BANCA D'ITALIA
EUROSISTEMA

Mercati, infrastrutture, sistemi di pagamento

(Markets, Infrastructures, Payment Systems)

Inside the black box: tools for understanding cash circulation

by Luca Baldo, Elisa Bonifacio, Marco Brandi, Michelina Lo Russo, Gianluca Maddaloni, Andrea Nobili, Giorgia Rocco, Gabriele Sene, Massimo Valentini

July 2021

Number 7

BANCA D'ITALIA
EUROSISTEMA

Mercati, infrastrutture, sistemi di pagamento
(Markets, Infrastructures, Payment Systems)

Approfondimenti
(Research Papers)

Inside the black box: tools for understanding cash circulation

by Luca Baldo, Elisa Bonifacio, Marco Brandi, Michelina Lo Russo, Gianluca Maddaloni, Andrea Nobili, Giorgia Rocco, Gabriele Sene, Massimo Valentini

Number 7 – July 2021

The papers published in the 'Markets, Infrastructures, Payment Systems' series provide information and analysis on aspects regarding the institutional duties of the Bank of Italy in relation to the monitoring of financial markets and payment systems and the development and management of the corresponding infrastructures in order to foster a better understanding of these issues and stimulate discussion among institutions, economic actors and citizens.

The views expressed in the papers are those of the authors and do not necessarily reflect those of the Bank of Italy.

The series is available online at www.bancaditalia.it.

Printed copies can be requested from the Paolo Baffi Library: richieste.pubblicazioni@bancaditalia.it.

Editorial Board: Stefano Siviero, Livio Tornetta, Giuseppe Zingrillo, Guerino Ardizzi, Paolo Libri, Cristina Mastropasqua, Onofrio Panzarino, Tiziana Pietraforte, Antonio Sparacino.

Secretariat: Alessandra Rollo.

ISSN 2724-6418 (online)
ISSN 2724-640X (print)

Banca d'Italia
Via Nazionale, 91 - 00184 Rome - Italy
+39 06 47921

Designed and printing by the Printing and Publishing Division of the Bank of Italy

Inside the black box:
tools for understanding cash circulation

by Luca Baldo*, Elisa Bonifacio**, Marco Brandi**, Michelina Lo Russo*,
Gianluca Maddaloni**, Andrea Nobili**,
Giorgia Rocco**, Gabriele Sene**, Massimo Valentini*

Abstract

In this study, we assess the main drivers of banknote circulation in Italy over the last 20 years by using a number of econometric tools proposed in the literature. We explore the role played by banknote flows from abroad and changes in the institutional framework, and we disentangle domestic demand for transaction purposes from other components, including liquidity hoarding. We find that changes in the legal limits on cash payments and money holdings for precautionary reasons explain the bulk of cash dynamics, while the share of transaction demand has declined over time, thus becoming less and less relevant. Finally, we find that, during the COVID-19 pandemic, the exceptional increase in cash circulation was mostly the result of both an increase in precautionary demand due to the rise in economic uncertainty, and restrictions on mobility, which resulted in a marked decline in lodgments at the central bank.

JEL Classification: E41, E42, G2.

Keywords: cash circulation, cash, payment habits, COVID-19 pandemic.

Sintesi

In questo studio vengono esaminate le principali determinanti della circolazione di banconote in Italia negli ultimi 20 anni, utilizzando diversi strumenti econometrici proposti in letteratura. L'analisi tiene contro del ruolo svolto dai flussi di banconote dall'estero e dei cambiamenti del quadro istituzionale e distingue tra la domanda di contante a fini transattivi e le altre componenti, come la riserva di valore. I risultati mostrano che l'andamento della circolazione è stato determinato soprattutto dalle modifiche ai limiti legali per i pagamenti in contanti e dalla domanda precauzionale, mentre il ruolo della domanda transattiva è diminuito nel tempo, diventando sempre meno rilevante. Infine, l'eccezionale aumento della circolazione durante la pandemia da Covid-19 è attribuibile sia a un rafforzamento della domanda precauzionale connesso all'incertezza economica sia alle restrizioni alla mobilità, che hanno determinato una marcata riduzione dei riversamenti di banconote presso la banca centrale.

* Bank of Italy, Directorate General for Markets and Payment Systems.

** Bank of Italy, Directorate General for Currency Circulation and Retail Payments.

CONTENTS

1 Introduction[1]

Understanding the dynamics of banknote circulation is crucial for central banks and policymakers. An economy requires a certain amount of available cash to function. Cash is a dominant means of payment as it is the only legal tender, ensures anonymity of transactions and is essential for the inclusion of socially vulnerable citizens, such as the elderly or lower-income groups. Moreover, cash plays the role of store of value and allows people to hold money for saving purposes without default risk. Furthermore, central banks need reliable forecasts of the demand for banknotes each year, in order to plan the production of new banknotes, and to avoid shortages or surpluses in the economy. Currency is also part of the monetary base and its long-run developments determine the size of central banks' balance sheets and, in turn, the monetary policy implementation framework.

The cross-country evidence based on hard data over a longer horizon showed that cash balances fell steadily in the decades after World War II, while recording sizable increases since 2000s, despite the ongoing rapid innovation in payment technologies. This phenomenon was not confined to a handful of economies, rather it was a broad one (Williams, 2017; Jobs and Stix, 2017; Ashworth and Goodhart, 2020a). Since diary surveys suggest that cash usage for transaction purposes is progressively declining (e.g. Bagnall *et al.*, 2016; Esselink and Hernandez, 2017; Bech *et al.*, 2018; ECB, 2020a), empirical research tried to explain the so-called "paradox of cash" by looking at the drivers of non-transaction cash demand.

Several authors refer to the role played by the precautionary demand during financial crises, when increased uncertainty in the economy bolsters the role of cash as a safe-haven asset. Cusbert and Rohling (2013), Bartzsch and Seitz (2015), Jobs and Stix (2017), Ashworth and Goodhart (2020a), Rosl and Seitz (2020), provided evidence, in this regard, for advanced economies that faced the global financial crisis in 2007-08 as well as euro-area countries hit by the sovereign debt crisis in 2011-12. Liquidity hoarding related to panic, however, should imply sharp, but temporary, increases in cash holdings, thus not representing the full-story behind persistent trends in circulation.

Other studies pointed out the international role of some currencies, such as the US dollar, the euro and the Swiss franc, which are commonly used and hoarded abroad (Hellerstein and Ryan, 2011; Stix, 2013, Bartzsch *et al.* 2013, Judson, 2017, Assenmacher *et al.*, 2017), thus arguing that increasing circulation could have reflected a surge in *foreign*, instead of *domestic* demand. A recent study by Lalouette *et al.* (2021) estimates that, at the end of 2019, between 30% and 50% of the euro circulation was outside the euro area, with the majority of outflows probably due to Germany (see also Bartzsch and Uhl, 2011; Bundesbank, 2018). Similar studies conducted for the US currency showed that almost 50% of the circulation of dollars is abroad.

Finally, Rogoff (2016) and Sands (2016) pointed out that cash, especially high-denomination notes, usually fuels transactions in the shadow economy, although international evidence does not allow reaching firm conclusions (see Jobs and Stix,

[1] We are grateful to Guerino Ardizzi, Gabriele Coletti, Massimo Doria, Paola Giucca, Gianmatteo Piazza, Ferdinando Sasso, Stefano Siviero and an anonymous referee for their insightful suggestions and remarks on a previous draft of this paper. The views expressed herein are those of the authors and do not necessarily reflect those of the Bank of Italy. All remaining errors are ours.

2017; Ashworth and Goodhart, 2014, 2020a; Seitz *et al.*, 2018) also because of the difficulty to have reliable estimates of the black and the informal economy.[2]

The spread of the pandemic from Covid-19 all over the world renewed interest on these issues. Several countries are experiencing exceptional increases in cash circulation but current circumstances are very different from any other past episode characterized by a surge in the demand for cash. Ashworth and Goodhart (2020b) have examined trends in cash circulation in countries affected by Covid-19 and pointed out that these patterns are puzzling given the unprecedented fall in consumption, which should require less cash in the economy. They speculate that the rise in cash balances is likely to reflect some panic-driven hoarding.

Recent contributions suggest complementary explanations. Households and firms used less cash during the pandemic because they spent less and less frequently, thus national policies aimed at limiting contagion affected the number and the size of withdrawals from ATMs and bank tellers. Alvarez and Argente (2020) argued that, in the case of the US, these facts are consistent with a simple generalization of the Baumol-Tobin model where the pandemic disrupts cash management decisions, thus increasing the transaction cost of using cash and inducing people to switch to other payment instruments. This outcome would imply increasing welfare costs, as households bear higher costs to be able to hold and use cash, as well as because of the imperfect substitutability across payment methods. The impact of the pandemic on cash is also discussed in Bank of England (2020): according to a survey by the ATM network carried out in April 2020, several technical explanations, also affecting the cash distribution cycle, would be behind the persistent surge in the UK cash demand. Finally, Zamora-Pérez (2021) argued that banknotes are circulating less actively than in the previous year, reflecting precautionary savings, as well as corroborating a weaker transactional demand. Reasons for this behaviour could include both uncertainty and reduced mobility, thus leading households to hold higher cash amounts and reduce withdrawals.

In the case of Italy, Ardizzi *et al.* (2020) relied on confidential and high frequency transaction data from payment systems and banknotes in circulation available at the Bank of Italy to assess the impact of Covid-19 in payment habits. They provided evidence that people switched from cash to card-based payments at the physical point of sale – with a higher use of contactless technology – and to on-line purchases. At the same time, they speculate that banknotes in circulation increased significantly because of a rise in the precautionary demand for cash, but also because of some technical factors affecting the cash distribution cycle.

In this paper, we assess the determinants of banknote circulation in Italy by combining data available at the central bank with a number of macroeconomic variables, using different econometric techniques. Our empirical analysis spans from models used in previous studies to other methods that represent a novelty in the literature and can be applied to data for other countries. We discuss pros and cons of the various tools and try to outline a unique picture about the determinants of cash circulation in Italy over the last decades. We disentangle the demand for cash for transaction purposes from liquidity

[2] One of the main methods for estimating the size of the shadow economy is the "currency demand approach", which is characterized by several drawbacks (see Schneider and Enste, 2002) and severe endogeneity problems in estimated equations for cash balances. The most recent literature estimates the shadow economy using techniques related to the class of unobserved component models. In this regard, Medina and Schneider (2019) built up a global database by estimating the size of the shadow economy for 157 countries.

hoarding and other non-transaction components, thus contributing to the policy debate about a phasing out or restrictions in cash usage.

Our results highlight a predominant role played by changes in legal limits on cash payments and precautionary motives in shaping long-run developments of banknote circulation, the latter especially in periods characterized by severe financial distress or high uncertainty in the economy. The contribution of the transaction component declined over time and is nowadays second-order, also reflecting the substitution effect of the widespread of alternative means of payment. Finally, we find that standard macroeconomic drivers do not explain part of the exceptional increase recorded in banknote circulation in the aftermath of the pandemic. Differently from the past, the increase in circulation is not due to large withdrawals from the public as occurred during panic-driven episodes, but by a collapse of lodgments to the central bank. An indicator capturing the lockdown-style measures taken to limit contagion explains the bulk of the acceleration in cash circulation during the pandemic, thus suggesting that part of the increase in the precautionary demand could have been "forced" by the restrictive measures rather than "voluntary".

The remainder of the paper is the following. Section 2 describes the data used in the empirical analysis and provides some stylized facts about banknote circulation occurred in the past. Section 3 offers some evidence about the use of alternative means of payment, while in Section 4 we show some estimates of a long-run demand equation for the case of Italy. In Section 5, we assess the determinants of cash balances using a structural model in a multivariate framework. Section 6 presents the "seasonal method" approach to obtain an evaluation of the non-transaction component in banknote circulation. In Section 7, finally, we summarize our main results and discuss the related policy implications.

2 Stylized facts

In this section, we present a number of stylized facts about cash circulation in Italy taking a long-term perspective and offering a comparison with the euro area. Our measure of cash circulation is cumulated net issuance of euro currency, namely the difference between the value of banknotes issued by the Bank of Italy (withdrawals), starting from the euro changeover, and the value of banknotes returned to the Bank (lodgments). This measure can differ from the true circulation in the economy as it includes banknotes issued in Italy and sent abroad, but it excludes notes issued abroad and in circulation in Italy.[3] Therefore, measures based on the cumulated net issuance, instead of the currency capital key, are the only definition permitting us to capture the impact of shocks specific to Italy on domestic circulation.

Figure 1 shows developments in cash circulation for both Italy and the euro area as a whole. From 2002 to 2019, three main phases can be detected: *a*) an upward trend in the aftermath of the cash changeover (2002-2010); *b*) a phase of negative growth (2011-2015); *c*) a period of a moderate and stable positive growth (2016-2019). Then, in 2020, following the breakout of the Covid-19 pandemic, a sudden and exceptional acceleration is observed. In what follows, we provide an in-depth assessment of such developments, describing the evolution of the main components of cash circulation and exploring their relationships with macroeconomic conditions, changes in the

[3] An alternative measure of cash circulation is the Italian share in the total euro-area currency in circulation, which mirrors the Italian share in the ECB's capital key and is computed each year on the basis of domestic population and nominal GDP.

institutional framework and the policy of cash management that could have affected the dynamics of cash circulation.

Figure 1a: Banknotes in circulation
(end-of-quarter data; billions of euros)

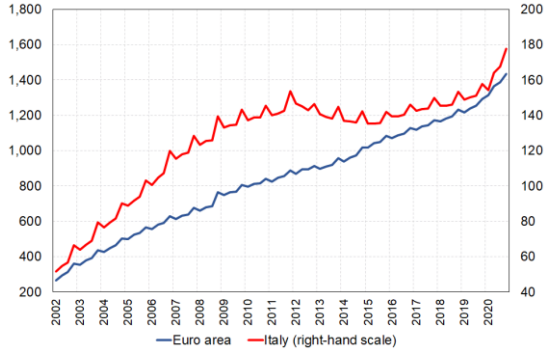
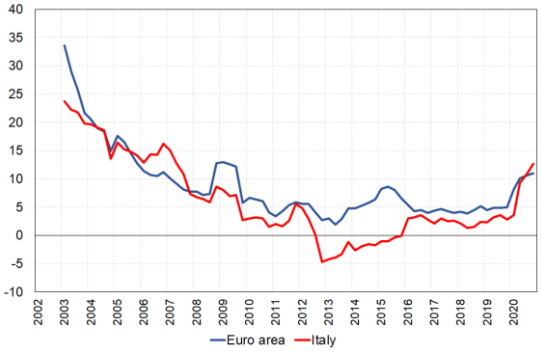


Figure 1b: Growth in circulation
(quarterly data; year-on-year growth rates)



Source: our computations on data from ECB and Bank of Italy.

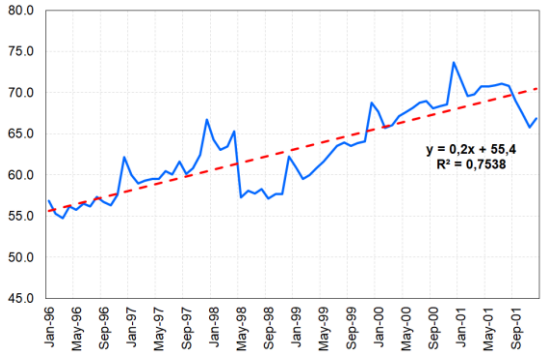
The period 2002-2010: the introduction of the euro, the global crisis and the role of foreign flows

On 1 January 2002, an entirely new currency, the euro, replaced the pre-existing national currencies of the member countries. In the following months and years, the demand for the new currency rose steeply. In Italy, the stock of euro banknotes in circulation doubled over the period 2002-2007 (from 66 billion to 122), recording an average annual growth rate by about 17%. The expansion was particularly strong in the aftermath of the cash changeover, while progressively attenuating in the following years and approaching to about 7% at the end of 2007. A similar pattern was observed for the euro area as a whole.

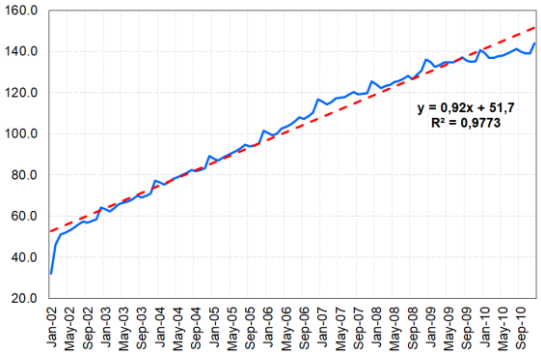
Are these developments exceptional in historical comparison? It is interesting to compare these trends with those prevailing before the introduction of the euro (i.e., over the period 1996-2001). In Figure 2, we show a simple linear interpolation of the cumulated net issuance before and after the adoption of the euro in Italy. The estimated coefficient of the linear trend is five times larger in the second sample. These simple interpolations provide evidence of an acceleration of banknote circulation in the aftermath of the cash changeover.

Figure 2: Cumulated net issuance in Italy: estimated trend before and after the cash changeover
(billions of euros; monthly data)

a) 1996-2001



b) 2002-2010



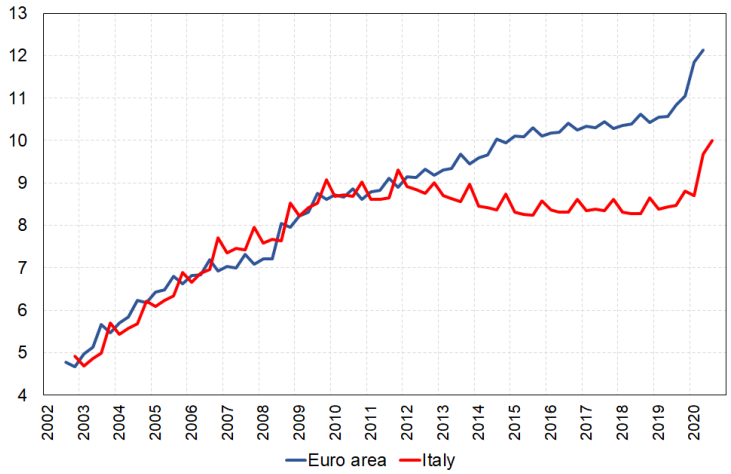
Source: our computations on data from Bank of Italy. *Notes*: The data before January 2002 were converted in euro at official rate Lira/Euro = 1,936.27.

How can we interpret these developments? The conventional wisdom is that, similarly to what happened in other euro-area countries, the strong dynamics in Italian euro banknotes in circulation reflected a number of factors (see Fisher *et al.*, 2004). The euro adoption implied the replenishment of stocks of hoarded banknotes by residents in the country up until the end of 2003, held not only in the domestic currency but also in currencies that played an international role (i.e., Deutsche mark, US dollar, Swiss franc). Moreover, with the exception of Netherlands and Germany, the euro adoption implied a substantial change in the denominational structure with respect to the past for most of the euro-area countries. In particular, the physical introduction of the euro has been connected with a move to higher-value banknotes, which may have led to a structural increase in the domestic demand for currency: before the changeover, Italy had only one denomination greater than €50 and four denominations less than or equal to €5. Finally, there was an increasing demand by non-euro area residents for both transaction and store-of-value purposes, before the introduction of the euro such demand usually characterized the German currency (Seitz, 1995).

A number of stylized facts may corroborate the view that the non-transaction component played a prominent role. First, the average growth rate in nominal GDP was about 3.8%. As a result, the cash-to-GDP ratio, a rough indicator of the domestic non-transaction component, rose from 4.9% in 2002 to 9.0% in 2010 (see Figure 3). Second, both middle- and high-denomination notes increased considerably, as people probably converted hoarding in the legacy currencies directly into largest denomination notes. By contrast, the value of low-denomination notes declined (see Figure 4).

Figure 3: Cash-to-GDP ratio

(quarterly data; % nominal GDP)



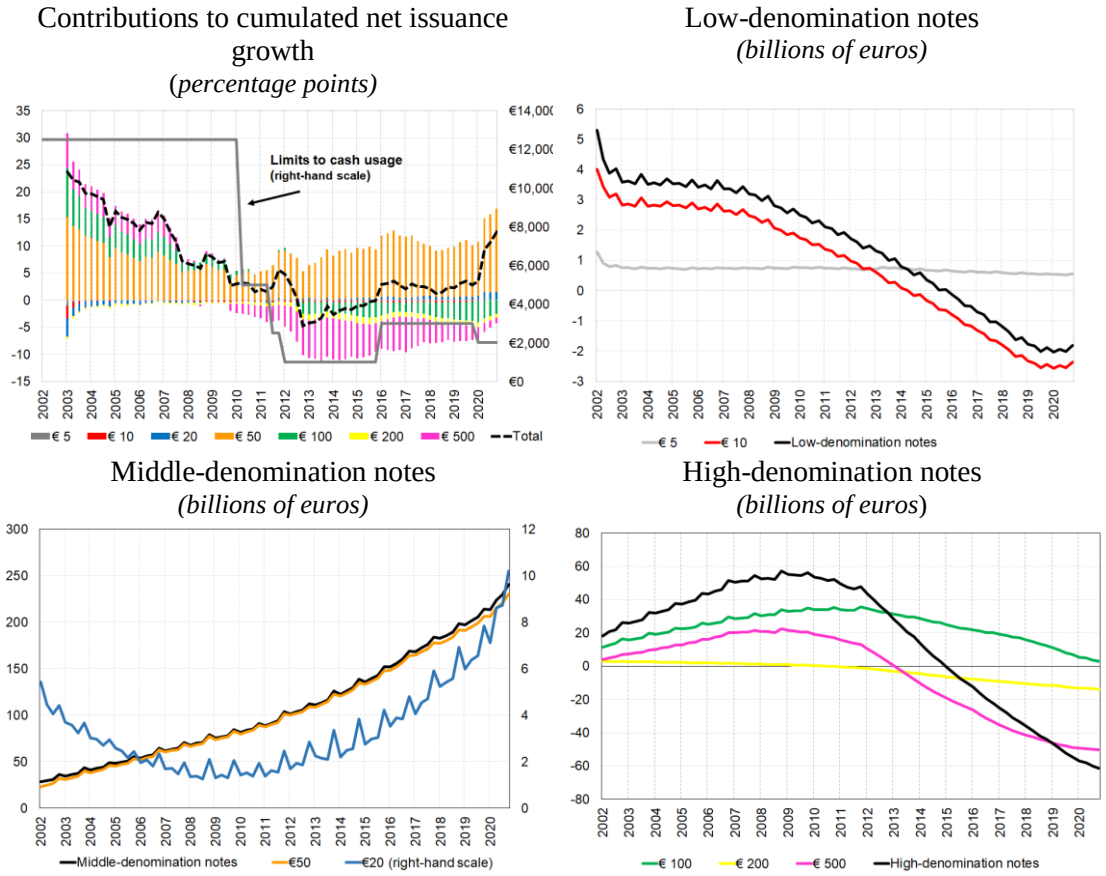
Source: our computations on data from Bank of Italy, ECB and Eurostat.

In the context of a declining long-term trend, an abnormal increase in the growth rate of circulation in Italy followed the collapse of Lehman Brothers in September 2008, albeit smaller in magnitude and less persistent with respect to other euro-area countries. In the fourth quarter of 2008 cumulated net issuance rose by about 9% (15% in the euro area), mostly reflecting a surge of withdrawals of €200 and €500 denominations (82% and 40% on a yearly basis, respectively). Circulation growth returned to decline significantly over the following three months, notwithstanding the beginning of the sovereign debt crisis in the euro area.

The macroeconomic conditions prevailing during the most acute phases of the financial crisis support the view that the dynamics of circulation largely reflected non-transaction motives. The ECB supported the financial system by injecting massive

amount of liquidity into the banking system and reducing interest rates toward the zero lower bound. Indeed, cash circulation often plays a relevant role as a store of value during periods of exceptionally low interest rates and severe financial strains.[4]

Figure 4: Cumulated net issuance: breakdown by denomination notes
(quarterly data)



Source: our computations on data from Bank of Italy.

We try to corroborate this interpretation by showing simple correlations between banknote developments and some macroeconomic variables. A useful metric of liquidity hoarding is the Currency-to-Deposit Ratio (CDR, hereafter) which usually peaks during financial crises when households and firms increase their precautionary cash holdings, as opposed to normal times, when it tends to co-move with shorter-term interest rates. The key mechanism is that a banking crisis leads to a situation in which bank deposits and cash become imperfect substitutes, which usually results into large withdrawals by the private sector. Using a trend-cycle decomposition based on a Hodrick-Prescott filter, we find that the trend component of CDR strongly correlates with the short-term interest rate while fluctuations in the cyclical component mirror the peak of the Composite Indicator of Systemic Stress (CISS, hereafter; Figure 5).[5]

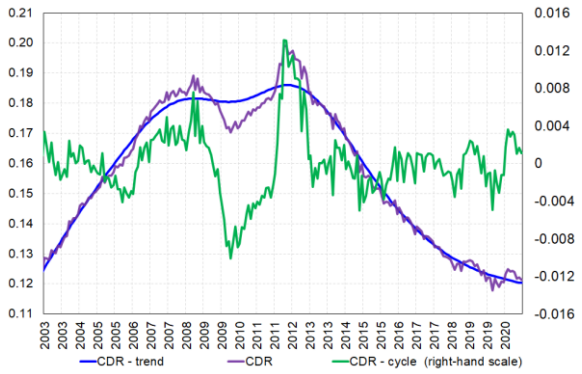
[4] During the financial crisis and, more generally up to 2015, foreign demand played a minor role. The euro was adopted by Cyprus and Malta (2008), Slovakia (2009), Estonia (2011), Latvia (2014) and Lithuania (2015). The effects of the euro's introduction in these countries on the total number and value of euro banknotes in circulation were very limited.

[5] The Composite Indicator of Systemic Stress is an indicator of financial tensions, whose specific statistical design is shaped according to standard definitions of systemic risk (see Hollo *et al.* 2012).

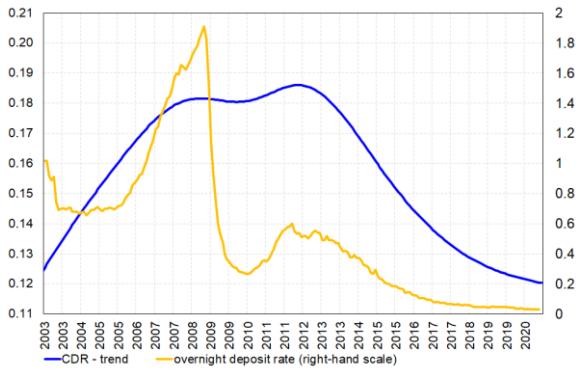
Figure 5. Developments in Currency-to-Deposit ratio

(monthly data)

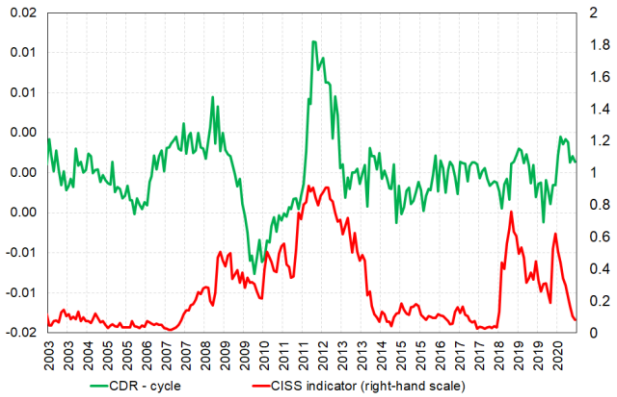
(a) Hodrick.Prescott decomposition



b) trend component and the overnight deposit rate



c) cycle component and the CISS indicator



Source: our computations on data from Bank of Italy and ECB Statistical Data Warehouse. *Notes*: CDR stands for the Currency-to-Deposit Ratio; its cycle and trend component are computed using a Hodrick-Prescott filter with "smoothness parameter" λ=129,600.

The financial crisis period was also characterized by a strong reduction in the legal limits to cash payments, which may help counteract tax evasion and money laundering.[6] The anonymity of cash transactions, indeed, makes banknotes the best option to exchange funds deriving from illegal activities or the informal economy.

We now discuss the role of banknote flows by non-residents. Before the introduction of euro, Italian Lira had a negligible foreign channel, net of some requests connected with tourism. The picture dramatically changed because of the increasing role of euro as international currency that partly offset the role of the dollar over the world. Moreover, circulation in the single euro-area countries is affected by the free migration of banknotes within member states. Foreign flows of banknotes for Italy, or any individual other euro-area country, is not directly measurable due to the lack of information. Several methods have been proposed in the literature to disentangle the amount of banknotes in circulation within a given country ("domestic circulation", hereafter) from the "foreign component". These methods can be broadly categorized into direct and indirect approaches (for a survey, see Lalouette *et al.*, 2021, and references therein).

[6] In Italy, legal limits to cash were introduced in 1991 and before the adoption of the euro it was set at 20,000,000 Italian lire; limits in euro, active since January 1, 2002, was at first a simple conversion of the mentioned amount in lire, corresponding to 10,329.14 euro. After a first revision, with an increase to 12.500 euro in December 2002, the limits for cash payments were unchanged until 2008.

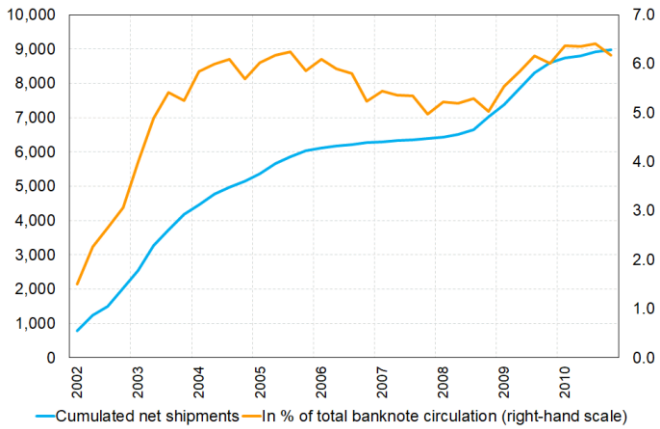
Direct approaches combine official statistics from several sources that are likely to capture the various channels through which international migration of euro banknotes can take place. The most relevant channels refer to shipments of euro banknotes abroad by banks that are active in the global market for currency dealing, euro banknotes taken abroad by travelers, and remittances by foreign workers.

Official data on the activities of wholesalers trading euro abroad provided by banking institutions to central banks allow to measure the difference between exports and imports of banknotes between euro-area countries and the rest of the world – so-called "net shipments" – and have been used to estimate a lower bound of the share of cash abroad (Lalouette and Esselink, 2018). Figure 6 shows Italian cumulated net shipments, which are available until the end of 2010 when countries outside the euro stopped demanding banknotes from Italy, mainly moving this demand to Germany and Austria. Accordingly, about 9 billion euros were estimated to circulate outside the euro area at the end of 2010, around 6% of total currency in circulation in Italy and about 9% of total euro-area net shipments.

In the case of Italy, tourism is an important source of inflows of euro banknotes. The Survey on International Tourism, conducted by the Bank of Italy since 1996 and used to estimate some items on the Balance of Payments, provides information on inflows and outflows of banknotes related to Italian people travelling abroad and foreign travellers entering Italy.

Figure 6: Cumulated "net shipments" of euro banknotes from Italy

(quarterly data; millions of euros; percentage points)



Source: our computations on data from Bank of Italy.

In this paper, we compute this foreign component as net inflows related to tourism minus official net shipments outflows.[7] When the foreign component exhibits positive values (i.e., inflows are larger than outflows in magnitude) banknotes from abroad can be interpreted as a "supplementary issuance" of cash to satisfy the domestic demand. Italy is a "net importer" of banknotes: the effect is likely to be more relevant for some denominations (€10, €200, €500), which indeed exhibit large negative values in terms of cumulated net issuance (i.e., lodgments are systematically higher than withdrawals; see again Figure 4). As a result, our reference measure of "domestic circulation" is

[7] We do not adjust for informal remittances flows, another channel of banknotes outflows/inflows that has been considered in Lalouette *et al.* (2021). As for the euro area, cumulated net cash remittance outflows represented in 2018 between 6.6% (€81 billion) and 24.6% (€302.5 billion) of total cash in circulation. Estimating the cash component of remittances is not straightforward, especially at a quarterly frequency. Ferriani and Oddo (2019) used annual data and provided an analysis of their determinants for Italy.

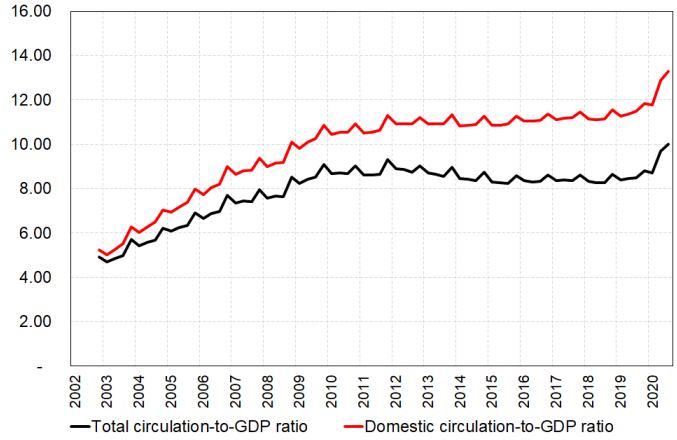
cumulated net issuance ("total circulation", hereafter) adjusted by foreign flows. Since Italy structurally imports banknotes from abroad, "total circulation" is systematically lower than "domestic circulation".

In Figure 7, we compare developments in "total circulation" and "domestic circulation", as a fraction of GDP and in annual growth rates. The main picture is that flows from abroad represent a structural component of domestic circulation. As for the period 2003-2007, the average contribution of such component to the total circulation growth amounted to about 3 percentage points over. Overall, tourism net inflows only partially explained the sustained growth of banknote circulation in this period.

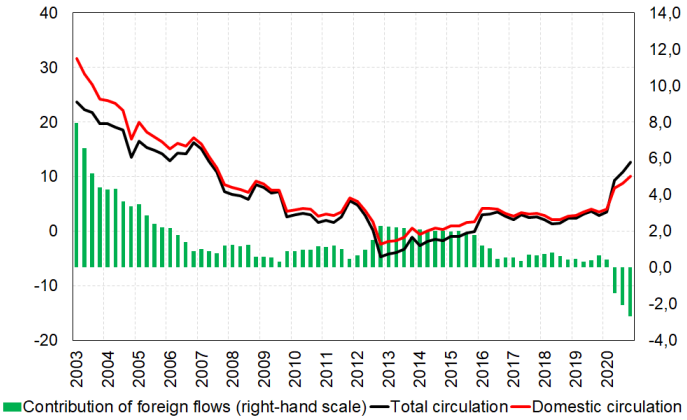
Figure 7: "Total" and "domestic" circulation

(quarterly data)

a) as a fraction of nominal GDP



b) year-on-year growth rates in percentage points



Source: our computations on data from Bank of Italy and Istat.

Indirect approaches usually rely on the application of the so-called "seasonal method", whose main features have been outlined in Sumner (1990), where it was applied to disentangle the transaction and the hoarding components for the demand of the US dollar. Porter and Judson (1996), Seitz (1995), Fischer *et al.* (2004), Bartzsch *et al.* (2011, 2017) extended this idea to the case of foreign cash holdings. The key assumption of the seasonal method is that some part of banknote circulation (e.g. the foreign and the domestic components for hoarding purposes) have no seasonality, differently from the domestic demand for transaction purposes. To approximate the domestic share for a specific country, one can assume that the seasonality of the domestic component can be proxied by that observed in a reference country whose

foreign demand for cash is negligible but whose remaining features are otherwise similar to those of the country of interest.[8]

In the case of Italy, the seasonal method is not a viable approach, given the difficulty to identify a reference country whose circulation can be safely assumed similar to that in Italy, except for the foreign component. Moreover, it is unrealistic to assume that the foreign component of banknote circulation in "net importer" countries such as Italy and other southern-European countries (Spain, Portugal or Greece) has no seasonality, due to the relevant role played by net inflows of banknotes related to tourism in some periods of the calendar year. The seasonal method can be instead more useful to disentangle the transaction and non-transaction component within the "domestic circulation", as described in more detail in Section 6.

The period 2011-2015: the sovereign debt crisis and changes in legal limits to cash

During the sovereign debt crisis, the dynamics of banknote circulation reflected two main factors. First, two strong reductions in the cash limits occurred in May 2010 (from €12,500 to €5,000 euro) and August 2011 (to €2,500 euro). Moreover, at the end of 2011 the so-called "Save Italy" decree furtherly lowered the limits for payments in cash to €1,000. This new limits and the announcement of more stringent anti-money laundering controls discouraged the withdrawals of the €200 and €500 notes, which became negligible, while leading to sharp and large lodgments to the Bank of Italy both of any notes accumulated in previous years and of new net inflows of notes from abroad (see Figure 8). Second, an exceptional rise in the growth rate of circulation occurred in the last quarter of 2011, when cumulated net issuance increased by 6%. These developments related to a sudden rise in demand for €50, following the dramatic surge in the Italian sovereign spread and the drop of confidence in the solvency of public debt.

The reduction in legal limits to cash payments undoubtedly had negative and long-lasting effects on circulation growth, as well as on the use of cash for transaction purposes. In 2012 and 2013, lodgments of €200 and €500 rose respectively by 64% and 23% on average. Lodgments of high-value banknotes were only partially offset by withdrawals of notes of intermediate size (€50 and €20 notes). As a result, overall circulation declined (the annual growth rate hit a low of -4.7% in 2012Q4). Moreover, the circulation-to-GDP ratio remained broadly stable over the period 2012-2015 (8.6% on average), notwithstanding the large decline in economic activity at the peak of the sovereign crisis and the subsequent moderate recovery. Nominal GDP contracted by about 1.1% in 2012-2013 while it expanded, on average, by 1.3% in 2014-2015.

Changes in the cash limits also led to a marked change in the composition of notes in circulation towards the use of lower denomination notes, with a consequent increase in the total number of banknotes in circulation. In particular, the €50 and the €20 euro

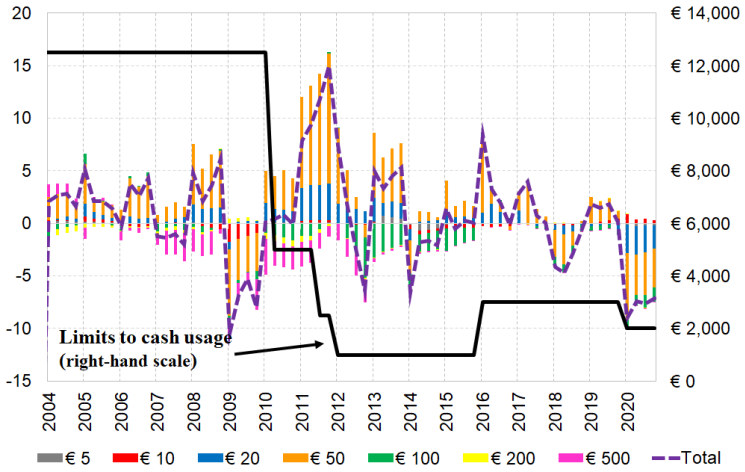
[8] Porter and Judson (1996) and Judson (2017) applied this method to the US case using Canada as a reference country, Fischer *et al.* (2004) to the euro area as a whole using Canada or France as a reference country, while Bartzsch *et al.* (2011, 2017) to the case of Germany using France as a reference country. Fischer *et al.* (2004) estimated the non-resident demand for domestic currencies in the range of 8-13% of the stock of currency in circulation in the euro area in 2000. According to Bartzsch *et al.* (2015), around 65%-70% of the volume of euro banknotes issued by the Bundesbank were in circulation outside Germany at the end of 2015; in this figure, 40-50 percentage points were in circulation outside the euro area, while 20-30 percentage points in other euro-area countries.

notes, largely distributed through ATMs, have increasingly made up for most of net cumulated issuance in Italy.[9]

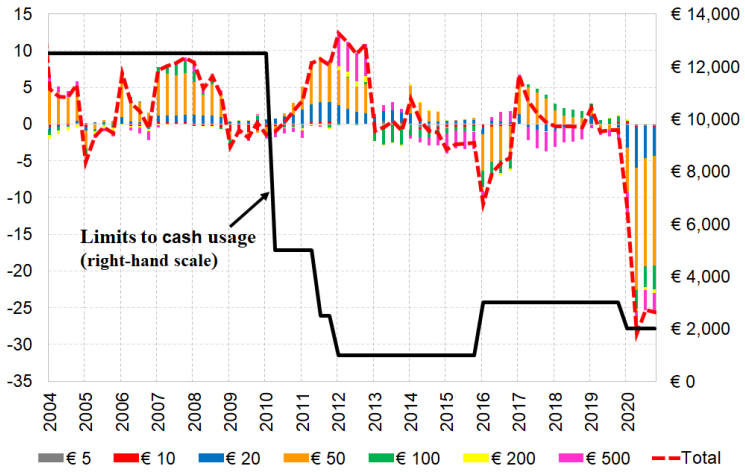
Figure 8. Banknote circulation and legal limits to cash usage

(quarterly data; year-on-year growth rates and contributions)

a) Withdrawals from the central bank



b) Lodgments to the central bank



Source: our computations on data from Bank of Italy.

The period 2016-2020: the discontinuation of the €500 issuance and the pandemic

In 2016, following a raise in the limits on cash payments to €3,000, the growth rate of circulation returned positive and cash-to-GDP ratio increased. However, the demand for high-value notes did not recover, nor was there any slowdown in new payment instruments (see Section 3), maybe also in relation with the announcement made by the ECB on May 2016 that the €500 banknote would no longer be issued. This announcement had an immediate impact in the euro area, with a partial replacement of €500 banknotes with €200 and €100 banknotes in the second quarter of 2016 and in the subsequent quarters, albeit at a weaker pace. In the following years, the growth in cumulated net issuance remained in Italy remained broadly stable around 3.0% on a

[9] In recent years, Bank of Italy invited commercial banks and the postal system to increase the pool of denominations available at ATMs. Following this invitation, in November 2018 the postal system started distributing the €10 at its ATMs.

yearly basis, thus suggesting that new cash limits did not imply a persistent acceleration in cash demand.

In 2020, a new exceptional increase in cash circulation occurred following the breakout of the Covid-19 pandemic. Cumulated net issuance rose by 9.3% on a yearly basis in the second quarter (9.9% in the euro area). This upward trend probably reflected the accumulation of precautionary stocks in the economy due to economic and political uncertainty. Households and businesses, indeed, may have decided to retain cash in the face of the dramatic recession and its implications for future employment and disposable income. However, other factors may have played a role. Lodgments of banknotes to the Bank of Italy, indeed, recorded an exceptional decline (-26.3% against -19.1% in the euro area; see Figure 9). A reduction was also recorded in withdrawals from the Bank of Italy but much less severe in magnitude (-7% against -9.5% in the euro area), thus mechanically resulting in more cash in circulation.

These patterns make the recent increase of cumulated net issuance different from any other surges observed previously, when withdrawals *increased* in value, rather than decreased. Not surprisingly, in 2020 the currency-to-deposit ratio did not rise at all. This is because deposits at commercial banks considerably increased as businesses and households refrained from spending, or were unable to spend, on some of their usual activities. In the same vein, tourism flows collapsed following the restrictions imposed to mobility across countries. In Italy, the "supplementary issuance" of cash from abroad turned negative, thus explaining only partly the large spike in cash circulation. Foreign component played a minor role in the euro area as well: net shipments of euro banknotes in 2020 were indeed negative by 4 billion euro (i.e., the amount of banknotes returned in the euro area exceeded that of banknotes sent abroad).

All these circumstances suggest that technical factors, not strictly related to macroeconomic conditions, have been at work, thus making it challenging to distinguish whether the increase of the non-transaction component was "forced" or "voluntary" in reaction to the pandemic. In this regard, it is important to remark that the so-called "cash distribution cycle" follows a complex path through the economy and involves multiple relationships between economic agents (see Calderini *et al.*, 2019). Commercial banks and the postal system, indeed, withdraw banknotes from the central bank and distribute them to households and firms via automated cash tellers or their branches, employing cash handler companies for such services. People spend those banknotes in shops, while retailers, in turn, deposit the cash received. At the same time, cash handlers collect banknotes from large retailers and commercial banks and lodge them to the central bank, or recirculate them in the economic system after checking for their authenticity and "fitness". The central bank issues new banknotes, also retains those that are unfit and counterfeit and *recirculates* those fitting appropriate quality requirements. The exceptional decline of lodgement of banknotes to the Bank of Italy during the pandemic could be related to the closure of non-essential business activities during the lockdown and, more generally, to difficulties for people to deposit money at the bank tellers. Therefore, banknotes may be circulating less actively than before, thus impairing the cash distribution cycle.

All actors involved in the cash cycle also strive to reduce costs. Increasing competition from other payment instruments is leading to a "search-for-efficiency" in the supply-chain, thus pushing intermediaries to change their policies. Commercial banks aim at shortening the cash cycle by investing in closer inter-bank co-operation or increasing the recirculation of banknotes directly at bank branches and close to the points of sale where cash is collected, as mirrored in the spread of cash recycling

machines. The picture is also evolving for the diffusion of new cash-supply channels in the retail sector, such as cash-in-shop and cash-back initiatives, where customers can electronically pay an amount higher than the value of a purchase, thus receiving the difference back in cash. In addition, the evolution of costs faced by cash handlers are likely to affect their withdrawals from and lodgments to the central bank, including the choice of the various denominations. This calls for a deep understanding of such factors with both theoretical and empirical works. In Appendix A, we try to make a step forward by presenting a theory for withdrawals at the central bank. In the model, withdrawals by cash handlers are a positive function of aggregate demand but also depend on the relative cost of recirculation with respect to the provision of banknotes at the issuing institution, thus driving a potential mismatch between withdrawals and macroeconomic conditions. However, the lack of information about costs faced by cash-handlers prevents us to validate such theory.

For the sake of completeness, it is important to mention a new reduction in the legal limits to cash usage in Italy to 2,000 euro in July 2020 and the announcement of a further reduction to 1,000 euro from January 1, 2022. These changes up to now have had no visible impact on the dynamics of banknote circulation.

3 Cash and other payment instruments

In this Section, we describe the main features of payment instruments that are alternative to cash for transaction purposes. The use of alternative payment instruments grew steadily in Italy over the last decades, also favoured by changes in the European regulatory framework as well as domestic initiatives. However, there is still a wide gap within the euro area in the adoption of electronic payments.

At the same time, as illustrated in the previous sections, the circulation has been constantly increasing. Considering the development of alternative payment instruments, the use of banknotes for retail transactions seems to have decreased, as indicated also by recent payment surveys. The decline in the use of cash could lead to a decrease in demand for cash, but this has not yet occurred.

3.1 Evidence from survey data

Quantitative evidence on the usage of other payment instruments is provided by survey data. The Bank of Italy's Survey on Household Income and Wealth (SHIW), conducted since 1993, contains some specific questions on households' payment habits. Figure 9 shows that the average monthly spending in cash remained basically stable (at around €850); the fraction of cash spent for private consumption declined to 47% in 2016 (from 65% in 1993), mirroring the increase in the number of people holding a payment card.[10]

Over the last few years, the ECB carried out several surveys among euro-area members where the respondents were asked to keep a diary of all the payments they make in the course of a single day. According to the 2016 Eurosystem's Surveys on the Use of Cash by Households (SUCH), the share of cash payments in *number* of transactions at point of sale was 86% in Italy compared with an average of 79% for the euro area. The share of cash payments in *value* was instead 68% in Italy and 54% in the euro area. About two thirds of Italians say that they usually carry more than €20 in cash

[10] These aggregate trends mask substantial heterogeneity across households. Micro data suggest that the propensity to use cash is higher for older people, residents in Southern regions, low-income households and negatively correlates with the level of education.

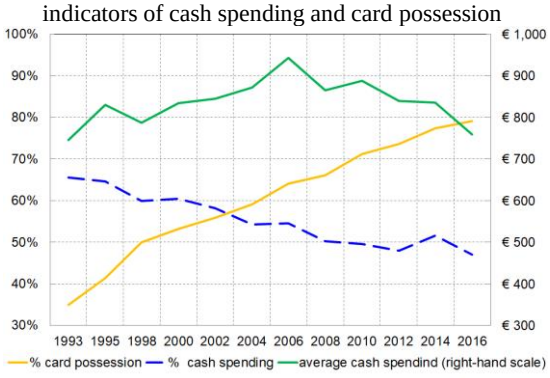
compared with just under half of euro-area residents (47%), while only 18% of Italians say they usually pay by card compared with 27% in the euro area (see Hesselink and Hernandez, 2017 and Rocco, 2019).

Three years later, the data from the 2019 Study on Payment Attitudes by Consumers at the Euro area (SPACE) showed that these figures had further changed in favour of non-cash payments. More precisely, the share of cash transactions in *number* of payments at point of sale declined to 82% in Italy, compared with an average of 73% in the euro area. The share of cash payments in *value* was 58% in Italy and 48% in the euro area (ECB, 2020a).

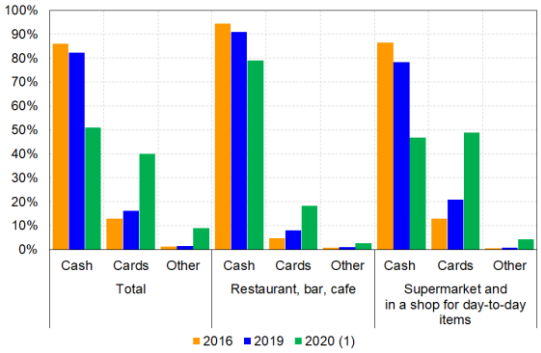
In July 2020, the ECB conducted an ad-hoc survey in all euro-area countries to measure the impact of the pandemic from Covid-19 on cash trends and payment habits (IMPACT). Albeit the answers are not directly comparable with those of previous surveys for the different sampling techniques, there is clear-cut evidence of a more pronounced substitution of cash in transactions. The results for Italy show that more than half of the respondents reported using cards and cash as they did before the start of the pandemic. However, 32% of those interviewed declared they used cash less often than before, while 27% used cards more often.

Figure 9. Indicators of payment habits from survey data

a) BdI Survey on Household Income and Wealth: indicators of cash spending and card possession



b) ECB surveys among euro-area countries: share of transactions by payment instrument



Source: our computations on data from Bank of Italy and ECB. *Notes*: (1) The IMPACT survey, conducted in July 2020, is a supplement to the 2019 survey to capture the effects of the Covid-19 pandemic on payment habits. Estimates are based on the last purchase made by each respondent.

People using cash less frequently also indicated – from a given list – some prevailing reasons for avoiding the use of cash in physical places since the pandemic started. They mentioned that paying electronically, especially with contactless cards, had become more convenient (48% of respondents). The risk of infection by the virus was another main driver: via banknotes for 27% of those interviewed and via hand contact or proximity to the cashier for 21%. Interestingly, access to cash was not a major issue. Looking forward, about 94% of the respondents who reported using cash less than before declared that they would probably continue to pay less with cash, thus suggesting a permanent change in payment behaviours even when the pandemic is over.

3.2 Evidence from payment system data

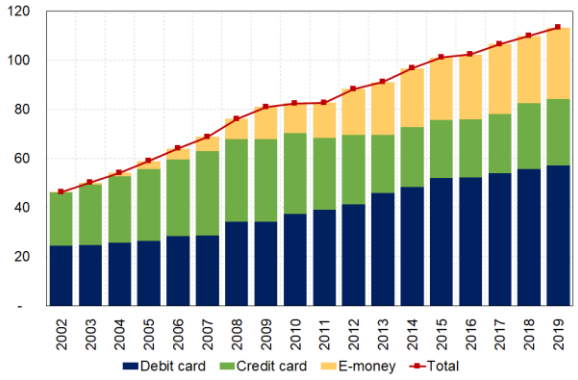
Hard data on electronic payments offer a complementary picture about payment habits in Italy. In recent years, the use of instruments alternative to cash for transactional purposes grew in Italy. Over the period 2002-2019 the number of non-cash transactions per capita increased by about 130% per cent in Italy, similarly to what observed in the euro area. However, the gap with the euro area remains wide: at the end of 2019 the

number of transactions per capita was well below the level observed in the euro area (125 compared with 286).[11]

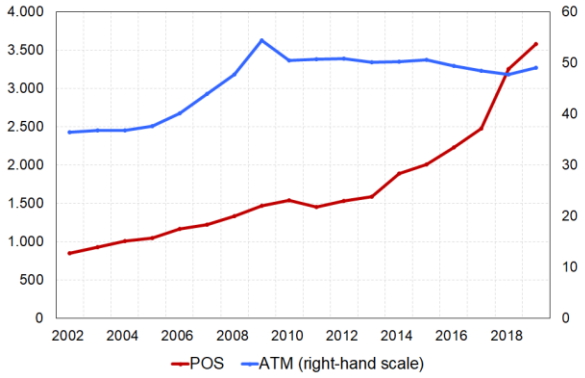
Nowadays cards represent the main alternative to cash for transaction purposes. Figure 11b shows the evolution of the number of payment cards in Italy. They more than doubled over the observed period, reaching 113 million at the end of 2019, debit cards account for 51%. The overall effect of the widespread use of cards on currency demand is *a priori* ambiguous. On the one hand, cards are used as a direct substitute for cash when making payments at the physical point of sale or for *e-commerce* transactions; this should imply a negative impact on the transaction component of banknote circulation. On the other hand, payment cards are also used to withdraw money from ATMs, thus increasing currency in circulation.

Figure 10. Trends in usage of payment instruments

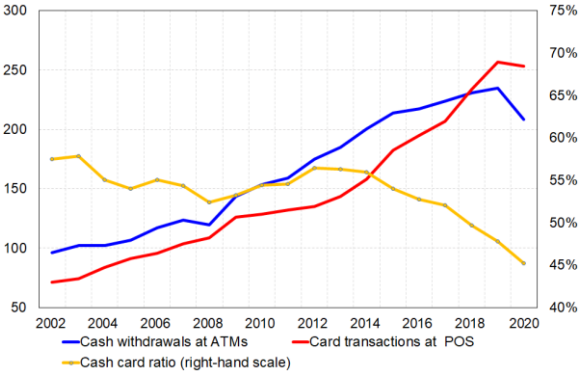
a) Number of payment cards
(annual data; million)



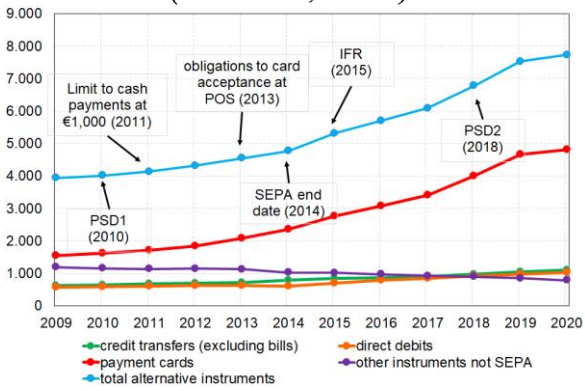
b) Number of ATMs and POS terminals
(annual data; thousands)



c) "Cash-card ratio"
(annual data; percentage points)



d) Number of cashless transactions and changes in regulation
(annual data; million)



Source: our computations on data from Bank of Italy and ECB Statistical Data Warehouse. *Note*: the cash-card ratio is calculated on debit and credit card data. Note: Postal Offices report number of ATMs from 2009; independent ATMs are reported from 2019.

As for the supply of cash, data on the number of ATMs show an upward trend until 2010 followed by a stabilization afterwards, as reported in panel b) of Figure 10. At the end of 2019, in Italy there were about 49,000 ATMs, i.e., 813 ATMs per million inhabitants; this is higher than the figure for France (785) but lower than those of

[11] There is some heterogeneity among Italian regions. The use of instruments other than cash is significantly lower in the South and Islands. These differences may reflect the different level of income and structural factors such as the production structure – also in terms of average firm size – and the supply of bank services (Ardizzi *et al.*, 2020).

Germany and Spain (1,147 and 1133, respectively). At the same time, POS terminals increased over the entire sample period, with a strong acceleration in 2013-19. At the end of 2019, there were about 3.5 million POS systems in Italy, more than in the other largest euro-area countries (1.3 in Germany, 2 in France, 1.7 in Spain).

The supervisory reports provided by intermediaries engaged in payment services allow us to compute some indicators of non-cash payments at quarterly frequency. In the empirical literature, the so-called "*cash-card ratio*", namely the ratio between the value of withdrawals at ATMs and card payments at POS, is a good proxy of households' preference for cash against electronic payments at the point of sale (see Ardizzi and Iachini, 2013). Panel c) of Figure 10 suggests that this indicator exhibits a clear downward trend since 2013, also reflecting important changes in the regulatory framework aimed at boosting electronic payments. Panel d) shows that a number of changes in regulation fostered the use of alternative payment instruments other than cash. Domestic initiatives, despite changes in the legal limits for cash payments, established legal obligations to card acceptance at the point of sale in 2012 and 2016. European initiatives such as the introduction of the Interchange Fee Regulation (IFR) in 2015 and the Payment Services Directive (PSD2) in 2018 and 2019 also played a significant role (see Ardizzi, 2013; Bank of Italy, 2020).

Finally, the Covid-19 pandemic dramatically affected payment habits, as a result of the fear of contagion and restrictions to social mobility (see Ardizzi *et al.*, 2020), leading to a higher preference for card payments at the point of sale and an acceleration in *e-commerce* transactions and the usage of more innovative payment instruments, such as *contactless* cards. The relationship between cumulated net issuance and the cash-card ratio is not clear-cut: a positive one is visible up to 2011, while a negative one occurs in the remaining period. We provide more details in this regard in the following Sections.

4 Standard cash demand equations in a univariate framework

In this Section, we try to condense most of the evidence presented in the previous section in a unified statistical framework and provide estimates of the demand for cash in Italy, as captured by "domestic circulation" or, alternatively, "total circulation". We also show some estimates for the various components of banknote circulation, in order to assess the heterogeneity in their relationship with macroeconomic conditions and technical factors affecting the cash distribution cycle.

4.1 Estimates for domestic circulation

We start our empirical analysis by evaluating the drivers of domestic circulation. Following the bulk of previous literature, we rely on standard econometric techniques aiming at identifying stable long-run relationships among cumulated net issuance and macroeconomic conditions. Accordingly, we model cash demand in an error correction framework to exploit potential long-run relationship between variables, as follows:

$$\Delta c_t = \lambda(c_{t-1} - \beta X_{t-1} - \alpha) + \sum_{i=1}^{p} \phi_i \Delta c_{t-i} + \sum_{i=1}^{q} \delta_i \Delta Z_{t-i} + \varepsilon_t$$

where c_t is a measure of banknote circulation; β is a vector of long-run parameters; X_t is a vector of variables affecting cash demand in the long-run and α is a constant; Z_t is a vector of variables affecting cash demand in the short-run, which may be different from those entering the vector X_t. All variables except the interest rates are in

logarithms. The speed of adjustment parameter is λ, and the parameters for the short-term dynamic terms are ϕ_i and δ_i. ε_t is a residual term.

Specifications of the demand for currency usually include in the long-run component a measure of the scale of transactions (e.g., nominal private consumption or GDP) and a short-term interest rate. As for the transaction component, we consider a broad economic measure such as nominal GDP or private consumption because not all transactions in the economy could be equally cash-intensive (see Goldfeld and Sichel, 1990; Mankiw and Summers, 1986). Our results are very similar using both variables. As for the role of interest rate, several papers used a money market interest rate. Alternatively, especially in a sample period characterized by negative policy rates, it may be preferable to relate cash demand to a measure of remuneration of bank deposits held by the private sector. Commercial banks are indeed reluctant to impose negative interest rates on retail bank deposits in order to avoid large outflows into cash. Ashworth and Goodhart (2020) documented potential nonlinearity in the estimated relationship between interest rates and net issuance, which may occur when interest rates approach to zero or become negative. As for the short-run component of the error correction specification, the main explanatory variable is the CISS indicator, the measure of financial tensions introduced and described in Section 2. Other studies captured the role of precautionary demand by means of indicators of financial tensions or simple dummy variables (see Cusbert and Rohling, 2013; Miller, 2017).

In order to ensure that the model is properly specified, an analysis of the stationarity properties is needed. We addressed the non-stationarity issue of the series resorting to a standard battery of unit root tests.[12] We consider the case with a constant term and resort to the BIC criterion for lag selection. As expected, we find that all considered series have a unit root. However, it is well known that standard unit root and cointegration tests may suffer short sample bias; a test with a low power can result in an excess rejection rate, indicating as stationary series which are not, this may happen more frequently with series including a trend. Therefore, the evidence presented in this Section should be interpreted with some caution.

Table 1 shows that the coefficients on economic activity and the deposit rate are statistically significant and enter the equation with the expected sign. The elasticity with respect to GDP is higher than unity and higher than the value of 0.5 suggested by Baumol and Tobin. Previous studies provided an elasticity to economic activity that is near one in several advanced countries but much higher for the euro area as a whole.[13] The semi-elasticity of cumulated net issuance with respect to the deposit rate is instead quite low; it implies that a permanent 100 basis point decrease in the deposit rate is associated to an increase in circulation growth by 0.1 percentage points. Several papers also estimated an interest rate elasticity that is negative but rather lower than had been expected. The speed of adjustment is low as well, indicating that it will take a while before a situation of short-run disequilibrium goes back to the path of the long-run equilibrium. Changes in the limits for cash payments show a positive and statistically significant coefficient.

[12] In particular, we consider the Augmented Dickey-Fuller (ADF) test, the Dickey-Fuller test with GLS detrending (DF-GLS), the Phillips-Perron (PP) test, the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) test and the Elliot, Rothenberg and Stock point optimal (ERS) test. One should mention that only the KPSS test postulates stationarity as the null hypothesis whereas the remaining consider a unit root in the null hypothesis. Results are available from the authors upon request.

[13] Recent works conducted for the euro area as whole considering GDP as the transactions variable are Calza and Zaghini (2015) and Jung (2016) for broad monetary aggregates. For empirical works relying on private consumption and cash circulation, see Rua (2018, 2020).

A 10% reduction in such limits is associated to a decline in circulation growth by about 0.4%. According to this estimate, the reductions in the limits that occurred in 2010Q2 and 2011Q4 accounted for a cumulated decline in circulation growth by about 4 percentage points.

Among the short-term dynamic terms, we find that changes in the CISS indicator enter significantly and with a positive sign, albeit in a non-linear fashion. Only exceptional fluctuations in such indicator have significant effects on cash demand as occurred during the most acute phases of the global and the sovereign debt crisis. The estimated coefficients suggest the contribution of the upward shift in the precautionary demand was 2.5 and 1.6 percentage points, respectively, in 2008Q4 and 2011Q4, which represent the bulk of the overall increase of banknote circulation in those quarters. The subsequent attenuation in financial tensions occurred in 2012Q1 implied a reduction in cash demand by only 0.3 percentage points.

Table 1. Estimated cash demand equations for Italy

	"Domestic circulation"				Total circulation
	2003Q1-2019Q4	2003Q1-2020Q4	2003Q1-2020Q4	2003Q1-2020Q4	2003Q1-2020Q4
	(1)	(2)	(3)	(4)	(5)
Long-run component					
Speed of adjustment	-0.079 ***	-0.046 **	-0.054 ***	-0.065 ***	-0.060 ***
GDP_{t-1}	1.712 ***	0.281	0.800	1.191 ***	0.886 ***
Deposit $rate_{t-1}$	-0.093 ***	-0.259 **	-0.193 ***	-0.119 ***	-0.093 **
Limits to $cash_{t-1}$	0.043 ***	0.127 ***	0.100 ***	0.063 ***	0.105 ***
Constant	0.279	0.979 **	0.808 **	0.664 **	0.806 ***
Short-run component					
$\Delta CISS_t$	0.002	0.007	-0.011	-0.001	0.180
$\Delta CISS_t$ * Global crisis	0.094 ***	0.100 ***	0.113 ***	0.100 ***	0.112 ***
$\Delta CISS_t$ * Sovereign debt crisis	0.134 ***	0.115 ***	0.139 ***	0.136 ***	0.173 ***
$\Delta CISS_t$ * COVID-19 crisis			0.212 ***	0.110 ***	0.171 ***
Stringency $index_t$				0.005 ***	0.006 ***
Adjusted R-squared	0.851	0.702	0.784	0.832	0.775

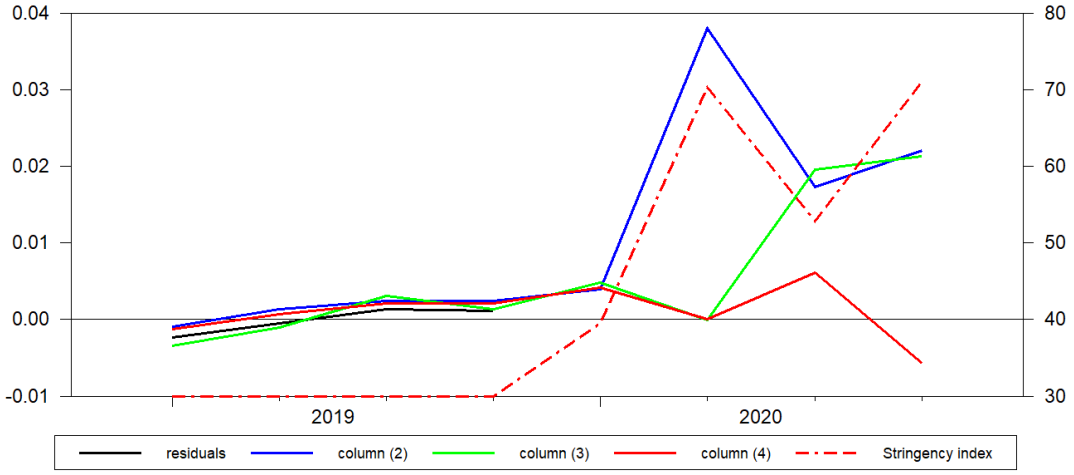
Notes: ***, ** and * indicate significance at the 1, 5 and 10 per cent level, respectively. Estimates based on Ordinary Least Squares (OLS). Inference is based on Newey-West robust standard errors adjusted for autocorrelation and heteroscedasticity in the residuals.

Extending the sample to include the surge in circulation during the pandemic from Covid-19 leads to dramatic changes in the estimated coefficients. In particular, the role of nominal GDP vanishes while the magnitude of the effect of the interest rate and legal limits to cash usage more than double in magnitude. The coefficient for the lagged long-run relationship declines considerably implying a much lower speed of adjustment. A Chow breakpoint test at the first quarter of 2020 rejects the null hypothesis of parameter stability, which is consistent with an exceptional currency demand behaviour not explained by standard drivers. Figure 11 reports the estimated residuals obtained with the various specifications and suggests unusual and persistent misalignments of cumulated net issuance from its main determinants.

The inclusion of changes in the CISS indicator interacted with dummy variables for the period characterized by the first wave of infections (i.e., 2020Q1-2020Q2) partly solve this problem, corroborating the view that the surge in currency stock effectively

reflected an increase in precautionary demand. The estimated coefficient implies that the worsening of financial conditions led to a positive contribution in circulation growth by about 4 percentage points, which represent the overall quarter-on-quarter change in banknote circulation in such period. It does not explain, however, the upward trend in the remaining part of year, corroborating the view that other factors have been at work.

Figure 11. Estimated residuals from cash demand equations for Italy



Notes: The estimated residuals refer to specifications presented in Table 1.

We take on board an indicator of social and mobility restrictions that may help to corroborate the hypothesis of an impairment in the cash distribution due to a change in consumers' and businesses' behaviour and the use of cash in the economy. To this end, we use the *Stringency Index* by Hale *et al.* (2021), which is a composite measure of the wide range of measures taken by Governments in response to the Covid-19 outbreak. This indicator is available for Italy at daily frequency and aims to track and consistently compare policy responses around the world, in terms of the severity of 'lockdown-style' policies that primarily restrict people's behaviour.[14] We obtain a quarterly time series by taking the simple average of daily data in each specific quarter (see Figure 12).

Interestingly, the dynamics of this indicator in 2020 is strongly correlated with the estimated residuals stemming from specification (2). We formally test the information content of the stringency index for cash demand. The indicator is qualitative, so assuming a linear relationship between its developments and cumulated net issuance is not necessarily appropriate. In any event, it allows us to assess this mechanism without considering simple dummy variables for each quarter of the year that do not have a clear economic interpretation.

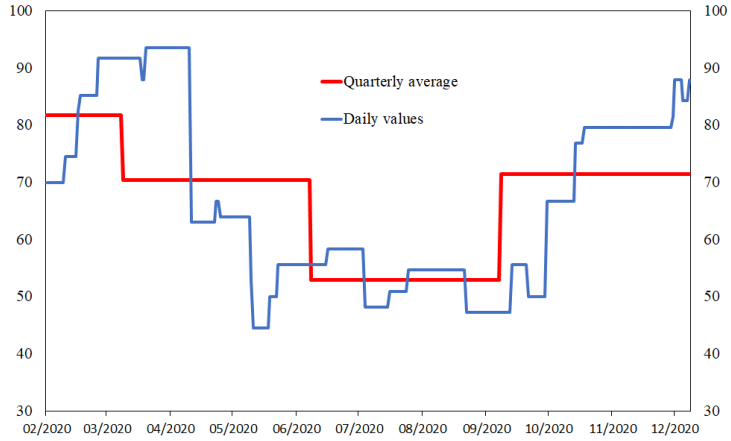
The new specification is reported in column (4). The stringency index enters significantly and with a positive sign and the estimated coefficient suggesting that such indicator contributed to the increase in banknote circulation by 2 percentage points, on average, in each quarter of 2020. The residuals obtained from this specification become close to zero in the second half of the year. The coefficient for the CISS indicator reduces in magnitude by one half, thus suggesting that in the second quarter of 2020 there is some collinearity with the stringency index, making challenging to properly separate the two effects. The coefficients of the other variables estimated over the full sample turns

[14] The indicator is rescaled to a value from 0 to 100, where 100 is the strictest policy. If policies vary at the subnational level, the index is shown as the response level of the strictest sub-region. The stringency index assumes a zero-value for all the sample period before 2020.

out more similar to those based on the pre-pandemic sample, albeit the long-run elasticity of cash demand to nominal GDP remains somewhat lower.

Figure 12. Developments in the "stringency index"

(daily data; index max=100)



Source: our computations on data from Oxford University.

Our interpretation of these estimation results is that the economic implications of a rise in the stringency index are observationally equivalent to those stemming from changes in precautionary demand, namely a reduction in economic activity as opposed to an increase in cash circulation. However, differently from the case of past financial crises, hoarding of cash primary originates from a collapse in lodgments to the central bank in relation to the mobility restrictions affecting people's behaviour and the technical constraints to the activity of cash handlers. In this regard, the disruption in consumers' cash management decisions induced a "forced" increase in precautionary demand during the pandemic. This differs from the "voluntary" rise in liquidity hoarding during financial crises that mostly related to an increase in withdrawals from the central bank in reaction to the fear of banks' failure or a collapse of the euro-zone.

We validate this hypothesis in the data by running separate regressions for lodgments and withdrawals. Both aggregates are expressed as quarterly flows and do not present a long-run trend nor significant co-integration relationships with other macroeconomic variables, as in the case of total circulation. For these reasons, also following the indications of stationarity tests, we run regressions for lodgments and withdrawals in log-levels in the spirit of Autoregressive Distributed Lag (ARDL) models, thus excluding the distinction between the long- and the short-run components, as follows:

$$y_t = \alpha + \beta y_{t-1} + \Gamma X_t + \Phi \Delta Z_t + \varepsilon_t.$$

The estimated coefficients in Table 2 deserve some comments. During the pandemic, the estimated elasticity to economic activity for lodgments is somewhat higher than that for withdrawals, meaning that this variable is more responsive to changes in the business cycle. The coefficient for the deposit rate, which enters the relationships in first differences, is negative and slightly significant for lodgements while it is positive and significant for withdrawals, indicating that reduced-form regressions hardly detect an important role played by the opportunity cost of holding cash. Limits to the usage of cash exert a stronger impact on lodgments, implying that the positive effect of an increase in such limits on circulation mainly transmits via such component. As for the effects of an increase in the CISS indicator, withdrawals from the central bank reacted positively during the global and the sovereign debt crisis, while the

estimated coefficients for lodgments show negative signs but smaller in magnitude. Therefore, the bulk of the surge in precautionary demand for cash during financial crises usually occurred via an increase in withdrawals. This picture completely reversed during the pandemic when the reaction to financial stress was much stronger for lodgments and so was the effect of the restrictions to mobility and their implications for the cash cycle, as captured by the *Stringency index*.

Table 2. Estimated equations for lodgments and withdrawals

	Lodgments		Withdrawals	
	2003Q1-2019Q4 (1a)	2003Q1-2020Q4 (1b)	2003Q1-2019Q4 (2a)	2003Q1-2020Q4 (2b)
Dependent variable$_{t-1}$	0.438 ***	0.500 ***	0.161 **	0.256 **
GDP$_t$	0.353 ***	0.291 ***	0.296 ***	0.230 ***
ΔDeposit rate$_t$	-0.059 *	-0.062 *	0.102 ***	0.106 ***
Limits to cash$_t$	-0.044 ***	-0.039 ***	-0.026 ***	-0.024 ***
ΔCISS$_t$	-0.051	0.000	0.023	0.065
ΔCISS$_t$ * Global crisis	-0.226 ***	-0.297 ***	0.397 ***	0.350 ***
ΔCISS$_t$ * Sovereign debt crisis	-0.282 ***	-0.288 ***	0.570 ***	0.513 ***
ΔCISS$_t$ * COVID-19 crisis		-2.617 ***		-0.037
ΔStringency index$_t$		-0.030 ***		-0.017 ***
Constant	9.167 ***	8.444 ***	16.371 ***	14.939 ***
Adjusted R-squared	0.923	0.892	0.727	0.743

Notes: ***, ** and * indicate significance at the 1, 5 and 10 per cent level, respectively. Estimates based on Ordinary Least Squares (OLS). Inference is based on Newey-West robust standard errors adjusted for autocorrelation and heteroscedasticity in the residuals.

4.2 Estimates for different denomination notes

We also explored whether the drivers of cash demand change according to the different denomination notes. People usually use high-denomination notes mostly for hoarding, while hold low-denomination notes only for transaction purposes. Such considerations imply that the elasticity of demand for high-denomination notes to the deposit rate and the CISS indicator should be higher (in absolute values) than for low-denomination notes. The elasticity of cash demand to economic activity should be instead larger for low-denomination notes than for high-denomination notes.

A related issue is that some regressors may enter the specification for some notes while not for others. For example, changes in the legal limits for cash payments or a proxy for the shadow economy may explain the demand for large denomination notes while not for smaller ones. At the same time, variables capturing substitution effects between cash and alternative means of payment could enrich the specifications for low-denomination notes while not for larger ones. The available empirical literature for the euro area provides evidence that the determinants of cash demand vary with denominations; however, the estimates differ country-by-country and do not allow to reach clear-cut conclusions (see Fischer *et al.*, 2004; Rua, 2018, 2020; Bartzsch *et al.*, 2015; Bartzsch and Seitz, 2016).

In the case of Italy, finding stable long-run relationships for the various denomination notes is very hard due to the relevant substitution occurred among denominations and the emergence of negative circulation for both small and large notes, which prevents the use of such variables in levels. Moreover, some time series present structural breaks in relation to specific technical factors, thus suggesting caution about the reliability of unit root tests and, in turn, of co-integration relationships. For these reasons, the reduced-form specifications do not take an error correction form with long- and short-run components.

A reasonable choice that helps in carrying out regressions is to consider three main classifications: *i*) €5-€10 for "small" notes; *ii*) €20-€50 for "middle" notes; *iii*) €100-€500 for "large" notes. Developments in these three classifications have been reported in Figure 4 and already discussed in Section 2. Cash circulation nowadays essentially reflects developments of €20 and €50 euros, which are also the notes fuelling the ATMs. Taking together, €5 and €10 exhibit a clear declining trend. Both €200 and €500 notes are characterized by negative flows since the sovereign debt crisis while €100 have positive flows but progressively reducing. Some observers state that the €50 banknote would be the smallest denomination note used for hoarding purposes.[15]

We, again, consider such data on circulation on a quarterly basis and seasonally adjust each classification before entering the various specifications. As cumulated net issuance records negative values in the case of both low- and high-denominations, as discussed earlier, we do not take any logarithm and consider equation specifications with the dependent variable expressed in first-differences. Another important aspect is that the adjustment for flows from abroad is not available for different denomination notes but only at the aggregate level. We tried to control for the impact of tourism channel by considering the number of travellers entering Italy as a proxy of flows of imported banknotes. Results are presented in Table 3 and highlight substantial heterogeneity across banknote denominations in terms of their determinants.

The fit of the regressions for high- and middle-denomination notes is very good; the one for low-denomination notes is acceptable. All variables present the expected sign. The inclusion of the Covid period in the estimation sample reduces the elasticity of demand of cash to standard macroeconomic variables (i.e., nominal GDP and the deposit rate), similarly to what happens in regressions for the whole "domestic circulation" (see again Table 1). However, for middle denominations the effect of aggregate demand remains highly significant.

Fluctuations in the CISS indicator show a positive and significant relationship with banknote circulation especially for high-denomination notes, in line with the view that increasing uncertainty feeds precautionary demand for high-value notes. However, the interaction terms between the CISS indicator and the various dummy variables for the crisis periods turns out to be significant also for middle denominations, indicating that people hoard banknotes using such notes as well. This outcome occurred during the global and the sovereign debt crisis, as well during the Covid-19 pandemic.

[15] Drehmann *et al.* (2002) pointed out that "there are two separate markets (needs) for currency, although the precise dividing lines between them are fuzzy". Amromin and Chakravorti (2009) provided a multi-country study where they select the middle-note category by determining which denomination is distributed by ATMs. Denominations above this threshold are categorised as "large" while those below this threshold are categorised as "small".

Table 3. Estimated equations for different denomination notes

	High-denominations		Medium-denominations		Low-denominations	
	2003Q1-2019Q4 (1a)	2003Q1-2020Q4 (1b)	2003Q1-2019Q4 (2a)	2003Q1-2020Q4 (2b)	2003Q1-2019Q4 (3a)	2003Q1-2020Q4 (3b)
ΔDependent variable$_{t-1}$	0.575 ***	0.534 ***	0.172	0.197		
ΔGDP$_{t-1}$	0.092 ***	0.018	0.089 ***	0.054 ***	0.006 ***	0.005
ΔDeposit rate$_{t-1}$			-1.220 *	-0.771		
Limits to cash$_t$	0.121 ***	0.137 ***	-0.084 ***	-0.072 ***		
ΔCISS$_t$	1.553 **	1.965 ***	-0.227	-0.138		
ΔCISS$_t$ * Global crisis	11.278 ***	7.597 ***	8.915 ***	7.937 ***		
ΔCISS$_t$ * Sovereign debt crisis	11.796 ***	10.986 ***	14.216 ***	14.206 ***		
ΔCISS$_t$ * COVID-19 crisis		10.226 **		24.609 ***		
Stringency index$_t$		-0.029		0.093 ***		0.002 ***
Denomination-specific regressors						
€500 ECB policy dummy	0.078	0.259				
Number of foreign travellers$_t$	-0.199	-0.319 *	0.500 ***	0.523 ***		
€10 cash handlers policy					0.111 ***	0.103 ***
Cash-card ratio$_t$					1.149 ***	1.182 ***
Constant term	-0.309	0.391	-0.683	-0.901	-0.869 ***	-0.883 ***
Adjusted R-squared	0.958	0.947	0.672	0.812	0.395	0.418

Notes: ***, ** and * indicate significance at the 1, 5 and 10 per cent level, respectively. Estimates based on Ordinary Least Squares (OLS). Inference is based on Newey-West robust standard errors adjusted for autocorrelation and heteroscedasticity in the residuals. Cumulated net issuance of each classification and nominal GDP are expressed in billions of euros. Limits to cash are expressed in thousands of euros. The *"€500 ECB policy*" is a dummy variable taking value 1 from 2016Q2 onwards. The *"€10 cash handlers policy*" is a dummy variable taking value 1 from 2019Q2 onwards.

As expected, changes in legal limits to cash usage positively affected higher denominations, while they have a negative effect on middle ones. This result corroborates the view that the decrease in limits to cash payments induced a decline in the circulation of high-denomination notes, partly compensated by an increase in the circulation of middle-denomination ones.

The coefficient for the number of foreign travellers is positive and strongly significant for middle-denomination notes, while it is negative and slightly significant for higher denominations only when including in the sample the pandemic period. These results may indicate that the "foreign component" has a more stable relationship with the demand for middle denominations, probably due to tourists' withdrawals at ATMs. However, the collapse of tourism witnessed in 2020 probably had negative effects also on the circulation of higher denominations.

As regards denomination-specific regressors, the dummy capturing the discontinuation of €500 issuance does not actually exert significant effects on the high denominations circulation, which had already fallen in previous years due to the reduction in cash limits. Cash handlers' distribution policy aiming at fostering circulation of €10, by the issuance through ATMs, is positive and highly significant in the equation for lower denominations and explains the attenuation in the downward trend observed in the most recent period. Finally, the cash-card ratio enters with a positive and significant coefficient on low denominations circulation. The coefficient is particularly large and suggests that the increase in the preference for card payments at the point of sale effectively mirrors the reduction in cash circulation of €5 and €10.

Finally, the stringency index is highly significant in the equations for middle- and low-denomination notes, the ones more related to consumers' spending, thus more affected by the social and mobility restrictions.

4.3 Robustness analysis

We test the robustness of our main results along several dimensions. The result are reported in Table B1 of Appendix B. First, we replace private consumption with nominal GDP. Second, we use the 3-month Euribor instead of the deposit rate. Third, we include indicators of trend innovation in transaction technology to detect substitution effects between cash and alternative means of payment. Previous literature included the number of POS terminals and ATMs into the long-run component of money demand equations. The increasing number of POS terminals may spur the use of credit and debit cards as an alternative means of payment putting downward pressure on the use of cash. The sign on the number of ATMs is instead a-priori ambiguous. From a theoretical viewpoint, inventory models à la Baumol-Tobin predict that consumers take into account the cost incurred per withdrawal, in addition to the opportunity cost (see Attanasio *et al.*, 2002; Alvarez and Lippi, 2009; Lippi and Secchi, 2009). An increase in the number of ATMs implies a lower transaction cost to consumers compared to the traditional over-the-counter withdrawal, thus resulting in a decline of cash balances. As a result, the long-run relationship between the number of ATMs and cash holdings could be negative. On the other hand, the widespread availability of ATMs may incentive people to use banknotes, in particular those denominations that are loaded in the terminals. Moreover, ATM providers demand the central bank more banknotes to fuel an increasing number of machines. These considerations call for a positive relationship between cash balances and the number of ATMs.[16]

As for Italy, we consider the number of ATMs and POS terminals, and the number of card payments (i.e., we sum up all payments made with credit and debit cards and e-money transactions). All variables are available from supervisory reports on annual basis. We convert them into the quarterly frequency using the Dalton disaggregation method. Finally, we explore the predictive content of the cash-card ratio based on debit card operations, which is available at quarterly frequency and can capture substitution effects on the transaction component of cash balances. We test each variable one at the time in the estimated regressions. There is no variable providing significant effects on cash demand, albeit all indicators enter into the long-run component with a negative sign consistently with a substitution effect. Moreover, the role of nominal GDP becomes not statistically significant in the specification including the number of ATMs. A relevant aspect is that our measures of transaction technology strongly correlate with the trend in economic activity making very difficult to detect substitution effects in cash-demand equations due to problems of collinearity among endogenous variables.

Finally, we take on board some measures of the shadow economy. The Italian National Institute of Statistics (Istat) provides the ratio of irregular employment to total employment, a fraction of the overall informal activity. An estimate of the shadow

[16] Some studies find a weak relationship between transaction cost variables and currency demand (see Drehmann *et al.*, 2002; Amromin and Chakrovorti, 2009). As for euro-area countries, Rua (2018) finds that short-run changes in card payments have a negative effect on cash demand in Portugal, especially as far as €200 and €100 banknotes are considered. By contrast, the availability of ATMs has a positive impact on the demand for €20 and €10 banknotes, as such denominations account for most of the banknotes loaded at ATM terminals. In this respect, Rua (2020) finds the same positive relationship between the number of ATMs and the long-run demand of €50 and €20 banknotes for the euro area as a whole.

economy as a whole is available only since 2011. Alternatively, we use the estimate provided by Schneider and Medina (2018) at the international level using a statistical approach that circumvents the circularity problem of estimating the shadow economy with cash figures. However, we do not find any significant role of such variables on our measure of cash balances.

5 Bayesian VAR models for banknotes in circulation

Reduced-form equations in a single-equation framework presented in the previous section are useful to explore the empirical correlation among variables but do not take into account all feedback effects among endogenous variables. In this Section, we rely on multivariate structural models, namely Bayesian VARs, to study the multiple-way link between cash developments and macroeconomic conditions at business cycle frequencies. This is a novelty in the existing empirical literature on the determinants of cash developments and we provide an approach than can be easily adapted to any other single country. We address three main research questions: (1) Is the relationship between economic activity, interest rate and banknotes in circulation shock-dependent? (2) If so, what is the contribution of transaction demand with respect to precautionary demand in the periods characterized by large fluctuations in cumulated net issuance? (3) Finally, can we better quantify the role of changes in legal limits to cash usage?

5.1 The benchmark small-scale specification

We consider a small-scale model including the following endogenous variables: "domestic" circulation, nominal private consumption, the deposit rate and the CISS indicator. The latter is our main shifter of cash demand for precautionary reasons. Data are quarterly and cover the period 2003Q1- 2020Q4, thus excluding the first year after the introduction of the euro, which is characterized by exceptionally large rises in cash demand. We express all variables in log- levels with the exception of the interest rate and the CISS indicator, which are in levels. We set the number of lags in the VAR to four, based on the serial correlation of the residuals.

We estimate the reduced-form of the model in a Bayesian framework, using a Minnesota setup for the prior distribution and a mixed estimation technique to obtain the posterior distribution of the coefficients (see Doan *et al.*, 1984). We, then, obtain the structural version of the VAR model by relying on sign restrictions on impulse responses following the methodology proposed by Canova and De Nicolò (2002) and Uhlig (2005) and refined by Rubio-Ramirez *et al.* (2010).

Accordingly, we postulate an inverse Wishart prior for the distribution of the variance-covariance matrix and a Gaussian prior for the distribution of the vector of coefficients. We rely on the so-called Minnesota prior for the vector of coefficients, whose logic is that each time series can be represented by a random-walk process.[17] Estimation and inference are obtained by relying on the two-step procedure described in Rubio-Ramirez *et al.* (2010). In the first step, it generates a random draw from the posterior distribution of the of the reduced-form parameters of the VAR. In the second

[17] Accordingly, in each equation of the system, all coefficients are equal to zero except the first own lag of the dependent variable, which is equal to one. Moreover, the prior distribution involves a linear decay of the prior standard deviation at higher lags, sets the relative tightness of other variables in a given equation to 1.0, and sets the prior standard deviation of the first own lag in each equation to 0.2. The prior variance is scaled based on estimates of the innovation variance obtained from fitting univariate AR(1) models to each variable. These assumptions imply a uniform-Gaussian-inverse Wishart prior for structural VAR models.

step, starting from one candidate identification matrix A_0 (i.e., a Choleski decomposition), the algorithm draws an arbitrary independent standard normal matrix and, using its "*QR* decomposition", generates an orthogonal matrix *Q*. Impulse responses are then computed using $A_0 \times Q$, the rotation of the initial identification matrix, and reduced-form parameters of the VAR. If impulse responses satisfy the sign restrictions, then the algorithm saves the matrix $A_0 \times Q$. In our simulations, we consider 20,000 draws from the posterior distribution of the reduced-from VAR and 20,000 draws from the independent normal matrix.

We identify three structural shocks that we consider particularly important for developments in cash demand. The identifying assumptions are shown in Table 4. All sign-restrictions imply a positive reaction of cash balances on impact in response to any of the three structural shocks.[18]

Table 4. Sign restrictions on impulse responses

	Aggregate demand	Precautionary demand	Monetary policy
Banknote circulation	+	+	+
Private consumption	+	-	+
Deposit rate	+	-	-
CISS indicator	-	+	-

Notes: all the shocks have a positive effect on banknotes in circulation. A "+" (or "-") indicates that the impulse response of the variable in question is restricted to be positive (negative) on impact, while a blank entry indicates that no restrictions is imposed.

The first shock reflects the *transaction demand* and postulates a positive co-movement between banknotes in circulation, private consumption and the interest rate. Following a boom in economic activity, the deposit rate increases as monetary policy reacts to inflationary pressures stemming from higher aggregate demand. The CISS indicator declines on impact as an expansion in economic activity reduces uncertainty and improve financial conditions. Following a shock to *precautionary demand*, both the CISS indicator and cash demand raise on impact, while consumption declines and monetary policy becomes expansionary to counteract the economic recession, thus lowering the deposit rate. The third shock relates to an easing in *monetary policy* and implies a negative co-movement between the deposit rate and banknote circulation. This differs from a precautionary demand shock, as the decline in the short-term interest rate boosts economic activity and reduces uncertainty in the economy.

In a multivariate model, the transmission mechanism of structural shocks becomes more complex because of the feedbacks among the variables. As for the effects of interest rates, a decline in the opportunity cost of holding cash leads to an increase in cash demand as store of value but also to an increase in economic activity, which in turn feeds after some periods into cash demand for transaction purposes. Similarly, financial

[18] We impose the sign-restrictions only on the impact responses of the variables as Canova and Paustian (2011) showed that this practice is robust to several types of model misspecification. We acknowledge that some studies have expressed concern that the Haar prior typically imposed in estimating sign-identified VAR models may be unintentionally informative about the implied prior for the structural impulse responses (Baumeister and Hamilton, 2015). However, it is very difficult to extend their alternative Bayesian approach in large systems with several structural shocks and the recent contribution by Inoue and Kilian (2020) shows that these concerns could be somewhat overstated.

strains usually raise the precautionary demand for cash but also depress economic activity, thus lowering the demand for transaction purposes. These simple examples sketch why it may be important to consider a structural multivariate model.

In the model specification, we take into account two important factors affecting the dynamics of circulation, namely legal limits to cash usage and the role of foreign demand. As to the former, we include the logarithm of legal limits as a pre-determined variable. A change in the limits is an institutional factor potentially affecting all endogenous variables but it does not respond to structural shocks. A formal assessment of the assumption of weak exogeneity has been tested with a battery of Granger causality test. The inclusion of this variable affects significantly the VAR baseline projections of cumulated net issuance (i.e., the long-run dynamics in absence of shocks in the economy), thus reducing the contribution of the unexplained component and avoiding a biased assessment of the contribution of structural shocks. We provide evidence in this regard by comparing the estimation results of specifications including and excluding legal limits to cash. As for the role of flows from abroad, we compare the simulations obtained using "domestic" circulation and "total" circulation.

We focus our discussion on two important outcomes. First, we compute impulse responses to evaluate the dynamic effects of structural shocks on the variable of interest. An important by-product of such estimates is the calculation of the short-run elasticity of cumulated net issuance to standard drivers of cash demand (i.e., economic activity and the deposit rate) conditionally to the structural shock hitting the economy, which allows a comparison with the elasticities obtained using reduced-form equations. Second, we provide new quantitative evidence on the relative contribution of the various shocks to the dynamics of cash circulation using a historical decomposition.

In Figure 13, we report the impulse responses of the endogenous variables to each structural shock, with the aim of assessing the dynamic effects over a four-year horizon. In particular, we compute the median and the 16th-84th percentiles of the distribution of impulse responses to a one standard deviation shock, computed from all saved identification matrices. In Table 5, we report the short-run elasticities of banknote circulation to macroeconomic drivers, computed as ex-post ratios of the median of the posterior distribution of impulse responses.

The effects of a transaction demand shock on cash circulation is sizable but not very persistent. In reaction to the shock, both private consumption and cumulated net issuance raise significantly with an impact-elasticity of about 0.6. The effect remains statistically significant up to one year ahead. Following a precautionary demand shock, as captured by an increase in the CISS indicator, the increase in cash circulation is quite persistent over time, even though the effects on the other variables are temporary. The conditional correlation with economic activity remains negative up to one year after the shock. Finally, the dynamic effects of low interest rates on circulation are also persistent, but small in magnitude. A 1-percentage-point decline in the deposit rate is associated to a 0.05 per cent increase in cash circulation. The conditional correlation between cumulated net issuance and economic activity is positive, but much smaller than in the case of an aggregate demand shock.

Overall, these results suggest that the observed elasticity of cash circulation to economic activity crucially depends on the structural shock hitting the economy. The estimated elasticity obtained in reduced form equations simply reflects the relative importance of the various shocks over the considered sample period.

Table 5. Short-run elasticities of banknote circulation

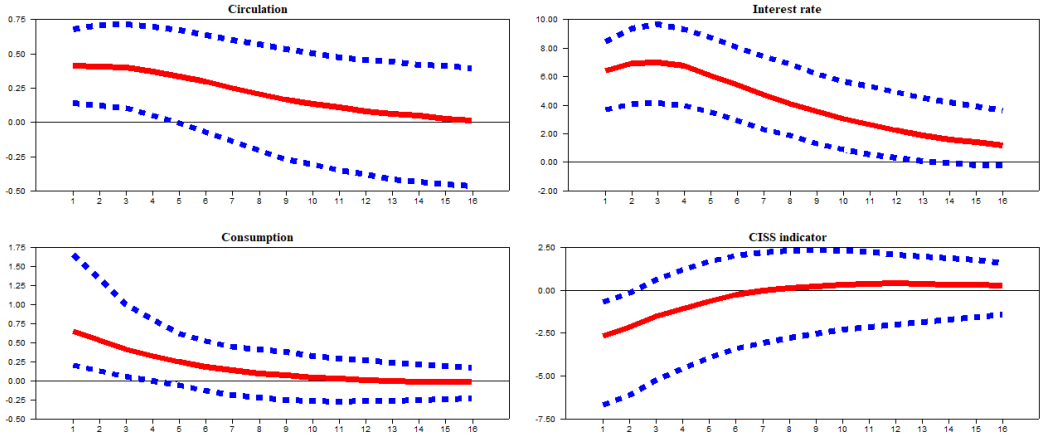
	Aggregate demand	Precautionary demand	Monetary policy
Elasticity of circulation to private consumption			
Domestic circulation: including limits to cash	0.63	-0.45	0.27
Domestic circulation: excluding limits to cash	0.67	-0.45	0.27
Total circulation: including limits to cash	0.74	-0.54	0.32
Elasticity of circulation to deposit rate			
Domestic circulation: including limits to cash	0.06	-0.45	-0.05
Domestic circulation: excluding limits to cash	0.07	-0.48	-0.05
Total circulation: including limits to cash	0.07	-0.64	-0.06
Elasticity of circulation to CISS indicator			
Domestic circulation: including limits to cash	-0.15	0.16	-0.05
Domestic circulation: excluding limits to cash	-0.15	0.17	-0.05
Total circulation: including limits to cash	-0.17	0.21	-0.06

Notes: Structural parameters are estimated over the period 2003Q1-2020Q4. Median of the posterior distribution of impulse responses on impact to the indicated structural shock. The elasticities of circulation to the different variables are computed as the ratio between the corresponding impulse response functions.

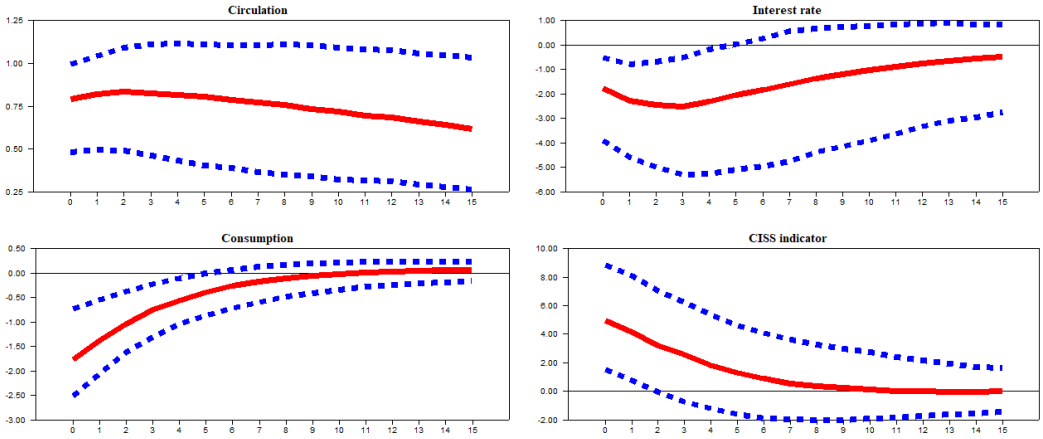
In panel a) of Figure 14, we show the contribution of the structural shocks to deviations from the baseline path of domestic circulation (i.e., the projection of the variable in absence of structural shocks) over the period 2006-2020. The historical decomposition deserves some comments. Deviations form baseline path are contained for most of the sample period, except for 2020, thus suggesting that the model makes a good job in explaining the developments in cash circulation. The contribution of the aggregate demand shocks is positive and very relevant in the first part of the sample (2006-2007). During the global crisis, the growth of circulation lied below the baseline path. The positive contribution stemming from the precautionary demand shock was more than counter-balanced by the negative contribution of aggregate demand shock associated to the severe economic recession.

Figure 13. Impulse responses to structural shocks: B-VAR model for domestic circulation

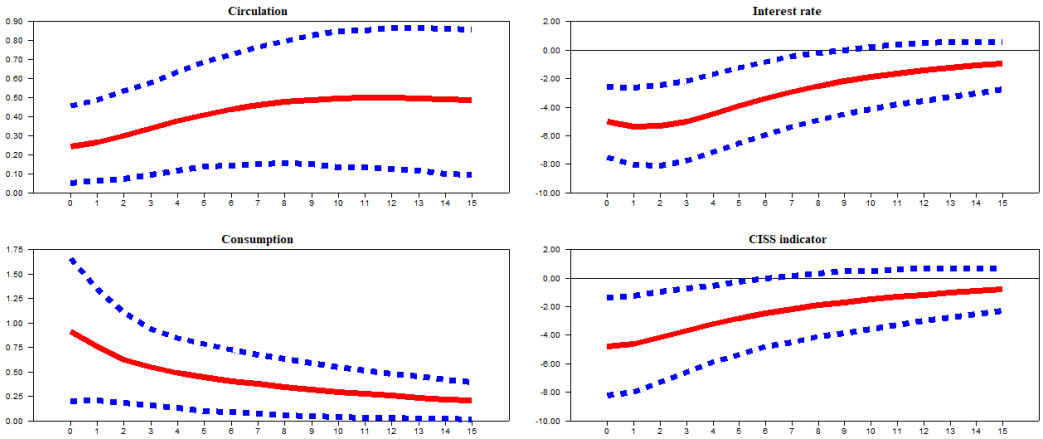
a) Positive transaction demand shock



b) Positive precautionary demand shock



c) Expansionary monetary policy shock



Source: our computations on data from Bank of Italy, ECB Statistical Data Warehouse and Istat.
Notes: the red solid line is the median of the posterior distribution of impulse responses to the indicated structural shock. The blue dashed lines represent the 16th and 84th percentiles of the posterior distribution. The forecast horizon is up to four years ahead. We measure domestic circulation as cumulated net issuance adjusted for flows from abroad.

As for the sovereign debt crisis, the VAR model interprets the exceptional surge in 2011 and the subsequent fall in 2012 mainly as the effects of changes in precautionary demand. The role of monetary policy shocks appears to be modest over the entire sample period, with the exception of the years after 2015, when the expansionary monetary policy followed by the ECB sustained economic growth. An interesting feature is that the contribution of aggregate demand shocks since 2013 is small in comparison with the contribution of other shocks.

In panel b) we zoom on the most recent period, characterized by the breakout of the pandemic and by a sudden and persistent increase in cash circulation. According to the model, since 2020 the growth of cumulated net issuance has increasingly deviated from its long-run trend. The deviation from the baseline path is sizable, reaching 8 percentage points at the end of 2020. The estimates suggest that two-thirds of such positive gap reflect an increase in precautionary demand, while one-fourth remains unexplained by the model. This outcome seems to support the claim made above that the recent acceleration is likely to reflect technical factors related to the cash distribution cycle that are difficult to be captured with standard macroeconomic variables.

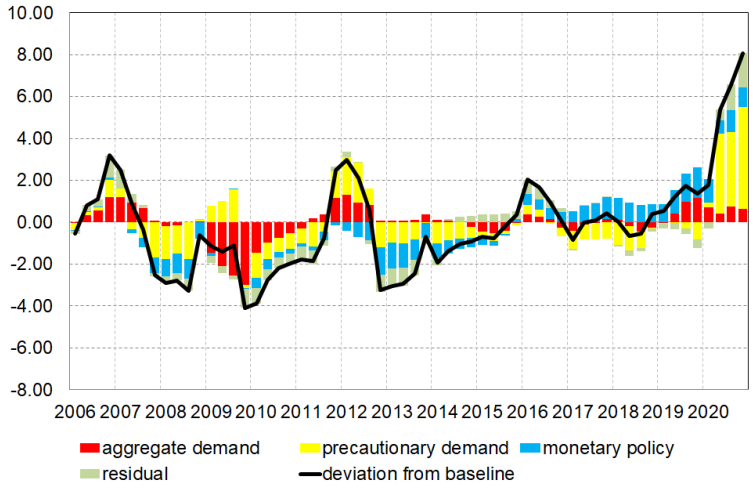
We again take on board the Stringency Index discussed in Section 4, which is included among the exogenous variables. In the model, the stringency index acts as a separate shock that can directly affect all endogenous variables, including economic activity and the CISS indicator. In this regard, it is observationally equivalent to a precautionary demand shock, since it implies a reduction in economic activity against an increase in both cash circulation and the CISS indicator for most of 2020. We then compute a new historical decomposition, which is reported in panel c). We find that the inclusion of the stringency index leads to much smaller deviations from baseline, which become even negligible in the second half of the year. As expected, the contribution of the precautionary demand shock vanishes away with the exception of the second quarter of 2020 when the CISS indicator effectively recorded an exceptional increase. Overall, this simulation confirms that an impairment in cash cycle, as captured by a simple indicator of restrictions to mobility and business, could be an alternative explanation behind the acceleration in cash circulation during the pandemic; however, its exact quantification remains difficult in this statistical framework.

Finally, we also address the potential substitution effects stemming from the increasing recourse to payment cards, by including the cash-card ratio as endogenous variable in the B-VAR model for domestic circulation. This requires identification assumptions to be formulated. Ardizzi *et al.* (2019) show that the cash-card ratio is strongly counter-cyclical and responds with a positive sign to uncertainty shocks that occurred in periods before the pandemic. A positive reaction of the cash-card ratio to a precautionary demand shock could be valid also for the pandemic period as uncertainty was surging and the economy was falling. However, with the widespread of infections the cash-card ratio significantly declined in the data, as the fear of contagion induced people to change dramatically their payment habits in favor of electronic payments (Ardizzi *et al.*, 2020). This implies that the cash-card ratio could decline in response to a precautionary demand shock. Overall, imposing robust sign-restrictions on such variable over the entire sample period is extremely challenging.

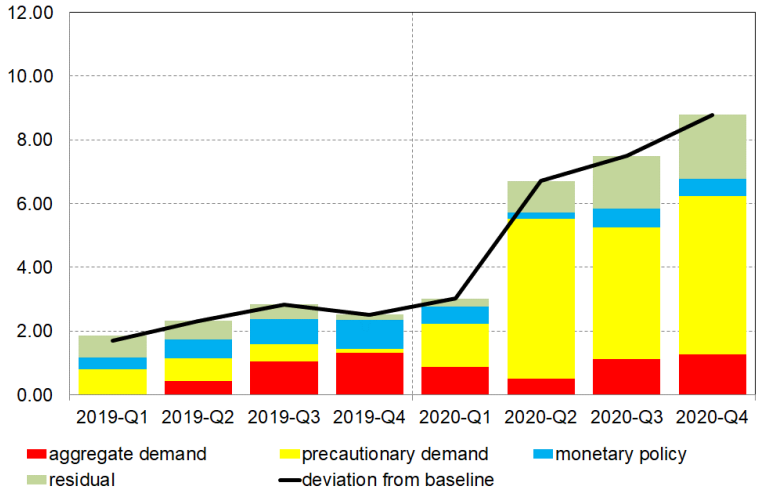
Figure 14. Historical decomposition of "domestic" circulation

(quarterly data; year-on-year growth rates)

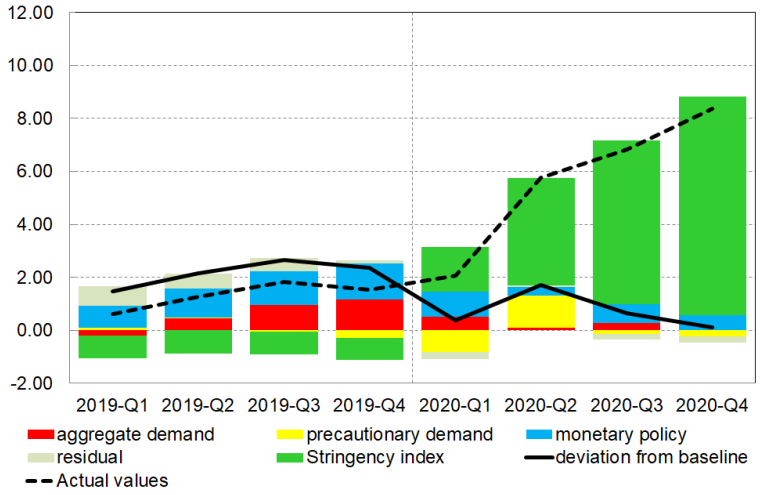
a) Sample period 2006-2020



b) Zoom on the pandemic period



c) Including the Stringency index



Source: our computations on data from Bank of Italy, ECB Statistical Data Warehouse, Oxford University and Istat.

We experimented with a number of alternative identification schemes. With all of them, the contribution of the unexplained component increases over the entire sample period. Hence, it appears that the use of the cash-card ratio does not help to identify the structural shocks underlying banknote circulation. This, one may argue, is probably due to the fact that the substitution effect stemming from the alternative means of payment is likely to be significant only for lower denomination notes, which represent a very small fraction of cumulated net issuance.

In Section 6, we better explore this issue using a different econometric approach.

5.2 Assessing the role of legal limits on cash payments

What is the role of legal limits in this statistical framework? We compare our benchmark estimates, as captured by both the impulse responses and the historical decomposition, with those obtained using a VAR model excluding legal limits from the specification. The impulse response functions are not sensibly affected (see Figure B1 in Appendix B). The effects of aggregate demand shocks seem to be more persistent but very similar in magnitude.

The impact of a precautionary demand shock somewhat attenuates, reflecting the strong correlation between legal limits to cash and the CISS indicator during the sovereign debt crisis. Including legal limits among variables, in our view, allows the structural model to better pin down the short-run effects of both transaction and precautionary demand shock. More generally, excluding the effects of the legal limits leads to higher short-run elasticities of banknote circulation conditionally to structural shocks.

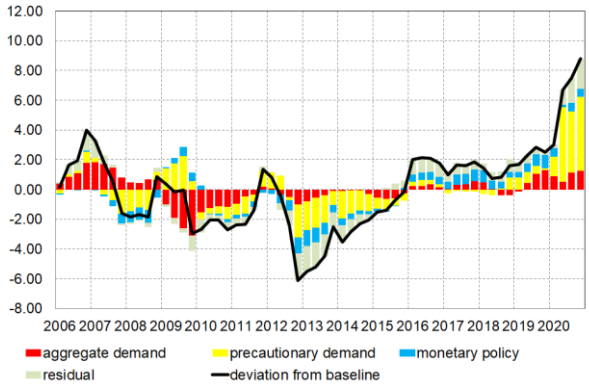
The historical decomposition reported in Figure 15 shows that the deviations of circulation growth from its baseline path tend to be more pronounced, especially in the aftermath of the sovereign debt crisis. The contribution of the unexplained component increases as well.

We compute the difference between the baseline forecast estimated with and without legal limits to cash in the model specification, in order to provide an assessment of the contribution of changes in the limits to circulation growth.

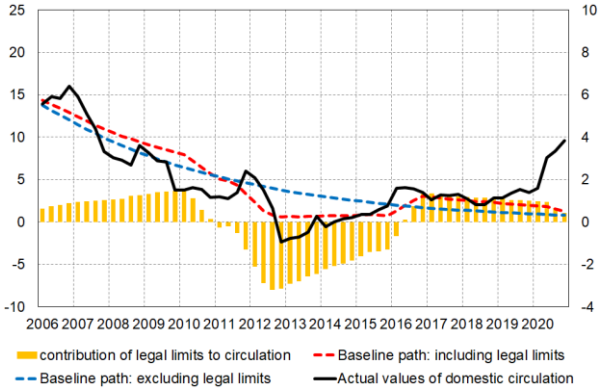
Over the period 2011-2015 the contribution of legal limits to the reduction in circulation growth was, on average, about 2 percentage points, with a peak of more than 3 percentage points in the second quarter of 2012. The average effect induced by the subsequent increase in the limits that occurred since 2016 was about 1 percentage point until the end of the sample period. Overall, these results confirm the important role of legal limits for cash payments in statistical models aiming at interpreting banknote circulation.

Figure 15. B-VAR model excluding legal limits to cash usage
(quarterly data; year-on-year growth rates)

a) Historical decomposition of domestic circulation



b) Baseline path and contribution of legal limits to cash payments



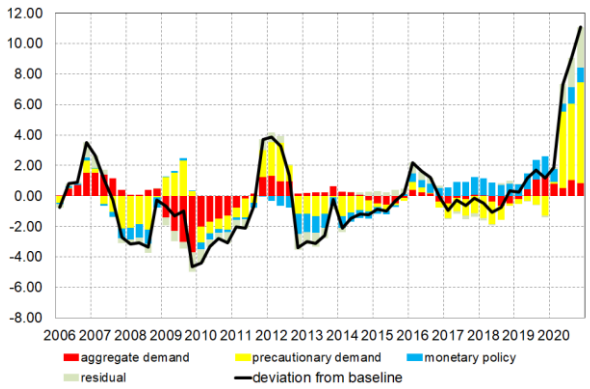
Source: our computations on data from Bank of Italy, ECB Statistical Data Warehouse and Istat.
Notes: the contribution of "legal limits to cash usage" is computed as the difference between the baseline path of the B-VAR model for domestic circulation including and excluding legal limits to cash usage from the model specification.

5.3 Assessing the role of flows from abroad

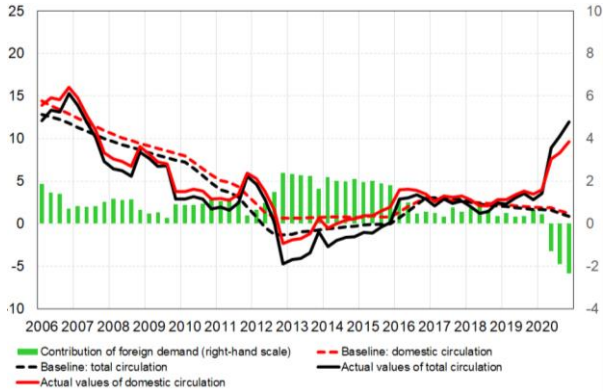
We now address the role of foreign demand in the B-VAR framework by replacing domestic circulation with total circulation. Most of the impulse responses look very similar to that obtained for domestic circulation (see Figure B2 in Appendix B). A notable exception is that we find a stronger reaction of banknote circulation in response to aggregate demand shocks. As for the historical decomposition, the main difference with the model for domestic circulation is that during the pandemic the deviation of total circulation growth from its baseline path becomes significantly larger by about 2 percentage points (see Figure 16). The relative contribution of the various shocks remains broadly unchanged, thus confirming the important role played by precautionary demand and that part of current developments is not explained by conventional drivers.

Figure 16. B-VAR model for total circulation
(quarterly data; year-on-year growth rates)

a) Historical decomposition of total circulation



b) Baseline path and foreign component



Source: our computations on data from Bank of Italy, ECB Statistical Data Warehouse and Istat.
Notes: the contribution of "foreign component" is computed as the difference between the annual growth rate of domestic circulation (i.e., total circulation adjusted for flows from abroad) and total circulation plus the difference between the baseline path of the corresponding B-VAR models.

In panel b) we provide an assessment of the contribution of foreign component over the sample. It is computed as the difference between the baseline path of the annual growth rate of domestic circulation and the baseline path of total circulation, as estimated by the corresponding B-VAR models. We find that flows from abroad boosted cash circulation for most of the sample period. Their contribution declined significantly in 2018-2019, reflecting the slowdown in global economic activity, and turned negative in 2020 by about 2 percentage points reflecting the collapse of tourism flows in our country during the pandemic and the associated mobility restrictions also across countries. Overall, these results suggest that the foreign channel of cash provision came to a halt with the pandemic but it does not tell the full story behind the surge in cash.

5.4 Lodgments and withdrawals

We now evaluate the determinants of withdrawals and lodgments. Accordingly, in the B-VAR model we replace cumulated net issuance with quarterly flows of such variables. The sign restrictions on the response of withdrawals remain the same of total circulation while in the case of lodgments we assume that such variable declines in response to a precautionary demand shock (see Table 5). A surge in cash holdings by the private sector due to uncertainty in the economy, indeed, can stem from an increase in withdrawals from the central bank as well as from a reduction in lodgments to the central bank. The latter occurs because households and small firms deposit less money to commercial banks and cash handlers receive a lower amount of banknotes from large retailers. As for the monetary policy shocks, the response of lodgments is a priori ambiguous. On the one hand, a decline in the opportunity cost of holding money would lead to a reduction in lodgments. On the other side, an expansionary monetary policy boosts economic activity, which, in turn leads to an increase in this variable. Here we assume a positive response, which provides better results in terms of historical decomposition but we also experimented with alternative assumptions.[19]

Table 5. Sign restrictions on impulse responses: BVAR model for withdrawals and lodgments

	Aggregate demand	Precautionary demand	Monetary policy
Withdrawals	+	+	+
Lodgements	+	-	+
Private consumption	+	-	+
Deposit rate	+	-	-
CISS indicator	-	+	-

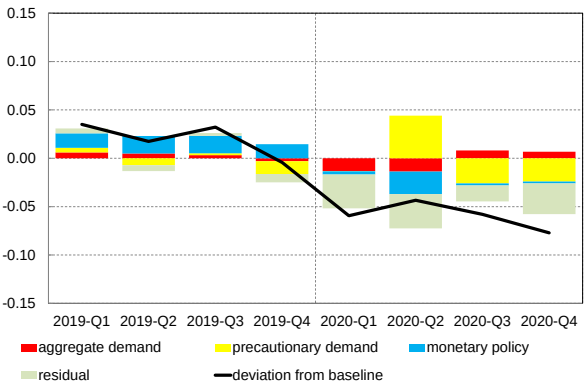
Notes: all the shocks have a positive effect on banknotes in circulation. A "+" (or "-") indicates that the impulse response of the variable in question is restricted to be positive (negative) on impact, while a blank entry indicates that no restrictions is imposed.

[19] One could take an agnostic view and leave unrestricted the response of lodgments following an expansionary monetary policy shock. In such case, the variable reacts positively, thus corroborating the view that the channel related to the opportunity cost of holding money is less relevant in the data. We also experimented an identification scheme imposing a negative reaction of lodgments to the monetary policy shock. Such identification scheme, however, is strongly rejected by the data, as the role played by the unexplained component increases in the historical decomposition of both lodgments and withdrawals.

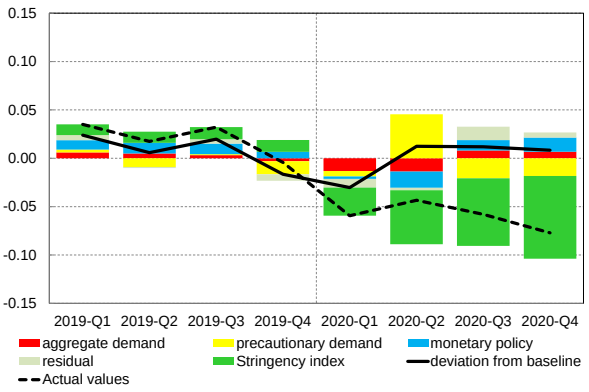
It is interesting to compare the response of the variables to the structural shocks. Figure B3 in Appendix B shows that lodgments are more responsive to business cycle fluctuations than withdrawals, thus confirming what we found with single-equation models in Section 4. More precisely, the estimated effect of aggregate demand shocks is double in magnitude for lodgments while more similar in persistence. Similar results are obtained as far as monetary policy shocks are considered. Finally, the impact of precautionary demand shocks is larger in magnitude for lodgments as well, which seems to be at odds with the idea that financial shocks primarily affect banknote circulation via an increase in withdrawals. However, this result essentially reflects what happens during the pandemic when precautionary demand shocks mostly transmitted via a reduction in lodgments to the central bank.

Figure 17. Historical decomposition of withdrawals and lodgments during the pandemic
(quarterly data)

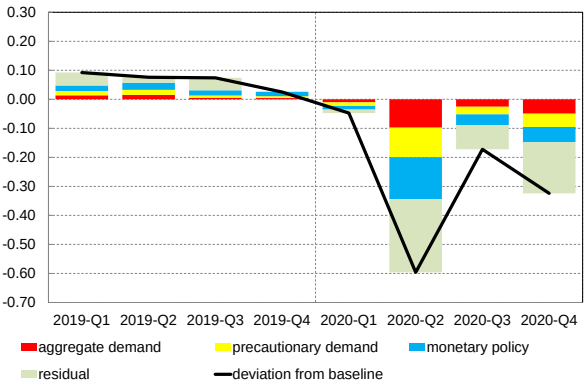
a) Withdrawals: excluding the Strigency index



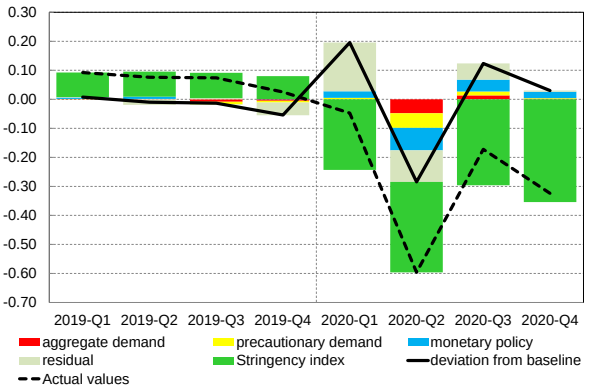
b) Withdrawals: inlcuding the Stringency index



a) Lodgments: excluding the Strigency index



b) Lodgments: inlcuding the Stringency index



Source: our computations on data from Bank of Italy, ECB Statistical Data Warehouse, Oxford University and Istat.

Evidence in this regard can be drawn by looking at the historical decomposition of each variable (see Figure B4). Precautionary demand shocks, as expected, sustained circulation growth via an increase in withdrawals especially during the global and the sovereign debt crisis while by means of a decline in lodgments during the pandemic in 2020. In Figure 17 we zoom, again, on the pandemic period and compare the results with an alternative BVAR model including the Stringency index among exogenous variables. The inclusion of the stringency index leads to much smaller deviations from baseline, especially in the case of lodgments. The contribution of the precautionary

demand shock remains important only in explaining the dynamics of withdrawals in the second quarter of 2020, while it becomes negligible in the historical decomposition of lodgments. Overall, these simulations confirm that the acceleration in cash circulation during the pandemic mostly reflected an increase in precautionary demand due to both uncertainty in the economy and the restrictions to people mobility and the activity of businesses and retailers, with the latter transmitting via a collapse in lodgments.

6 Estimation of transaction demand using the 'seasonal method'

In this Section, we provide an estimate of the amount of cash in circulation in Italy used for transaction motives. We apply the so-called "seasonal method" to our reference measure for domestic circulation. This approach was firstly proposed by Sumner (1990) for the US dollar and has been used in a number of papers for other currencies (Assenmacher *et al.*, 2019; Bartzsch and Uhl, 2017; Judson, 2017; Finlay *et al.*, 2020).

This method postulates that the time series of domestic circulation is simply the sum of the transaction component and the amount of banknotes used for other purposes, including hoarding, as follows:

$$CIRC_t = CIRC_t^T + CIRC_t^H \qquad (2)$$

where each times series is modelled as a multiplicative seasonal process involving a trend-cycle component and a seasonal component. Accordingly, equation (2) can be rewritten as follows:

$$CIRC_t = T_t S_t = T_t^t S_t^t + T_t^h S_t^h \qquad (3)$$

The estimation of the different components is based on the main assumption that the non-transaction component does not show any seasonal pattern (i.e., $S_t^h = 1$ for any t). Let define β_t the share of banknotes used for transaction purposes, then, the equation for domestic circulation can be re-written as follows:

$$T_t S_t = \beta_t T_t S_t^t + (1 - \beta_t) T_t \qquad (4)$$

Accordingly, we compute the share of banknotes used for transaction purposes (β_t) as:

$$\beta_t = \frac{S_t - 1}{S_t^t - 1} \qquad (5)$$

where S_t is the vector of seasonal factors of the (observed) time series of banknotes in circulation that can easily be derived with a standard seasonal adjustment method. S_t^t is the vector of the seasonal factors of the time series of banknotes in circulation for transaction purposes, which is unobserved and proxied by a reference variable that should plausibly exhibit the same seasonal pattern.

Albeit equation (5) implies that we could estimate the transaction component at each point in time (i.e., we could obtain a monthly time series of the transaction component if the proxy variable is observed at monthly frequency), this hardly holds in practice. Indeed, it is unlikely that for any t the seasonal coefficients are actually significantly different from 1. Therefore, we can only estimate the share of the transaction component at an annual frequency, by taking into account for each year *j* the months when we observe a peak and a trough in the seasonal factors. For our time series the spikes and the troughs occur in December and February, respectively. As a result, equation (5) becomes:

$$\beta_j = \frac{S_{dec,j} - S_{feb,j+1}}{S_{dec,j}^t - S_{feb,j+1}^t} \qquad (6)$$

A crucial issue in the application of the "seasonal method" is the choice of the reference variable whose seasonal component should match that of banknote circulation. Previous literature used the seasonal factors of small-denomination notes (see Assenmacher *et al.*, 2019, for example). Since in Italy cumulated net issuance of small denomination notes is actually negative, we cannot rely on such variable. Therefore, we experiment with a wide range of alternative indicators that capture the seasonal pattern of private consumption in Italy: specifically, we use a number of indicators available at monthly frequency and regularly used at Bank of Italy for forecasting economic activity (see Aprigliano *et al.*, 2019; Delle Monache *et al.*, 2021). We consider the following variables: the monthly data on households' expenditure provided by Confcommercio – the Italian General Confederation of enterprises, professions and self-employment – also with a breakdown between goods and services; the retail trade turnover (excluding services) provided by Istat; debit card payments at POS obtained from transaction data recorded in BI-COMP – the Italian retail payment system managed and supervised by Bank of Italy. Each indicator has pros and cons and the use of more variables allows us to provide a range of the stock of the transaction component.

Another important aspect is that the seasonal amplitude (i.e., the difference between the peak and the trough of each calendar year) of domestic circulation is less pronounced than the seasonal amplitude of indicators, as the latter are *flows* rather than *stocks*. We follow the approach proposed by Fischer *et al.* (2004) and re-write equation (6) as follows:

$$\beta_j = \frac{S_{dec,j} - S_{feb,j+1}}{\gamma(S^{cons}_{dec,j} - S^{cons}_{feb,j+1})} \qquad (7)$$

where γ is a factor taking into account the elasticity of the demand for cash with respect to consumption; therefore a good candidate is the B-VAR model presents on Section 5. Accordingly, we take the elasticity of the demand for cash with respect to consumption from Table 4 and the scaling factor is set equal to 0.67.

The estimates of the transaction component obtained with each of the proxy variables are presented in Figure 18. Panel a) indicates that the share of banknote circulation used for transaction purposes declined from a range of 30-43% in 2002 to a range of 13% to 25% in 2019. [20] In 2020 the share of banknotes used for transaction purposes declined markedly to a range between 12% and 21%, confirming that the exceptional increase in domestic circulation in the context of the pandemic is explained by other factors than the transactional demand for cash.

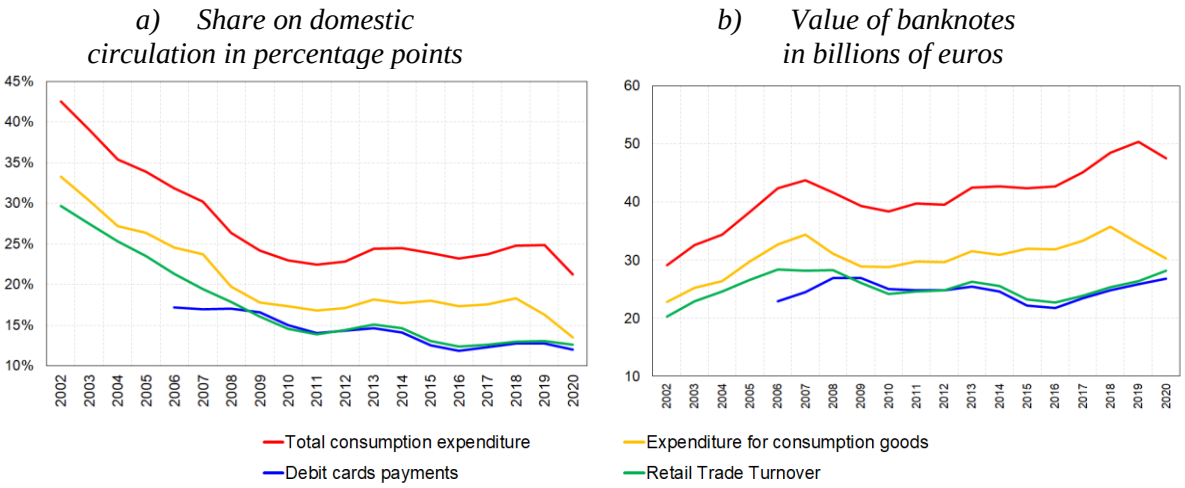
Our results are broadly in line with estimates for other euro-area countries. The estimates for 2019 by Zamora-Pérez (2021), based on several approaches[21] suggest a value of 20-22% for the euro area as a whole, albeit the upper and lowest bounds would imply a possible range between 13% and 30%. Bundesbank (2018) estimated via the seasonal method that in 2016 about 20% of the domestic circulation of German-issued banknotes is used for transaction purposes. The amount of banknotes used for transaction purposes in Italy is slightly increasing until 2006, irrespectively of the reference variable used for its estimation (Figure 18b), and roughly stabilizes thereafter.

[20] The upper bound is obtained using the monthly variable on total consumption by Confcommercio, whereas the lower bound reflects the estimated based on both retail trade and debit card payments.

[21] Estimates of the value of banknotes held for transactions in the euro area is based on three approaches: (i) the seasonal method, (ii) the return frequency method and (iii) an analysis of the issuance of the Europan Series (i.e. the second series of euro banknotes). These provide insights as to the size and nature of domestic transactional demand for banknotes.

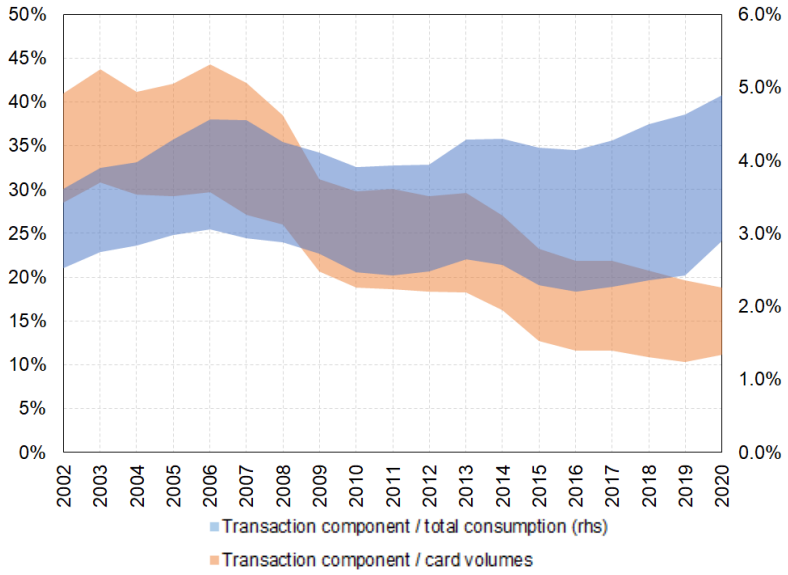
The small fluctuations of the transaction component in Italy since 2011 and its declining trend as a share of domestic circulation are consistent with the results of the B-VAR model, whereby a relatively small portion of the growth rate of domestic circulation is explained by aggregate demand shocks. However, such developments seem to be in contrast with the declining usage of cash in payments, also related to the widespread of alternative means of payment. A possible explanation is that the decline in the preference for cash over the last fifteen years effectively reduced the amount of cash payments with respect to card transactions; on the other hand, as private consumption is expressed in nominal terms, the amount of cash in circulation mechanically increased following the path of economic activity. Figure 19 shows that the ratio between the transaction component of banknote circulation over the value of total card payments exhibits a persistent declining trend after 2008, while the ratio over total consumption remained broadly stable.

Figure 18. Banknotes used for transaction purposes in Italy
(annual data)



Source: our computations on data from Confcommercio, Eurostat and Bank of Italy.

Figure 19. Transaction component of cash circulation: ratio over the number of card payments and consumption
(annual data; percentage data)



Source: our computations on data from Confcommercio, Eurostat and Bank of Italy.

7 Concluding remarks

In this paper, we discuss developments in banknote circulation in Italy over the last decades, including the role played by technical factors related for its main components, the contribution of changes in the institutional framework to cash usage and the correlation with macroeconomic conditions. Using a rich dataset and a variety of econometric tools, we also disentangle cash demand for transaction purposes from other components, namely liquidity hoarding and the precautionary demand.

We find a predominant role played by changes in legal limits on cash payment in shaping long-run developments of banknote circulation and by precautionary reasons, especially in periods characterized by severe financial distress or high uncertainty in the economy. The contribution of the transaction component declined over time and is nowadays of a second-order, also reflecting the substitution effect of the widespread of alternative means of payment. Finally, we find that standard macroeconomic drivers do not explain part of the exceptional increase recorded in banknote circulation in the aftermath of the pandemic. This time seems to be different from the past in some important aspects. First, the increase in circulation is not due to large withdrawals from the public, as occurred during panic-driven episodes, but by a collapse of lodgments to the central bank. A simple indicator capturing the lockdown-style measures taken to limit the infections explains the bulk of the acceleration in cash circulation during the pandemic, thus suggesting that the increase in the precautionary demand could have been "forced" by the restrictive measures rather than "voluntary". This distinction is not only semantic but provides evidence of an impairment in the cash cycle. Finally, the recent reduction in the limits to cash payment of last summer did not result in visible effects on circulation growth, as the other mechanisms explained above are playing a much larger role.

While it is too early to draw firm conclusions, we argue that a relevant break in cash-management decisions is probably occurring in the economic system. People are changing their payment habits and increasing their holdings of money stock for precautionary reasons, in connection with the need of maintaining social distancing and lowering the frequency of interactions with the banking and the postal system. Looking forward, the ongoing design and implementation of a Central Bank Digital Currency will represent a complementary mean of payment to the supply of cash by central banks, thus satisfying cash demand for transaction and hoarding purposes and leading to a completely new paradigm (ECB, 2020b). Last but not least, professional cash handlers could probably accelerate an on-going revision of their policy in the supply-chain with the aim of shortening the cash distribution cycle to reduce costs. These developments will pose new challenges when modelling the empirical relationship between cash circulation and the macroeconomy.

References

Alvarez, F.E., Argente, D. (2020), Cash-Management in Times of Covid-19, *B.E. Journal of Macroeconomics*, revised and resubmit.

Alvarez, F.E., Lippi, F. (2009), Financial innovation and the transactions demand for cash, *Econometrica*, 77, 363-402.

Alvarez, F.E., Lippi, F. (2017), Cash burns: An inventory model with a cash-credit choice, *Journal of Monetary Economics*, 90, 99-112.

Amromin, G., Chakravorti, S. (2009), Whither Loose Change? The Diminishing Demand for Small-Denomination Currency, *Journal of Money, Credit and Banking*, 41, 315-335.

Aprigliano, V., Ardizzi, G., Monteforte L. (2019), Using Payment System Data to Forecast Economic Activity, *International Journal of Central Banking*, 15(4), 55-80.

Arango, C., Huynh, K.P., Sabetti, L. (2015), Consumer Payment Choice: Merchant Card Acceptance versus Pricing Incentives, *Journal of Banking and Finance*, 55, 130-141.

Ardizzi, G. (2013), Card versus cash: empirical evidence of the impact of payment card interchange fees on end users' choice of payment methods, *Journal of Financial Market Infrastructures*, 1(4), 73-105.

Ardizzi, G., Iachini, E. (2013), Why are payment habits so heterogeneous across and within countries? Evidence from European countries and Italian regions, Bank of Italy, Occasional Papers no. 144.

Ardizzi, G., Nobili, A., Rocco, G. (2020), A game changer in payment habits: evidence from daily data during a pandemic, Bank of Italy, Occasional Papers no. 591.

Ashworth, J., Goodhart, C.A.E. (2014), Trying to glimpse the 'grey economy', VoxEU.org, 8 October.

Ashworth, J., Goodhart, C.A.E. (2020a), The surprising recovery of currency usage, *International Journal of Central Banking*, 16(3), 239-277, June.

Ashworth, J., Goodhart, C.A.E. (2020b), Coronavirus panic fuels a surge in cash demand, CEPR Discussion Paper no. DP14910.

Assenmacher, K., Seitz, F., Tenhofen, J. (2019), The demand for Swiss banknotes: some new evidence, *Swiss Journal of Economics and Statistics*, 155, 14 (2019).

Bagnall, J., Bounie, D., Huynh, K.P., Kosse, A., Schmidt, T., Schuh, S., Stix, H. (2016), Consumer cash usage: a cross-country comparison with payment diary survey data, *International Journal of Central Banking*, 12(4), 1-61.

Bank of England (2020), Cash in time of Covid, Quarterly Bulletin 2020 Q4.

Bartzsch, N., Rösl, G., Seitz, F. (2011), Foreign demand for euro banknotes issued in Germany: estimation using indirect approaches, Bundesbank Discussion Paper Series 1 no. 21/2011

Bartzsch, N., Rösl, G., Seitz, F. (2013), Currency movements within and outside a currency union: The case of Germany and the euro area, *The Quarterly Review of Economics and Finance*, 53, 393-401.

Bartzsch, N., Seitz, F. (2016), Cash holdings in Germany and the demand for "German" banknotes: What role is there for cashless payments?, *Transforming payment systems in Europe* (pp. 111-148), Palgrave Macmillan, London.

Bartzsch, N., Seitz, F., Setzer, R. (2015), The demand for euro banknotes in Germany: Structural modelling and forecasting, MPRA Paper 64949, University Library of Munich, Germany.

Bartzsch, N., Uhl, M. (2017), Domestic and foreign demand for euro banknotes issued in Germany, International Cash Conference 2017 - War on Cash: Is there a Future for Cash?, 25-27 April 2017, Island of Mainau, Germany.

Baumeister, C., Hamilton, J.D. (2015), Sign restrictions, vector autoregressions, and useful prior information, *Econometrica*, 83, 1963-1999.

Bech, M., Faruqui, U., Ougaard, F., Picillo, C. (2018), Payments are a-changing but cash still rules, Bank for International Settlement Quarterly Review, 67-80.

Bundesbank (2018), The demand for euro banknotes at the Bundesbank, Deutsche Bundesbank Monthly Report, March 2018.

Calderini, M., Longo, A., Rinaldi, R., Rocco, G., Sasso, F. (2019), "The cash cycle in Italy: trends, players and strategies", BANCARIA, no. 12, December.

Calza, A., Zaghini, A. (2015), Shoe-leather costs in the euro area and the foreign demand for euro banknotes, Bank of Italy, Working Paper Series no. 1039.

Canova, F., De Nicolò, G. (2002), Monetary disturbances matter for business fluctuations in the G-7, *Journal of Monetary Economics*, 49(6), 1131-1159.

Canova, F., Paustian, M. (2011), Business cycle measurement with some theory, *Journal of Monetary Economics*, 58(4), 345-361.

Cusbert, T., Rohling, T. (2013), Currency demand during the Global Financial Crisis: evidence from Australia, Reserve Bank of Australia Research Discussion Paper 2013-01.

Delle Monache, D., Emiliozzi, S., Nobili, A. (2021), Tracking economic growth during the Covid-19: a weekly indicator for Italy, Bank of Italy, Covid-19 Note, January 2021.

Drehmann, M., Goodhart, C., Krueger, M. (2002), The challenges facing currency usage: will the traditional transaction medium be able to resist competition from the new technologies?, *Economic Policy*, 17(34), 193-228.

Esselink, H., Hernandez, L. (2017), The use of cash by households in the euro area, ECB Occasional Paper Series no. 201, November.

European Central Bank (2020a), Report on the Study on the payment attitudes of consumers in the euro area (SPACE).

European Central Bank (2020b), Report on a digital euro, October 2020.

Ferriani, F., Oddo, G. (2019), More distance, more remittance? Remitting behavior, travel cost, and the size of the informal channel, *Economic Notes*, Banca Monte dei Paschi di Siena SpA, 48(3), November.

Finlay, R., Staib, A., Wakefield, M. (2020), Where's the Money? An Investigation into the Whereabouts and Uses of Australian Banknotes, *Australian Economic Review*, 53(1), 22-34.

Fischer, B., Kohler, P., Seitz, F. (2004), The demand for euro area currencies: past, present and future, ECB Working Paper Series no. 330.

Goldfeld, S.M., Sichel, D. (1990), The demand for money, *Handbook of Monetary Economics*, 1990, vol. 1, Chapter 08, 299-356.

Hale, T., Angrist, N., Goldszmidt, R., Kira, B., Petherick, A., Phillips, T., Webster, S., Cameron-Blake, E., Hallas, L., Majumdar, S., Tatlow, H. (2021), A global panel database of pandemic policies (Oxford Covid-19 Government Response Tracker), *Nature Human Behaviour*.

Hellerstein, R., Ryan, W.A. (2011), Cash dollars abroad, FRB of New York Staff Report no. 400.

Hollo, D., Kremer, M., Lo Duca, M. (2012), CISS-a composite indicator of systemic stress in the financial system, European Central Bank, Working Paper Series no. 1426.

Inoue, A., Kilian, L. (2020), The role of the prior in estimating VAR Models with sign restrictions, FRB of Dallas Working Paper no. 2030.

Jobs, C., Stix, H. (2017), Doomed to Disappear? The Surprising Return of Cash Across Time and Across Countries, CEPR Discussion Paper no. DP12327.

Judson, R. (2017), The Death of Cash? Not So Fast: Demand for US Currency at Home and Abroad, 1990–2016, Deutsche Bundesbank International Cash Conference 2017 – War on Cash: Is there a Future for Cash?.

Jung, A. (2016), A portfolio demand approach for broad money in the euro area, ECB Working Paper no. 1929.

Lalouette, L., Esselink, H. (2018), Trends and developments in the use of euro cash over the past ten years, *Economic Bulletin Articles*, European Central Bank, vol. 6.

Lalouette, L., Zamora-Pérez, A., Rusu, C., Bartzsch, N., Politronacci, E., Delmas, M., Rua, A., Brandi, M., Naksi, M. (2021), Foreign demand for euro banknotes, ECB Occasional Paper no. 253, January 2021.

Lippi, F., Secchi, A. (2009), Technological change and the households' demand for currency, *Journal of Monetary Economics*, 56(2), 222-230.

Mankiw, N.G., Summers, L. (1986), Money Demand and the Effects of Fiscal Policies, *Journal of Money, Credit and Banking*, 18(4), 415-429.

Medina, L., Schneider, F. (2018), Shadow economies around the world: what did we learn over the last 20 years?, IMF Working Paper no. 18/17.

Medina, L., Schneider, F. (2019), Shedding light on the shadow economy: A global database and the interaction with the official one, CESifo Working Paper no. 7981.

Miller, C. (2017), Addressing the Limitations of Forecasting Banknote Demand, Paper for the International Cash Conference 2017 hosted by the Deutsche Bundesbank, April 25-27.

Panetta, F. (2020), Beyond monetary policy - protecting the continuity and safety of payments during the coronavirus crisis, European Central Bank.

Porter, R.D., Judson, R.A. (1996), The location of US currency: How much is abroad, Fed, Research Bulletin, 82, 883-903.

Rinaldi, R. (2017), The role of cash in payment transactions, speech at the Salone dei Pagamenti 2017.

Rocco, G. (2019), The use of cash in Italy: evidence from the ECB Study on the use of cash by households, Bank of Italy, Occasional Papers no. 481.

Rogoff, K.S. (2016), The Curse of Cash, Economics Books, Princeton University Press.

Rua, A. (2018), Modelling currency demand in a small open economy within a monetary union, *Economic Modelling*, 74, 88-96.

Rua, A. (2020), Modelling currency demand: the case of the euro, *Empirical Economics*.

Rubio-Ramirez, J.F., Waggoner, D., Zha, T. (2010), Structural Vector Autoregressions: Theory of Identification and Algorithms for Inference, *Review of Economic Studies*, 77(2), 665-696.

Sands, P. (2016), Making it Harder for the Bad Guys: The Case for Eliminating High Denomination Notes, Harvard Kennedy School, M-RCBG Associate Working Paper Series no. 52.

Schneider, M.F., Enste, D. (2002), Hiding in the shadows: the growth of the underground economy, International Monetary Fund, IMF Economic Issues 2002/001.

Seitz, F. (1995), The circulation of Deutsche Mark abroad, Deutsche Bundesbank, Discussion Paper Series 1: Economic Studies 1995, 01e.

Stix, H. (2013), Why do People Save in Cash? Distrust, Memories of Banking Crises, Weak Institutions and Dollarization, *Journal of Banking & Finance*, 37, 4087-4106.

Sumner, S.B. (1990), The Transactions and Hoarding Demand for Currency, *Quarterly Review of Economics and Business*, 30, 75-89.

Uhlig, H. (2005), What are the effects of monetary policy on output? Results from an agnostic identification procedure, *Journal of Monetary Economics*, 52(2), 381-419.

Williams, J.C. (2017), Cash is dead! Long live cash!, *Finance & Development*, June 2017, 54(2).

Zamora-Pérez, A. (2021), The paradox of banknotes: Understanding the demand for cash beyond transactional use, *Economic Bulletin Articles*, European Central Bank, vol. 2.

Appendix A. A simple theoretical model for withdrawals at central banks

In this Section, we sketch a simple model describing the behavior of a generic cash handler (i.e., a bank or a cash in transit company) operating in Italy. A cash handler, in order to provide banknotes to the economy (over the counter or through ATMs), may withdraw cash from the central bank or, alternatively, put back into circulation banknotes previously collected from the economy, which have passed authenticity and fitness checks.[22] When deciding between these two options, provided the denominations demanded are in their availability, cash handlers try to minimize their costs.[23]

We refer to a single period decision problem, assuming that both cash handlers and the central bank have in stock all the amount of banknotes necessary to satisfy the demand in the economy. Let r and b be the volumes of banknotes recirculated by cash handlers and withdrawn at central bank counters, respectively: the sum of the two quantities must equal the cash withdrawn by the public (at bank counters and ATMs), denoted with D. Cash-handlers choose r and b by solving the following problem:

$$\min_{r,b} C(r,b) = c_1 r^2 + c_2 b^2 + K$$

sub

$$r + b = D$$
$$0 < b \leq D$$
$$0 \leq r < D$$

Cash handlers then minimize a continuous cost function, defined as the sum of the variable costs of recirculation and withdrawal at the central bank, on the basis of the parameters c_1 and c_2, and a fix cost K.[24] c_1 and c_2 represent the unit costs of recirculation and withdrawal at the central bank, respectively; they depend on the logistic organization adopted by cash handler, on the quality of banknotes in circulation[25] and on regulation on the activity of cash handling.[26]

As for the binding constraints, $b > 0$ because cash handlers will always require the central bank to replace a minimum volume of unfit banknotes, which is not possible to put back into circulation. Moreover, $b \leq D$ because the central bank is supposed to be able to provide all banknotes requested by the market in relation to its role of issuance authority. On the contrary, r could be equal to zero, if cash handlers deem economically efficient to take on banknotes only by central bank, but cannot equal D in connection to the replacement of unfit notes.

---

[22] These operators must lodge to the central bank the banknotes not passing "fitness" and authenticity checks.

[23] There is no full correspondence between the denominations collected by cash handlers and those asked by the economy. The demand for €20 and €50 is predominant among all operator, since these denominations are loaded into ATMs. In addition, due to the ratio of banknotes found unfit during the selection process, the demand cannot be satisfied only by recirculation, and therefore withdrawals by the central bank cannot be null.

[24] The goal of this model is to show that b^* is not only correlated with cash demand but also depends on variables directly correlated with the cash cycle, a simple cost function form is enough for our scopes.

[25] Inefficient internal organization may cause low productivity determining a rise in costs. The same effect could manifest if the quality of banknotes in circulation worsens: indeed this makes it harder to check for authenticity and fitness, lowing productivity and rising costs.

[26] In the euro area, cash handlers are subject to supervision by central banks. Stronger supervisory regulations may result in changing costs and induce changes in cash handlers' preferences.

Optimal solutions are:

$$b^* = \frac{c_1 D}{(c_1+c_2)} \text{ and } r^* = \frac{c_2 D}{(c_1+c_2)}.$$ [27]

In the case $c_1 = c_2$, cash handlers will be indifferent between the two sources of supply because recirculation and withdrawal from the central bank have the same unit cost.[28] In the case $c_1 \neq c_2$, it is interesting to observe, by calculating the partial derivatives, that:

1. increases in demand induce increases in withdrawals from the central bank:

$$\frac{\partial b^*}{\partial D} = \frac{c_1}{c_1 + c_2} > 0$$

2. b^* is increasing with respect to c_1: cash handlers will make a larger use of central bank withdrawals if the unit cost of recirculation increases:

$$\frac{\partial b^*}{\partial c_1} = \frac{c_2 D}{(c_1 + c_2)^2} > 0$$

3. b^* is decreasing with respect to c_2: withdrawals from the central bank tend to decrease with an increase in the cost of provision from the issuing institution:

$$\frac{\partial b^*}{\partial c_2} = -\frac{c_1 D}{(c_1 + c_2)^2} < 0$$

These results show the relationship between withdrawals from the central bank and one variable at a time, assuming all others constant. To infer information about changes in b^* induced by simultaneous changes in *D*, c_1 and c_2 we compute its differential:

$$\Delta b^* = \frac{c_1}{c_1 + c_2}\Delta D + \frac{c_2 D}{(c_1 + c_2)^2}\Delta c_1 - \frac{c_1 D}{(c_1 + c_2)^2}\Delta c_2$$

from which we deduce that withdrawals at the central bank might not change even if there is a variation in the demand of cash as long as this change is equal to:

$$\Delta b^* = 0 \Leftrightarrow \Delta D^* = \frac{D(c_1\Delta c_2 - c_2\Delta c_1)}{c_1(c_1+c_2)} = k.$$

Similarly:

$$\Delta b^* > 0 \Leftrightarrow \Delta D > k \text{ and } \Delta b^* < 0 \Leftrightarrow \Delta D < k$$

In particular, if $\Delta c_1 = \Delta c_2 = 0$ or $c_1\Delta c_1 = c_2\Delta c_2$ then $c_1\Delta c_1 - c_2\Delta c_2 = 0$ and $\Delta D^* = 0$.

If $\Delta c_1 \neq 0$ or $\Delta c_2 \neq 0$ or $c_1\Delta c_1 \neq c_2\Delta c_2$, instead, $c_1\Delta c_2 - c_2\Delta c_1 \neq 0$ and cash handlers would be prompted to revise their choices possibly with counter-intuitive behaviors in some cases. Suppose, for example, that $\Delta D = a$, with $0 < a < k$, due to an increase in economic activity. In this case, looking at the solutions showed above, cash handlers would reduce withdrawals from the central bank by responding to an increase in demand with an increase in recirculation. Thus, the analysis suggests that variations in the costs of provision incurred by cash handlers can lead to severe mismatches between developments in the demand for cash and withdrawals from the central bank.

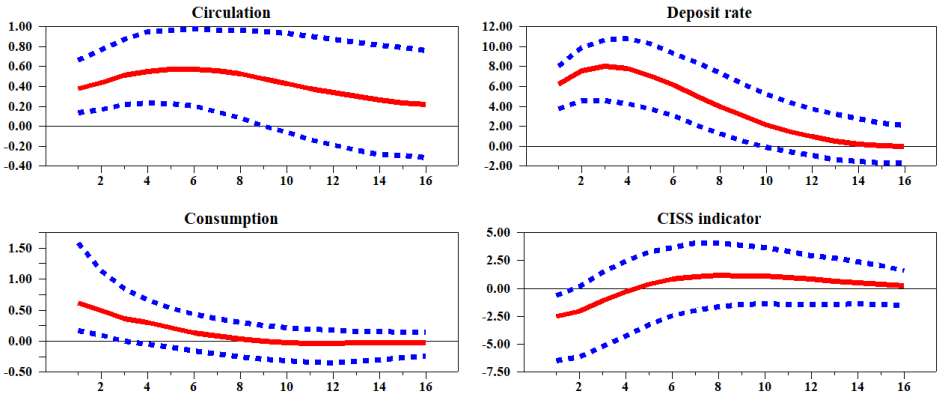
[27] It could be shown that the corner solution $(r^*; b^*) = (0; D)$ is inconsistent with optimality conditions; therefore $b^* \epsilon\ (0, D)$ and $r^* \epsilon\ (0, D)$.

[28] Indeed, when $c_1 = c_2$, b^* depends only on *D* and the ratio of banknotes sorted to unfit.

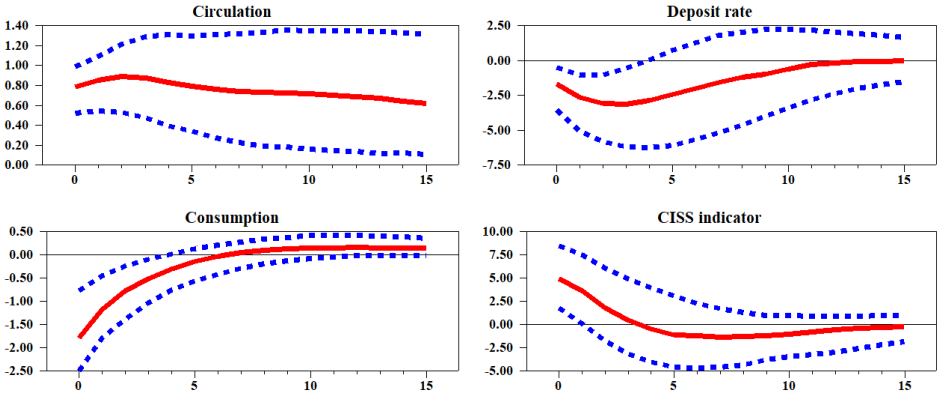
Appendix B. Other figures and tables

Figure B1. Impulse responses to structural shocks: B-VAR model for domestic circulation excluding legal limits to cash

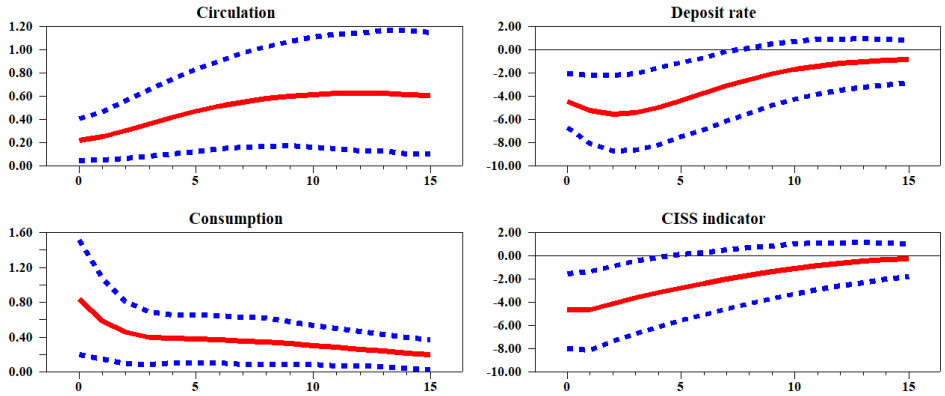
a) Transaction demand shock



b) Precautionary demand shock



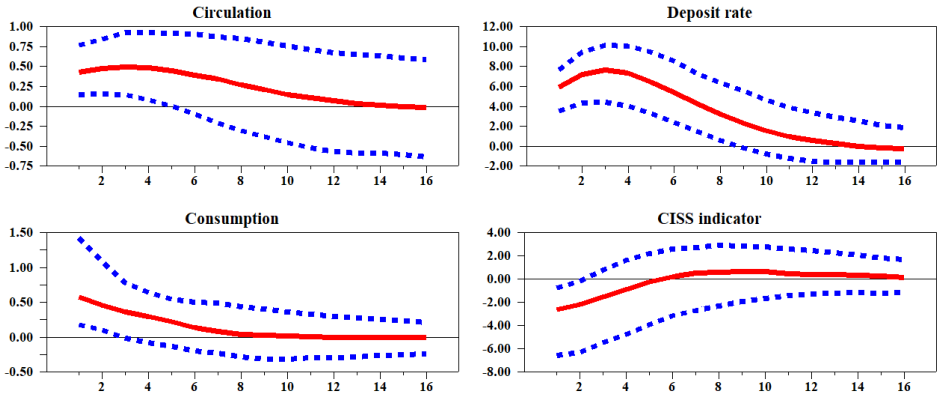
c) Expansionary monetary policy shock



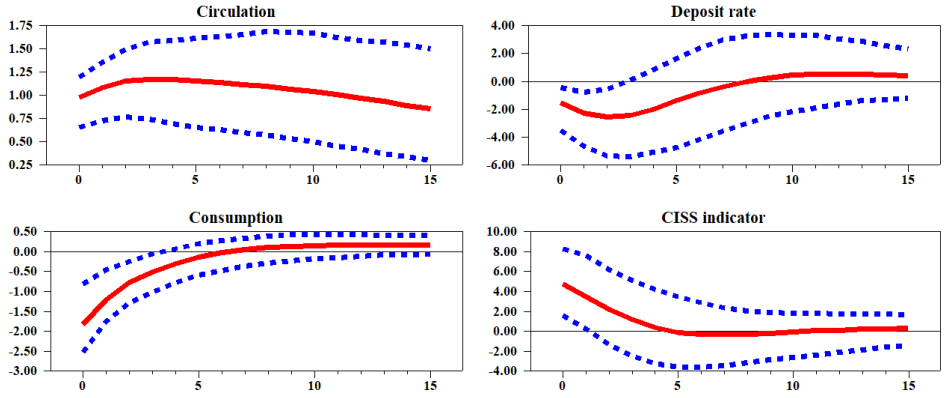
Notes: the red solid line is the median of the posterior distribution of impulse responses to a one standard deviation indicated structural shock. The blue dashed lines represent the 16th and 84th percentiles of the posterior distribution. The forecast horizon is up to four years ahead. We measure domestic circulation as cumulated net issuances adjusted for flows from abroad.

Figure B2. Impulse responses to structural shocks: B-VAR model for total circulation

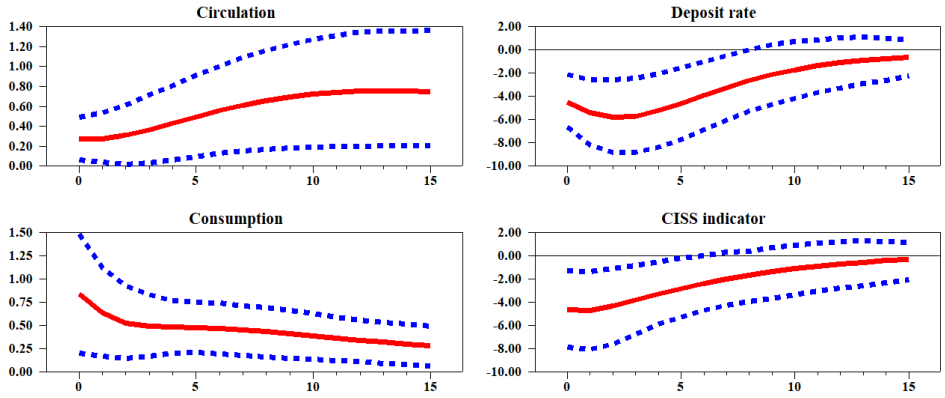
a) Transaction demand shock



b) Precautionary demand shock



c) Expansionary monetary policy shock



Notes: the red solid line is the median of the posterior distribution of impulse responses to a one standard deviation indicated structural shock. The blue dashed lines represent the 16th and 84th percentiles of the posterior distribution. The forecast horizon is up to four years ahead. We measure total circulation as cumulated net issuances unadjusted for flows from abroad.

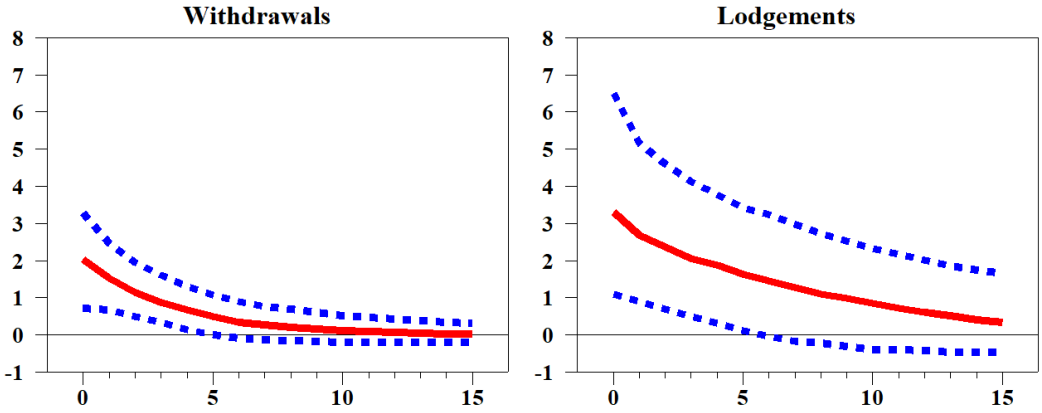
Table B1. Estimated cash demand equations for Italy: robustness analysis

	(1)	(2)	(3)	(4)	(5)	(6)
Deterministic component						
Constant term	0.454 ***	0.365 **	-0.285	0.699 **	0.010	0.352 ***
Dummy variables						
Cash limits (16q1)	0.017 ***	0.017 ***	0.017 ***	0.018 ***	0.017 ***	0.017 ***
Covid-19 (20Q1-20Q4)	0.037 ***	0.033 ***				
Long-run component						
Speed of adjustment (λ)	-0.074 ***	-0.073 ***	-0.085 ***	-0.048 *	-0.071 ***	-0.076 ***
GDP_{t-1}		1.589 ***	2.353 ***	1.417	2.394 ***	1.645 ***
$Consumption_{t-1}$	1.568 ***					
$Deposit\ rate_{t-1}$	-0.095 ***		-0.129 ***	-0.146 ***	-0.141 ***	-0.092 ***
$3\text{-month Euribor}_{t-1}$		-0.023 ***				
$Limits\ to\ cash_{t-1}$	0.068 ***	0.063 ***	0.047 ***	0.092 ***	0.046 ***	0.054 ***
$Number\ of\ POS\ terminals_{t-1}$			-0.118			
$Number\ of\ ATMs_{t-1}$				-0.081		
$Number\ of\ instruments_{t-1}$					-0.310	
$Cash\text{-}card\ ratio_{t-1}$						-0.158
Short-run component						
$\Delta CISS_t$	0.001	0.002	-0.001	0.002	-0.001	0.001
$\Delta CISS_t$ * Dummy 08Q4	0.093 ***	0.088 ***	0.102 ***	0.102 ***	0.103 ***	0.095 ***
$\Delta CISS_t$ * Dummy 11Q4	0.138 ***	0.156 ***	0.135 ***	0.160 ***	0.135 ***	0.153 ***
$\Delta CISS_t$ * Dummy 12Q1	-0.182 ***	-0.234 ***	-0.117 ***	-0.224 ***	-0.085	-0.208 ***
$\Delta CISS_t$ * Dummy 20Q1	0.179 ***	0.181 ***				
$\Delta CISS_t$ * Dummy 20Q2	0.057 ***	0.063 ***				
Adjusted R-squared	0.879	0.879	0.885	0.889	0.884	0.882

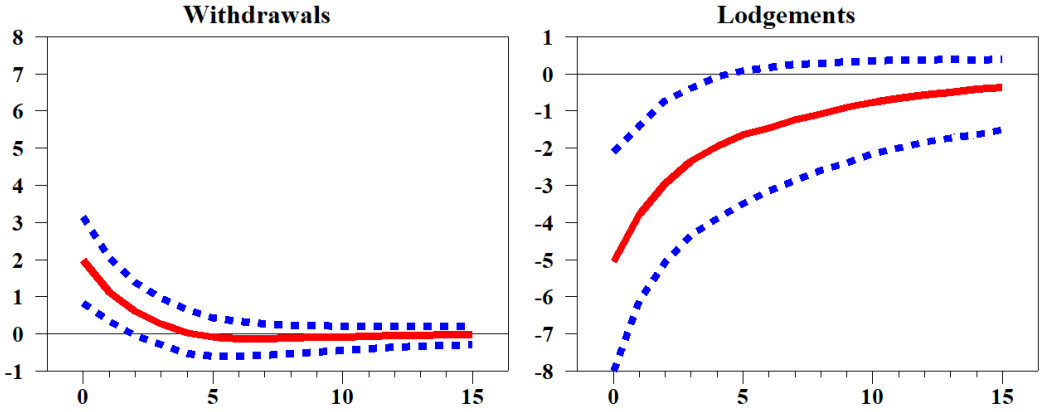
Notes: ***, ** and * indicate significance at the 1, 5 and 10 per cent level, respectively. Estimates based on Ordinary Least Squares (OLS). Inference is based on Newey-West robust standard errors adjusted for autocorrelation and heteroscedasticity in the residuals. Estimates based on the sample period 2003Q1-2019Q4.

Figure B3. Impulse responses to structural shocks:
B-VAR model for withdrawals and lodgements

a) Transaction demand shock



b) Precautionary demand shock



c) Expansionary monetary policy shock

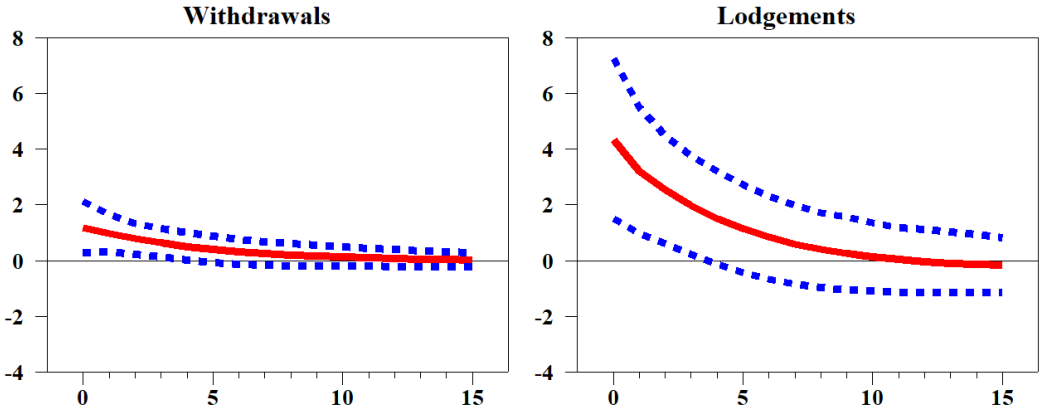
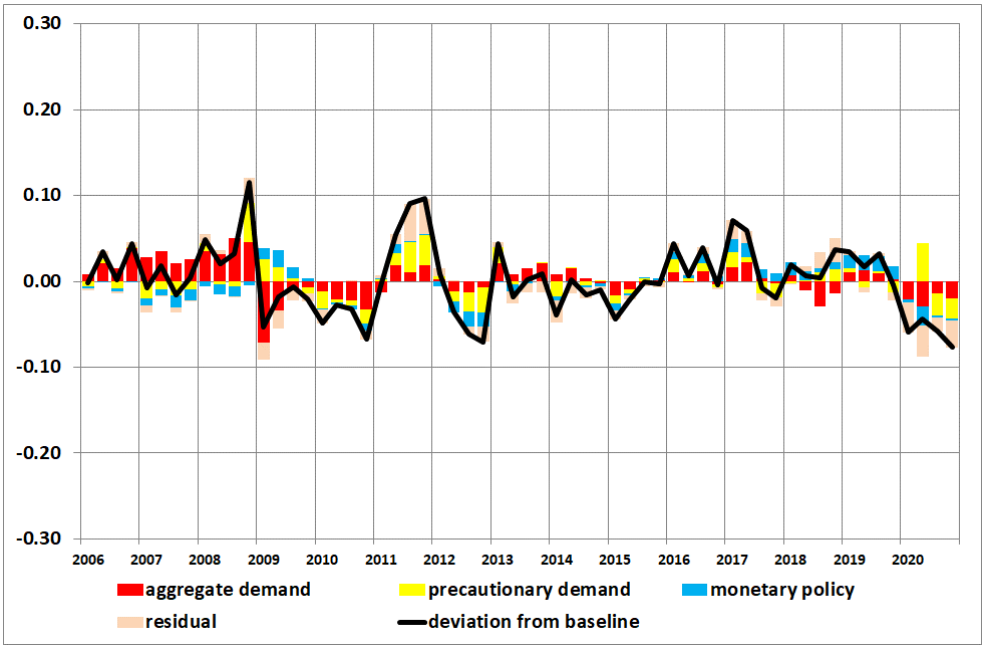


Figure B4. Historical decomposition of withdrawals and lodgements
(quarterly data; year-on-year growth rates)

a) Withdrawals



b) Lodgements