshold of 1000 and 3000 euro translates into 4 banknotes of 500, 10 banknotes of 200 and around 20 banknotes of 100. The last two are more convenient than smaller denominations, and are not more difficult to store in a pocket or a wallet than the first one, being more convenient for payments with values below the threshold.

[47]The not interacted dummies are absorbed by time fixed effects.

payment limit occurred in our sample period (which are reported in Figure A.14). As a further robustness check, Tables A.12 and A.13 report the estimates when both the store-of-value and the transactions shock are included in the demand function for 100, 200 and 500 notes. The results confirm the main results of this section. The interaction of rates with the store-of-value shock had no impact also on 100 and 200 notes, while the interaction with the transactions shock had an impact only on 100 and 200, but not on 500. Other denominations had no impact for both shocks. Taken together, the results in this section bring substantial evidence on the role played by the transactions demand for cash with NIRP (in line with evidences in Liñares-Zegarra and Willesson, 2021), and in particular high-value transactions.

Table 10: Currency Demand - Evidence from the Transactions Shock

Dependent variable: currency demand in mln of euro				
	100		200	
	[A.4]	[A.24]	[A.4]	[A.24]
Interest rate	-2.978 ***	-3.005 ***	0.033	0.026
	(0.449)	(0.449)	(0.070)	(0.070)
Transactions shock * interest rate		-3.635 ***		-0.706 ***
		(1.565)		(0.246)
Bank FE	Y	Y	Y	Y
Year-Month FE	Y	Y	Y	Y
$\bar{R}^2$	0.87	0.87	0.87	0.87
Observations	6,284	6,284	5,998	5,998

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The columns contain estimates for equations [A.4], [A.24], [A.4] and [A.24] respectively. Appendix A.5 contains the relative formulas. Rates on current accounts in percentage points. The dependent is the value in euro of the net monthly currency withdrawals of each commercial bank. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. The variable "Transactions shock" is a dummy that switches to one when the store-of-value shock hit on January 2016. Observation period: Jan 2010 - Jun 2018.

5.5 High Frequency Analysis around Shock Dates

In this section, we exploit the high frequency of currency operations data to study the effects of the transactions and store-of-value shocks at rates above and below the break rate estimated in Section 4 (κ). Such analysis would help us to have further evidence on whether the higher demand for currency at interest rates below the estimated breakpoint is driven by higher transactions or store-of-value demand of currency. This exercise allows us to put together our evidences on the presence of a breakpoint and the greater role played by transactions demand. The possibility of exploiting high frequency data strengthen the reliability of the findings because it permits to control more powerfully for unobserved heterogeneity at the bank level using a narrow time interval. Again we focus on the demand for banknotes hit by the two shocks, as no effects on the other notes are found. With our daily data we estimate the following model:

$$\begin{aligned} c_{d,b,100\&200/500} &= \alpha_{post} I(d > d_{shock}) + \alpha_{post,below} I(d > d_{shock}) I(r_{d,b} < \kappa) \\ &+ r_{d,b}[\beta_{post,below} I(d > d_{shock}) I(r_{d,b} < \kappa) + \beta_{post} I(d > d_{shock}) + \beta_1] \\ &+ \mu_b + \epsilon_{d,b,100\&200/500}, \end{aligned} \quad (2)$$

where d is the observation day, d_{shock} is the day in which the transactions or store-of-value shock hit, $c_{d,b,100\&200/500}$ is the demand for 100 and 200 or 500 at bank b in day d, $r_{d,b}$ is the rate at bank b observed in the month of day d, μ_b are banks' fixed effects.

Table 11: Currency Demand around Shock Dates-
Evidence from Daily Data

Dependent variable: currency demand in mln of euro

Store-of-value shock			
Post shock	-0.0782	-0.0149	-0.0166
	(0.0494)	(0.0317)	(0.0297)
Post shock * below κ	0.1111	0.1987	0.1767
	(0.2462)	(0.1458)	(0.1358)
Interest rate * below κ * post shock	2.9835	-1.4190	-1.0387
	(3.8997)	(2.3007)	(2.1625)
Interest rate * post shock	0.0357	-0.0712	-0.0574
	(0.1054)	(0.0695)	(0.0657)
Interest rate	-0.3356	-0.2296 *	-0.1650
	(0.2412)	(0.1298)	(0.1086)
Bank FE	Y	Y	Y
Banknote denomination	500	500	500
R^2	0.75	0.78	0.79
Observations	2,139	3,681	4,434
Pre-shock period	1/11/14 - 31/12/14	1/10/14 - 31/12/14	1/3/14 - 31/12/14
Post-shock period	1/1/15 - 31/01/15	1/1/15 - 29/02/15	1/1/15 - 31/03/15
Transactions shock			
Post shock	-0.0939 *	-0.0323	-0.0317
	(0.0550)	(0.0372)	(0.0347)
Post shock * below κ	0.4332 **	0.3561 ***	0.3086 ***
	(0.1726)	(0.1184)	(0.1059)
Interest rate * below κ * post shock	-6.3083 **	-5.1956 **	-4.5512 **
	(3.0624)	(2.1080)	(1.9151)
Interest rate * post shock	0.0347	-0.0057	0.0062
	(0.1668)	(0.1148)	(0.1065)
Interest rate	0.1766	-0.0662	0.0498
	(0.3272)	(0.2345)	(0.1821)
	0.7196	0.6791	0.4892
	(1.4521)	(1.0054)	(0.8665)
Bank FE	Y	Y	Y
Banknote denomination	100 & 200	100 & 200	100 & 200
R^2	0.38	0.41	0.42
Observations	4,126	6,911	8,260
Pre-shock period	1/12/15 - 31/12/15	1/11/15 - 31/12/15	1/10/15 - 31/12/15
Post-shock period	1/1/16 - 31/01/16	1/1/16 - 28/02/16	1/1/16 - 31/03/16

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. Rates on current accounts in percentage points. The dependent is the value in euro of the net monthly currency withdrawals of each commercial bank. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank.

In the first panel of Table 11 we look at time intervals around the date of the store-of-value shock, in the second around the date of the transactions shock. The observation periods considered are one, two and three months before and after the shock date, which turns in about 40, 80 and 120 days per bank and denomination. From the estimated coefficients we can see that the demand for currency was significantly higher for interest rates below κ after the transactions shock, but not after the store-of-value shock (as indicated by the coefficient for Post shock * below τ). The same result holds for the marginal effect of the interest rates (Interest rate * below τ * post shock). Currency demand for transactions motives increased more at lower rates especially below the estimated breakpoint. These results are robust to changes of time interval that preserve the narrowness of the observation period and a meaningful length.

6 Conclusions

Estimating the effect of interest rates on currency holdings when the ELB is approached is key for policy makers to understand the response of depositors to monetary policy. A significant shift from commercial bank deposits to currency can have financial stability implications and hamper monetary policy transmission. It could impact funding and profitability of banks, and potentially interest rates on bank loans and credit to the real economy. It is thus important to understand whether deposits are rapidly converted in currency and, possibly, if the conversion is driven by transactions or store-of-value purpose, as they can have different magnitudes and dynamics.

We study currency demand when negative policy rates were introduced in the euro area using Italian data. The demand shows a discontinuity when rates on bank deposits approach zero, suggesting a change in agents' behavior. We show that preferences for currency holdings may suddenly vary in this new domain, estimating a break below 0.10 per cent interest rate on deposits, with net withdrawals about ten times higher. Nevertheless, the additional amount of currency in circulation when this threshold is crossed is limited. We estimate that on average a reduction of 5 basis points in deposits rates of a bank from 0.15 to 0.10 implies that 0.16 per cent of its deposits are converted in currency. A reduction of 5 basis points from 0.05 to 0 implies a 1.70 per cent conversion.

This threshold may be interpreted as the point after which bank deposits are perceived by the public to pay almost nothing, as currency. It is different from (and higher than) the ELB, which is slightly negative given the storage and other costs related to currency. In addition, the ELB is usually referred to policy rates, while our threshold is estimated for interest rates on deposits. In our sample the threshold maps with a deposit facility rate equal to -0.4. Our results point toward a major role played by the transactions demand. The store-of-value demand looks less prominent, which reconciles with the limited amount of additional currency holdings observed. From this standpoint, we can interpret our threshold as a pre-ELB that marks an area after which, in the spirit of the Baumol-Tobin model (and others built on it), agents start to find useless actively minimizing their currency inventories because rates on deposits are not significantly higher than zero anymore.

Therefore slightly negative rates do not trigger relevant currency hoarding for store-of-value purposes, especially if rates on deposits do not go below zero, but things can change if they go further below and turn negative. The approach proposed here can be applied in other institutional (even in jurisdictions that did not implement NIRP) or future environments with deeper negative rates to assess whether other breakpoints materialize implying more severe conversions in currency and eventually detect the ELB timely. From this perspective, the paper informs the debate about the effects of NIRP and the policy tools to curb its side effects, CBDC (central bank digital currency) included.

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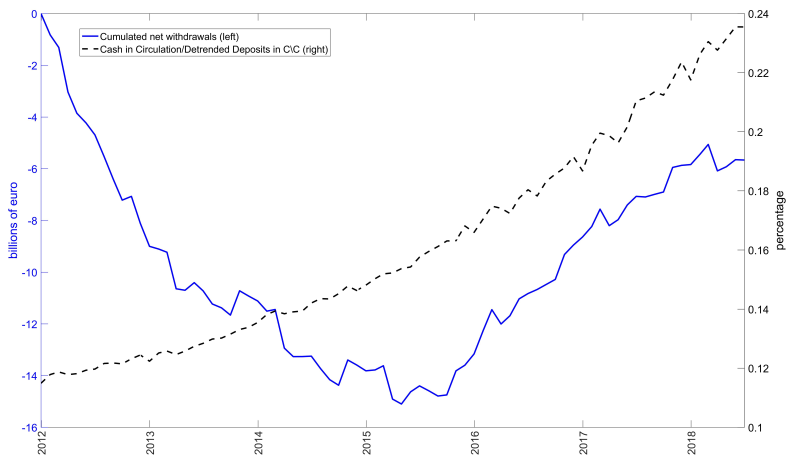
Appendix

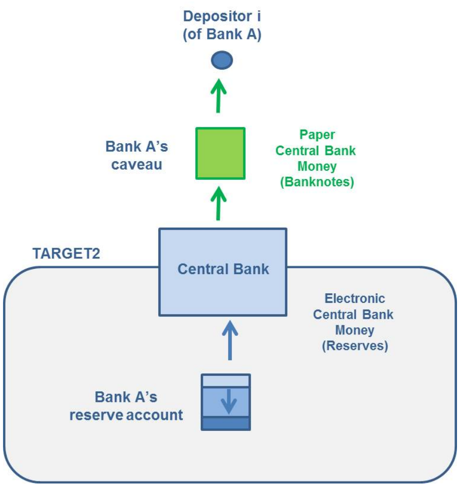
A.1 Appendix - Additional Descriptives and Figures

Figure A.1: Currency over Deposits



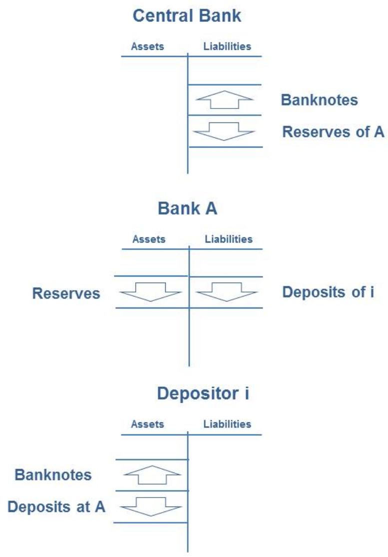
Notes. Monthly data. Blue line: moving average (5 observations) of cumulated net withdrawals expressed in billions of euro. Black line: currency in circulation over deposits of both households and firms. The starting point for currency in circulation is taken from the Italian central bank balance sheet. The other values are derived adding monthly effective net withdrawals, as measured by the blue line. Cross border private shipments of banknotes are not considered here and are impossible to know exactly. The aggregate deposits are calculated using the same dataset used for the rates, the MIR dataset. We summed households and firms detrended overnight deposits.

Figure A.2: Currency Operations



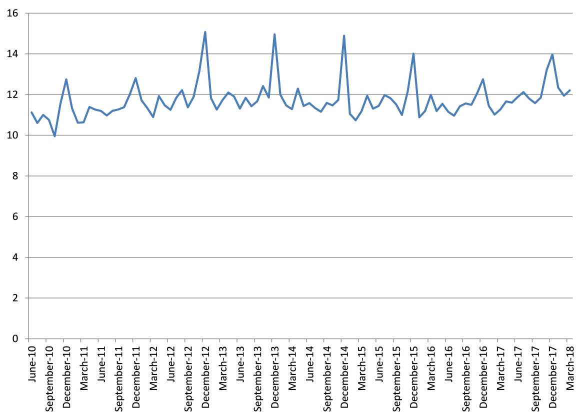
Notes. Depositor i (the blue dot) demands currency through her bank A, which in turn obtains the notes (through its caveau, the green square) from the central bank (the azzure square) against reserves (its account is the square in the beige box) in the real-time gross settlement system (RTGS), TARGET2 (the beige box) for the eurozone. Green arrows represent transfers of currency, blue lines represent transfers of reserves.

Figure A.3: Balance Sheet Perspective



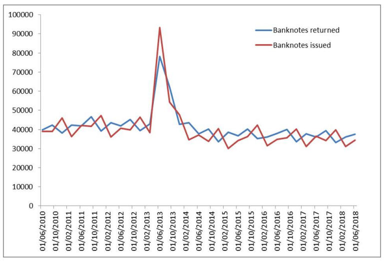
Notes. Central bank, commercial bank A and depositor i of bank A simplified balance sheets. Upward arrows represent an increase of the respective item, downward arrows represent a decrease of the respective item, which is labeled on the right of the arrow for liabilities and on the left of the arrow for assets. Items different from banknotes, reserves and deposits are omitted for clarity.

Figure A.4: Italian Banks' Caveau

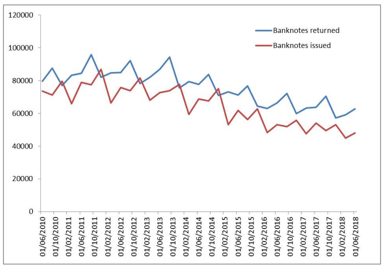


Notes. Source: Bank of Italy (Accounts Matrix). Value of banknotes held at the end of month by Italian bank in their caveau expressed in billion euro. Observation period: June 2010 - March 2018.

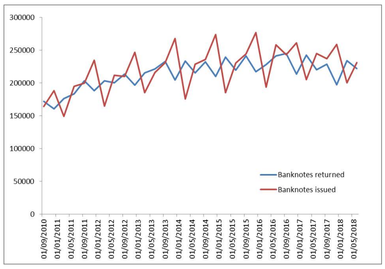
Figure A.5: Banknotes issued by and returned to the Bank of Italy by Denomination



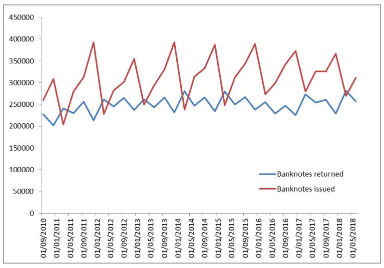
(a) 5



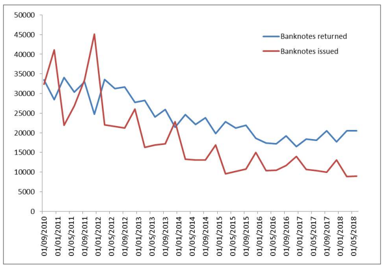
(b) 10



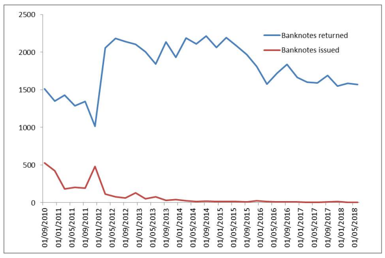
(c) 20



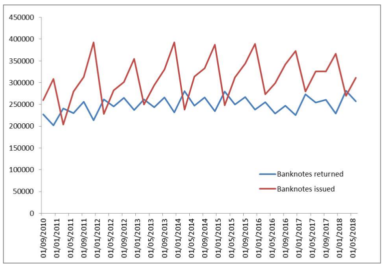
(d) 50



(e) 100



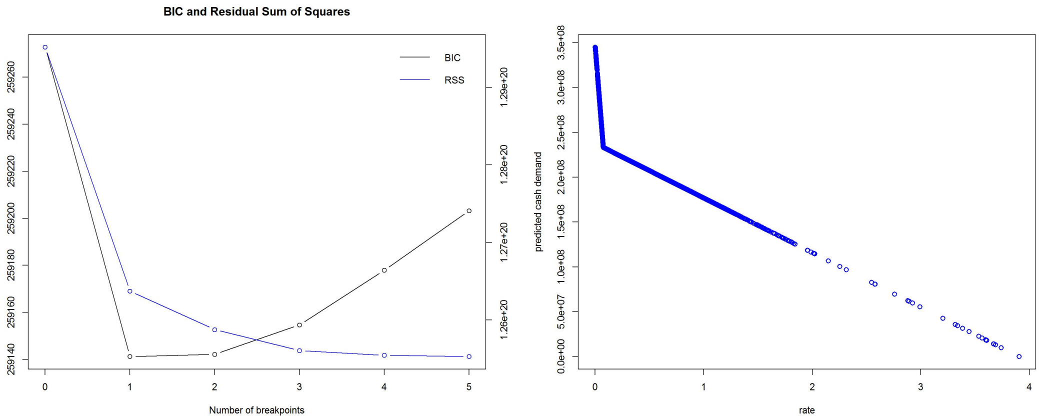
(f) 200



(g) 500

Notes. Number of notes issued by and returned to the Bank of Italy's branches for each denomination. Trimester data. The blue line is the number of notes returned, the red line is the number of notes issued. Source: Bank of Italy, Payment System Statistics, `https://www.bancaditalia.it/pubblicazioni/sistema-pagamenti/2018-sistema-pagamenti/en_statistiche_SDP_26102018.pdf?language_id=1`.

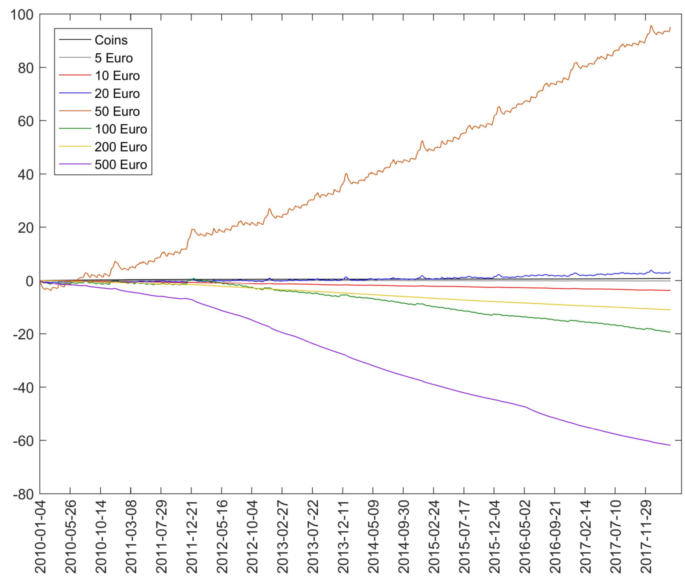
Figure A.6: Structural Breaks in the Relationship between Currency Withdrawals and Rates - Graphical Evidence



(a) BIC - RSS (b) Fit

Notes. Panel (a): y-axis: Bayesian information criterion (BIC) which is equal to $BIC = log(n)k - 2log(\hat{L})$ where $\hat{L}$ is the maximized value of the likelihood function of the model, k is the number of parameters estimated by the model, n is the number of data points. Panel(b): y-axis: expected currency withdrawals, x-axis rates on deposits. See Zeileis et al. (2001) for more details on the implementation of the Bai and Perron (1998) test for multiple endogenous break points.

Figure A.7: Net Withdrawals by Denomination in Italy

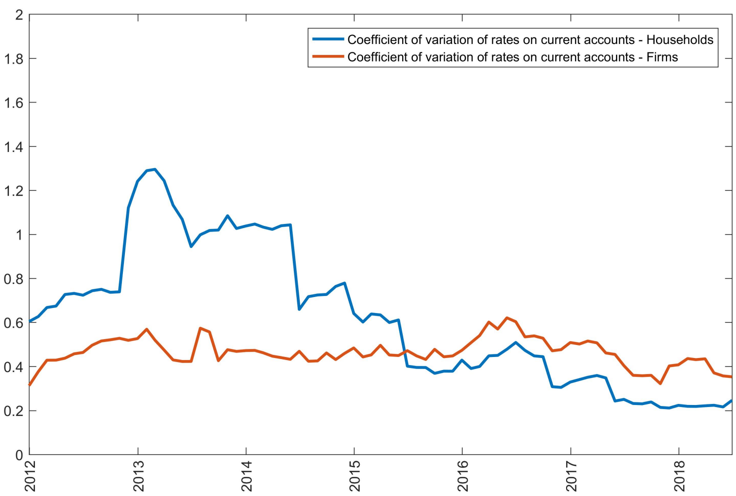


Notes. Source: Bank of Italy (Currency Circulation Management database). Cumulated net withdrawals from January 2010 to March 2018, expressed in billion euro. Net withdrawals are calculated as the sum of gross currency withdrawals of all Italian commercial banks minus the sum of gross currency deposits. Each line represents the banknote which has the same color.

A.1.1 Additional Descriptives and Figures - Interest Rate Variation

Figure A.8 plots the coefficient of variation for rates on deposits of households and firms. It seems that there is enough variation in any cross section of the sample. To see it in more detail, we plot the distributions of rates over time in Figure A.9, using box plots. The central mark indicates the median, and the bottom and top edges of the box indicate the 25th and 75th percentiles, respectively. The whiskers extend to the most extreme data points not considered outliers, and the outliers are plotted individually using the '+' symbol. Interestingly, we can see that dispersion decreased approaching the zero rate. In practice, banks do not charge negative rates to their clients, so they meet a bound for nominal rates at zero. At the same time the skewness of the distribution increased dramatically, with left tail squeezed by the lower bound.[48] Nevertheless, it seems that even at the end of the sample, when the dispersion reaches its minimum, the interval is 80/40 bp wide. We also need that from one time observation to another enough banks change their rates. In Figure A.10 and A.11 we report respectively the number of banks that changed the rate on deposits, the median and interquartile interval of these changes as a percentage of the average rate in the previous time. We can see that the percentage of banks changing deposit rates is high and these changes are often different from zero. From this preliminary analysis it seems that there is enough dispersion in interest rates.

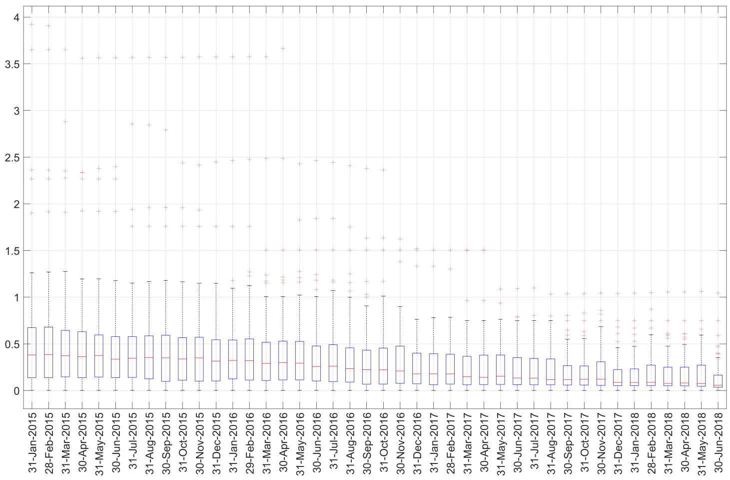
Figure A.8: Coefficient of Variation of Interest Rates



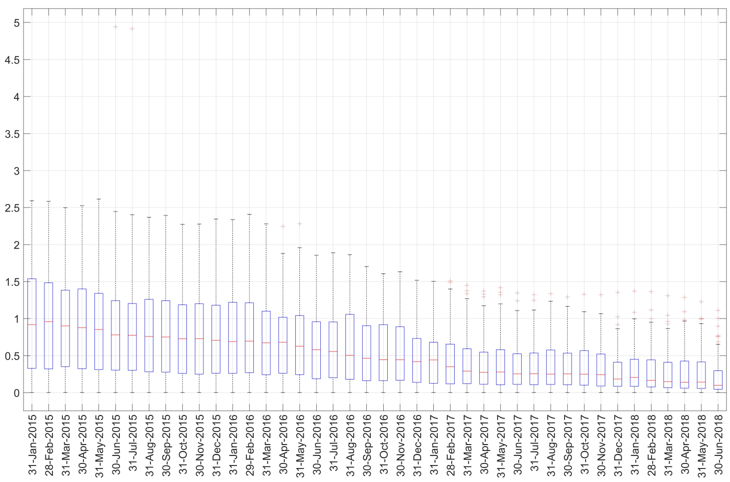
Notes. Monthly data. Coefficient of variation of rates on overnight bank accounts for households and firms. Observation period: Jan 2012 - Jun 2018

[48]It may be that banks increased fixed costs to counterbalance the impossibility of charging negative interest rates on customers. We show in Section A.4 that this is not an issue for our results.

Figure A.9: Dispersion in Interest Rates over Time



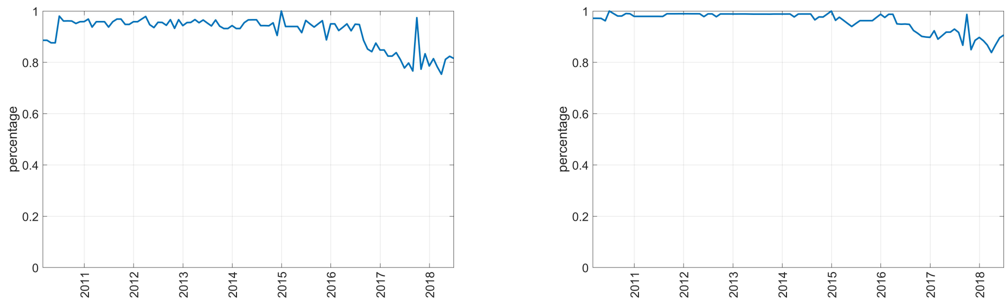
(a) Households



(b) Firms

Notes. Monthly data. Box plots computed for rates on bank accounts across banks for households and firms. The central mark indicates the median, and the bottom and top edges of the box indicate the 25th and 75th percentiles, respectively. The whiskers extend to the most extreme data points not considered outliers, and the outliers are plotted individually using the '+' symbol. Observation period: Jan 2015 - Jun 2018.

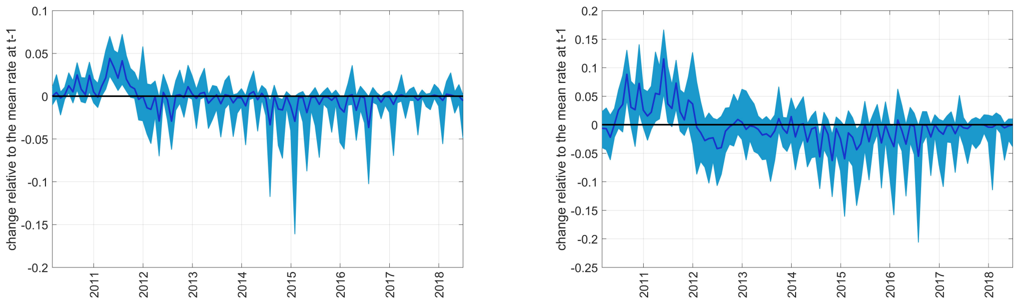
Figure A.10: Banks Changing Deposit Rates over Time



(a) Households (b) Firms

Notes. Monthly data. Percentage of rate changes on accounts for households and firms across banks. A bank changes its rates if from a month to the following one its average rate on deposits changes. Observation period: Jan 2010 - Jun 2018.

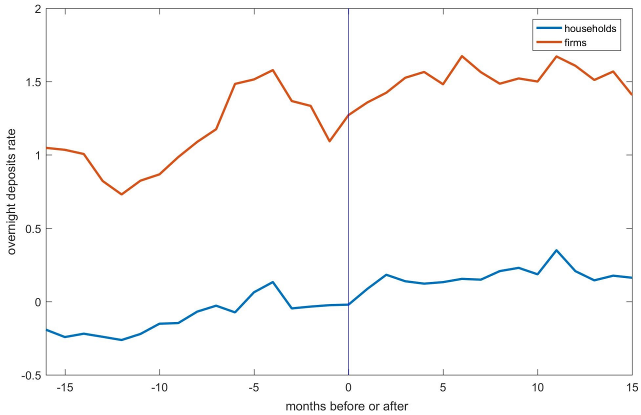
Figure A.11: Deposit Rate Change Intensity over Time



(a) Households (b) Firms

Notes. Monthly data. Interquartile interval (light blue area) and median (blue bold line) of deposit rates' changes over the mean rate at the previous time: $pct_p(\Delta r_{b,t})/\bar{r}_{t-1}$, where $p = 25, 50, 75$ is the relative percentile. Rate changes on bank accounts for households and firms.

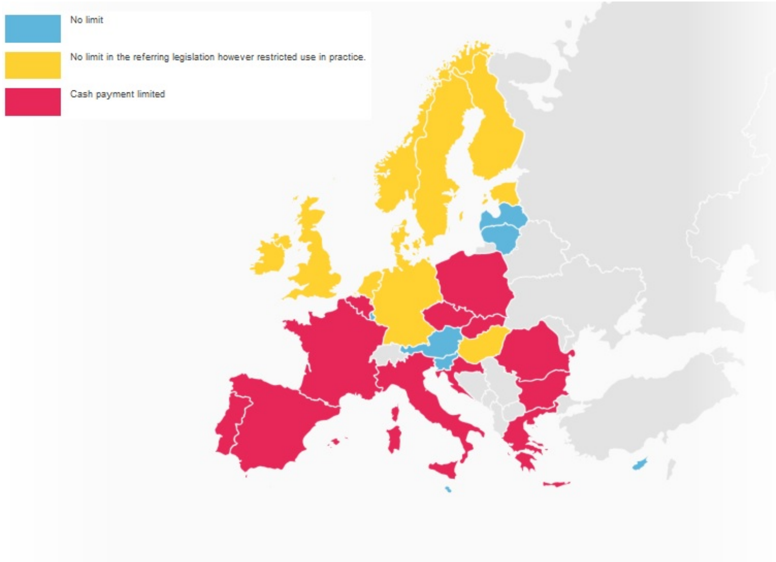
Figure A.12: Interest Rates Variation around Distress Episodes



Notes. Y-axis: Rates on overnight deposit accounts in percentage points for household and firms. X-axis: months around a distress episode. We consider 15 months before the episode and 15 months after. The vertical line represent the month in which the shock is detected. We take the spread from the average rate in the market and divide it by the standard deviation of the rate distribution for each month, in order to compare periods with high dispersion versus low dispersion periods and variation of average interest rates. Distress episodes are detected using the estimation procedure in Rainone (2021) for the Italian banking system in the period 2012-2018.

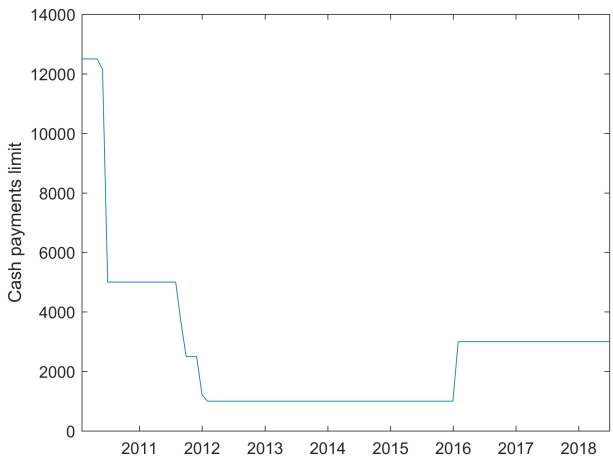
A.1.2 Additional Descriptives and Figures - Payment Limit Variation

Figure A.13: Currency Payment Limit Across European Countries



Source: The European Consumer Centre network (ECC-Net) - German Branch website. `https://www.evz.de/en/consumer-topics/buying-goods-and-services/shopping-in-the-eu/cash-payment-limitations/`

Figure A.14: Currency Payment Limit Variation in Italy over Time



Notes. Monthly data. Currency payments limit imposed by the Italian law. If a month contains a change, the average limit is computed, considering the number of days for which each limit held.

A.2 Confounding Factors

The impact of the interest rate on currency demand is difficult to estimate at the macro level, as both influence or are influenced by other macro variables simultaneously. Below we list some of these confounding factors.

Macro-economic Factors. Prices, production, wages and unemployment co-move both with interest rates and currency demand. For example, an increase in families' disposable income or a higher propensity to consumption can impact the stock of banknotes in circulation (Karni, 1973), while at the same time it may induce the central bank to change policy rates. By reacting to these macro-economic variables, also other monetary policy tools (like quantitative easing and market operations) may be used jointly with policy rates and impact the demand for currency at the same time. Fiscal policy may also affect both the demand for currency and policy rates. Both fiscal and monetary policy, together with other macroeconomic factors may also change the term structure and depositors' preferences over the assets' space.

Credit and Financial Risk. Differently from deposits at commercial banks, banknotes are guaranteed by the central bank. In the case of euro the guaranteeing entity is also a supranational institution. Currency can become more attractive for risk-averse agents (Stix, 2013) when the risk of the banking system is perceived as particularly high. In such a situation, it is possible that the central bank changes its policy rates, as the Eurosystem did during the sovereign debt crisis.

Technological Change, Payment Instruments and Services. The availability of new banking services, payment instruments, systems and infrastructures can reduce the utility of holding currency to settle transactions, raising its relative cost (Columba, 2009; Lippi and Secchi, 2009; Mercatanti and Li, 2017). Currency holding cost can increase also without a major shift in existing technology, due to shocks in consumers' preferences and incentives (Arango et al., 2015; Schuh and Stavins, 2010; Van der Cruijsen et al., 2017), costs of alternative payment methods or heterogeneous transaction costs (Briglevics and Schuh, 2014). Structural changes may characterize these variables and macro factors simultaneously, interest rates included.

Shadow Economy. Currency is preferable to electronic payment instruments, as long as the anonymity of transactions is concerned (Ardizzi et al., 2014; Cagan, 1958; Schneider, 1986; Tanzi, 1980), so more intense shadow economic activity may increase the demand for currency. We can not exclude that changes in shadow economic activity are correlated with other macro-economic variables and policy tools, like interest rates. For example, merchants may declare a lower share of income during recessions, when income is declining per se.

A.3 Appendix - Additional Results

Different Functional forms. Here we estimate our main equation using different functional forms for the relationship between currency demand and interest rates. Table A.1 reports the estimates of β using different specifications for model (1). We define $C^S_{t,b} = \sum_{\tau}^{T} \Delta C_{t,b}$, where τ is the initial month (January 2010) and $\Delta C_{t,b}$ is the net currency withdrawal (gross currency withdrawals minus gross currency deposits) of bank b at time (month) t. We set $C^S_{t,b}$ as the dependent variable in the first four columns, $\Delta C_{t,b}$ in the following two, and $log(C^S_{t,b})$ in the last two.[49] For all specifications the effect of the interest rate is negative and significant, as expected. The linear effect is above 130 million euro when we control for time and bank fixed effects. The quadratic term is not significantly different from zero. Nevertheless, the effect is significant also if we consider $\Delta C_{t,b}$ as the dependent variable, being above 30 million euro, suggesting a non linear relationship between $C^S_{t,b}$ and $r_{t-1,b}$.

Table A.2 reports the same results when we consider separately interest rates for households and firms. Unfortunately, we do not know currency withdrawals separately for households and firms, thus these estimates do not provide exact and separate effects for the two types. Nevertheless, they can inform about the effect of rates applied to the two types

[49] The log-log specification (in which also the rate is expressed in log) is not computable because for some banks in some times $log(C^S_{t,b}) = 0$.

Table A.1: The Effect of Deposit Rates on the Demand for Currency

Dependent variable: currency demand in mln euro

	linear		linear-quadratic		Δ cash		log	
	[A.3]	[A.4]	[A.5]	[A.6]	[A.1]	[A.2]	[A.7]	[A.8]
Interest rates	-467.176 ***	-137.186 ***	-466.697 ***	-134.779 ***	-40.391 ***	-32.538 ***		
	(42.381)	(32.094)	(42.389)	(32.207)	(4.630)	(4.335)		
Interest rates^2			-29.600	17.524				
			(43.528)	(19.596)				
log(Interest rates)							-90.839 ***	-47.249 **
							(11.395)	(10.170)
Bank FE	N	Y	N	Y	N	Y	N	Y
Year-Month FE	N	Y	N	Y	N	Y	N	Y
$\bar{R}^2$	0.018	0.820	0.018	0.820	0.018	0.722	0.010	0.819
Observations	6,420	6,420	6,420	6,420	6,420	6,420	6,420	6,420

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The estimated model in is square brackets. Weighted average of interest rates on overnight deposit accounts for household and firms in percentage points. The dependent is the cumulated value in million of euro of the net monthly currency withdrawals of each commercial bank, with the exception of the fifth and sixth column, where it is the net monthly currency withdrawals. Net currency withdrawals are measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. Observation period: Jan 2010 - Jun 2018.

on the aggregate demand for currency. On average, the effects on currency demand look higher when we consider interest rates on households' deposits. For the latter also the log specification is not computable, because many banks set interest rates equal to zero only for households and not for firms. This might indicate a higher elasticity of the demand for households.

A potential issue when we use $C^S_{t,b}$ as the dependent variable is that it can keep track of the evolution of the stock of banknotes demanded by bank b depositors, but the initial stock is set equal to zero, as we do not know the exact value of the stock of banknotes held by these depositors. In this case, if the initial stock of banknotes in the pockets of banks' depositors is highly heterogeneous, observations across banks may not be correctly comparable. In order to tackle this issue we can estimate the initial point. For example, we can set the initial points proportional to the share of deposits at time τ: $\tilde{C}_{b,\tau} = C_{CB,\tau}\frac{D_{b,\tau}}{D_\tau}$, where C_{CB} is the amount of notes in circulation at time τ,[50] the initial point, $D_{b,\tau}$ is the amount of deposits of bank b at time τ and $D_\tau = \sum_b D_{b,\tau}$. In the first eight columns

[50]Which is estimated using the currency liability in the central bank balance sheet.

of Table A.3 we report the results when we use these initial points. We can see that the results do not differ substantially from Table A.1. In the last two columns we also included the term $s_{b,t} = \frac{D_{b,t}}{D_t}$, to control for the dynamics of the relative share of deposits for each bank, as banks increasing their deposits may have higher net withdrawals. In all these specifications the linear effect is around 140 million euro. Given that initial points may be imprecisely estimated, in what follows we will mainly focus on net currency withdrawals, $\Delta C_{t,b}$, which is the most precise measure we have. In addition once we secured enough evidence on the simple linear relationship in levels, it is more interesting to look at what happens to net currency withdrawals at very low interest rates.

Households and Firms

Table A.2: The Effect of Deposit Rates on the Demand for Currency

Dependent variable: currency demand in mln euro

	linear		linear-quadratic		Δ cash		log	
	[A.3]	[A.4]	[A.5]	[A.6]	[A.5]	[A.6]	[A.7]	[A.8]
Non-financial firms								
Interest rates	-296.157 ***	-130.973 ***	-608.298 ***	-334.702 ***	-19.997 ***	-20.116 ***		
	(27.801)	(23.368)	(71.206)	(57.506)	(3.043)	(3.164)		
Interest rates^2			150.993 ***	75.755 ***				
			(31.720)	(19.542)				
log(Interest rates)							-70.942 ***	-22.779 **
							(10.510)	(9.816)
Bank FE	N	Y	N	Y	N	Y	N	Y
Year-Month FE	N	Y	N	Y	N	Y	N	Y
$\bar{R}^2$	0.017	0.820	0.021	0.821	0.007	0.722	0.007	0.819
Observations	6,420	6,420	6,420	6,420	6,420	6,420	6,420	6,420
Households								
Interest rates	-652.709 ***	-261.855 ***	-976.239 ***	-391.319 ***	-21.806 ***	-30.261 ***		
	(57.917)	(42.557)	(90.103)	(75.926)	(6.362)	(5.770)		
Interest rates^2			230.595 ***	56.573 ***				
			(49.252)	(27.480)				
log(Interest rates)							n.c.	n.c.
							n.c.	n.c.
Bank FE	N	Y	N	Y	N	Y	N	N
Year-Month FE	N	Y	N	Y	N	Y	N	N
$\bar{R}^2$	0.016	0.820	0.03	0.820	0.002	0.721	n.c.	n.c.
Observations	6,420	6,420	6,420	6,420	6,420	6,420	6,420	6,420

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The estimated model in is square brackets. Rates on overnight deposit accounts in percentage points for household and firms. The dependent is the cumulated value in million of euro of the net monthly currency withdrawals of each commercial bank, with the exception of the fifth and sixth column, where it is the net monthly currency withdrawals. Observation period: Jan 2010 - Jun 2018. n.c. stands for "not computable". The presence of zero interest rates does not allow for the computation of the log function.

A.4 Appendix - Robustness

Estimated Initial Points and Deposit Weights

Table A.3: Estimated Initial Points and Deposit Weights

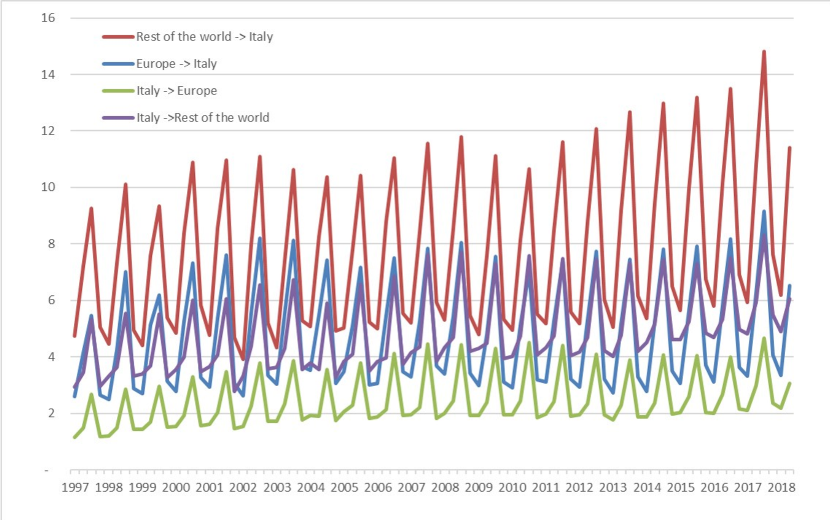
Dependent variable: currency demand in mln euro

	log-log		log		linear		linear-quadratic		linear with deposit weights	
	[A.13]	[A.14]	[A.13]	[A.14]	[A.9]	[A.10]	[A.11]	[A.12]	[A.17]	[A.18]
log(Interest rate)	n.c.	n.c.	-1,790.219 ***	-56.097 **						
	n.c.	n.c.	(195.087)	(14.338)						
Interest rate					-9,708.628 ***	-139.632 ***	-9,693.697 ***	-137.989 ***	-1,296.280 ***	-147.521 ***
					(723.492)	(45.257)	(723.562)	(45.419)	(384.012)	(45.265)
Interest rate^2							-922.712	11.963		
							(743.006)	(27.635)		
Bank FE	N	Y	N	Y	N	Y	N	Y	N	Y
Time FE	N	Y	N	Y	N	Y	N	Y	N	Y
$\bar{R}^2$	n.c.	n.c.	0.013	0.999	0.027	0.999	0.027	0.999	0.734	0.999
Observations	6,420	6,420	6,420	6,420	6,420	6,420	6,420	6,420	6,420	6,420

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The estimated model in is square brackets. Rates on overnight deposit accounts in percentage points for household and firms. The dependent is the cumulated value in million of euro of the net monthly currency withdrawals of each commercial bank, with the exception of the last two columns where it is the net monthly currency withdrawals. Observation period: Jan 2010 - Jun 2018. n.c. stands for "not computable". The presence of zero interest rates does not allow for the computation of the log function. In the last two columns the term $s_{b,t} = \frac{D_{b,t}}{D_t}$ is included. $D_{b,t}$ is the amount of deposits of bank b at time t and and $D_t = \sum_b D_{b,t}$. The initial points computed multiplying the amount of notes in circulation for the share of deposits in January 2010 for each bank. The amount of notes in circulation is approximated using the currency liability in the central bank balance sheet.

Banknotes across the Borders

Figure A.15: Banknotes across the Borders - Tourists' Flows and Expenses



Notes. X-axis: time in quarters. Y-axis: travelers' expenses in billions of euro. 'departure' -¿ 'destination'. Italy is excluded from Europe and rest of the word. The touristic expenses include all the goods and services purchased by the tourist but those related to the travel from and to the holiday destination. Includes for example tickets for museums, accommodation, transportation within the country of destination, taxi, restaurants, souvenirs, etc. Source: Bank of Italy `https://www.bancaditalia.it/statistiche/tematiche/rapporti-estero/turismo-internazionale/tavole/index.html`

A.4.1 IV Estimates - Additional Results

Table A.4: Instrumental Variable Estimation
- Different functional forms -

	Linear			Log		
	Full sample	Subsample	IV	Full sample	Subsample	IV
Interest rate	-137.186 ***	-129.373 ***	-1,745.170 ***			
	(32.094)	(56.813)	(320.320)			
log(Interest rate)				-47.249 **	-255.652 ***	-773.577 ***
				(10.170)	(30.188)	(106.366)
Bank FE	Y	Y	Y	Y	Y	Y
Year-Month FE	Y	Y	Y	Y	Y	Y
F stat			19.394			44.732
Observations	6,420	2,887	2,887	6,420	2,887	2,887

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. Weighted average rates on overnight deposit accounts in percentage points for household and firms. The dependent is the cumulated value in million of euro of the net monthly currency withdrawals of each commercial bank. The IV estimates are performed using the instruments listed in Table A.5. Observation period: Jan 2010 - Jun 2018.

Table A.5: Instrumental Variable Estimation
- First Steps -

Dependent variable: interest rates

	linear	log
Domestic securities	4.2187 ***	0.8810 ***
	(0.2935)	(0.1620)
Interbank borrowing	-1.6793 ***	-0.8402 ***
	(0.2265)	(0.1250)
Interbank lending	2.8058 ***	1.2800 ***
	(0.3386)	(0.1869)
NPL	0.0551	-0.2105
	(0.6303)	(0.3478)
Tier 1	0.0118	0.0050
	(0.0308)	(0.0170)
Loans	1.4614 ***	-0.2132
	(0.3122)	(0.1723)
Bank FE	Y	Y
Year-Month FE	Y	Y
F stat	19,394	44,732
Observations	2.887	2.887

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. Rates on overnight deposit accounts in percentage points for household and firms. Weighted average rates on overnight deposit accounts in percentage points for household and firms. Assets and liabilities are expressed as a percentage of total assets. Observation period: Jan 2010 - Jun 2018.

A.4.2 Bank Time-varying Balance Sheet Structure

In Table A.6 we report the results of our main specification augmented with bank-specific time-varying controls. We can see that the coefficient is unchanged.

Table A.6: Bank Time-varying Controls

Dependent variable: currency demand in mln euro			
	Full sample	Subsample	Subsample
Interest rate	-32.538 ***	-46.197 ***	-45.375 ***
	(4.335)	(7.454)	(7.571)
Bank FE	Y	Y	Y
Year-Month FE	Y	Y	Y
Bank Time-varying controls	N	N	Y
Observations	6,420	2,887	2,887

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. Weighted average rates on overnight deposit accounts in percentage points for household and firms. The dependent is the value in million of euro of the net monthly currency withdrawals of each commercial bank. Observation period: Jan 2010 - Jun 2018.

A.4.3 Deposits Sensitivity to Rates

Our results could be biased if customers with deposits in banks with low interest rates close their accounts, withdraw all their funds in currency and deposit them to another bank with higher rates. To check whether this could be an issue, we regress the amount of deposits on rates, bank and time fixed effects. We estimate the following deposit demand equation,

$$D_{t,b} = \alpha + \beta r_{t,b} + \eta_t + \mu_b + \epsilon_{t,b}.$$

The results are showed in Table A.7. In the first column, the aggregate amount (weighted average of households and firms' deposits) does not seem to be reactive to rates. When looking separately at households and firms (second and third column), we find that households' deposits do not increase significantly with the rate, while firms' deposits do. This could be explained by the fact that firms used more intensively overnight deposits to store value in the sample period (which contains the sovereign debt crisis), also because it was more difficult to obtain credit lines or loans (see Casiraghi, 2020); then hoarding on overnight deposits at higher interest rates was better for them. Households seem to be less likely to change bank for higher interest rates, as they primarily maintain deposits as the most liquid assets to settle payments. In light of these results we do not think that deposit sensitivity to rates could hamper our results. Firstly, deposits do not vary significantly with rates at the aggregate level. Secondly, households constitute the majority of deposits (75 percent), and thirdly firms are more likely to use digital transfers instead of converting in currency, as their deposits are on average much bigger and risky to be physically transferred in currency.

Table A.7: Deposits Sensitivity to Rates

Dependent variable: deposits in mln euro

	All	Households	Firms
	[A.30]	[A.30]	[A.30]
Interest rate	-116	364	380 ***
	(264)	(238)	(66)
Share on total deposits		0.75	0.25
Bank FE	Y	Y	Y
Time FE	Y	Y	Y
$\bar{R}^2$	0.93	0.94	0.87
Observations	6,420	6,420	6,420

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The estimated model in is square brackets. Rates on and amount of current accounts respectively in percentage points and millions. The dependent is the value in euro of the deposits of each commercial bank at the end of month t. Observation period: Jan 2010 - Jun 2018.

A.4.4 Further Results on Banknotes Heterogeneity

In Table A.8 we regress net currency withdrawals of small banknotes separately on rates to non-financial firms and households. From this table we can see that the effect is always negative and significant across all the specifications. The marginal effect of rates on households is significantly higher than the one for firms. When we regress net currency withdrawals for big notes, the results are different. Indeed, from Table A.9 we can see that the effect is often not distinguishable from zero and barely significant in few specifications. There is no substantial difference if we use rates on households or rates on firms.

Table A.8: The Demand for Small Notes

Dependent variable: currency demand in mln of euro			
	[A.21]	[A.22]	[A.23]
Interest rate on non-financial firms	-6.119 ***	-4.815 ***	-4.896 ***
	(0.589)	(0.990)	(0.976)
Bank FE	N	Y	Y
Time FE	N	Y	Y
Denomination FE	N	N	Y
$\bar{R}^2$	0.00	0.28	0.30
Observations	25,512	25,512	25,512
Interest rate on households	-9.570 ***	-7.517 ***	-7.568 ***
	(1.228)	(1.798)	(1.774)
Bank FE	N	Y	Y
Time FE	N	Y	Y
Denomination FE	N	N	Y
$\bar{R}^2$	0.00	0.28	0.30
Observations	25,512	25,512	25,512

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The estimated model in is square brackets. Rates on bank overnight deposit accounts in percentage points for household and firms . The dependent is the value in million euro of the net monthly currency withdrawals of each commercial bank. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. Observation period: Jan 2010 - Jun 2018.

Table A.9: The Demand for Big Notes

Dependent variable: currency demand in mln of euro

	[A.21]	[A.22]	[A.23]
Interest rate on non-financial firms	1.394 ***	-0.453 *	-0.505 **
	(0.203)	(0.258)	(0.243)
Bank FE	N	Y	Y
Time FE	N	Y	Y
Denomination FE	N	N	Y
$\bar{R}^2$	0.00	0.59	0.63
Observations	18,466	18,466	18,466
Interest rate on households	5.306 ***	-0.426	-0.520
	(0.422)	(0.467)	(0.882)
Bank FE	N	Y	Y
Time FE	N	Y	Y
Denomination FE	N	N	Y
$\bar{R}^2$	0.00	0.59	0.63
Observations	18,466	18,466	18,466

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The estimated model in is square brackets. Rates on bank overnight deposit accounts in percentage points for household and firms . The dependent is the value in million euro of the net monthly currency withdrawals of each commercial bank. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. Observation period: Jan 2010 - Jun 2018.

Table A.10: Demand for Single Denominations by Type of Depositor

Dependent variable: net monthly currency withdrawals in mln euro

	5	10	20	50	100	200	500
	[A.4]	[A.4]	[A.4]	[A.4]	[A.4]	[A.4]	[A.4]
Interest rate on non-financial firms	-0.202 ***	-0.079	-4.515 ***	-14.192 ***	-1.762 ***	0.121 ***	0.434
	(0.031)	(0.105)	(0.756)	(2.186)	(0.329)	(0.052)	(0.294)
Bank FE	Y	Y	Y	Y	Y	Y	Y
Time FE	Y	Y	Y	Y	Y	Y	Y
$\bar{R}^2$	0.65	0.93	0.79	0.73	0.87	0.87	0.83
Observations	6,154	6,268	6,333	6,367	6,284	5,998	6,184
Interest rate on households	-0.309 ***	-0.131	-6.944 ***	-21.854 ***	-2.251 ***	0.336 ***	0.725
	(0.056)	(0.190)	(1.372)	(3.978)	(0.599)	(0.095)	(0.534)
Bank FE	Y	Y	Y	Y	Y	Y	Y
Time FE	Y	Y	Y	Y	Y	Y	Y
$\bar{R}^2$	0.65	0.93	0.79	0.73	0.87	0.87	0.83
Observations	6,246	6,268	6,333	6,367	6,284	5,998	6,184

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The estimated model in is square brackets. Rates on current accounts in percentage points for household and firms. The dependent is the value in euro of the net monthly currency withdrawals of each commercial bank for each denomination. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. Observation period: Jan 2010 - Jun 2018.

A.4.5 Further Results on Transactions and Store-of-value Shocks

Table A.11: Transactions Demand - Payment Limit Variation

Dependent variable: currency demand in mln of euro

	100	200
	[A.26]	[A.26]
Non-financial firms		
Interest rate	-7.101 ***	-0.918 ***
	(1.616)	(0.260)
Interest rate*$(max_L - L)$	-471 ***	-92 **
	(139)	(22)
Bank FE	Y	Y
Year-Month FE	Y	Y
$\bar{R}^2$	0.87	0.87
Observations	6,284	5,998
Households		
Interest rate	-1.793 ***	0.045
	(0.385)	(0.062)
Interest rate*$(max_L - L)$	-9	-22 **
	(60)	(10)
Bank FE	Y	Y
Year-Month FE	Y	Y
$\bar{R}^2$	0.87	0.87
Observations	6,284	5,998

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The estimated model is in square brackets. Rates on current accounts in percentage points for household and firms. The dependent is the value in euro of the net monthly currency withdrawals of each commercial bank in mln. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. L is the payment limit at time t, max_L is its maximum over the observation period: Jan 2010 - Jun 2018. The coefficient of Rate*$(max_L - L)$ is multiplied by one million to make it visible.

Table A.12: Transactions Demand - Robustness Check: Including Store-of-value shock

Dependent variable: currency demand in mln of euro

	100		200	
	[A.24]	[A.28]	[A.24]	[A.28]
Non-financial firms				
Rate	-1.711 ***	-1.742 ***	0.125 ***	0.118 ***
	(0.333)	(0.333)	(0.055)	(0.055)
Store-of-value shock * interest rate		1.301		0.312 *
		(0.914)		(0.147)
Transactions shock * interest rate	-0.151	-1.210	-0.263 *	-0.516 ***
	(1.005)	(1.251)	(0.160)	(0.200)
Bank FE	Y	Y	Y	Y
Year-Month FE	Y	Y	Y	Y
$\bar{R}^2$	0.87	0.87	0.86	0.86
Observations	6,384	6,384	6,095	6,095
Households				
Rate	-2.650 ***	-2.636 ***	0.250 ***	0.250 ***
	(0.604)	(0.605)	(0.098)	(0.099)
Store-of-value shock * interest rate		-0.638		-0.036
		(1.713)		0.281)
Transactions shock * interest rate	-6.135 ***	-5.617 ***	-1.227 ***	-1.198 ***
	(1.851)	(2.316)	(0.303)	(0.380)
Bank FE	Y	Y	Y	Y
Year-Month FE	Y	Y	Y	Y
$\bar{R}^2$	0.87	0.87	0.86	0.86
Observations	6,384	6,384	6,095	6,095

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The estimated model in is square brackets. Rates on current accounts in percentage points for household and firms. The dependent is the value in euro of the net monthly currency withdrawals of each commercial bank. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. The variable "Store-of-value shock" is a dummy that switches to one when the store-of-value shock hit on January 2015. The variable "Transactions shock" is a dummy that switches to one when the store-of-value shock hit on January 2016. Observation period: Jan 2010 - Jun 2018.

Table A.13: Store of Value Demand - Robustness Check: Including Transactions Shock

Dependent variable: currency demand in mln of euro		
	500	
	[A.25]	[A.28]
Non-financial firms		
Rate	0.487 *	0.503 *
	(0.292)	(0.292)
Store-of-value shock * interest rate	0.576	0.037
	(0.646)	(0.810)
Transactions shock * interest rate		1.210
		(1.095)
Bank FE	Y	Y
Year-Month FE	Y	Y
$\bar{R}^2$	0.83	0.83
Observations	6,281	6,281
Households		
Rate	0.414	0.435
	(0.529)	(0.530)
Store-of-value shock * interest rate	0.469	-0.365
	(1.223)	(1.552)
Transactions shock * interest rate		1.813
		(2.077)
Bank FE	Y	Y
Year-Month FE	Y	Y
$\bar{R}^2$	0.83	0.83
Observations	6,281	6,281

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The estimated model in is square brackets. Rates on current accounts in percentage points for household and firms respectively. The dependent is the value in euro of the net monthly currency withdrawals of each commercial bank. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. The variable "Store-of-value shock" is a dummy that switches to one when the store-of-value shock hit on January 2015. The variable "Transactions shock" is a dummy that switches to one when the store-of-value shock hit on January 2016. Observation period: Jan 2010 - Jun 2018.

Table A.14: Currency Demand - Evidence from Store-of-value Shock

Dependent variable: currency demand in mln of euro

	500	
	[A.4]	[A.25]
Non-financial firms		
Interest rate	0.434	0.428
	(0.294)	(0.295)
Store-of-value shock * interest rate		0.370
		(0.649)
Bank FE	Y	Y
Year-Month FE	Y	Y
$\bar{R}^2$	0.83	0.83
Observations	6,184	6,184
Households		
Interest rate	0.725	0.724
	(0.534)	(0.534)
Store-of-value shock * interest rate		0.132
		(1.229)
Bank FE	Y	Y
Year-Month FE	Y	Y
$\bar{R}^2$	0.83	0.83
Observations	6,184	6,184

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The estimated model in is square brackets. Rates on current accounts in percentage points for household and firms. The dependent is the value in euro of the net monthly currency withdrawals of each commercial bank. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. The variable "Store-of-value shock" is a dummy that switches to one when the store-of-value shock hit on January 2015. Observation period: Jan 2010 - Jun 2018.

Table A.15: Transactions Demand - Evidence from Transactions Shock

Dependent variable: currency demand in mln of euro

	100		200	
	[A.4]	[A.24]	[A.4]	[A.24]
Non-financial firms				
Interest rate	-1.762 ***	-1.764 ***	0.121 ***	0.119 ***
	(0.329)	(0.329)	(0.052)	(0.052)
Transactions shock * interest rate		-0.301		-0.240 *
		(0.997)		0.154
Bank FE	Y	Y	Y	Y
Year-Month FE	Y	Y	Y	Y
$\bar{R}^2$	0.87	0.87	0.87	0.86
Observations	6,284	6,284	5,998	6,095
Households				
Interest rate	-2.251 ***	-2.281 ***	0.336 ***	0.329 ***
	(0.599)	(0.599)	(0.095)	(0.095)
Transactions shock * interest rate		-5.568 ***		-1.016 ***
		(1.833)		(0.292)
Bank FE	Y	Y	Y	Y
Year-Month FE	Y	Y	Y	Y
$\bar{R}^2$	0.87	0.87	0.87	0.87
Observations	6,284	6,284	5,998	6,095

Notes. * : $p < 0.10$; **: $p < 0.05$; ***: $p < 0.01$. Standard errors are reported in round brackets. The estimated model in is square brackets. Rates on current accounts in percentage points for household and firms respectively. The dependent is the value in euro of the net monthly currency withdrawals of each commercial bank. It is measured as the difference between the sum of currency delivered to minus the sum of currency withdrawn from the central bank. The variable "Transactions shock" is a dummy that switches to one when the store-of-value shock hit on January 2016. Observation period: Jan 2010 - Jun 2018.

A.5 Estimated Equations

Different Functional Forms

$$\Delta C_{t,b} = \alpha + \beta r_{t-1,b} + \epsilon_{t,b}, \tag{A.1}$$

$$\Delta C_{t,b} = \alpha + \beta r_{t-1,b} + \eta_t + \mu_b + \epsilon_{t,b}, \tag{A.2}$$

$$C^S_{t,b} = \alpha + \beta r_{t-1,b} + \epsilon_{t,b}, \tag{A.3}$$

$$C^S_{t,b} = \alpha + \beta r_{t-1,b} + \eta_t + \mu_b + \epsilon_{t,b}, \tag{A.4}$$

$$C^S_{t,b} = \alpha + \beta_1 r_{t-1,b} + \beta_2 r^2_{t-1,b} + \epsilon_{t,b}, \tag{A.5}$$

$$C^S_{t,b} = \alpha + \beta_1 \beta_1 r_{t-1,b} + \beta_2 r^2_{t-1,b} + \eta_t + \mu_b + \epsilon_{t,b}, \tag{A.6}$$

$$C^S_{t,b} = \alpha + \beta log(r_{t-1,b}) + \epsilon_{t,b}, \tag{A.7}$$

$$C^S_{t,b} = \alpha + \beta log(r_{t-1,b}) + \eta_t + \mu_b + \epsilon_{t,b}, \tag{A.8}$$

Initial Points

$$\tilde{C}_{t,b} = \alpha + \beta r_{t-1,b} + \epsilon_{t,b}, \tag{A.9}$$

$$\tilde{C}_{t,b} = \alpha + \beta r_{t-1,b} + \eta_t + \mu_b + \epsilon_{t,b}, \tag{A.10}$$

$$\tilde{C}_{t,b} = \alpha + \beta_1 r_{t-1,b} + \beta_2 r^2_{t-1,b} + \epsilon_{t,b}, \tag{A.11}$$

$$\tilde{C}_{t,b} = \alpha + \beta_1 \beta_1 r_{t-1,b} + \beta_2 r^2_{t-1,b} + \eta_t + \mu_b + \epsilon_{t,b}, \tag{A.12}$$

$$\tilde{C}_{t,b} = \alpha + \beta log(r_{t-1,b}) + \epsilon_{t,b}, \tag{A.13}$$

$$\tilde{C}_{t,b} = \alpha + \beta log(r_{t-1,b}) + \eta_t + \mu_b + \epsilon_{t,b}, \tag{A.14}$$

$$log(\tilde{C}_{t,b}) = \alpha + \beta log(r_{t-1,b}) + \epsilon_{t,b}, \tag{A.15}$$

$$log(\tilde{C}_{t,b}) = \alpha + \beta log(r_{t-1,b}) + \eta_t + \mu_b + \epsilon_{t,b}, \tag{A.16}$$

$$\tilde{C}_{t,b} = \alpha + \beta r_{t-1,b} + \rho s_{t,b} + \epsilon_{t,b}, \tag{A.17}$$

$$\tilde{C}_{t,b} = \alpha + \beta r_{t-1,b} + \rho s_{t,b} + \eta_t + \mu_b + \epsilon_{t,b}, \qquad [A.18]$$

Structural breaks

$$\Delta C_{t,b} = \alpha_1 I(r_{t-1,b} > \kappa) + \beta_1 r_{t-1,b} I(r_{t-1,b} > \kappa) + \alpha_2 I(r_{t-1,b} \leq \kappa) + \beta_2 r_{t-1,b} I(r_{t-1,b} \leq \kappa) + \epsilon_{t,b}, \qquad [A.19]$$

$$\Delta C_{t,b} = \alpha_1 I(r_{t-1,b} > \kappa) + \beta_1 r_{t-1,b} I(r_{t-1,b} > \kappa) + \alpha_2 I(r_{t-1,b} \leq \kappa) + \beta_2 r_{t-1,b} I(r_{t-1,b} \leq \kappa) + \eta_t + \mu_b + \epsilon_{t,b}, \ \kappa = \kappa^* \qquad [A.20]$$

where κ^* is the breakpoint estimated by the structural break point method (Bai and Perron, 1998, 2003).

Small and Big Notes

$$\Delta C_{t,b,S|B} = \alpha + \beta r_{t-1,b,S|B} + \epsilon_{t,b,S|B}, \qquad [A.21]$$

$$\Delta C_{t,b,S|B} = \alpha + \beta r_{t-1,b,S|B} + \eta_t + \mu_b + \epsilon_{t,b,S|B}, \qquad [A.22]$$

$$\Delta C_{t,b,S|B} = \alpha + \beta r_{t-1,b,S|B} + \eta_t + \mu_b + \omega_d + \epsilon_{t,b,S|B}, \qquad [A.23]$$

Payment Limit and Banking system monitoring

$$\Delta C_{t,b,100/200} = \alpha + \beta_1 r_{t-1,b} + \beta_{Trans} r_{t-1,b} * I(t > S_{Trans}) + \eta_t + \mu_b + \epsilon_{t,b,100/200}, \qquad [A.24]$$

$$\Delta C_{t,b,500} = \alpha + \beta_1 r_{t-1,b} + \beta_{Store} r_{t-1,b} * I(t > S_{Store}) + \eta_t + \mu_b + \epsilon_{t,b,500}, \qquad [A.25]$$

$$\Delta C_{t,b,100/200} = \alpha + \beta_1 r_{t-1,b} + \beta_{Trans} r_{t-1,b}(max_{L_t} - L_t) + \eta_t + \mu_b + \epsilon_{t,b,100/200}, \qquad [A.26]$$

$$\Delta C_{t,b,100/200/500} = \alpha + \beta_1 r_{t-1,b} + \beta_{Store} r_{t-1,b} * I(t > S_{Store}) + \beta_{Trans} r_{t-1,b} * I(t > S_{Trans}) + \epsilon_{t,b,100/200/500}, \qquad [A.27]$$

$$\Delta C_{t,b,100/200/500} = \alpha + \beta_1 r_{t-1,b} + \beta_{Store} r_{t-1,b} * I(t > S_{Store}) + \beta_{Trans} r_{t-1,b} * I(t > S_{Trans}) + \eta_t + \mu_b + \epsilon_{t,b,100/200/500}, \qquad [A.28]$$

Bank-Year Fixed Effects

$$\Delta C_{m,y,b} = \alpha + \beta r_{m,y,b} + \eta_{m,y} + \mu_{b,y} + \epsilon_{m,y,b}, \tag{A.29}$$

Deposits

$$D_{t,b} = \alpha + \beta r_{t-1,b} + \eta_t + \mu_b + \epsilon_{t,b}, \tag{A.30}$$

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