CEREM

CENTRAL EUROPEAN REVIEW OF ECONOMICS AND MANAGEMENT

Vol. 5, No. 4, December 2021

ISSN 2543-9472
e-ISSN 2544-0365

WSB University
in Wrocław

Wyższa Szkoła Bankowa
we Wrocławiu

CENTRAL EUROPEAN REVIEW OF ECONOMICS AND MANAGEMENT

Volume 5, Number 4
December 2021

Editor:

Wim WESTERMAN

Towards Smart Finance

CENTRAL EUROPEAN REVIEW
OF ECONOMICS AND MANAGEMENT

Vol. 5, No. 4

Publisher: Wyższa Szkoła Bankowa we Wrocławiu (WSB University in Wroclaw)
ul. Fabryczna 29-31, 53-609 Wrocław, Poland

Contact: Tomasz Rólczyński, Tomasz.rolczynski@wsb.wroclaw.pl, +48 71 376 23 43, ul. Fabryczna 29-31, 53-609 Wrocław, Poland

The journal is reviewed according to the principle of double blind peer review, as well as in compliance with the standards of the Polish Ministry of Science and Higher Education. CEREM is a continuation of the WSB University in Wrocłąw Research Journal (Zeszyty Naukowe WSB we Wrocławiu – ISSN 1643-7772; eISSN 2392-1153)

CEREM is registered in the IC Journal Master List, and indexed in the Central and Eastern European Online Library (CEEOL), Index Copernicus, Google Scholar, EconStor and BazEkon

ISSN 2543-9472; eISSN 2544-0365
Cover and logo design: Sebprojekt.pl
Publisher: Wyższa Szkoła Bankowa we Wrocławiu (WSB University in Wroclaw), ul. Fabryczna 29-31, 53-609, Wrocław, Poland

CONTENTS

CENTRAL EUROPEAN REVIEW
OF ECONOMICS AND MANAGEMENT

ISSN 2543-9472; eISSN 2544-0365

Vol. 5, No. 4, 7-8, December 2021

www.cerem-review.eu
www.ojs.wsb.wroclaw.pl

Introducing the special issue in CEREM: Towards Smart Finance

Wim WESTERMAN

The need for smart solutions

The Central European Review of Management (CEREM) welcomes special issues on timely topics. The current Special Issue aims to contribute to the development of smart solutions in finance, which is thought to be a next stage in changes observed since the 1990s. With the traditional "world class" model of (central) bank financing being at stake, finance solutions are increasingly moving toward flexibility and implementing new ideas.

How can the good-old role of finance, all that has to do with the flow of money in households, firms and beyond, in today's thrilling society change for the better? This question is way too broad to be covered in just a bundle of papers in CEREM. Nevertheless, in the current issue, authors from various disciplines share their insights on what is happening in an ever more important field of economics and management.

Correspondence address: Wim WESTERMAN, University of Groningen, Faculty of Economics and Business, Landleven 2, 9747 AE Groningen, The Netherlands. E-mail: w.westerman@rug.nl.
Received: 10.12.2021, Accepted: 10:12.2021
doi: http://dx.doi.org/10.29015/cerem.937

Topical overview of this issue

The role of finance in the society has not changed much over time for centuries. Money flows between finance suppliers and customers via various but in essence stable channels, such as private investors, financial intermediaries and financial markets. Yet, an increasing number of shocks, including the recent COVID-19 pandemic outbursts, have questioned the system. The special issue addresses some of these topics.

As the economy as a whole shifts from responding to recovery, many issues come to the fore when overthinking today's fast-forward ("FF") finance world. What can be noted about money creation and new (crypto-) currencies? How do the current low interest rates impact on the corporations in the financial system? How can liquidity be upheld soundly in crisis times? What about issues of disorder versus stability?

Outcome of the special issue

The reader (m/f) is encouraged to overthink smart ("lean and mean") finance solutions. Not just when being a finance policy maker, one may expect to receive some challenging insights. You will learn about facts and analyses and agree or disagree with the views provided. Nevertheless, one way or the other, after having read the special issue, the reader may want to confirm that the role of finance will never be as it was before.

CENTRAL EUROPEAN REVIEW
OF ECONOMICS AND MANAGEMENT

ISSN 2543-9472; eISSN 2544-0365

Vol. 5, No.4, 9-32, December 2021

www.cerem-review.eu
www.ojs.wsb.wroclaw.pl

Corporate liquidity in normal and crisis times: what is the best yardstick?

André Bastiaan DORSMAN

Vrije Universiteit Amsterdam, The Netherlands

Wim WESTERMAN

University of Groningen, The Netherlands

Received: 07.06.2021, Revised: 18.10.2021, Accepted: 25.10.2021
doi: http://dx.doi.org/10.29015/cerem.927

Aim: This paper is meant to investigate measures that help to assess corporate liquidity in both normal and crisis periods, to find out what matters on corporate liquidity in crisis times.

Design / research methods: We provide an overview of relevant liquidity measures used by both professionals and academics, apply regular liquidity measures on three major European electricity suppliers, study three local cases to find out how the recent COVID-19 crisis affected liquidity and provide an overview of liquidity management on 27 electricity, oil/gas and other multinational firms.

Conclusions / findings: Liquidity measures concentrate on cash ratios, working capital ratios and in specific the cash conversion cycle (CCC). In crisis times, whereas priorities do change, liquidity measures should not. In the COVID-19 crisis, firms go for leaner operations, as well as financing adjustments when needed.

Originality / value of the article: We plead for keeping a close eye on the CCC in both good and bad times. The article provides various recommendations to academics and practitioners.

Keywords: cash, working capital, cash conversion cycle, crisis, liquidity measures.
JEL: G30, M41.

Correspondence address: Wim WESTERMAN, University of Groningen, Faculty of Economics and Business, Landleven 2, 9747 AE Groningen, The Netherlands. E-mail: w.westerman@rug.nl.

1. Introduction

After what was with hindsight just a first wave of the COVID-19 pandemic-induced economic crisis, PwC UK (Windaus et al. 2021) surveyed global working capital practices of large firms. It was shown that during the first half of 2020, their Days of Sales Outstanding (DSO), Days in Inventory (DIO) and Days in Payment Outstanding (DPO) had risen by 15%, 18% and 17% respectively. The net working capital cycle had increased by five days. This deterioration had not been equalized over the industries though. The automotive sector, the aerospace, defense & security sector and the energy & utilities sector were the worst performers, whereas e.g. the pharmaceutical & life sciences sector unsurprisingly even did better than before. The study called for "Act Now to Recover", but also to prepare for long lag times when recouping, since cash flows would get worse first before being better. This makes it wise to point at warning indicators on liquidity.

On 25 March 2020, in the beginning of the COVID-19 crisis, the daily financial newspaper "Het Financieele Dagblad", published a quick research (Kakebeke, Segenhout 2020), on firms whose shares were included in the leading Dutch stock index AEX. They compared for each AEX company the cash position with the net profit and showed that the ratio cash/net profit varied between 12.43 (Galapagos) to 0.09 for RELX, suggesting that a high ratio means that the company is well equipped to withstand the crisis. Such a conclusion is wrong. Rather than the profit as such, the quality of it matters. In case of Galapagos, the profit was very small and every component related to this small figure looked good. If we may believe the authors, the publisher RELX seemed to be in serious trouble. Just 9% of the profit of this company was held in cash. Again, such an idea is not helpful. The liquidity measure used, cash/profit, is uncommon in research and reveals an accounting bias in that it is related to profit not cash flows. Moreover, rather than cash, working capital (in a narrow sense) deserves specific attention to assess a firm's liquidity.

The above statement warrants further explanation and requires more in-depth study. In this paper, we will do so in multiple ways. Firstly, we will provide an overview of general liquidity measures used in both practice and academia. It shows that cash or net working capital to sales or assets ratios, as well as operating and cash conversion cycles are indeed common types of yardsticks and that performance results found do not differ that much per measure. Secondly, we measure the liquidity of three major Dutch electricity suppliers in various ways. These types of firms are interesting because of their country-specific supply chains and their interconnections with the rest of the economy. It shows that under stable conditions the actual liquidity measure chosen does not really influence the assessment. Thirdly, we have three cases on how normally (abundantly) growing small/medium sized Dutch firms actually managed their liquidity when coping with crisis sales losses and sales volatility. The firms share a comparable supply chain role and age profile, but two are in the energy sector and the other is not. Fourthly, we compare 27 large multinational companies on their liquidity management, quite evenly split on electricity, oil/gas and other firms. It shows that the three types of companies employ various operational and financial strategies to keep their cash levels positive. Working capital considerations provoke intensified operational strategies to manage cash conversion cycles, but also short-term financing and long-term solvency (including dividend payout) policies do matter. In fact, profit considerations played a minor role and showed to be rather an outcome than a yardstick. Overall, we hold that various liquidity measures do matter in non-crisis (normal) and crisis times for electricity, oil/gas and other firms alike, but instead of cash-to-profit, other cash ratios or for that matter working capital ratios, are not the yardsticks that help to draw most interesting conclusions from. We instead suggest practitioners to closely monitor the cash conversion cycle at any time.

Our research question can now be formulated as follows: *"Which measures are helpful in assessing corporate liquidity in both normal and crisis times?"* We have studied the question by reading academic and practice literature, doing discussions and interviews, and at times giving right-on help with more than ten small firms, as well as studying whereabouts of up to 30 large firms. The research period ends with the first wave of the recent "COVID-19" crisis in the first semester of 2020. To answer our research question, we proceed as follows. Section 2 contains an overview of relevant liquidity measures used by both professionals and academics. Next, in section 3, regular liquidity measures on three major Dutch electricity suppliers are discussed. Then, section 4 provides a description of pre- and in-crisis liquidity management of three Dutch trade/service/exploration firms. Section 5 has an overview on 27 large electricity, oil/gas and other multinationals in the same respect. We discuss our study's key findings and implications for research and practice in section 6.

2. Liquidity measures: cash and working capital

A company is liquid when it can meet scheduled commitments with available resources (cf. Vernimmen et al. 2018: 206). Perhaps the oldest liquidity measure of modern times is the cash level ("money in the pocket") in terms of coins and bank notes. Now virtually vanished bank instruments such as checks, promissory notes and bills of exchange are included here too. Whereas observers may speak in terms of "cash", they nowadays readily include current accounts, deposits and liquid investments as well, thus to arrive at what is commonly called "cash and near cash". It makes sense to relate cash levels to activity measures such as sales, working capital or assets, to account for size differences of corporations. The standard literature does so in various ways (cf. Sagner 2014; Ross et al. 2019; Vernimmen et al. 2018) and rules of thumb allow for e.g. 2% of cash ("one week") to 8% of cash ("one month"). Cash levels can also be scaled by performance measures such as revenues, margins and interest. However, instead of cash rather cash flow is referred to then, despite of the common term "cash coverage ratio". Remark that observers may refer to cash levels in terms of days instead of amounts, using terms such as cash burn rates and cash turnovers.

When taking a broader perspective, corporate liquidity can be measured in terms of working capital. This may include cash items, but rather refers to the sum of (work in progress and) inventories, accounts receivable and accounts payable, in order to distinguish between cash and working capital. Working capital (gross) equals to current assets and net working capital deducts current liabilities, as is commonly done in practice. Working capital definitions can exclude specific items such as inventories and be dealing with all, some or one of its key elements specifically. As with cash, observers may relate working capital to activities and scale it by sales or assets in various ways to account for size differences of firms (cf. Sagner 2014; Vernimmen et al. 2018; Ross et al. 2019). Working capital levels can also be scaled to performance measures such as revenues, margins and interest. Observers may also refer to working capital levels in terms of days instead of amounts, using terms such as working capital turnovers and conversion cycles. The latter have well been used to measure corporate liquidity in modern times (Westerman 2015; Dorsman, Westerman 2019). The operating cycle is the period between the arrival of inventory and the receipt of cash on sales. The cash cycle leaves out the accounts payable period and starts when inventories are paid for. In practice, many refinements can be made (Talonpoika et al. 2016).

Around 1990, one of the present authors was teased by colleagues with a lecture slide titled “Cash management: is there any science?”, with “science” referring to statistical research and cash management also covering working capital management. Admittedly there was something into it at the time, but the picture has been changing remarkably, see e.g. Opler et al. (1999), Faulkender and Wang (2006), Aktas et al. (2015), as well as Seifert and Gonenc (2018). Firm-specific factors acknowledged to influence cash and working capital levels include size (larger firms need relatively less liquidity), age and growth (more mature firms may be less liquid), profitability (firms with higher earnings can be relatively less liquid), cash flow riskiness and R&D expenditures (less volatile firms need less liquidity), capital expenditures/ acquisitions, short/long term leverage and dividend payouts (all being reciprocal with liquidity). Of the above measures, profit is the least helpful one. It is a lousy measure for determining whether the firm can sustain a liquidity shock. Instead, one should look at whether the firm makes money with its operations and digging into the operations to assess their quality is needed. Also, taking a broader look can be useful. General economic factors noted by the literature refer to interest rate levels, sector specifics, governance styles and more. The literature is moreover keen to point out that not a high or low liquidity but rather an optimal level should be targeted at. More liquidity may incur lower costs due to a lower probability on a costly shortage of liquidity and needs an investment with a low or no return that therefore lowers the benefits. The more a firm deviates from its benchmarked optimal liquidity in terms of cash and/or working capital, the less its economic (net present) value becomes. In other words, there is a trade-off between liquidity risk and financial returns. Given the short-term nature of liquidity management, issues may especially raise in crisis times.

3. Measuring the liquidity of electricity firms in pre-crisis times

Dorsman and Van Montfort (2019) showed that the finance issue is becoming more and more important in the electricity industry. They state that the TSO (Transmission System Operator), who is responsible for balancing the grid (electricity network), in fact acts like a clearinghouse. The BRP's (Balancing Responsible Parties) are in that view the clearing members who fully guarantee the risk position of their clients. In the Netherlands, there are three main clearing members in the electricity market, namely Eneco, E.ON and Vattenfall. The financial strength of these main clearing members is important for the health of the (financial) electricity network in the Netherlands. Below, we study the financial strength of these electricity companies.

In the Netherlands, the electricity market is a day-ahead market. On day t the BRP's have to submit their program for day t+1 to TenneT, the Dutch TSO. Futures markets with stocks and bonds as underlying values work with (additional) margins. No margins paid means no deal. That is not the case on the electricity market. The TSO asks only a very small margin that is insufficient when there is a liquidity issue of one of these main clearing members. As long as the liquidity position of a clearing member is not an issue, absence of margins is not directly a problem. However, E.ON and Vattenfall are both facing a large solvency problem. The energy switch from fossil fuels to renewable assets means that those two companies own stranded assets (coal-fired and nuclear plans). The stock price of E.ON was remarkably reduced from € 14.46 (April 14, 2015) to € 9.52 (Dec. 31, 2019), while during this period the DAX (the German stock exchange index) increased from 12,227.60 to 13,249.01.

Whereas regular companies have a positive working capital position, trading companies face an issue. Looking at the working capital of the latter, they have very limited inventories and their clients have to pay them on a monthly base, while the trade companies themselves pay their obligations after a longer period. In other words, those trade companies have a negative working capital. Another industry with a negative working capital is the retail sector, take for example the Dutch / Belgian firm Ahold Delhaize. In addition, when a regular firm is growing, an additional investment in working capital is necessary, necessitating a cash outflow. However, when the investment in working capital is negative, growth incurs a cash inflow. This can be a reason why clients are “invited“ with high discounts to buy the products of the retailers. A higher turnover creates a cash inflow for a retail firm. The old electricity (system) traders are all former state-owned companies and are not used to compete with each other. They created an oligopolistic market structure with a weak competition between the three main (system) traders, E.ON, Vattenfall and Eneco. Nevertheless, a reduction of the turnover can also hit the liquidity position of these trading companies in the same way as the position of the retailers that operate in a more competitive market.

About a decade ago, Nuon was split up in Liander (network) and Nuon (trade). Later, Vattenfall bought Nuon and renamed it after some time. Essent eventually came in the hands of the German firm E.ON, with its network company Enexis being run as an independent firm. Eneco remained independent, it was sold to Mitsubishi in early 2020. Together, Eneco, E.ON and Vattenfall lead the Dutch energy trading sector at a joint market share of more than 80%. In Table 1 below, several balance sheet items of E.ON, Vattenfall and Eneco are compared for the years 2017, 2018 and 2019. The amounts for both E.ON and Eneco are in euro (EUR), with the amounts for Vattenfall being in Swedish kroner (SEK, with 1 SEK = € 0.095 on June 30, 2020). We added the sales and assets data to make the amounts more comparable. We moreover included cash data and do not see much variation in this respect over time, except for Vattenfall that showed record high investments in electricity grids in 2018.

Table 1. Inventories (INV), accounts receivable (A/R) and accounts payable (A/P) of E.ON, Vattenfall and Eneco for 2017–2019 (amounts for E.ON and Eneco in million EUR, for Vattenfall in million SEK)

	E.ON			*V-fall*			*Eneco*		
Item	2019	2018	2017	2019	2018	2017	2019	2018	2017
INV (A)	1252	684	794	13353	13647	16687	158	178	58
A/R (B)	14319	5445	5781	26345	26003	23437	655	722	650
A/P (C)	16686	7637	8099	27809	29482	23872	1417	1517	1224
(A+B-C)	-1115	-1508	-1524	11889	10168	16252	-604	-617	-516
Cash	3602	5357	5160	10,604	17094	8805	537	504	465
Sales	41484	30253	37965	166360	152091	135114	4271	4100	3309
Assets	98566	54324	55950	450780	462608	409132	5968	5763	5656

Sources: Annual reports 2018 and 2019 of E.ON, Vattenfall ("V-fall") and Eneco.

The sum of Inventories (INV) plus Accounts receivable (A/R) and minus Accounts payable (A/P) is negative for E.ON and Eneco and positive for Vattenfall ("V-fall"). The reason for a positive value for Vattenfall is that it is not only a trader, but also a producer of energy. Her assets include fossil fuel plants and renewables plants. Eneco on the other side is rather a trader. E.ON was in September 2016 split up in two companies, Uniper and E.ON. The fossil fuel part went to Uniper and the renewables part to E.ON. In other words, the stranded assets went to Uniper. E.ON retained the trading activities and the production facilities of renewables. So, it is still a combination of a trader and a producer. Compared to Vattenfall the focus of E.ON is more on the trading side, while E.ON is compared to Eneco relatively more of a producer.

It is interesting to point at a political risk component here. Take the Vattenfall example. Clients of Vattenfall receive a bill for electricity and gas containing various charges, including an amount for fixed electricity costs (Liander), an amount for variable electricity costs, an amount for fixed gas costs (Liander), as well as an amount for variable gas costs. On average, the Dutch yearly bill exists of 3,100 kWh electricity and 1400 m^3 gas. Vattenfall bills her clients € 0.20 for every kWh electricity (including charges), at an electricity price on the market of about € 0.02. For gas, these amounts are € 0.80 respectively € 0.03. The oligopolistic market enables trade companies to make a huge margin. Dutch taxpayers do not realize that they pay large amounts to Stockholm (Vattenfall) and Berlin (E.ON) to compensate depreciations on stranded assets.

4. In-crisis liquidity: a trading firm, an energy solutions firm and a gas exploration firm

Case research especially fits when studying a contemporary phenomenon (cf. Yin 2018). Below, we discuss three cases (as of June 30, 2020) on Dutch firms that were highly affected by the COVID-19 crisis. They were selected to fit with the samples as shown above and below, with the case firms' size of operations being relatively small on purpose though. Two firms are in the energy industry and the other elsewhere, at a varying focus on production versus sales/service. Their multinational flavour differs from low to high. Much of the data that was collected can only be obtained when there is a trust relationship between the researcher and the firm. This was established via credible middlemen or long-standing contacts. The firms were willing to cooperate at short notice and were very open to the researchers, with on-site visits, formal and informal talks, as well as interview report notes being involved. Public data accessed via het internet, including company websites, completed the data gathering.

The first case is about an abundantly growing trading firm that lost most of its sales instantly, put the core business on hold, started trading fixed assets quickly and controlled its working capital sharply to maintain a zero cash level. The second case is about a firm developing energy solutions for the real estate sector that had to cope with various activity levels of its customers that eventually also changed much over time. The sales decline and volatility caused the firm to monitor its cash and working capital levels closely. The third case refers to a gas exploration firm witnessing a sizeable drop in demand during the COVID-19 pandemic and before, which has hurt its cash position and affected its working capital, but specifically has led to a stronger focus on savings and especially free cash flow.

Zuivelrijck

Together with a companion, René van der Veen founded Zuivelrijck in 2010. This seemed to be a weird undertaking at the time, especially because both of them had ample experience in the focal business of coffee milk in The Netherlands. As René puts it: “a venture capitalist told that he had never heard such a weird idea: it is a niche product, in a declining market, with one giant player.“ The Dutch typically drink their coffee with a special cream, but to a declining extent. One firm dominates the market: FrieslandCampina. Whereas production of organic coffee milk might attract some sensitive customers, two small entrants had already experience with this, although none of them produced portion cups. However, with some idealism and a lean business model, with Zuivelrijck acting as a product development and trading company under its own Zuivelrijck branded products, the partners were convinced that the firm would become sustainable.

In the beginning, things were tough. René recalls the first batch: “others saw a pallet with nicely packaged cups of coffee milk, but to me it was working capital“. Eventually most of it had to be written off and was used for sampling to prevent waste, but the latter turned out to be a sound marketing investment. The market became willing and grew exponentially later. This repeatedly caused working capital and even cash problems in the firm though, which were met by paying business partners partially no earlier than when receivables were collected and with loans from private persons. Add-on products such as sugar sticks and chocolate milk completed the product portfolio and the firm started making profits, enabling René to buy out his business partner. Whereas growth was still way above double-digit percentages, it was however kept under control by slowing it down. Lastly, the sale of milk foaming machines became a new product line that fitted well with the existing business.

René had anticipated on the crisis by cleaning up his working capital and cash position as much as possible upfront. Yet, the main out-of-home (bars, hotels, etcetera) market dried up from one day to another and declined by 90% with most orders being cancelled instantly. What to do? Of course, Zuivelrijck also put its core business on hold as far as possible and thought to be fair. “It was as if I had to restart all over again”, René recalls. While soon finding out that “everyone” had liquidity problems whereas Zuivelrijck was relatively little affected, the firm acted as a “fixed asset” trader in its coffee machines by paying upfront for relatively cheap machines and reselling them fast for little higher prices to various types of customers. “I was looking at my bank account all the time”, René comments. And for the rest, Zuivelrijck helped its relations to stay in business and keeping them liquid as well.

“When someone cannot pay he simply cannot”, René says, especially referring to the small business partners. On its turn, Zuivelrijck was also helped by customers to stay liquid. Since the company had the wrong industry code, by not being a wholesaler but a supplier to the wholesalers in the out-of-home market, government support could not be counted on. “It would not have been much, but could have created more rest”, René feels. However, after almost eight weeks of slow business, the market seemed to be slowly picking up on the sudden news that the out-of-home lockdown would dwindle soon. “Some wholesalers started placing small orders and we also placed new productions”, René tells with some relief.

When being asked on his yardsticks, René is very clear. Profit, or for that matter even less dividends or so, is not really a measure in start-up and crisis times and although profit and equity are figures that count in terms of company valuation, operational and financial cash flows are way better even then. Cash flows take into consideration account receivables, account payables and loans positions that affect much of the fate of a company such as Zuivelrijck. Both gross and individual working capital items have to be matched with each other. The cash flow should be able to cover financial obligations and therefore cash at hand becomes the final yardstick. In the end, the very competitive business of Zuivelrijck is margin driven. Margins and cash flows are the two daily measures that René considers, with growth being an important indicator for organization and strategy considerations.

HVE

Tanju Özel is co-owner and Chief Operating Officer of Huis voor Energie (HVE), which develops energy solutions in real estate. HVE holds and Özel vividly argues that peak load is an issue in national electricity grids. Stock building is therefore necessary and especially long-distance transport is harmful. Smart local grids and ESCo (Energy Service Company) solutions are asked for[1]. HVE can service the transitions needed. Its energy directors partner up to make property energy-resistant for the future, with solar panels, heat pumps, smart meters and more. While still being young but building upon over 20 years of experience, they service real estate companies and real estate administrators, real estate vacancy managers, housing corporations and house owners' associations in the Netherlands and (until recently) Belgium.

Organizations may want to outsource their energy supply and management. If so, HVE can initiate, install and operate the ESCo's. The role of HVE in the ESCo may vary from a start-up phase consultant to a long-term manager and participant in the ESCo. HVE can help with financing the investment needed. No financing nor assets risks have to be taken up by the participants at all, since ESCo's can charge them monthly fees covering management fees, depreciation and financing costs. The typical financial constructions that HVE offers pretty much resemble operating leases, with market value resale prices. "While we are a social firm, HVE's business cases underlie strict net present value requirements", Özel points out.

Ideally, the cash flow generated by one investment would offer the money for the next one. Yet, because of the up-front financing needed and moreover being a growing firm itself, HVE employs external financing from supply chain partners and commercial banks. "It is much like a pick here and a pick there", Özel confirms. He has to accept though that banks go for (consolidated) large volumes. Measures that he monitors include earnings before interest, taxes and amortization (EBITA), debt or equity-to-assets and debt service coverage ratio (DSCR). Next to this, financing

[1] An energy service company (ESCo) is a company that is engaged in developing, installing and financing comprehensive, performance-based projects, typically 5–10 years in duration, centred around improving the energy efficiency or load reduction of facilities owned or operated by customers (Vine 2005). For more information about ESCos, see also Kangas et al. (2018), as well as Pätäri and Sinkkonen (2014).

peaks and gaps can be mitigated via HVE's cash position (related to sales) and its current account at the bank. Dividends are not used for this purpose.

With negligible supplies and more accounts receivables than accounts payables from both its project and consulting activities, the net working capital of the newcomer HVE is positive, other than the relatively old and large firms in the electricity sector. It is paramount that timely working capital and cash management is a prerequisite needed to maintain a healthy liquidity then. A company such as HVE takes counterparty risks and has to plan, monitor and track its liquidity positions. Large firms are rather payment condition setters than accepters and small parties may be riskier. A detailed and strict corporate liquidity planning down to even a weekly basis helps in this respect. Also, controls on individual cash and working capital items down to a project basis are made frequently. Moreover, HVE staff stays in regular contact with both suppliers and customers to safeguard a fluent flow of cash flows.

At the start of the COVID-19 crisis, some of the HVE partners, being often small or medium sized, encountered liquidity problems and stretched their activities. While having a financial buffer itself and being only little flexible in downsizing, HVE was keen to renegotiate both account receivables and corresponding account payables conditions, such as to sustain good operating and financial relationships and maintaining a healthy liquidity position. "I looked at the bank account all the time", Özel recalls. He added accounts receivables and payables positions to this. When the situation slowly normalized later, Özel maintained this habit.

Vermilion Energy

Vermilion Energy Netherlands B.V. belongs to a Canada-based Group of oil and gas firms. In the Netherlands, the firm explorers, develops and operates onshore and offshore natural gas fields. The Dutch head office is located in the seaport of Harlingen, with a technical service unit (also hosting the European head office) in Amsterdam and four main treatment centers that process the gas before it goes into the Dutch grid. Established in 2004, Vermilion Energy Netherlands B.V. holds a number two onshore position in the Dutch market. Both as a Group and in the Netherlands, governance, strategy and performance goals are driven by a stakeholder approach. With a defensive asset portfolio, the Dutch unit aims at free cash flows as well as growth to create long-term value. The long-term vision translates into an annual planning that is detailed on a monthly basis for operating and cash management purposes.

The Toronto and New York listed Group has felt the pressure of lowered demand (especially in terms of prices) in the course of the COVID-19 crisis. Its quarterly free cash flow has turned negative and the monthly dividend has been suspended. The Group's cash level has fallen remarkably, also relative to sales and the accounts payable and receivable position have been much fluctuating. Following the fall of commodity prices, the value of derivatives on the balance sheet has risen though. The Group recognizes exacerbated risks on commodity (oil and gas), interest (revolving credit facility) and currency (US dollar and Euro) positions, but financial covenants can be satisfied and the corporate liquidity is not at stake.

Sven Tummers is the Managing Director of Vermilion in the Netherlands. While being the first Dutchman in this job, he maintains regular contacts with Canadian head-office staff, nowadays more virtually than before. Also, weekly unit MT meetings can readily be held virtually. Unfortunately, on-site visits and physical meetings have been hindered by the COVID-19 crisis. Still, personal acquaintance with the 100+ hired staff and beyond is evermore needed and sought for in sometimes unconventional ways. This helps to keep the morale high and to keep running the unit lean, with effective and sensitive market responses.

Vermilion witnessed a combination of factors hitting the gas market by early 2020, such as gradually but deep falling natural gas futures prices, cheap LNG transshipments via the Dutch port of Rotterdam and US/EU tensions on the almost completed Nord Stream 2 Baltic Sea gas pipeline. It must however be noted that operations and investments in the oil sector can be stretched less easily than in the gas sector. Operational expenditures (OPEX) and capital expenditures (CAPEX) are curtailed vividly. "All eyes on cash flow management", Tummers says. Safety, health and environmental standards are always prioritized, however.

While financial risk management and cash management are done by the Group, the Dutch unit is involved in discussions about this. Working capital management is an issue in terms of occasional receivings and payments timing, but general accounts receivables and accounts payables policies have not been changed lately. However, the unit's focus did alter. Whereas Earnings before Interest, Taxes, Depreciation and Amortization (EBITDA) is still a base performance measure and trade-offs on internal dividend payouts versus capital investments remain important, "barrels" (read: volumes and sales) have given way to "funds" (free) cash flows.

5. Liquidity of electricity, oil/gas and other multinational firms in the COVID-19 crisis

In section 4, we described the whereabouts of three small to large sized Dutch firms serving the local market during (the first wave of) the COVID-19 crisis. We did so by relying upon both public and non-public information. We also studied the fare of 28 large firms that were supposed to have been hurt by the consequences of the pandemic. Indeed, almost all of them experienced a demand breakdown. One of firms, a financial company that was surprisingly little hurt, was assured anonymity. This left us with 27 almost all multinational firms from various sectors. Apart from the others (10), the oil/gas (10) and electricity firms (7) stand out. It must be noted that the distinction made between the latter two industries is somewhat fluent.

Table 2a. Liquidity of electricity sector companies during the COVID-19 crisis (as of June 30, 2020)

Name company	*Nationality*	*Crisis effect*	*Specific remarks*
Enexis	Dutch	limited	share price?, debt costs?, dividend fine
Engie	French	moderate	business lines affected, dividend stop
E.ON	German	limited	share price falls, debt costs up, dividend up
Greenchoice	Dutch	unknown	disruptive market, debt costs?, dividend?
National Grid	British	limited	U.S. business affected, no dividend cut
RWE	German	limited	share price falls, debt costs up, dividend up
Vattenfall	Swedish	moderate	cash falls, debt costs up, dividend cut

Source: authors' own elaborations.

We provide a general overview on the electricity firms first. Interestingly, two firms from section 3 (E.ON and Vattenfall) are sampled here as well. They do not stand out though. Showing very timely data, Vattenfall seems to be affected by the COVID-19 crisis the most, given its cash shortfall. It must be noted though that its liquidity position was already deteriorating before, following unusual electricity grid investments. All of the studied firms seem to have been hurt by financial problems with their customers. This affects their debt position and dividend cuts are occasionally found in the business. Notably, the dividend of RWE is even intended to rise however. The difference may be due to the turnaround that RWE has just gone through. The relative corporate emphasis on sales versus production may also account for inter-firm variety. Lastly, public data on Greenchoice (joint venture) and Enexis (non-listed firm), are limited and conclusions must be drawn with care.

Table 2b. Liquidity of oil/gas sector companies during the COVID-19 crisis (as of June 30, 2020)

Name company	*Nationality*	*Effect crisis*	*Specific remarks*
Baker Hughes	American	limited	CAPEX cut, debt costs /dividend stable
BP	British	moderate	assures liquidity, dividend cut 2019
Chevron	American	moderate	CAPEX/OPEX cut, debt ratio/dividend OK
ENI	Italian	moderate	supplies rise, share buyback limited
ExxonMobil	American	moderate	loss Q1, OPEX/CAPEX cut, dividend stable
Fugro	Dutch	moderate	assuring liquidity, OPEX cuts, no dividend
Royal Dutch Shell	Dutch	moderate	CAPEX/OPEX cut, buyback/dividend cut
Sasol	S. African	moderate	“bad” project, production cut, high debt
SBM Offshore	Dutch	limited	“safe” business model, financials sound
Total	French	limited	finance/dividend sound, future unsure

Source: authors’ own elaborations.

As with the electricity sector, all of the oil/gas companies studied do suffer from the COVID-19 crisis. They namely curtail operating costs and capital expenditures. As to their liquidity, the firms keep a close eye. Although changes were noted, it seems as if positions were already at desired levels. Unsurprisingly, downstream firms suffered more than upstream firms that may also have a leaner business model. Having said this, it must be noted that comparable firms, such as Shell and BP on one hand versus Chevron and ExxonMobil on the other hand, fare differently. This seems to be due to their financial position at the start of the crisis and not to their varying home base (Europe versus USA). Furthermore, oil and gas bear market prices do also impact on the sector. Lastly, it must be noted that Baker Hughes, Fugro and SBM Offshore are subcontractors. Interestingly, in early March, just before the COVID-19 crisis struck, Fugro placed new shares. The crisis then halved the share price. A bond issue came just too late support the ill-fated capital structure. It had to be withdrawn by the firm.

Table 2c. Non-energy sector companies' liquidity during the COVID-19 crisis (as of June 30, 2020)

Name company	*Nationality*	*Effect crisis*	*Specific remarks*
Air France - KLM	French	severe	cash burn, capacity cut, gov't support
Ajax	Dutch	moderate	financial base OK, sales down, costs cuts
Apple	American	negligible	financials sound, dividend/buybacks up
Boeing	American	moderate	"blow", loss, bond flotation, dividend cut
Heineken	Dutch	moderate	bond flotations, bonus/dividend cut
Lufthansa	German	severe	asset/cost/dividend cut, gov't support
ING	Dutch	moderate	less profit, supports clients, dividend cut
Philips	Dutch	limited	profit falls, financials OK, stock dividend
Randstad	Dutch	moderate	fin. base sound, cost/bonus/dividend cut
Royal Flora Holland	Dutch	moderate	loss, bank facility, supply chain financing

Source: authors' own elaborations.

The table above shows remarkable differences. Unexpected by even itself, the U.S. hardware and software firm Apple was hardly hurt by the COVID-19 crisis, whereas e.g. the Dutch health care and consumer products firm Philips was affected. Business went even worse with airline and aircraft firms alike, but it must be noted that Boeing was already suffering from a safety crisis. Anyway, subsequent the pattern was much the same: firms pressed costs and investments, lowered asset bases, did away with (cash) dividend and share buyback (if being around), borrowed money or had to lend it and even went for government support (airline firms).

Interestingly, bonuses seemed to be cut only case-wise. Here and there, rather hesitatingly, shareholders indicated to be willing to step in for help.

6. Conclusion and recommendations

From the above, our research question on helpful liquidity measures can be answered in a very basic way. Corporate liquidity can be assessed with any decent measure shown in the literature. Yet, some measures are better than others are and some may be even misleading. To start with the latter: book measures confuse, especially when not being real-time. When the first wave of the COVID-19 crisis began, all of the studied firms showed (pretty) healthy balance sheet and income statement positions. Whether net working capital was negative or positive did not matter, as long as actual cash levels were fine, as they most likely all were. Under such circumstances, it does not matter much whether a firm monitors accounting stocks or market value stocks, profits or cash flows, in- and output or actual throughput.

But in crisis situations, all may be different. The baseline of a crisis is normally that account receivables positions swallow whereas cash positions dwindle at the same time. Traditional accounting measures such as cash/sales or cash/assets become pretty useless then, since the first may even go up because of falling sales and the latter may be (with net assets: close to) stable. Profits are quite unaffected when a company has a high operating leverage, but cash levels may fall sharply as long as accounts payables positions do not drop in tandem. Book measures do not point quickly at operational and financial reconsiderations needed. They do not take into account actual cash levels and may ignore timely supply chain issues.

The small/medium-sized local case firms studied knew this. Whereas they do partially reason in accounting terms (in terms of equity and profits) for convenience reasons, they quickly adapt to actual cash levels and cash flows as soon as problems in the supply chain emerge. Account receivables and account payables are tightly linked to each other, as is done with account payables and inventories. It is understood that cash levels are supported when working capital levels are subdued and dividend cuts may do well too (Snijders et al. 2009).

The baseline with the 27 firms studied was that they had to maintain a rock-bottom liquidity base. Whereas some of the firms seemed to have a liquidity and solvency buffer (by accident or on purpose), others were less likely to be in a favorable start position and needed help. The issue of which liquidity measure to look at appears to be largely redundant under such circumstances. Whether focusing on sales, profits, cash flows, cash burns or whatever does not seem to matter. Or does it? Remarkably, some firms seem to fare better than others. Is operational flexibility doing the job? Then it might also be that focusing on operations-type of measures is asked for, which calls for using conversion cycles as key financial yardsticks.

Corporate liquidity is twinned with corporate finance, making the financial supply chain perform its linking job. Corporate finance is by action equalized to corporate investment. Cash in and cash out are aligned to strengthen the operational supply chain. In other words: the cash conversion cycle (CCC) is focused upon then. When the CCC drives corporate liquidity, operations are viewed with a liquidity lens. The three case firms thus go for ever leaner operations, with operational throughput measures being top of mind.

The 27 multinational firms sampled may have sensed the above as well, since there is much awareness of supply chain issues nowadays. Nevertheless, more than half of them were found trapped in a liquidity crisis, pretty much regardless their industry (oil/gas, electricity, or other). This may be due to their low operating leverage, but this does not distinguish them much from companies that feel less liquidity pressure. A positive net working capital position induced by the business model does also not really set these companies apart. Nevertheless, many had to cut down on planned dividend payouts, share repurchases and bonuses, whereas some needed bank loan or owner's equity support.

To sum up the conclusion, our research question was: *"Which measures are helpful in assessing corporate liquidity in both normal and crisis times?"* With just little exaggeration, the answer could be*: "pick the cash conversion cycle and delve into its base constituting parts: accounts receivables, accounts payables and* *inventories"*. The hick-up is though, that circumstances may also ask for non-operational measures that are related to short-term and even long-term financing. Especially firms that are financed sharply or whose supply chains are hurt most may need to resort to this.

This brings us to our recommendations. It is tempting to view the COVID-19 crisis as both a liquidity crisis and again a financial crisis, this time due to non-financial firms being serviced with "sharp" financing. It is striking to note that the solvency went down with some of the sampled firms before the COVID-19 crisis started, or that they had (also) a relatively high share repurchase level, whereas with some of them bonuses were also found to be sizeable. In that sense, efforts of e.g. the Dutch government to (further) cut down on debt financing advantages can be supported. Maybe it is worthwhile to reintroduce share repurchase taxes, to prevent firms from being tempted to lower equity levels this way. Lastly, all of this may be linked to sound solvency and liquidity requirements. Government should not bail out greedy owners (again).

Governments can set fitting regulations however, not just on levels of solvency and liquidity requirements, but also on how these can be met in a decent way. An example is on payment conditions, which refer to issues such as due times, discount terms and interest rates. During the COVID-19 crisis, it has become clear that many firms have been willing to be flexible and it is advisable to develop sound supply chain customs that support such behavior. However, since negotiation bases between especially large and small companies may differ much, it is paramount that obligations due are paid for as soon as possible and reasonable. The plans of e.g. the Dutch government to reduce payment times to at most 30 days can be welcomed.

Having said this, it is most important that companies should take their own responsibility to safeguard their liquidity with real-time measures. In a recent contribution, Deegan (2020) points at the usefulness of cash flow dashboards that display reporting and forecast data that are related to key financial performance indicators (KPI's). Five metrics generally take a central position: the cash walkthrough that depicts the steps from an opening balance to a closing balance, consolidated actual and forecast cash positions, the total actual and forecast available liquidity, net debt and covenants, as well as actual versus forecast differences and variances. Such a list may especially help large firms and may have to cover additional fields.

For example, even more recently, McKinsey & Company (Grube et al. 2020) has published a list of monthly KPI's for CFO's that takes on board COVID-19 crisis lessons learned. An array of working capital (A/R, A/P and inventory), CAPEX, OPEX and balance sheet items are featuring here. Also, the cash conversion cycle is referred to explicitly. Liquidity goes beyond cash and even beyond working capital. Therefore, taken together, the two lists would or should ring a bell with both the local and multinational companies in our study. However, firms may want to use and adapt such checklists for their own purposes, we feel.

Strangely, the above-listed issues are not well-studied. Also, our study is only explorative, although we have taken on board experiences from multiple companies and advisories. Our sample was by no means meant to be statistically representative. However, we did strive for analytical representativeness: finding out what matters on corporate liquidity in crisis times. Whereas it must be noted that our research does not go beyond the first semester of 2020, with a new COVID-19 wave globally speeding up just a quarter later and still being around a year later, we do not feel that our initial views will be challenged much. Nevertheless, further study is advisable.

Actual liquidity measures used and their relative importance cannot be drawn from annual reports. Whereas tough econometrical modelling may be useful in the end, baseline of the research input will be data that have to be supplied by firms. We however feel that they may be much willing to do so, with the support that we have had for this study by a wide range of practitioners already indicating this, especially when a trusted two-way relationship exists. Nevertheless, the type of (30+ firms) case survey study that comes to fore then costs much time. Having said this, a broad research coalition may take some of the barriers away. And even if not, we hope that stubborn researchers do take up such a study anyway. Also, the methodology of Aktas et al. (2015), who study with statistical techniques excess working capital to look for optimums, may be helpful for further econometrical study in this respect, that is: as soon as time permits and not just because it would be more "scientific".

Meanwhile, firms will have learned from the COVID-19 crisis and take more precaution. To help with a very basic rule of thumb advice, we give them in consideration to double their rock bottom limits on cash, working capital and solvency. While this may be overdoing for many firms, it is also relatively cheap to do so, at least nowadays. New optimums can be sought for by stumbling in the dark and building up experience to arrive at acceptable solutions at first, but artificial intelligence systems such as increasingly applied in treasury management may do a better job in the end (Polàk et al. 2020). Having said this, we feel that proper sensing will still be needed anyway.

Acknowledgements

The authors thank René van der Veen, CEO/owner of Zuivelrijck, Tanju Özel, CTO of HVE and Sven Tummers, managing director of Vermilion Energy Netherlands, for sharing their insights and company data. We thank students of the University of Groningen for helping with collecting data. Special thanks go to Mark Schouten (VU University, Amsterdam), who was involved in an early stage of the study. Johan van Ophem and Katarzyna Kurek (both Wageningen University, the Netherlands) both reviewed paper drafts and participants at the 14th ISINI conference (September 2020, Poland) and the 8th CEVI conference (May 2021, Belgium) provided comments. All errors and omissions are of course our own.

Glossary

A/P	Accounts Payable
A/R	Accounts Receivable
BRP	Balancing Responsible Parties
CAPEX	Capital expenditures
CCC	cash conversion cycle
DAX	Deutscher Aktienindex (the German stock exchange index)
DIO	Days in Inventory
DPO	Days in Payment Outstanding
DSCR	Debt service coverage ratio
DSO	Days of Sales Outstanding
EBITA	Earnings before interest, taxes and amortization
EBITDA	Earnings before interest, taxes, Depreciation and amortization
ESCo	Energy Service Company
INV	Inventories

KPI	Key finance performance indicators
LNG	Liquid natural gas
MT	Management team
OPEX	Operational expenditures
SEK	Svensk Krona (the currency of Sweden)
TSO	Transmission System Operator

Bibliography

Aktas N., Croci E., Petmezas D. (2015), Is Working Capital Management Value-Enhancing? Evidence from Firm Performance and Investments, "Journal of Corporate Finance", vol. 30(C), pp. 98–13.

Deegan C. (2020), The Necessity of Real-Time Cash Flow Dashboards, The Global Treasurer, August 13, https://www.theglobaltreasurer.com/2020/08/13/ [05.12.2021].

Dorsman A.B., van Montfort C.A.G.M. (2019), The Grid: From a Technical to a Finance Issue. Who Bears the Financial Risk?, Working Paper, Free University Amsterdam, May.

Dorsman A.B., Westerman W. (2019), What Drives Working Capital Levels?, "Hacettepe University Journal of Economics and Administrative Sciences", vol. 37 no. 1, pp. 41–63.

Faulkender M., Wang R. (2006), Corporate Financial Policy and the Value of Cash, "The Journal of Finance", vol. 61 no. 4, pp. 1957–1990.

Grube C., Park S.-Y., Rüden J. (2020), Moving from Cash Preservation to Cash Excellence for the Next Normal, McKinsey Corporate Finance Practice, September, https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/moving-from-cash-preservation-to-cash-excellence-for-the-next-normal [05.12.2021].

Kakebeeke P., Segenhout J. (2020), AEX bedrijven kunnen eerste klap van de coronacrisis goed zelf opvangen, "Het Financieele Dagblad", March 25.

Kangas H., Lazarevic D., Kivimaa P. (2018), Technical Skills, Disinterest and Non-functional Regulation: Barriers to Building Energy Efficiency in Finland Viewed by Energy Service Companies, "Energy Policy", vol. 114(C), pp. 63–76.

Opler T., Pinkowitz L., Stultz R., Williamson R. (1999), The Determinants and Implications of Corporate Cash Holdings, "Journal of Financial Economics", vol. 52 no. 1, pp. 3–46.

Pätäri S., Sinkkonen K. (2014), Energy Service Companies and Energy Performance Contracting: Is There a Need to Renew the Business Model? Insight from a Delphi Study, "Journal of Cleaner Production", vol. 66 no. 1, pp. 264–271.

Polàk P., Nelischer C., Guo H., Robertson D.C. (2020), "Intelligent" Finance and Treasury Management: What We Can Expect, "AI & Society", vol. 35 no. 2, pp. 715–726.

Ross S., Westerfield R.W., Jaffe J. (2019), Corporate Finance, 12th edition, McGraw-Hill Education, New York.

Sagner J.S. (2014), Working Capital Management: Applications and Cases, John Wiley & Sons, Hoboken, NJ.

Seifert B., Gonenc H. (2018), The Effects of Country and Firm-Level Governance on Cash Management, "Journal of International Financial Markets, Institutions & Money", vol. 52, pp. 1–16.

Snijders B., Gonenc H., Westerman W. (2009), On Dividends and Share Return: Dividend Cuts Help in Crisis Outbreaks, "Journal of Corporate Treasury Management", vol. 3 no. 1, pp. 8–10.

Talonpoika A., Kärri T., Pirttilä M., Monto S. (2016), Defined Strategies for Financial Working Capital Management, "International Journal of Managerial Finance", vol. 12 no. 3, pp. 277–294.

Vernimmen P., Quiry P., Dallochio M., Le Fur Y., Salvi A. (2018), Corporate Finance: Theory and Practice, 5th edition, Wiley, Hoboken, NJ.

Vine E. (2005), An International Survey of the Energy Service Company (ESCO) Industry, "Energy Policy", vol. 33 no. 5, pp. 691–704.

Windaus D., Rosier H., Brady A. (2021), Working Capital Study 20/21: Act Now to Recover, PwC UK.

Westerman W. (2015), Working Capital Management Programs: Yesterday, Today, Tomorrow, "Journal of Modern Accounting and Auditing", vol. 11 no. 4, pp. 210–217.

Yin R.K. (2018), Case Study Research and Applications: Design and Methods, 6th ed., Sage, Thousand Oaks, CA.

CENTRAL EUROPEAN REVIEW
OF ECONOMICS AND MANAGEMENT

ISSN 2543-9472; eISSN 2544-0365

Vol. 5, No.4, 33-60, December 2021

www.cerem-review.eu
www.ojs.wsb.wroclaw.pl

A new digital currency system

Kees VAN HEE

Eindhoven University of Technology, Nederland

Jacob WIJNGAARD

University of Groningen, Nederland

Received: 24.06.2021, Revised: 13.09.2021, Accepted: 26.11.2021
doi: http://dx.doi.org/10.29015/cerem.929

Aim: The aim of this paper is to describe the construction of a new system for digital currency governed by the central bank, Central Bank Digital Currency (CBDC). Although the system uses cryptography, it is a new alternative for crypto currency like the Bitcoin. Today there is a global discussion about the process of money creation by the commercial banks and the need for CBDC available for a broad public. There is almost no literature how such a system could be constructed. In this paper we fill this gap. The system we describe, uses modern cryptography that guarantees privacy on the one hand but that allows for traceability on the other hand. Also we consider the possibilities for new fintech initiatives and the new role of commercial banks.

Research methods: The research method can be classified as design research since we present a high-level model of the system as a proof-of concept. So it proofs that such a system is feasible in principle. It is expected that the paper contributes to the discussion on CBDC systems.

Conclusions: It is shown that it is indeed possible to design a CBDC system that is far more efficient than the well-known crypto currency systems. But the system uses one distributed system for transaction processing governed by the Central Bank or a trusted third party. This might be seen as a drawback but the system is performing only very elementary transactions that are easy to verify.

Originality: The approach is new. Although existing cryptography techniques are used, the system as such is a completely new alternative for CBDC.

Implications: The paper shows that a CBDC system is relatively easy to construct and so this paper could play a role in the transition to such a system in reality.

Keywords: monetary systems, payment systems, central banks, software
JEL: E51, E58, E59

Correspondence address: Jacob WIJNGAARD, Professor emeritus, Operations, University of Groningen, Nederland. E-mail: j.wijngaard@rug.nl. Kees VAN HEE, Professor emeritus, Computer Science, Eindhoven University of Technology, Nederland. E-mail: k.m.v.hee@tue.nl.

1. Introduction

In this paper we give a motivation for Central Bank Digital Currency and we describe a model for a Central Bank Digital Currency-system (CBDC-system). The main function of such a system is facilitating payments between *economic actors*, such as households, businesses, banks and the government. The currency in this system is only so-called *base money* created by the Central Bank (CB). Although we are in favor of a cashless society with only one digital currency, the CBDC-system can also function when these wishes are not fulfilled. There are many papers about the pros and cons of such a system, but very little attention is paid to the technical and organizational feasibility of such a system. Our view on CBDC is very close to that of Bordo and Levin (2017), although we dive deeper in the technical and organizational issues. Most authors, including Bordo and Levin, seem to think that it is possible to make a digital look-a-like of a coin or bank note that can be transferred between two parties in isolation. That is not the case and we show how to deal with this.

In this paper we present a model of a CBDC-system which can be seen as a *proof-of-concept*, i.e. a proof that it is feasible to build such a system. The model is not a *blue print* for such a system. The model is useful in understanding what is possible, impossible and what is difficult or easy to realize. For example one could use the model to evaluate the requirements formulated by monetary authorities, e.g. the ECB (report on the digital euro, ECB 2020). Sometimes system requirements are such that it is impossible to build a system obeying the requirements, or it is extremely complicated to build it.

The system we propose differs essentially from the existing banking system. For instance, the digital currency is not stored at a bank, but with the actor and banks play no direct role in money transfer between two actors. But many features are similar to the existing monetary system which makes migration and public acceptance easy. The system we propose is meant for base money only and therefore we call it CBDC-system, but it can be used for other monetary systems as well. We consider the monetary system from the perspective of the users of the monetary system and not so much from the perspective of banks, because the system is meant for these users. If the system we propose is realized, banks will get another role which requires a serious transition. We address this only briefly.

In section 2 we describe the drawbacks of the existing system and we give arguments for a CBDC-system. In the sections 3 until 5 we describe the CBDC payment model. Section 6 shows how this payment model facilitates additional financial functionality. In section 7 we sketch the new role of the banks. In section 8 we sketch the broader potential of the payment system: how it can help in preventing tax evasion and how it can be used to improve the payment of VAT and income tax. It also helps to create the possibilities for new rule-based monetary policies. In section 9 we discuss the implementation and migration process. Performance issues are included here. Conclusions are formulated in section 10.

The CBDC-system heavily leans on modern cryptography. In the paper we left out as much as possible of these techniques, but in Appendix 1 we give in a nutshell the relevant notions of cryptography.

2. Motivation

The present monetary system has two important drawbacks and both are caused by the commercial banks. The first drawback is that the vast majority of our money is created and stored by banks. Today we have two forms of money, *cash* (coins and bank notes) and *demand deposits* (balances on current bank accounts). Cash is part of the so called *base money* (see e.g. Ryan-Collins et al. 2011). The rest of the base money is invisible for normal *economic actors*. It consists of the *reserves* of (commercial) banks and the government, at the CB. A demand deposit is (only) a *claim* on base money. Such claims are generally accepted and form the main part of the available money. Today about 95% of our money is claims on base money and if all economic actors would cashing in their claims, this would be a disaster because banks don't have the base money. This is one of the drawbacks of the existing system. The most fundamental element of the debate about the role of the banks is the question whether banks should be allowed to *create* money in the form of demand deposits. Bank credits are a strange form of money. Nevertheless, from

1971, after the abolition of the Bretton Woods agreement, it has functioned well for a while. By adapting the interest rate for reserves, the availability of credit was controlled, and through this the whole economy. And especially during the period 1985 – 2005, the system appeared to be really "under control". That is why that period is called "the great moderation". In between, however, there are serious doubts. It is clear that the banks have played an important role in the emergence of the financial crisis. The American mortgage market (supported by the US government) was the biggest culprit, but the lack of transparency and the sale of too complex financial products contributed as well (see e.g. Roubini, Mihm 2010). The structural freedom of banks due to the current monetary system is often seen as the root cause. There are different proposals for improvement, including sharper restrictions with respect to liquidity and solvability (see e.g. Admati, Hellwig 2013), better monitoring and control and narrow banking (banks concentrate on payment and saving and give credit only insofar as that can be guaranteed absolutely) (see Kay 2009).

There are general rules with respect to reserves and liquidity (Basel I, II and III). But the position of a bank is judged afterwards and the judgement of the different categories of assets and the validity of the rules are not always clear (see e.g. Admati, Hellwig 2013). This implies that the banks have in fact a large freedom with respect to the creation of money, because the claims are rarely cashed.

The second drawback of the present monetary system is the cumbersome way the money transfer is performed by commercial banks, often with help of card schemes like Master card or Visa. It is very complicated and therefore inefficient. The payment role of banks emerged for practical reasons: if an actor X has to transfer an amount A to actor Y then X has to go to the bank and withdraw the money then move to Y and then Y should deposit the money at his bank. If X and Y happen to have the same the bank, it is easier to subtract the amount A of account X and add it to account Y. So then the bank performs the payment. In case they have different banks a similar procedure could be done where the banks do the money transfer for a batch of actors. It is done in two steps: *clearing,* the update of the accounts and *settlement*, the transfer of money between the banks, which is less than the sum of the individual transfers because transactions in a batch can cancel out each other.

We propose to give all economic actors access to the base money and use that for all payments, through a payment system that functions independently of the banks. The option to give all economic actors access to base money has been and is being explored rather widely already, for instance in Sweden and in the Eurozone[1]. But in these explorations the current banking model is not disputed. CBDC is seen as a form of cash, digital cash, next to the still existing physical cash. Such a hybrid system is very ambiguous. On one hand actors get access to base money, but on the other hand this access has to be restricted to protect the current banking model. In our opinion such a system is doomed to fail, the system is becoming more complex, banks are still able to create money and banks and CB are becoming competitors. Our proposals go much further and are in the same spirit as the proposals by the Positive Money movement in the UK (see Jackson, Dyson 2012). These proposals have not received serious attention in the main stream literature[2], but the suggestions of Bordo and Levin (2017) come close. They propose also a more complete switch to CBDC although they leave the role of the banks more or less unchanged.

In the CBDC-system we describe here, only the CB can create and destroy money. Commercial banks have as main function savings and lending. Probably they will also develop new financial services on top of the CBDC-system. Of course there is a need for borrowing money in the market. The CB will only lend money to banks. The CBDC-system has the following advantages:

- There is only digital currency created by the CB
- Money is stored by the actors themselves
- Money transfer is very easy: only the essential functions are performed by the CBDC-system in a very efficient and secure way

---

[1] Sweden was rather early (see Sveriges Riksbank 2017). The Bank for International Settlements gave it also serious attention (see BIS 2018) and now the ECB is exploring the possibilities (see ECB 2020).
[2] This is clear from the special issue in the "Cambridge Journal of Economics" (see Ingham et al. 2016).

- The system is an ideal platform for additional financial services (see section 6)
- The system has good features to avoid money laundry and tax evasion (see section 8)
- The system has good features for rule-based monetary policies (see section 8 and Wijngaard, Van Hee 2021 for an elaboration)

Many people are afraid of a centralized system where a Big Brother could control everything. For that reason crypto currencies were invented, the first one by David Chaum (Chaum 1983) in 1983 and later the Bitcoin by Nakamoto (Nakamoto 2008) in 2008. From the latter system there are many new variants available. In our CBDC-system the information stored is extremely limited. The system is only facilitating transactions and does not store these data and so the system does not know the balances of the actors. So the Big Brother problem is solved in this CBDC-system.

A big problem of crypto currency is the *double spending* problem: how to avoid that the same money is spent twice or more times. That is why systems like the bitcoin system have introduced the so-called block chain which is extremely time and energy consuming. In our system double spending is solved by the CBDC-system in a trivial way. So that is also an advantage.

3. Essential features of the CBDC-system

In principle it is possible to construct a digital look-a-like of a physical currency, i.e. a coin or bank note. However, that is unnecessarily complicated. This is also noted in Bordo and Levin (2017), but here it will be explained in more detail. If we pay with cash we always have to look for the right coins and then we often receive change in return because we did not have the exact change. It is much easier to have only a e-wallet with one amount, the *balance* of an account and then one can pay any amount less or equal to the balance. So it is more efficient to store one amount: the balance of the account. This is the same as in the well-known banking system that we are using today, and that feature is worth to keep in a CBDC-system. Even in the *bitcoin system* there are also no “digital coins” or “digital bank notes”, although the term “bitcoin” suggests this. However there the *transactions* are stored, which means that if actor X pays an amount A to actor Y then Y records this transaction and he may spend this A, i.e. transfer it to some other actor, at a later stage. So in order to pay a large sum the payer has to find enough transactions to do the payment and if there is not an exact match, he has to transfer the change to himself as a new transaction. This is even more laborious than a cash equivalent. Coins and bank notes have complex marks on it and bank notes have a unique identifier, a string of characters . One of the main characteristics of physical currency is that it can be transferred between two actors in *isolation*, i.e. without any contact with a third party. Of course a forger can try to ‘copy’ a physical currency. In order to verify a coin or bank note one inspects the marks on the coin or bank note. It is practically impossible to verify if the currency is unique, i.e. if its identifier does not occur twice or more times in the monetary system.

Suppose a digital equivalent of a physical currency unit is just a single sequences of bits. Then we could encode this bitstring such that it can be verified that it satisfies all the official characteristics of the currency (see Appendix 1). But it is always very easy to copy it! And then we have a new currency unit that satisfies all the criteria. So we cannot conclude that it is a copy.

This is the big difference between physical currency and digital currency: it should be impossible to spend the currency twice. This *no double spending* is one of the most important requirements of the system. It is impossible to see whether a bitstring is a copy or the original one and so to prevent that digital currency in the form of just a bitstring is spent twice or more times.

In the *bitcoin* system there is a *public database*, called a *blockchain* that keeps track of all bitcoin transactions. The owner of bitcoins possesses a *reference* to this database. And in this database data can never be changed, data can only be added. So if there was a payment with some currency unit, it can be traced and so it cannot be repeated.

Also in our system, with accounts and balances, there is a public database besides the information people store in their own database, i.e. the *digital wallet* on a smartphone. The information in the public database is essential in preventing actors to spend their currency unit twice. This implies that it is not possible to perform so-called *off-line transactions*, because it is always necessary to verify that the client is not spending the same currency twice[3]. However it is possible to have an off-line payment system on top of the CBDC-system. This off-line payment system can be provided by banks or other financial service providers (cf. section 6).

An important requirement is that the CB does not become "Big Brother" so it must facilitate payments but it should not keep track of the money the actors possess. Of course it might be that the government wants to check for money laundering, but that will be done outside of the CBDC-system. In the next section we will show that it is sufficient to store a "fingerprint" of the transactions.

4. Building blocks

We consider one currency zone, like the dollar zone or the euro zone. All currency is CBDC and only the CB can create and destroy currency. Money transfer is done through the system. So banks don't play a role in payment processing, but they will still play an essential role in the economy (see section 7).
In the following description we use as little as possible notions from cryptography. In the Appendix 1 these notions are elucidated. What we need is a *fingerprinting* mechanism and a *secure message passing* system.
The system has the following building blocks:

- Actors have *accounts,* as many as they like. An account is an abstract object that is "owned" by the actor and that is stored on the hardware of the actor or in a *cloud* of a service provider operating on behalf of the actor. The account has several properties such as a *unique account identity* and the identity of the actor. But the most essential property of the account is the *balance*, i.e. the amount of currency on the account. This balance is at least zero, so it is never negative. An exception is made for banks. If they have a license of the CB, they are allowed to borrow from the central bank. In order to do this, banks

[3] The ECB, in her report on the digital euro (see ECB 2020), stresses the importance of offline functionality. It is questionable whether they are aware of the full consequences.

have, besides the normal accounts at the CB also *C-accounts* (credit accounts), with a balance <= 0. All other actors may borrow money from other actors, in particular from banks, but not from the CB. It is also possible that the government has C-accounts, so that the government can borrow directly from the CB.

- There is a *public database* as part of the CBDC-system and in that database there is some data of the accounts, but neither the balance itself nor the transactions themselves. What is stored is a *digital fingerprint* of the balance account. One way to realize this is by a so-called *hash function*, also called a *one way function*. A one way function is a function H such that it is easy to calculate H(X) for some character string X, but if H(X)=Y and only Y and H are known, then it is practically impossible to calculate X. This fingerprint is necessary to verify if the account information of the actor is not manipulated. The public database is called "public" because all actors have access to it. We avoid the term "central" database because it will be a distributed database, i.e. a network of databases, but all under control of the CB.
- There is a *clearing house* function in the CBDC-system. Here the most basic payment action is performed: the increase of the balance of the *acquiring* actor and the decrease of the balance of the *paying* actor. The well-known *settlement* function is not necessary because it is just the two actors and the public database.
- A *secure transmission* system to send messages between actors and the CB. This transmission system could be independent of the CB and it should satisfy the following properties:
    - *Integrity*: messages should reach their destination without changes made by others.
    - *Confidentiality:* nobody is able to read the content of the message except the addressee. This property can be guaranteed by proper encryption.
    - *Authenticity*: the addressee can verify the senders identity. This is done by a *digital signature*.

These transmission requirements are realizable by today's encryption technology (see the Appendix 1). It is possible that these systems will improve in the future, specifically if quantum computers can be used, but the functions of the CBDC-system will be the same (see section 6).

With these building blocks we will construct the CBDC-system. The CB can be seen as a *trusted third party* for payments between two actors. But this does not mean that the CB keeps record of the values of balances of the actors. We only let the CB keep a fingerprint of the balance and maybe also of the transactions. The last is not necessary for the payments but can be useful for other type of verifications (see section 8).

5. Payment processing

Here we will sketch the main function of the system: the transfer of money from one account to another. Each actor has one or more accounts in the CBDC-system. And because it is a very large system, for a whole payment zone, we assume that the public database of this system is distributed, which means that it is a *network of connected database servers*. We may call it a *dedicated computing cloud*. Each account is assigned to a specific database of the network. We call them *CB-server* or just *server*. Each of these servers stores many account objects. Remember that from each account only the fingerprint of the current balance and maybe the fingerprints of transactions are stored here. Further all actors store their current balance record on a private server. This can be a PC at home, a smartphone or a server in the cloud from some service provider. It is possible and advisable to store the balance record in more than one place. We call such a private server an *e-wallet,* which term is usually restricted to storage on a smartphone. The data stored in these databases is as follows.

The e-wallet stores *account records* of the form:

[accountid: X, date: T, balance: B, nonce: N]

Where X is the identity of the account, T the date and time of last update, i.e. of the last money transfer, B is the balance at that time and N is just a random sequence of bits called *nonce*, generated by the CBDC-system at the last transfer. The nonce is a technicality used for the fingerprint. We call this record the *e-wallet record*.

The database of the CB-servers stores records (referring to these wallet records) of the form:

[accountid: X, date: T, nonce: N, fingerprint: H (X.T.B.N)]

Where the function H is a one-way function for character strings and X.T.B.N is the character string formed by concatenation of the strings X, T, B and N. We call this the *CB-record*. Of course the CB-server stores also the identity data of the actors and which accounts they possess. But we do not consider them here.
An actor might want to verify that his account record is the current one, for instance to prove his credibility. He then has to send it, in a secure way, to the CBDC-system and the system reads X.T.B.N from it, computes H(X.T.B.N) and compares it with the fingerprint in its own account record of the actor. If they are identical, then the CBDC-system can confirm the correctness of the e-wallet account.
For other purposes than pure payment, it is useful to add another attribute in the account records: a *sequence number* of the balance update. With such a number it is possible to see if a set of updates is *complete*, i.e. not missing an element.

Note that if the actor loses his e-wallet record he loses the money as well! Therefore it is recommended to make copies of these records in a secure way. An actor is also obliged to store his wallet in a save place and to give access to his potential heirs. If it is stolen by some intruder that person can only read the balance but he can’t withdraw money from it, because the intruder does not have the digital signature. The intruder can also change the account record in the e-wallet, but that makes it invalid. This is as serious as losing the record, but no intruder can steal the money or put money on the account, since the CB-server has the fingerprint of the current e-wallet record and only the actor can send a payment instruction with his digital signature.

Next we consider the *kernel protocol* to transfer an amount A from actor X to actor Y. First of all X and Y should reach an *agreement* to transfer the money. This will be done outside the scope of the CBDC-system. But at some point in time they will both produce a record that shows their intention and is sent with their digital signatures to the CBDC-system. These *common transaction records* will look like:

[from: X, to: Y, amount: B, label: L]
The label L could be empty, but there are good reasons to label a transaction. Examples are an invoice identity or a VAT classification. Note that the CBDC-system does not do anything with this label, except that it is part of the fingerprint.
The *kernel protocol* has the following steps:

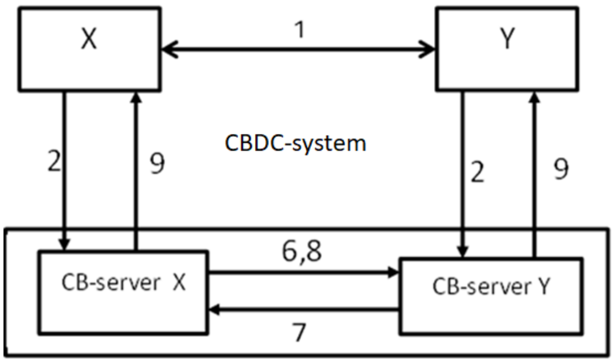
1. X and Y agree on a money transfer of amount B from X to Y. They produce both the same (common) transaction record. This first step is performed outside of the CBDC-system.
2. X and Y both send each their account record and the common transaction record in a secure message, signed with their digital signature, to the CBDC-system, in fact to their own CB-server.
3. The CB-servers check the authenticity of the messages by the digital signatures.
4. They check the account records (by checking the fingerprints).
5. If the balance of X is insufficient for the transaction, then the CB-server of X sends a return message with a disproval and also a similar message to the database of the acquirer, who returns a similar message to the acquirer.
6. If the balance of X is sufficient, his CB-server sends the transaction record to the CB-server of Y.
7. The CB-server of Y compares the (common) transaction records of both actors and if identical, which proves that they both agree upon the transaction, he updates the balance of the account of Y by adding B and confirming it to the CB-server of X.
8. Then the CB-server of X updates his account by subtracting B from the balance, and informs the CB-server of Y.

9. Then both CB-servers send to their actors a secure message with digital signature and the updated e-wallet record with a fresh nonce.
10. Both CB-servers delete the transaction information after updating their CB-record with the fingerprint as described above.

As mentioned before, it is possible, and recommended, to extend the storage of the CB-servers with fingerprints of the approved transaction records besides the account records This creates the possibility to verify the *transaction history* of an account. We emphasize that it only facilitates the *verification* of a sequence of transactions that is presented by the actor or service provider on behave of the actor. The reason is that the system stores only the fingerprints of the transaction records and not the transaction records themselves.

In Figure 1 we display the different components of the CBDC-system and the numbers refer to the messages produced in each of the 10 steps of the protocol. It is possible that X and Y share the same CB-server, i.e. the CB-server X equals CB-server Y. The kernel protocol is very simple and is the essence of money transfer. So it never has to change in the future. Maybe there will come better ways of secure message passing or better one-way functions, but that does not change this protocol. The protocol is so simple that it must be possible to give mathematical proofs for the correctness of an implementation, which makes verification by EDP (electronic data processing) auditors superfluous.

Figure 1. Payment processing



Source: authors' own elaboration.

The protocol looks very similar to the way the banks operate today. The essential differences are: (1) the use of CBDC (i.e. base money) instead of demand deposits (claims on base money), (2) a clear split in the currency: the money of an actor is his account balance and that balance is stored by the actor in his e-wallet and not at the CB and (3) commercial banks don't play a role in this process.

The CBDC-system does not store the balance but is able to verify the content of the e-wallet. So the CBDC-system can't do anything with the money of the actors.

Note that the communication within the CB-server can be secured in the same way as between these databases and the e-wallets. But since it is one system it can be done with fewer security measures.

6. Additional functionality and financial services

When two persons want to transfer money from one to the other, they can use their smartphones. There should be an app (application) such that one actor creates the (common) transaction record by asking first the account identity of the other and sends the transaction record to the other. Both send it, with their e-wallet record that they store on their smartphone, to their CB-server. The rest is as the kernel protocol. From the user point of view this will not differ much from the payment apps that are available today. Households will have several accounts and they will have applications to balance their e-wallet records. A similar procedure can be applied for payments with PC's or tablets. The e-wallet can be stored locally or somewhere in the cloud.

When a consumer wants to pay for products in a shop a similar procedure can be followed. The cash register of the shop determines the amount the consumer has to pay and the consumer provides his account identity either by a card or with his smartphone. Then the shop and the consumer follow the steps of the kernel protocol.

Note that these functions are in fact implementations of the first step of the kernel protocol and are outside of the CBDC-system.

In practice there are all kinds of special transactions, such as a *deferred payment* and the *direct debit.* The first occurs when the exact amount of a transaction is not known at the moment the transaction starts, e.g. in case of parking or refuel of gasoline. The protocol only differs in the first step of the protocol. First X and Y have to agree on a maximum amount that X will pay to Y in exchange of the delivered product or service. That has to be verified by the CB-server of X. Then the real (common) transaction records are determined and the transaction is handled by the kernel protocol.

The *direct debit* occurs when there is a contract between actors X and Y such that Y may collect automatically, which is usual for utility businesses. In this case the protocol starts with an authorization message from X without an amount and Y adds the amount in the answer message later. But here Y can send this kind of transaction messages unlimited until X sends a message to retract the authorization. This means that the first step can be organized as a preliminary process outside of the kernel protocol.

A typical service would be to offer *off-line payments* with a smartphone app. These payments could work in the following way:

- Actors create a special account for off-line payments and they put enough money on it from their normal payments account, usually small amounts for shopping or leisure like activities. This amount is stored by the smartphone app in a so-called *off-line wallet*. This account is blocked for payments not made by the smartphone app.
- When actor X wants to pay an amount B to actor Y, they have to agree on such a transaction with help of the smartphone app and then the common transaction record is stored on both smartphones. The total amount of the transactions generated in this way can’t be larger than the amount coming from the special account of the payer.
- As soon as they make contact with the CBDC-system the transactions are processed in the order of occurrence and the content of the wallet is adapted. Only when both actors of a transaction had contact with the CBDC-system, the transaction can executed. This because both actors must agree upon a transaction.

In the practice of payment services there are more payment variants. But they can be implemented on top of the proposed CBDC-system, because front-end systems can preprocess more complicated transactions and derive the kernel transactions form it and send it to the CBDC-system So the system should provide sufficient public interfaces (API's, application program interfaces) such that financial service providers, including banks, can create their own functions on top of the CBDC-system. This is precisely in accordance with the European PSD2 rules[4].

Besides the transaction-related functions the CBDC-system also has *management functions*, such as creation, combining, splitting and deleting accounts. But this is all quite standard functionality. It is important to keep the kernel protocol so small as possible and to have additional functions in the *financial service layers* on top of the CBDC-system. They can be delivered by fintech companies or banks could move into this direction (see section 7).

A more comprehensive financial service is a bookkeeping service that adds information to transactions, such that they can be recorded directly in the general ledger. Existing services as factoring and credit loan are other examples. A new service could be automatic VAT computation and payment (see section 8).

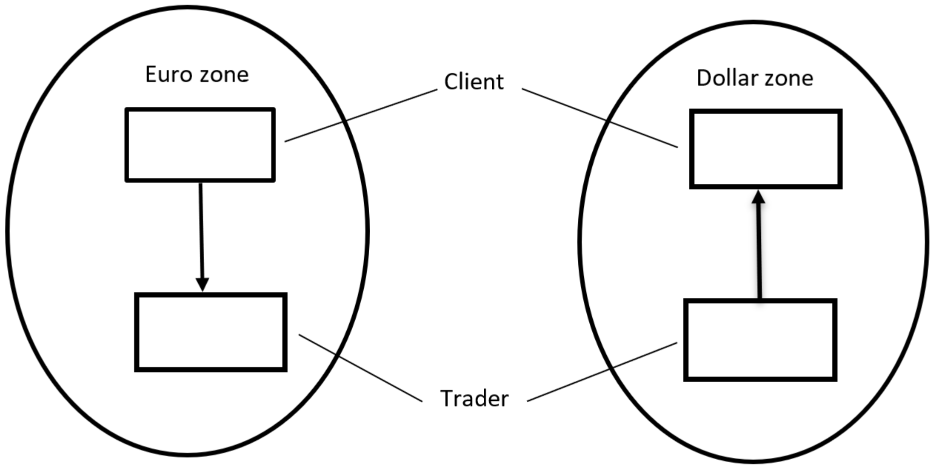
Probably there will emerge service providers offering more complex transactions. Like we have seen in the former section, they split these transactions up into kernel transactions. while they administer all kind of additional information for the actors. This will be the playing field of new *fintech* businesses, but also old services of existing financial institutions will migrate to his layer.

Of course there will be trade with other payment zones. This can be facilitated by actors in the role of *foreign exchange trader*. Such a trader has an account in each zone, e.g. one in the euro zone and one in the dollar zone, see Figure 2. The trader receives from an euro actor an amount of euro's on its account and sends this actor, who also has a dollar account, a corresponding amount of dollars on its dollar account in the other zone. He should have enough buffer in euros and dollars to play this game successfully. Often banks will play the role of *foreign exchange* trader. In

[4] See the website of the ECB.

fact there do not exist "cross border" payments, but only payments between payment zones.

Figure 2. Currency exchange



Source: authors' own elaboration.

Of course there should be oversight on the services in the financial services layer. But the advantage of the CBDC-system is that it becomes much easier for providers of new services to enter this layer. Comparable with the app stores for smart phones and tablets.

7. New role of banks

Banks play today an essential role in payments and in storage of money. Both functions will be taken over by the CBDC-system. So banks will have to focus on mediation between actors with savings and actors that want to borrow money and their main task will be the analysis of credit risks. Actors who have superfluous CBDC can put it on a CBDC savings account, i.e. an account of the actor for which the bank has access rights. The bank is allowed to put its money on one of its accounts (the *investment switch*) until it has found borrowers. So the savings will be only a very short time on the investment switch of the bank. Of course the bank will pay less interest to the lender than it receives from the borrower. The difference is a reward for mediation and for the risk that the borrower is not able to refund. To guarantee that there are sufficient credit possibilities, banks have the exclusive right to borrow money from the CB.

The approach here is different from the PM approach (Jackson, Dyson 2012). They propose that actors transfer their superfluous CBDC to the *investment pool* of a bank. The bank has to keep track of the amounts contributed by the different actors. It functions for these actors as a kind of savings account at the bank. It would be tempting then for the banks to develop a service where they perform payments between clients with such savings accounts. That would mean that they keep their existing payment system! Today banks periodically compute what they have to transfer for their clients to another bank and they also compute what they will receive for their clients from another bank (called *clearing*) and the difference of these amounts is 'transferred', called *settlement,* which means that the banks update their own accounts. Keeping this payment system should not be possible because it bypasses the CBDC-system and so the traceability of payments. It is clear that this process requires several transactions involving the accounts of the CBDC-system. Therefore it will be a natural task of the banks to provide such transaction services for their clients. So banks stand foremost to provide additional financial services as mentioned in section 6.

8. Money laundering, taxation and monetary policy

Money laundering

In order to detect and to prevent money laundering the tax office needs the traceability of transactions. A CBDC-system *without cash* makes this easy. The CBDC-system stores fingerprints of balances and transactions. So the CBDC-system has no direct information of the financial data of the actors. But it can be used for verification purposes. So if the tax office wants to verify a certain financial transaction sequence it asks the actor to provide the transaction data. In order to verify that these data are the correct ones and that no transactions are missing, the tax office can compute the finger prints of these data and ask the CBDC-system for the sequence of fingerprints. If they are the same then the tax office knows the actor is honest. Of course this requires a retention obligation similar as what we have to day. In order to facilitate this process, a financial service provider could perform this transaction recording process for actors. This means that these actors do not use the CBDC-system themselves, but via their provider, for instance a bank!

Taxation

Transactions between businesses and households and also between businesses and businesses involve the payment of VAT. Instead of bookkeeping of these taxes and periodical settlement, an interesting possibility is to do these payments real-time. This means that each transaction should have some additional attributes identifying the type of transaction (using this label L), and then the tax payment can be done automatically. Maybe this is also a good option for wage related taxes. Note that these attributes can also be useful for detection of money laundering. So this is typically a very useful additional service for businesses that can be combined with the transaction recording mentioned before.

Monetary policy

The focus of monetary policy is to keep the buying power stable and to have sufficient money in the system to facilitate the credits that are necessary for economic development. The main tools of monetary policy are the interest rate on base money and more direct interventions in the money quantity by buying or selling government bonds. Stability in general is important. That is why there has been a quest for general rules. The Taylor rule (Taylor 1993) is one of the more serious proposals. The main stream conclusion is that a rule based policy is insufficient, that discretion is always necessary[5]. Bordo and Levin (2017) stress that a complete CBDC-system (and without cash!) gives new opportunities. The zero lower bound on the interest rate on base money is removed and they propose an

[5] Taylor (1993) also stresses that it is always a combination, but that it is important nevertheless to have such a rule.

adapted Taylor rule. See Buiter (2009) for a more complete analysis of the removal of the zero lower bound.

But a complete CBDC-system gives more opportunities than only breaking the zero lower bound, as described in detail in Wijngaard, Van Hee (2021). Instead of stabilizing the price level it is also possible to index the account balances, monitor the price development and compensate the account balance for possible increases. This option is also mentioned by Bordo and Levin (2017), but not selected. It can nevertheless be a useful option. A further option in this spirit is to link the account balances to some easy to monitor proxy of the GDP, e.g. the total sum of payments from households to businesses in the past year. Then the money is a kind of share in the economy and so it is not only fiduciary money but it has some real value. Being able to label the transactions is essential here again[6].

9. Implementation, migration and performance

It is very important that the migration of the existing monetary system to the new one proceeds smoothly. An incremental change strategy, in which a big change is realized in small steps, is preferable to a big-bang strategy where the new system has to be used at once. The introduction of the euro was a comparable operation with also a more or less incremental migration process.

The implementation of the CBDC-system mainly concerns the organization of the accounts and the software to realize the transactions. We should start with the implementation of the kernel protocol. The banks can keep a big part of their existing functions so that they have the time to prepare for competition with other providers of payment services in the financial service layer such as payment service providers, ICT businesses, providers of cloud services, telecom operators and accounting firms.

Although the real operation requires a comprehensive planning, we sketch here only the most important steps:

[6] In a separate paper we are going to explore this issue of rule-based monetary policies further (Wijngaard, Van Hee 2021).

1. The first step is to convert the money that banks have created into CBDC. This is just an administrative step: all banks obtain a C-account with a (negative) balance that equals exactly the money they have created, i.e. the demand deposits. It is a matter of monetary policy if the CB charges them with interest, either positive or negative.
2. For all actors CBDC-accounts will be created at the same time. Almost all actors will have already accounts at a bank and these accounts have a unique number. So it is obvious to use these numbers also for the accounts in the CBDC-system. In fact we copy the bank accounts into the CBDC-system. Note that negative values in the CBDC-system are not allowed, so if a negative bank account is "copied", the bank should provide a loan in order to make the CB-account zero.
3. In the beginning the protocol is as in Figure 1, but X and Y are the "bank of X" and the "bank of Y". So the digital payments will be performed via the banks: they will store the balance records for their clients and if an actor gives a payment order, the bank will produce the transaction record and retrieve the two balance records, send this all to the CBDC-system and receive the updated balance records for the client. In case of a money transfer between two clients of the same bank it is easy. If the transfer is between accounts at different banks, the bank of the payer will request the balance record of the receiver at his bank. By way of the encryption there is no risk of fraud, but the banks have to protect the privacy of the clients, both payers and receivers. This step requires a software effort of the banks, but the clients do not notice the difference with the existing system. The banks can use the already available TIPS developments[7]. This gives banks an advantage as financial service provider. Once this step is realized, other actors may provide these functions as well. In principle everybody can do it himself and most likely big businesses will do that.
4. For consumer transactions, mainly in shops and hospitality and catering services, we must make a distinction between cash and card transactions. The cash transactions will die out in time. So an actor can pay with cash in shops for some time, but the change is added to his account from the shop account. Also at

[7] TIPS stands for Target Instant Payment Settlement, the development launched by the ECB to realize real time payments. See the website of the ECB.

banks actors can convert cash to digital, i.e. the amount of cash is added to the balance record of the actor. But nobody can obtain cash anymore.

5. Credit card transitions are similar as today: the credit card company is paying the bill and later he will invoice the consumer.
6. For debit card payments, the existing systems have to be adapted. Today one uses in the euro zone mostly the C-TAP protocol, where the transactions are processed via the debit card organizations (e.g. Master Card, with Maestro, Visa with V-pay) via a payment terminal in the shop. This will change completely, as described in section 6. The role of the debit card will change: it is only a way to communicate an account identity.

An important question is what happens if there is a major power outage. Of course all balance records should be stored in several places, for instance in the cloud. The transactions continue when the power is up again. Maybe a few transactions are lost and have to be renewed. During the outage there is still some payment possible between mobile devices and systems with power back up if the CBDC-system is still up. Of course the CBDC-system should have the best possible power back up. This is not different from the existing systems.

Another important question is of course if this system is technically feasible. To make a rough estimate of the computational efforts and the required storage capacity we focus on the eurozone. There are about 350 million people living in this zone[8] and if we add the businesses and other organizations we estimate a need for one billion accounts. With an average storage of ca 1 MB per account the CBDC-system needs a storage capacity of ca 1 petabytes.

There are about 2.10^{11} payment transactions per year in the eurozone[9]. This means on average ca 6000 transaction per second and 10.000 in the peaks hours. The computing time per transaction per processor is small (ca 100 milliseconds). The computations consist of decryption and encryption of the messages and in between the trivial updates of the account records and the fingerprinting of these records. So we need 1000 processors to handle this payment workload. With 4 processors per server that means 250 servers each with 4 terabytes of storage capacity each, spread

[8] See https://en.wikipedia.org/wiki/Eurozone [1.12.2021]

[9] See www.ecb.europa.eu/stats/payment_statistics/payment_services/html/index.en.html [1.12.2021].

geographically over the eurozone. With a proper *load balancing* algorithm the accounts can be distributed in such a way that each server in the CBDC-system has about the same workload. In this way the system is *scalable* and the performance is controllable. For safety and security reasons it is wise to back up copies of each account on several other servers while only one server is managing (hosting) the account. So the probability of the loss of an account can be made as small as the probability that a meteorite destroys the earth.

10. Conclusion

This paper is meant to contribute to the debate on the role of banks in the financial and monetary system. Specifically the creation of money by banks is considered as a mistake. The most natural way to remove the creation of money from the banks, is to make the base money available for all economic actors. Base money today consists of coins and bank notes and of the reserves of banks and government at the CB. In the form of coins and bank notes it is already available for all actors. But that is not scalable to large amounts and large number of transactions. A CBDC-system as sketched in this paper is a much better solution. It makes payments between two actors much easier and real time. It is feasible to create such a system and to migrate from the existing monetary system.

The CBDC-system is owned by the CB or the government. So it is in a sense a monopolist. But it is only a low level infrastructure for payments. Competing parties offering these basic functions would make it less efficient and less transparent, like the existing monetary system. However the fintech layers on top of the CBDC-system offer plenty of space for entrepreneurship and competition. In fact the CBDC-system is a great enabler of competition in the financial industry. Also the CBDC-system can be a great enabler for monetary and tax policies (see Wijngaard, Van Hee 2021, forthcoming).

We do not advocate a crypto currency like the Bitcoin. These systems arise from the fear of a government controlled system. The price they pay to solve the double spending problem, is exorbitant computer power and energy consumption in the block chain. So real-time payments are not feasible. And such a currency gives no stability whatsoever. We believe that the CB and government are the right party to provide the monetary system and to determine the monetary policy, of course with separated authorities. It is transparent, efficient and relatively easy to control.

The existing monetary system is not designed by engineers but has grown by way of an organic process. We think "it is time to govern the further growth by a good design".

Appendix 1. Cryptography in a nutshell

We use cryptography for three purposes: fingerprinting, digital signatures and confidential message passing. For fingerprinting we use *hash functions*. An hash function H makes from a big character string a shorter one. So H applied to a string A gives as shorter string B: H(A)=B. There are well-known examples of hash functions that we used already before computers exist. The *checksum* is such an example. There we add the digits of a large number and use that sum as a hash of the large number. The goal is often to have a shorter representation of the first string, to *identify* the original string. In theory this can go wrong, because there exist several long strings that are mapped by H to the same short string. The checksum is a very bad example, since if we switch two digits the hash remains the same. In practice such a collision seldom happens, because the number of big strings that we use is 'negligible' small compared to the total number of strings on which we could apply the hash function. So hash functions are not *injective* and also not *invertible* such as the key pairs of an asymmetrical encryption system. But it costs very much computing time to find a string X if you only know Y and that H(X)=Y. A frequently used hash function is called SHA-256 (Secret Hash Algorithm 256; Gilbert, Handschuh 2003) which is developed by NSA (National Security Agency).

That is why hash functions are used to protect the *authenticity* of data. This is why a hash code of data can be used as *fingerprint*. For instance if one wants to send a message M and one wants to guarantee that the message will not be altered during sending, then one sends M and separately H(M). If the receiver reads L instead of M he can see that the message is manipulated because when he computes H(L) he sees that it differs from H(M). The same system can be applied to files. At the moment a file M is stored, the value H(M) is computed and stored separately. As soon as the file M is retrieved one also retrieves H(M) to check if file M has been altered. The probability that such a manipulation will not be detected is negligible.

The basis of most cryptography techniques is the time consumption of the computation of the *discrete logarithm* of a very large number with 100 to 1000 digits. All computations take place with numbers smaller than a very large number N. This is realized by an operation called *modulo* or *mod* for short, which is defined as: X *mod* N is the remainder of X by division of N, which means subtracting of N from X so many times that a number between 0 and N remains. In this system we can have the classical multiplication mod N, for instance X.Y *mod* N where X.Y is the classical multiplication and then then remainder by division by N. And so we can compute the X-power of a number g, g^X *mod* N, where g is multiplied by itself X-1 times. Note that it is easy to compute g^X *mod* N even for very large X, since we compute $g.g=g^2$, $g^2.g^2=g^4$,$g^4.g^4=g^8$, etc. (all computations are *mod* N). So g^X *mod* N requires about ${}^2\log X$ multiplications.

A *discrete logarithm* is the computation of X if Y, g and N are given and $Y=g^X$ mod N. We can denote this solution by $X={}^g \log_N(Y)$, just like the well-known classical logarithm, but the subscript N indicates that we use the *mod* operation. For large numbers, these computations are taking many years on a very fast computer and therefore they are considered as practically impossible.
Instead of this classical multiplications with binary numbers there is another computational system, consisting of the set of all points with coordinates (x,y) on an *elliptic curve*. They satisfy the equation $y^2=x^3+a.x+b$ for some numbers a and b (cf. Koblitz 1987). On this set there is a special *multiplication operation*, namely if we draw a straight line through two arbitrary points on the curve, there is exactly one other intersection of the curve. If we mirror this point on the x-axis we obtain again a point on the curve and we define that point as the result of the multiplication. The set with this multiplication operation behaves like the number system *mod* N. (it is a mathematical group.) Here the same discrete logarithm can be defined and the computation effort of it is orders of magnitude is larger than for the binary numbers given above. Elliptic curve cryptography is considered currently as the most safe system.

One of the major tricks, due to Diffie and Hellman (1976) is to create a *secret key* for encryption of messages. All actors share some information: the numbers g and N. Each actor A has a *secret key*, i.e. a large binary number that we also denote with A. Further there is a *public register* where all the *public keys* are registered. The public key of A is g^A.

If A and B want to exchange messages they can look up in the public register each other's public key, i.e. g^A and g^B respectively. Then A computes $(g^B)^A$ and B computes $(g^A)^B$ and these are the same. Nobody else can do this. So A and B have the same secret key without exchanging information! With this secret key they can encrypt and decrypt their messages. Using the same key is called a *symmetric encryption system* and there are many good ones. The problem is that both actors have to agree upon the key, but the Diffie-Hellman trick makes it a safe procedure.

In case one party starts the communication, say A, he can also choose a random binary number Y and send this to B as g^Y. Then A can compute $(g^B)^Y$ and B can compute $(g^Y)^B$ which is also the same key and it can be a different one for each communication, which is obviously more safe. The only drawback is that B can't verify that A is the sender. Therefore A sends in the first encrypted message $(g^B)^A$ as his *digital signature* to B. Note that the digital signature of A is different for each receiver B.

Another famous encryption system is called *RSA-encryption*, named after the inventors Rivest et al. (1978). This is an *asymmetric encryption system* where everybody has a secret and a public key, like in the system above, but these key pairs have an extra property, namely that the secret key can be used to decrypt a message encoded with the public key and vice versa, a message encoded with the public key can be decoded by the secret key. In this way there is no exchange of keys necessary in a communication. The computation barrier to crack the code is also the computation effort of the discrete logarithm. It is also easy to create a digital signature with this system. Suppose A wants to send a message to B and he wants to prove his identity. Then A sends a message with his name and his name also encrypted with his secret key. The result is encrypted with the public key of B. Then B can decode the message with his secret key and he sees the name of A and looks up the public key of A and he decrypts the message further and sees that it is indeed

A. The efficiency of the elliptic curve cryptography with Diffie-Hellman is more efficient.

Bibliography

Admati A., Hellwig M. (2013), The Bankers New Clothes, Princeton University Press, New York.

BIS (2018), Central Bank Digital Currencies, https://www.bis.org/cpmi/publ/d174.pdf [01.09.2021].

Bordo M.D., Levin A.T. (2017), Central Bank Digital Currency and the Future of Monetary Policy, NBER Working Paper Series 23711.

Buiter W.H. (2009), Negative Nominal Interest Rates. Three Ways to Overcome the Zero Lower Bound, "The North American Journal of Economics and Finance", vol. 20 no. 3, pp. 213–238.

Chaum D. (1983), Blind Signatures for Untraceable Payments, in: Advances in Cryptology, Chaum David, Rivest Ronald L., Sherman Alan T. (eds), Springer, Boston, MA, pp. 199–203.

Diffie W., Hellman M.E. (1976), New Directions in Cryptography, "IEEE Transactions on Information Theory", vol. 22 no. 6, pp. 644–654.

ECB (2020), Report on a Digital Euro, https://www.ecb.europa.eu/pub/pdf/other/Report_on_a_digital_euro~4d7268b458.en.pdf [01.09.2021].

Gilbert H., Handschuh H. (2003), Security Analysis of SHA-256 and Sisters, in: Selected Areas in Cryptography. SAC 2003. Lecture Notes in Computer Science, vol 3006, Matsui M., Zuccherato R.J. (eds.), Springer, Berlin, Heidelberg, pp. 175–193.

Ingham G., Coutts K., Konzelmann S. (2016), Introduction: 'Cranks' and 'Brave Heretics'. Rethinking Money and Banking after the Great Financial Crisis, "Cambridge Journal of Economics", vol. 40 no. 5, pp. 1247–1257.

Jackson A., Dyson B. (2012), Modernising Money. Why Our Monetary System Is Broken and How It Can Be Fixed, Positive Money, London.

Koblitz N. (1987), Elliptic Curve Cryptosystems, "Mathematics of Computation", vol. 48 no. 177, pp. 203–209.

Kay J. (2009), Narrow Banking. The Reform of Banking Regulation, Centre for the Study of Financial Innovation, https://bankunderground.co.uk/wp-content/uploads/2016/07/c8439-narrowbanking2cthereformofbankingregulation2cbyjohnkay.pdf [01.09.2021].

Nakamoto Satoshi (2008), A Peer-to-Peer Electronic Cash System, https://bitcoin.org/bitcoin.pdf [01.09.2021].

Rivest R.L., Shamir A., Adleman L. (1978), A Method for Obtaining Digital Signatures and Public-Key Cryptosystems, "Communications of the ACM", vol. 21 no. 2, pp. 120–126.

Roubini N., Mihm S. (2010), Crisis Economics. A Crash Course in the Future of Finance, Penguin Books, London.

Ryan-Collins J., Greenham T., Werner R., Jackson A. (2011), Where Does Money Come from, New Economics Foundation, London.

Sveriges Riksbank (2017), The Riksbank's e-krona project: Report 1, https://www.riksbank.se/globalassets/media/rapporter/e-krona/2017/rapport_ekrona_uppdaterad_170920_eng.pdf [01.09.2021].

Taylor J.B. (1993), Discretion versus Policy Rules in Practice, "Carnegie-Rochester Conference Series on Public Policy", vol. 39, pp. 195–214.

Wijngaard J., Van Hee K. (2021), Design of a rule-based monetary policy in a Central Bank Digital Currency system, "Central European Review of Economics and Management", vol. 5 no. 4, pp. 61-95.

CENTRAL EUROPEAN REVIEW
OF ECONOMICS AND MANAGEMENT

ISSN 2543-9472; eISSN 2544-0365

Vol. 5, No.4, 61-95, December 2021

www.cerem-review.eu
www.ojs.wsb.wroclaw.pl

Design of a rule-based monetary policy in a Central Bank Digital Currency system

Jacob WIJNGAARD

University of Groningen, Nederland

Kees VAN HEE

Eindhoven University of Technology, Nederland

Received: 23.06.2021, Revised: 10.10.2021, Accepted: 25.10..2021
doi: http://dx.doi.org/10.29015/cerem.928

Aim: This paper presupposes a purely Central Bank Digital Currency (CBDC) based system. Its aim is to describe how such a system facilitates complete new possibilities to design a suitable monetary policy. More specifically, the purpose is to show that the available monetary tools can be used to design a rule-based monetary policy that guarantees stability of purchasing power and interest rates.

Research methods: The paper is design oriented. It describes how the monetary system could function The important monetary variables are defined and their relationship is described. To illustrate these variables and their relationship, simulation results of their behavior are added.

Conclusions: It is shown that it is indeed possible to design a monetary policy that is rule based and guarantees stability of purchasing power and interest rates. Crucial elements in the design are linking the balances of the CBDC-accounts to a proxy of the domestic product and replacing the use of government bonds by allowing the government to borrow from the Central Bank and giving households and businesses the opportunity to open a savings account at the Central Bank.

Originality: The approach is completely new. It is the result of rethinking the possibilities of a complete transition of bank money to CBDC.

Implications: The paper shows that a more absolute transition to the use of CBDC makes it possible to establish a clearer and more stable monetary practice, and that it is necessary therefore to revise monetary theory.
Keywords: Design, CBDC, Rule-based, Monetary policy, Inflation correction, Domestic product proxy
JEL: E42, E43, E52, E58, E63.

Correspondence address: Jacob WIJNGAARD, Professor emeritus, Operations, University of Groningen, Nederland. E-mail: j.wijngaard@rug.nl. Kees VAN HEE, Professor emeritus, Computer Science, Eindhoven University of Technology, Nederland. E-mail: k.m.v.hee@tue.nl

1. Introduction

The current monetary system is a two-tiered system. The Central bank (CB) issues base money, including cash and bank reserves. That is the first tier. The commercial banks issue claims on base money (e.g. demand deposits). That is the second tier. As of recently, the possibility to give more parties access to base money is seriously considered. It is called Central Bank Digital Currency (CBDC). In its most extreme form it makes the money creation function of the commercial banks superfluous and leads to a one-tiered system: all economic actors pay each other with base money. This extreme option has not much support yet among bankers, monetary economists and politicians, but it is worth to explore the possibilities, also the possibilities with respect to monetary policy.

The goal of monetary policy is to keep the purchasing power of the currency stable. In the current system this appears to be difficult. The main tool of the CB is to control the rate at which the banks can borrow base money from the CB. This tool appears to be ineffective now. To keep control the CB has to switch to some form of Quantitative Easing (QE) and that is not very effective either. And the lack of transparency and stability in the monetary policy leads in itself to dynamics. A transfer to a CBDC based system gives the opportunity to redesign the monetary policy. In a companioning paper (Van Hee, Wijngaard 2021) we describe how such a CBDC based system can be organized. In this paper we focus on the monetary policy.

Section 2 discusses why it is necessary to redesign the system and gives a short description of the proposals developed in the companioning paper (Van Hee, Wijngaard 2021). Section 3 explores the tools that are available in a CBDC based system to develop a monetary policy. In sections 4-7, we show how these tools can be used to design an attractive monetary policy. Important elements are: linking the current accounts to a proxy of the domestic product and replacing the use of government bonds by the use of specific savings accounts. This results in a rule based monetary policy with automatic inflation control and stable risk-free interest rates. Section 8 gives conclusions and suggestions for further research.

2. Towards a new monetary system

The current monetary system is an *organically grown* system. Its weaknesses became apparent by way of the financial crisis of 2008 and have been described sufficiently broad (e.g. Roubini, Mihm 2010; Admati, Hellwig 2013). We propose to *design* a new monetary system.

Today we have two forms of money, *cash* (coins and bank notes) and *demand deposits* (balances on current bank accounts). Cash is part of the so called *base money* (see Ryan-Collins et al. 2011). The rest of the base money is invisible for normal *economic actors*: households and businesses. It consists of the *reserves* of (commercial) banks and the government, at the CB. A demand deposit is (only) a *claim* on base money. Such claims are generally accepted and form the main part of the available money. Banks are able to create these claims more or less freely. Note that these claims are digital, so, it is a form of digital money. Today ca 95% of our money is claims on base money and if all economic actors would cashing in their claims, this would be a disaster because banks don’t have the base money at hand. Bank credits are a strange form of money indeed. Nevertheless, from 1971, after the abolition of the Bretton Woods agreement, it has functioned well for a while. By adapting the interest rate for reserves, the availability of credit was controlled, and through this the whole economy. And especially during the period 1985–2005, the system appeared to be really “under control”. That is why that period is called “the great moderation”. In between, however, there are serious doubts. Banks have played an important role in the emergence and proliferation of the financial crisis. The American mortgage market was the biggest culprit, but the lack of transparency and the sale of too complex financial products contributed as well (see Roubini, Mihm 2010). There are general rules with respect to reserves and liquidity (Basel I, II and III). But the position of a bank is judged afterwards and the judgement of the different categories of assets and the validity of the rules are not always clear (see Admati, Hellwig 2013). This implies that the banks have in fact a (too) large freedom with respect to the creation of money, because the claims are rarely cashed and all checks and balances are directed to a smooth continuation of the system. This made it easy for them to participate in these risky products and spread the problems in that way.

This is a fundamental weakness in the existing system. It is directly connected with the two-tiered character of the system, that we use bank money, claims on base money, while we are not very interested in the use of cash, the only form of base money accessible to us. It is time to widen the role of base money (or CBDC) and have that as our primary form of money, the only legal tender. So, the CB creates the money and the main role of the banks is to intermediate between lenders and borrowers. Our proposal for such a new system is described in (Van Hee, Wijngaard 2021). It is inspired by the proposals of the Positive Money movement (Jackson, Dyson 2012) in the UK (see Huber 2017 for an overview of the positive money movement), but differs in some respects and is more explicit in its design, especially regarding privacy and security. Here we sketch the main elements. It is completely different from the developments considered by the Central Banks in e.g. Sweden and the eurozone, where one explores the possibilities to *combine* the introduction of CBDC with continuation of the current system (see Sveriges Riksbank 2017; ECB 2020).

- Actors have *CBDC-accounts,* as many as they like. An account is an abstract object that is "owned" by the actor and that is stored on the hardware of the actor or in a *cloud* of a service provider operating on behalf of the actor. The account has several properties such as a *unique account identity* and the identity of the actor. But the most essential property of the account is the *balance*, i.e. the amount of currency on the account. This balance is at least zero, so it is never negative.
- An exception is made for banks. If they have a license of the CB, they are allowed to borrow from the central bank. In order to do this, there are besides the normal accounts at the CB also *C-accounts* (credit accounts), with a balance <= 0. To borrow from the CB, a bank can just transfer some money from her C-account to another account, making the balance on the C-account more negative.
- The (central) government has also such a C-account, to be able to borrow from the CB.
- All other actors may borrow money from other actors, in particular from banks, but not from the CB.

- Actors may use one of their accounts as a *bank savings account*. That means that they give a bank access to it and allow the bank to use the balance for loans to other actors. Of course, they have to do so under certain conditions (interest, term, …). Note that as long as the money is on the savings account it is not lended yet. As soon as it is lended to another actor, the money moves from the savings account to the account of the borrower. The bank administers this process.
- There is a *public database* as part of the CBDC-system and in that database there is some data of the accounts, but neither the balance itself nor the transactions themselves. What is stored is a *digital fingerprint* of the balance account. This is done by applying a one-way function or hash function to the account record and store this value. It can be used to verify the authenticity of an account record presented by the actor for updating, by applying this one way function to the current account record and compare the outcome with the stored value. The database is called "public" because all actors have access to it. We avoid the term "central" database because it will be a distributed database, i.e. a network of databases, but all under control of the CB. This database could be constructed as a blockchain, although we don't see any particular advantage of that.
- There is a *clearing/settlement* function in the CBDC-system. Here the most basic payment action is performed: the increase of the balance of the *acquiring* actor and the decrease of the balance of the *paying* actor. And there is a *secure transmission system* to send messages between actors and the CB, including the authentication of the sender and the integrity and confidentiality of the message.
- It is to expect that service providers are going to develop different kinds of services, to integrate the payments with the financial and management control of the actors. Since all actors use the same CBDC-system, this is a very open, competitive world.

The CB can be seen as a *trusted third party* for payments between two actors. But this does not mean that the CB keeps record of the values of balances of the actors.

We only let the CB keep a fingerprint of the balance and maybe also of the transactions.

In this paper we focus on the *monetary policy* that can be applied in combination with such a CBDC-system. If necessary it is possible to create off-line payment possibilities and we assume therefore that *physical cash is no longer used*. There will be a transition period where CB-cash exists in parallel to CBDC, however we just consider the final state with *only CBDC* here.

3. Exploring the tools for a monetary policy

Here we consider the case of one country with one CBDC-system. In most countries the main goal of the monetary policy is to control the price level. Until recently, the aim of the ECB was to realize an inflation of 2% or a little less. This is a very narrow goal and indeed difficult to realize. Since the summer of 2021, the goal was changed into "an average inflation of 2%". This gives more freedom to deviate from the 2% and it may also help in realizing that the public keeps expecting an inflation of 2% even if that inflation is now lower. This inflation target protects the purchasing power of the public. We are going to design a different system to protect the purchasing power. But we want more. We should not be happy with only stability of the purchasing power of consumer goods, we also want to realize stability of the yield of saving and investing and, to keep it symmetric, of the cost of borrowing. Risks cannot be controlled, but it may be possible to control the risk-free interest rate. This is related to taking care of sufficient credit possibilities, sufficient for a prospering economy, a goal that is explicitly included in e.g. the monetary goals for the US[1]. We use the wider goal of a stable purchasing power in this broad sense.

In case of such a CBDC-system there are many tools available to realize this goal. CB and government have both an important role. The CB makes the money available and determines the conditions. The government is important through its fiscal policy and because of the way deficits are financed.

---

[1] See the website of the FED: https://www.federalreserve.gov/faqs/what-economic-goals-does-federal-reserve-seek-to-achieve-through-monetary-policy.htm.

1) *Interest rate on reserves*. Currently, the main tool for the CB is the interest rate for the reserves of the banks. In the new system, all actors have CBDC (which is base money) and there is no physical cash anymore. So, the interest tool is richer now. It is not restricted to values >=0 ("breaking the lower bound"[2]) and it is possible of course to distinguish between different types of actors and different conditions of availability. Note that a negative interest on CBDC can also be interpreted as a tax on having CBDC, a liquidity tax.
i) *Banks can borrow from the CB*. The interest rate on such loans is an important tool.
ii) Households and businesses can be allowed to start a *savings account with the CB*, for longer term deposits. The interest rate on such savings accounts is also an important tool.
2) *Indexing account balances*. It is possible to index the account balances to the price level, to keep the purchasing power of the account balance constant. This necessitates a monitoring process that keeps account of the changes in the price level $p(t)$. Each account can only be adapted at transaction moments, because the CB only keeps the fingerprints of the accounts and their balances. When indexed, the balance is multiplied with $p(t)/p(t_l)$, with t_l the last time the account was updated[3]. One step further is to link the account balances to some proxy of the nominal domestic product (*DP-linking*), instead of to the price level. All payments from households to businesses during the last year could serve as such a proxy. Since all payments or at least almost all payments are in CBDC it is possible to monitor these payments real time by labelling the transactions of the accounts (household accounts and business accounts) by the type of transaction.
3) *Transaction tax*. The way the government is financed is an important factor in the realization of stability. We assume that the government is at least partly financed by taxation. Changes in the value added tax (VAT) have also influence on the price stability. An increase in the price level could be compensated for by a reduction in the VAT. Changes in the deductibility of interest on mortgages

[2] See Buiter (2009) for a general treatment of this issue of "breaking the lower bound".
[3] Bordo and Levin (2017) mention this possibility, but choose for the interest tool to keep the price level stable.

influence the credit possibilities. It is important to distinguish these taxes from the liquidity tax, the tax on the *account balance* that is mentioned in point 1).

4) *Monetary financing of government deficits*. Government deficits can be financed monetarily by borrowing from the CB. In our system, the interest rate for such loans is by definition equal to 0, since the CB is owned by the government. Note that this is also stressed in the Modern Monetary Theory (MMT)[4].
5) *Government activity on the financial market*. It is also possible to let the government be active on the financial market by selling different kinds of bonds. By using the dynamics of the financial market, the government may be able to reduce the cost of a deficit, but these activities contribute also to these dynamics.

It is clear that designing a good monetary policy is a multi-dimensional decision problem. And the use of government tools and CB tools have to be determined in combination. Of course it is necessary to structure it. We propose to structure it towards *rules* and *discretion*. What are the rules? Who (which institution) monitors the rules and decides whether and how they have to be adapted. Where are we going to require discretion? An important question here is whether and how to involve politics. Somehow in this structure the role of the CB and the role of the government have to become clear.

The next four sections are devoted to the description of one specific possible design of the monetary policy, where we use DP-linking and a government that borrows only from the CB. The DP-linking is described in section 4, together with a simplified version of the policy. The complete policy is described in section 5. The policy is almost completely rule-based. In section 6, we discuss the limits of this rule-based character of the policy. We also discuss how to organize the necessary decision making: the rules, the tuning of the parameters, the space for discretion and the bargaining. In section 7, we sketch how such a policy could look like in the eurozone, a case of more countries with one CBDC-system.

[4] See Kelton (2020) for a general description of MMT. An important element in MMT is the structural role of the government in monetary policy and the acceptance of government deficits in stimulating the economy.

4. Linking the accounts to a proxy of the domestic product

This section explains how to link the content of these accounts to a DP-proxy. The aim of this is to secure the purchasing power of the accounts. We are not going to secure the purchasing power of one currency unit, but the purchasing power of the total balance of each of the accounts.

First we will formulate this linking for an arbitrary macro-economic (aggregate) variable that can be monitored real time. Let $A(\cdot)$ be such a continuously available variable. Linking the current accounts to $A(\cdot)$ means that the balance of each current account is adjusted to $A(\cdot)$ each time a transaction takes place. Only at such moments the CBDC-system has access to the accounts. Suppose the accounts i and j are involved in a transaction that takes place at time t. Let $C_i(\cdot)$ and $C_j(\cdot)$ be the balances of these accounts. Just before the execution of the transaction, the balances are reset in the following way[5]:

$$C_i(t) := \frac{A(t)}{A(t-\varepsilon_i)} \cdot C_i(t) \qquad (1)$$

with $t - \varepsilon_i$ the time (in years) of the previous transaction with respect to account i, and a corresponding update for account j. The update is executed by the CBDC-system, together with the execution of the payment.

If the variable $A(\cdot)$ represents a stable economic value and reflects broad price changes, the linking procedure helps to secure the purchasing power of the current accounts. But it is important that it is continuously available. We propose to use a proxy of the domestic product, *the total sum of all payments by households, for (new) real goods and services during the past year*. We call this variable $D(\cdot)$. To keep track of $D(\cdot)$, it is necessary to label the transactions. In Appendix 1 we discuss the definition of this proxy and the way of labelling in more detail.

With DP-linking the content of an account follows price increases as well as productivity increases. This may make it attractive for investors to put money on an account and just leave it there, enjoying the general productivity increases as return

[5] := stands for "going to be equal to".

on investment on this account. This necessitates to "tax" the linked account. Instead of the DP-proxy, $D(t)$, the *taxed DP-proxy*, $e^{-\tau t} \cdot D(t)$[6], is used. Equation (1) is replaced then by:

$$C_i(t) := e^{-\tau \varepsilon_i} \frac{D(t)}{D(t-\varepsilon_i)} \cdot C_i(t) \quad (2)$$

The liquidity tax τ (per year) has to be sufficiently large to form an effective incentive to spend money instead of just keeping it.

We have to explain in more detail why this (liquidity) tax is necessary. The variable $D(t)$ does not include any intermediate economic activity: the build-up of inventories, the production of intermediate products and of production equipment, the development of production processes and of know-how, etcetera. This reservoir of investments is going to contribute in the future to the value of $D(\cdot)$. Part of these investments is privately owned. The ownership can be direct or via a share or a loan. This private part of the reservoir may be expected to be stable. So the value of these private investments grows with $D(\cdot)$. Let $W(t)$ be the value of these investments at time t and let $\Delta W(t) = W(t+1) - W(t)$. The reservoir is owned by a relatively small part of the population. That implies that only little of the yield is consumed. Let ω be the yield per unit of value and c the consumption rate and let $W_n(t)$ be the contribution of new investors. Then:

$$\Delta W(t) = (1-c) \cdot \omega \cdot W(t) + W_n(t) \quad (3)$$

The fraction c is small and $W_n(t)$ is also small compared to $W(t)$[7]. That means that the growth of $W(\cdot)$ is rather close to ω. So, the *average* yield on risky investments is rather close to the growth of $D(\cdot)$. That means that without liquidity tax it may become attractive not to spend the money. Just keeping it on the account gives a risk free growth that is close to the average yield of investing it in another way.

---

[6] The function $e^{-\tau t}$ is the solution of the equation $\frac{df}{dt} = -\tau f(t)$, so the result of applying a proportional tax τ to $f(t)$.

[7] See Piketty (2014), Chapter 5.

By choosing $\tau = g + 0.02$, with g the growth rate of the DP, we realize a yearly reduction of the purchasing power of 2%. But a smaller τ may be sufficient. In the current system, a sufficiently large inflation is necessary to keep the monetary policy effective (see Bordo, Levin 2017). In our system it is sufficient to choose τ so large that hoarding the money is not attractive.

The purchasing power is controlled by linking the account balances to a taxed DP-proxy. One may worry that that may lead to more instability of the prices. In Appendix 2 we give the results of a simulation experiment with respect to this point. It shows that linking the account balances may lead to some extra price instability. This does not lead to extra instability of the purchasing power, however. It may nevertheless be attractive to seek ways to stabilize the prices. But that is not part of the monetary policy in our view. The monetary policy controls the purchasing power, not the prices.

The taxation reduces the total amount of money. It is easy to compensate this reduction by adding the same amount of money to one of the accounts of the (central) government. We call this the *monetary tax account*. This leads to a very simple monetary policy: the account balances are linked to $e^{-\tau t} \cdot D(t)$, the CB transfers immediately what is taxed to the monetary tax account of the government, the government takes care of its own deficits by borrowing on the financial market and the banks have to use superfluous money of other actors to perform their crediting function. This policy is going to be a reference point in the further design of the monetary policy. Let $M(t)$ be the amount of money at time t. Since $M(t)$ remains in line with $D(t)$ and since $M(t) \cdot V = D(t)$, with V the velocity of circulation of the money, this policy keeps this velocity constant[8].

The aim of this *taxed DP-linking* is to make further inflation control superfluous. The DP-proxy forms a stable and real basis for the value of the current accounts. There is a time delay however. It is possible that the current prices increase faster than the prices of a year ago and the average price over the last year. In principle it is possible to work with the DP over a shorter period. But seasonality is so significant that it is difficult to construct a stable DP-proxy then. So, we have to accept this time delay.

[8] This is the Fisher equation, with the right hand side written in another way.

If the (nominal) growth of $D(\cdot)$ is smaller than τ, the taxed DP-proxy is decreasing and the balance is also decreasing. It will take time for households to get used to this and it may anyway be inconvenient to apply it also for the household accounts that are used for daily shopping. It may be useful therefore to give households the opportunity to exclude (some of) their accounts from the linking, under the condition that the balance remains below a certain limit.

Once we have this DP-linkage for the account balances, it becomes easy to express the balance of an account as a fraction of the DP. Suppose the DP is about 10^{12} currency units. Then one could speak of 1 *pico-DP* instead of 1 unit. If an account with a balance of 1 pico is not used for transactions, the balance after a year is equal to $e^{-\tau} \cdot 1$ (pico), while the balance in currency units is more complex because it depends also on changes in the (nominal) DP.

It is straightforward to formulate loans also in this DP-linked way. We call that *pico-loans*. A loan of 100 pico for 2 year, with an interest of 1% implies that one has to pay each year 1 pico interest and one has to pay back 100 pico at the end of the year 2[9]. Having all loans and bonds in this DP-linked form leads to a situation where all assets and liabilities are expressed in pico. The DP-proxy forms a stable and real basis for the financial assets. Transactions with respect to real goods and services remain in currency units. This is the basis for the (taxed) DP-linking. The continuously available DP-proxy serves as the exchange rate.

5. Designing the monetary policy

In this section we describe how the simple, reference monetary policy described in the previous section can be improved. We keep the linking to a (taxed) DP-proxy, $D(t)$. This guarantees the purchasing power of the account balances. In the simple policy of Section 4, the total amount of CBDC is kept equal to a constant fraction of $D(t)$, say $\mu \cdot D(t)$ by adding the liquidity tax immediately to the monetary tax account

[9] Compare this with the already existing inflation indexed bonds. See the Wikipedia page: https://en.wikipedia.org/wiki/Inflation-indexed_bond. Kamstra, Shiller (2008) suggest to go a step further and link the bonds to the GDP. They call this trills (one-trillionth of Canada's GDP). This is worked out and related to pension building.

of the government. Possible deficits of the government have to be financed by borrowing at the financial market and the banks are not allowed to borrow from the CB. This monetary system has the following drawbacks:

a) The government contributes to the dynamics of the financial market and makes itself dependent of it, instead of stabilizing it.

b) Banks are inflexible with respect to their credit supplying function. Households and businesses may make too little money available.

c) It is unclear how to determine the right amount of CBDC. Too little CBDC may hinder productive investments, too much CBDC may lead to speculation and instability of the financial markets.

d) There are no tools to realize the stability of the risk-free interest rate.

We will discuss how to overcome these drawbacks and develop additional rules.

The first important point is to accept that the CB is government-owned. So, giving the CB the opportunity to create more money (CBDC) and then adding this extra money to the monetary tax account of the government account is equivalent with not changing the amount of money and allowing the government to borrow freely (interest = 0) from the CB. We choose this latter option: the government may borrow freely from the CB and the money creation function of the CB is restricted to keeping the balances linked to $D(t)$ and adding the liquidity tax to the monetary tax account of the government. In this respect our approach is getting close to the Modern Monetary Theory (MMT) (see Kelton 2020). That means that we have to deal with the double-function of government expenses. In the first place to take care that the essential functions to support the society can be performed and in the second place that the monetary function of providing sufficient liquidity, credit supply and general monetary stability can be performed. The role of the CB is to monitor and safeguard this second function, but, of course, it has only very partial control over the government expenses.

To prevent that extra government expenses lead to too much CBDC in the economy, we introduce *CB savings accounts*. These accounts are made attractive for actors with superfluous CBDC. They have to deposit the money for a longer term (e.g. more than a year), but pay less liquidity tax, $\sigma < \tau$, instead of τ. This *reduces the amount of (liquid) CBDC* in the economy immediately, but can also be used as a *signal* *that there is too much CBDC*. We assume that really productive investments have a yield $>= 0$ (see section 4). So, if we keep $\sigma > 0$, a large total balance on these savings accounts signifies that there are no really productive investments available anymore.

To guarantee sufficient credit supply, we allow banks to borrow CBDC from the CB by transferring money from their C-account to another account, making the balance on the C-account (further) negative[10]. This *increases the amount of CBDC* in the economy immediately, but the total amount that is borrowed can also be used a *signal that there is too less CBDC* in the economy. The interest paid by the banks to the CB is transferred immediately to an account of the government, just like the liquidity tax.

These two signals can be used to *control the amount of CBDC* in the economy. Here we differ from the MMT approach. In MMT the main signal for too much CBDC is inflation, indicating a lack of production capacity. Our approach is insensitive for inflation, because of the DP-linking. We presume that the two signals suggested here are more sensitive for the amount of CBDC that is needed in the economy.

The interest ρ that banks have to pay on the loans from the CB determines an upper limit on the *interest that has to be paid in the economy for a risk- free investment*. The upper limit for the interest to pay on a loan from the (commercial) bank for a risk-free investment is equal to $\rho + a$, with a an allowance for cost and profit of the bank. It is an upper limit, because part of the CBDC a bank has available is from deposits of other actors; the interest the bank pays on these deposits is already attractive for the owners if it is larger than $-\sigma$, because that is what actors receive on a CB savings account. . So, we have to choose $\rho > -\sigma$ to realize that it is attractive for actors to make their superfluous money available to the banks. But by keeping ρ close to $-\sigma$, the variations of the interest rates remain restricted.

A deposit on a CB savings account is more or less comparable with the possession of a long term government bond in the current system (or the reference system of section 4). People use these bonds as a secure savings possibility, as a part of their pensions. A CB savings accounts could give that same opportunity. This should be

[10] A critique on the Positive Money inspired proposals is that there is lack of credit possibilities (Fontana, Sawyer 2016). See Dyson et al. (2016) for a reaction.

taken into account in interpreting the total balance on the CB savings accounts as signal for too much CBDC in the economy. Only if the total balance on the savings accounts gets larger than some critical value, it may be interpreted as signal that there is too much CBDC in the system. This critical value is also an important monetary policy parameter. Maybe, it is even possible to make the liquidity tax on a savings account equal to 0 as long as the balance remains below a certain limit or to have separate "pension" accounts without liquidity tax. But these options are not worked out in this paper.

In the rest of this section, we make the just described system more precise with a more formal model. All variables are expressed as fractions of $D(t)$. We distinguish state (or "stock") variables and flow variables. First we introduce the state variables.

1) $E(t)$ is the total amount of CBDC on accounts in the economy at the start of day t. The economy consists of households, banks and businesses. Service producing government organizations and local governments are also interpreted as businesses[11]. The C-accounts of the banks are not included here and the CB savings accounts are also excluded. So, transferring CBDC to a CB savings account reduces $E(t)$ and banks borrowing from the CB increase $E(t)$.
2) $CB(t)$ is the total amount of CBDC that banks have borrowed from the CB at the start of day t.
3) $S(t)$ is the total amount of CBDC on CB savings accounts, at the start of day t.
4) The difference $S(t) - CB(t)$ is the net economy savings. It is called $NS(t)$.
5) $G(t)$ is the total amount of CBDC on accounts of the central government (the C-account not included), at the start of day t.
6) $CG(t)$ is the total amount of CBDC borrowed by the central government (through her C-account) at the start of day t.
7) Define $NG(t)$ as the net CBDC balance of the government: $NG(t) = G(t) - CG(t)$.

For all state variables $F(\cdot)$ we define $\Delta F(t) = F(t+1) - F(t)$.

[11] See Appendix 1 for a more detailed explanation.

Now we describe in more detail what happens during an arbitrary day t, the flow variables and the relationships between the variables.

1) The CB receives the liquidity tax and the interest on the C-accounts of the banks and pays this right away to the government. We call this $CBG(t)$. So:

$$CBG(t) = \tau' \cdot E(t) + \sigma' \cdot S(t) + \rho' \cdot CB(t) \tag{4}$$

with $\tau' = 1 - e^{-\tau/365}$ and σ' and ρ' defined in the same way.

2) We define $U(t)$ as the net government payments in day t (the payments minus the received taxes). The contributions through the CB ($CBG(t)$) are not included here. Together with the previous point, this implies:

$$\Delta NG(t) = CBG(t) - U(t) \tag{5}$$

3) Changes in $E(t)$ are caused by this government surplus (or deficit) of (5) and by changes in $NS(t)$:

$$\Delta E(t) = E(t) - \Delta NG(t) - \Delta NS(t) \tag{6}$$

4) Changes in $NS(t)$ are determined by the economy actors, households, businesses and banks. The "market" so to speak. In case of a perceived shortage of liquidity, $NS(t)$ is increased, in case of a perceived surplus of liquidity, $NS(t)$ is reduced. A simple way to model such a mechanism is to define E_R as the perceived requirement and assume for $\Delta NS(t)$:

$$\Delta NS(t) = \alpha \cdot (E(t) - E_R) \tag{7}$$

with α a constant > 0. Reality is probably more complex. This is just to illustrate the mechanism. If more erratic behavior is thought to be appropriate, it is possible to add a stochastic term to E_R. Note that the equations (4), (5) and (6) are accounting equations, while this equation (7) tries to model economy behavior.

5) The net economy savings, $NS(t)$ can be increased in two ways, by increasing the savings $S(t)$ or by reducing the bank loans from the CB, $CB(t)$. The allocation of $\Delta NS(t)$ to S(t) and CB(t) is determined by ρ, σ and the importance to keep some risk free savings at the savings accounts with the CB. We could model this allocation mechanism by assuming a lower limit, S_N for $S(t)$. This stands for the savings that are required as part of the pensions. The allocation can be modeled then by assigning a positive $\Delta NS(t)$ insofar as it is possible to $CB(t)$ and a negative $\Delta NS(t)$ insofar as it is possible to $S(t)$ (keeping $S(t) \geq S_N$). This results in:

$$CB(t+1) = \max\{0, CB(t) - \Delta NS(t)\}$$
$$\text{and } S(t+1) = NS(t+1) + CB(t+1) \qquad \text{if } \Delta NS(t) \geq 0 \tag{8a}$$

$$S(t+1) = \max\{S_N, S(t) + \Delta NS(t)\}$$
$$\text{and } CB(t+1) = S(t+1) - NS(t+1)) \qquad \text{if } \Delta NS(t) < 0 \tag{8b}$$

We assume here that the limit S_N remains constant over time. It results in a situation where $S(t) > S_N$ and $CB(t) > 0$ do not occur simultaneously. To make it more realistic one could add a stochastic term to S_N, making it vary over time[12].

To take the signals for too much CBDC and for too little CBDC seriously, they have to be used by the government to control the government surplus/deficit: $U(t) > CBG(t)$ or $\Delta NG(t) < 0$, a government deficit, leads to more CBDC in the economy, $U(t) < CBG(t)$ or $\Delta NG(t) > 0$, a government surplus leads to less CBDC. In case of a completely exogenous, autonomous $U(t)$, the system is not well controlled. If $NS(t) < S_N$, households can only realize the necessary risk-free savings by increasing $CB(t)$. So, the government has to create a deficit to correct this. If $NS(t) > S_N$, there is more than enough to facilitate the required risk-free savings. So, the government has to create a surplus to correct this. Problem is that S_N is not precisely known and may also be varying. One could work with an upper estimate S_U of S_N and a lower estimate S_L of S_N and apply the following rule:

[12] That necessitates to adapt formula's (8a/b) a little.

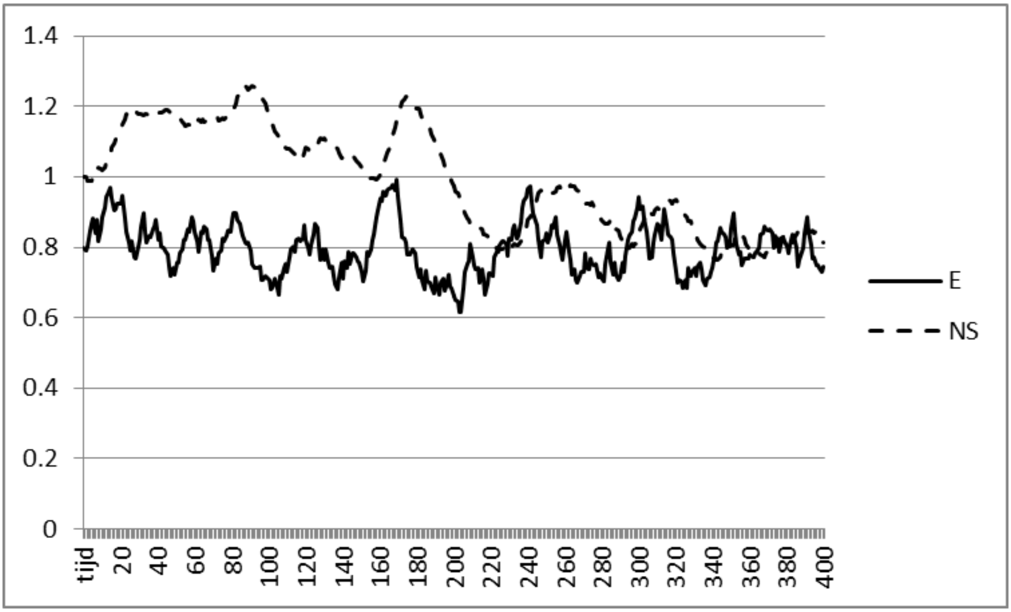
$\Delta NG(t) \leq \gamma \cdot (NS(t) - S_L),\quad$ if $NS(t) \leq S_L$ (9a)

$\Delta NG(t) \geq \gamma \cdot (NS(t) - S_U),\quad$ if $NS(t) \geq S_U$ (9b)

And no restrictions if $S_L < NS(t) < S_U$.

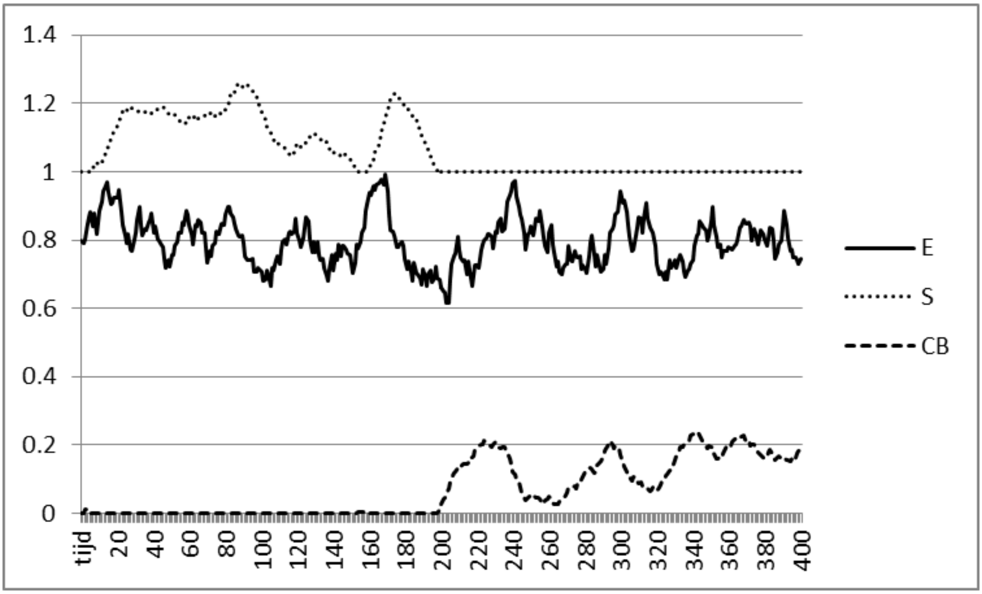
A way to explore these rules is to *simulate* their effect for the case where the government surplus is equal to some stochastic variable with mean 0. The stochastic variable is truncated then by the rules (9a) and (9b). If we combine this with expression (7), the behavior of $E(t)$ and $NS(t)$ is completely determined. We will show some simulation results. For the parameters α,γ we assume $\alpha = \gamma = 0.1$. The perceived requirement E_R is assumed to be equal to $0.8 + e$, with e uniformly distributed on [-0.1,+0.1]. The stochastic variable for the government surplus is uniformly distributed on [-0.05,+0.05]. For the bounds in (9a/b) we choose $S_L = 0.8$, $S_U = 1.2$. Figure 1 gives characteristic results (just one realization of the two stochastic variables) for 400 periods. Think of the periods being equal to 0.1 year. The course of $NS(t)$ being given, the allocation procedure of equations (8a/b) determines then the course of $S(t)$ and $CB(t)$. We use here $S_N = 1$. See fgure 2 for the results. In figure 3 we see the effect of adding variability to S_N. We add a uniformly distributed stochastic variable ([-0.1,+0.1]). We lose the property that $S(t) > S_N$ and $CB(t) > 0$ do not occur simultaneously. But the total effect is small. That suggests that the system is insensitive for the precise allocation of $\Delta NS(t)$ over $S(t)$ and $CB(t)$.

Figure 1. Characteristic simulation results for $E(t)$ and $NS(t)$.



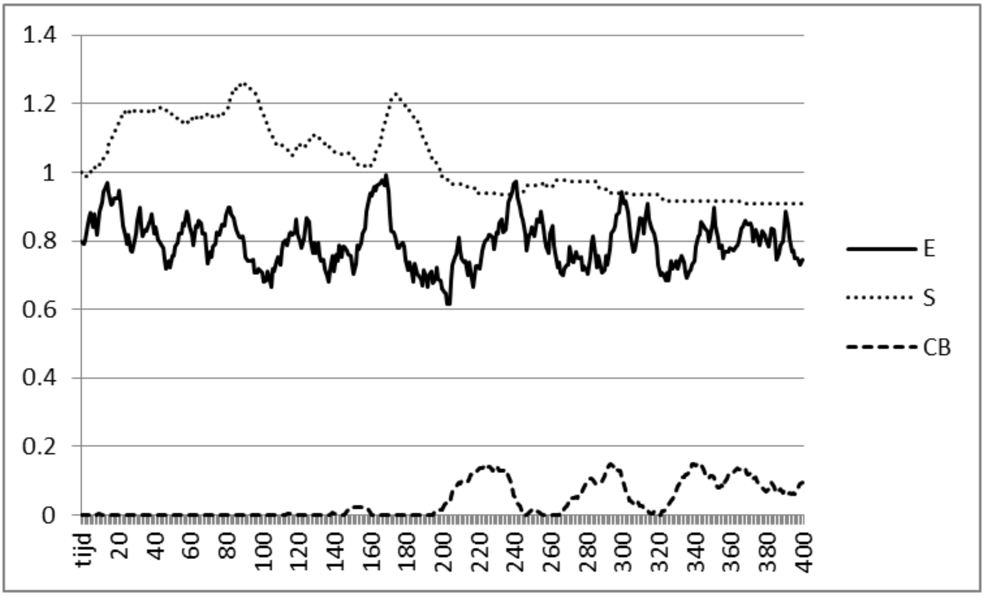
Source: authors' own elaboration

Figure 2. $NS(t)$ split into $S(t)$ and $CB(t)$



Source: authors' own elaboration

Figure 3. $NS(t)$ split into $S(t)$ and $CB(t)$, S_N varies stochastically



Source: authors' own elaboration

The example is arbitrary. We do not try to give a precise and realistic model of what is going to happen in reality. The simulations are just meant to show how the mechanisms described in equations (7), (8a/b) and (9a/b) work, how the behavior of the market (equations (7) and (8a/b) can be stabilized by rules for the behavior of the government (equations (9a/b)).

The total monetary system consists of the following elements:

a) The precise definition of the DP-proxy, $D(t)$.
b) The liquidity tax τ.
c) The limit H on the balances of the household accounts that are free of liquidity tax and the precise conditions for such accounts.
d) The reduced liquidity tax σ, and the precise conditions for a CB savings account.
e) The interest rate ρ on a loan from the CB, and the precise conditions for such a loan.
f) Guidelines for the feedback on $NS(t)$, including a way to deal with the critical limit S_N for the amount of risk-free savings that is considered to be adequate.

The variable $D(t)$ and the parameters τ, ρ, σ can be fixed, except during a first learning period. The parameter S_N varies with the demographic situation and it is well possible to develop rules about how it has to vary. The feedback mechanism is most complicated, because this interferes directly with the government expenses.

The independence of the CB from the government that is suggested with respect to the current monetary system is a fiction. The feedback that is necessary, namely of $\Delta NG(t)$ on $NS(t)$, complicates the monetary system, but it is better to accept it. That means that when discussing the government surplus or deficit, it is also necessary to consider the monetary situation. Maybe it is not possible to develop a fixed rule that links the government expenses completely with (only) $NS(t)$. The development of the prices and the functioning of the financial markets are also relevant here. But we expect that $NS(t)$ is an important signal and the necessity of feedback on it has to be taken seriously.

6. Rules versus discretion or rules & discretion. Near-money and extreme disturbances

The monetary system developed in the previous sections is aimed to be rule-based. That is a system where the decisions to be taken are predetermined by a public and transparent rule. That means in this case that the definition of $D(\cdot)$ has to be fixed and its definition and value have to be publicly available, that the parameters τ, ρ, σ have to be fixed, that there is a rule determining the parameter S_N and, finally, that there is a rule for the guidelines with respect to the government expenses that takes care of the feedback on $NS(t)$. It is clear that a pure rule-based system is not possible. Especially the last point is complicated. It has to be explored further. But, hopefully, the insensitivity of the system for changes in the total amount of CBDC in the economy is helpful here. The backbone of the rules is the linking of the account balances to $D(t)$.

The debate on rules versus discretion with respect to monetary policy is a classical one. People agree that a rule-based system has advantages. It is attractive that everybody knows the rules and can act accordingly. That it is not necessary for the different actors to anticipate on possible changes and for the CB to anticipate on these anticipations. See e.g. Stokey (2002) for model analyses illustrating how discretion with respect to the policy adds to unnecessary volatility. Rules that have been proposed are e.g. the k-percent rule of Friedman (increase the amount of money each year with k%) (see Friedman 1960) and the Taylor rule (relating the interest to pay on base money to the differences of actual inflation and norm inflation and actual growth and norm growth) (see Taylor 1993). Most rules are inflation oriented. But the performance of the rules is rather poor[13]. There is rather broad acceptance that the developments in the economy are so unpredictable that following fixed rules leads to a too low performance with respect to inflation, stability and economic development in general. We have to relate our proposal to this debate.

6.1. The role of near-money

Goodhart and Jensen (2015) argue that the distinction between two schools of monetary economics, the currency school and the banking school is important to understand the debate. The currency school separates money creation and financial intermediation. Payments are in this single currency. The banking school accepts that it is also possible to pay with demand deposits created and guaranteed by banks, possibly on a fractional reserve basis[14]. For the currency school it is essential to have a good way to establish the total amount of money. That is the main way to control the inflation. And, of course, the currency school proponents look for some general rule to determine the amount of money. The banking school is more pragmatic here. People can settle their transactions with money or with demand deposits or with whatever form of "near-money[15]". That brings about a variety of tools to influence the financial system and given this variety it is does not make sense to try to stick to fixed rules. The banking school goes for flexibility and discretion. An argument that may also play a role is that discretion gives also much more freedom to the CB. It is not only discretion, but it is *their* discretion, while rules can be discussed publicly and politically.

[13] It has to be noted that rules like that of Taylor are not even intended to be mechanistically applied. They serve rather as benchmark to make the CB monetary policy more transparent and easier to communicate. See also Levin (2014).

[14] This discussion goes back to Ricardo and his proposals for the establishment of a National Bank.

[15] Near money consists of highly liquid assets which are not cash, but can easily be converted into cash.

The banking school is main stream, but since the financial crisis of 2008 there has been a revival of the currency school. People have associated this crisis with the growing complexity of the monetary and financial systems. This complexity has led to a difficult to control growth of the financial sector, and the lack of transparency that came with it has resulted in various ways to abuse the possibilities (Roubini, Mihm 2021). So, there are good reasons to simplify, and one of the possibilities is to separate again money creation and financial intermediation. Goodhart and Jensen (2015) have some sympathy for this separation and see the advantages, but warn that it is difficult to determine a "hard and fast" distinction between money and near-money. The approach developed here belongs to the currency school. We presuppose indeed, that our money, CBDC, is used for all transactions or at least for all payments from households to businesses. The balances are linked to $D(t)$, the total sum of all these payments over the past year. This makes the system less sensitive for changes in the total amount of CBDC, but it is certainly important that using CBDC is by far the most important way to settle transactions. Otherwise, $D(t)$ is getting unstable as proxy of the DP.

Currently the most important forms of near-money are *Money Market Funds* (MMF) and *foreign currency* or *Bitcoins* and other crypto currency. We discuss these below.

1. MMF. The body of an MMF is formed by liquid bonds (close to their redemption date). An MMF can be used in the same way as bank deposits. If the payee requires payment in CBDC, the MMF share can be exchanged in CBDC just in time. Some payees may agree with direct payment in MMF. It is not to expect however, that the yield on liquid bonds is much higher than the yield on CBDC balances ($-\tau$ or $-\sigma$, depending on where it is stalled). And it is not necessary to use this option for security reasons, since CBDC is completely safe. Households are certainly not going to use it for their payments.

2. Foreign currency/bitcoins. Another possibility to deal with a surplus of liquidity (CBDC) is to exchange it for some foreign currency and change it back as soon as necessary. This may be attractive in times that $D(t)$ is not increasing while in other countries (or in the bitcoin world) the purchasing power of the currency remains stable. If the transactions are still settled with CBDC, this does not lead to a decrease of $D(t)$ and $D(t)$ is still a good basis for linking. To guarantee this is essential for our system. It is helpful here to have government and semi-government organizations requiring payment in CBDC. Maybe it is possible to determine that all transactions that have to be *accountable* are in CBDC.

6.2. Extreme disturbances

So, the backbone of the system, the taxed linking to $D(t)$ is rather robust. It works in all more or less normal circumstances, also if $D(\cdot)$ decreases temporarily. In exceptional circumstances, however, like the actual Corona crisis, it is necessary to apply discretion. In such cases we have to be aware of the fact that $D(t)$ is in fact an estimate of the future $D(t)$. The link has to be suspended until the economy is back to normal.

6.3. Decision making

The system is mainly rule-based. The rules are developed by the CB, but have to be agreed upon by government and parliament. This necessitates public and political discussion, first about the structure of the system. In a parallel paper (Van Hee, Wijngaard 2021) we explained how it is possible to migrate the current system into this one. So, it is feasible, but it is certainly a major change. We are not going to reflect on the possible discussions, but we just presuppose a situation where the structure of the system is accepted. The definition of $D(t)$ looks rather a-political. That is different, however, for τ, σ, ρ. But it may be helpful here that it is possible to work with a learning period. The same holds for the limit H on the household accounts that are free of liquidity tax. The final values of the parameters could be the result then of a gradual process of convergence. The parameter S_N is more dynamic, because it is also related to demographic changes. The CB has to develop general rules and discuss these publicly. The elements that are most open for discussion are the guidelines with respect to the feedback on $NS(t)$. It may be possible to develop explicit guidelines. But each year, the actual feedback is going to be the result of political decision making with respect to government expenses. Hopefully it is possible to develop bandwidths that are politically acceptable. How wide these bandwidths have to be depends on the sensitivity of the monetary performance (stability of purchasing power and of risk-free interest) for changes in the precise feedback. This has to be explored.

7. The eurozone

In the previous sections we considered the situation with one currency and one country and government. Is it possible to apply the same approach in the eurozone, with one currency and 19 governments/countries?

If we want to keep this idea of linking the account balances to a macro-economic variable, it has to be one and the same variable, a proxy $D(t)$ for the domestic product of the whole eurozone. There is a considerable heterogeneity within the eurozone, so, price levels may vary significantly from country to country. But as long as the price changes correspond, the automatic inflation correction through the linking works well. The parameters τ, ρ, σ are eurozone-wide. There is no option to make these country dependent. But that is different for the parameter S_N and the feedback on $NS(t)$, using e.g. the parameters S_L and S_U Here we have the possibility to make the system country dependent. Let $E_i(t), CB_i(t), S_i(t), NS_i(t), G_i(t), CG_i(t), NG_i(t)$ be the country specific forms of the corresponding variables, defined in section 5. We assume that the liquidity tax and the interest paid by banks for loans of the CB are transferred to the country of the account owner. We need to organize the feedback of $\Delta NG(t)$, so of all $\Delta NG_i(t)$ on $NS(t)$, so on all $NS_i(t)$. How can we translate, for instance, the feedback suggested in section 5 to this case with more countries? Refer to equations (9a/b).

Most straightforward is to choose (for all i):

$$\Delta NG_i(t) \leq \gamma \cdot (NS_i(t) - S_{Li}) \text{ if } NS_i(t) < S_{Li} \qquad (10a)$$
$$\Delta NG_i(t) \geq \gamma \cdot (NS_i(t) - S_{Ui}) \text{ if } NS_i(t) > S_{Ui} \qquad (10b)$$

It is possible of course to choose as well different control parameters γ_i for the different countries. It is not necessary to let the guidelines for government budgets be based on this kind of rules. But these rules illustrate well how the individual characteristics of the countries with respect to saving, leading to differences in S_{Ni} , can be taken into account. It is interesting to compare this with the guidelines that are used currently: a government deficit should not be higher than 60% of the DP.

8. Conclusions and suggestions for further research

This paper fits in the general movement of exploring the possibilities of Central Bank Digital Currency (CBDC) in our monetary systems. The weaknesses of the current systems became clear during the financial crisis of 2008 and its aftermath. These weaknesses are also connected with the two-tiered character of the system (base money and claims on base money): we use almost only bank money, claims on base money, while we are not very interested in the use of cash, the only form of base money accessible to us. It is widely agreed upon that it is time to widen the role of base money (or CBDC). The main stream is to fit this into the current system, so to have digital cash next to physical cash without changing the two tiered character of the system. We propose to go a big step further and make the system one-tiered, skip the use of physical cash and have CBDC as our primary form of money, the only legal tender[16]. That leads to a situation where the CB creates the money and the main role of the banks is to intermediate between lenders and borrowers.

The basis for such a new system, the payment system, is described in Van Hee and Wijngaard (2021). The main elements are sketched in section 2 of this paper. The rest of this paper is devoted to the exploration of the possibilities that such a change gives for the design of the monetary policy. An overview of the monetary tools that are available is given in section 3. In the sections 4 to 7 the tools are used to design one specific monetary policy. The first step is to link the account balances to a proxy of the DP. This is described in section 4. It makes the monetary system insensitive for price changes and conserves the purchasing power of the economic actors. The second step, described in section 5, is to allow that the government can borrow freely from

[16] In Van Hee and Wijngaard (2019) we discussed how ambivalent and dysfunctional such a marginal introduction of CBDC is.

the CB. This brings our proposal rather close to the Modern Monetary Theory (MMT). Bonds are not any longer necessary to finance the deficits of the government and not any longer available for the public as a secure form of saving. Instead of that we introduce the possibility to open a savings account with the CB that is relatively attractive. A too high total balance on these savings accounts can be used as a signal that there is too much CBDC in the economy and may lead to guidelines to restrict the government expenses. A high total amount of CBDC borrowed by the banks can be used as signal that there is too less CBDC in the economy. The two steps, described in section 4 and 5, lead to a monetary system with automatic inflation control and stability with respect to credit possibilities, savings possibilities and risk-free interest rate. The monetary policy is rule-based. The limits of this rule-based character of the policy are discussed in section 6. In the sections 4 to 6, we assume that there is one government with one CB, whereas in section 7 we explore the consequences of having more governments with one CB, like in the eurozone.

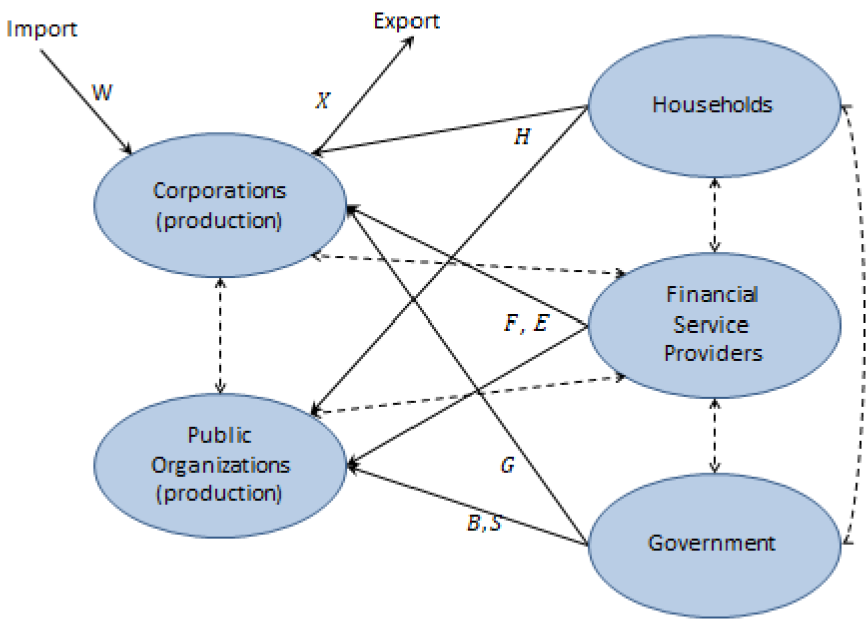
Looking at these results, we may state that the monetary policy that is developed is sufficiently attractive to warrant further consideration. It shows that the possibilities resulting from a switch to a CBDC based system are indispensable. Further research is necessary of course, to work out the designed monetary policy in more detail, but also to explore alternative policies.

We are not going to formulate a complete list of future research issues, however, because it starts anyway with the question of how to convince the community of bankers and monetary economists that the current system may have failed and that we have to consider a switch to a CBDC based system with as main role for the banks to intermediate between lenders and borrowers.

Appendix 1 The construction of a suitable DP-proxy.

We start with a somewhat alternative definition of the DP, Y. A definition that is close to the definitions normally in use, but that makes it easy to derive a simple approximation, $D(t)$ that can be monitored throughout the whole year. See figure 1.1.

Figure 1.1. Constructing a simplified version of the DP



Source: authors' own elaboration

The left hand side of the figure gives the producing organizations, the right hand the consuming organizations. The consuming organizations are Households, Financial Service Providers and Government, the producing organizations are (private) corporations and producing public organizations. The producing public organizations are for instance schools, hospitals, departments for the maintenance of roads and bridges, waterworks and sewerage, housing, etc. So, the government is split into a productive part and a non-productive part. In the non-productive part we find for instance: general direction (central and local), tax offices, etcetera. The precise distinction between productive and non-productive is not elaborated here, but is an important step in the detailed design of the DP.

Only the drawn arrows are included in the DP. These stand for expenses from consumers to producers. So, the expenses between producing organizations are not counted. Production is only counted when it is consumed.

All household expenses to producing organizations, H, are part of the DP. So, buying a house is also included. Direct expenses for health care are also included. The payments for health care that are made on behalf of insured households are included in E. Other insurances are treated in the same way. So, the payments made by a fire insurance company to a building company, for an insured household are included in E. The expenses of Financial Service Providers that are necessary to build and maintain their own organization (the operational costs) are included in F. The insurance premiums of households are included in the dashed arrow from Households to Financial Service Providers. Insurance premiums of corporations and (producing) public organizations and payments to these organizations made by financial service providers because of that are represented by dashed arrows from and to Financial Service Providers and are not included in the DP. The intermediating role of the Financial Service Providers has no direct effect on the DP [17]. Payments for financial products are anyway excluded from the calculation of the DP.

The expenses for the own organization (the operational costs) of the (non-productive) government are included in G. Subsidies for services for households are included in S. The other contributions from the government to public organizations are included in B. The precise split between productive and non-productive government is important here. For instance the household contribution for water and sewerage. Whether that is modelled as a tax paid to a tax office or as a service contribution directly paid to the producing organization depends on the precise split between government and producing public organizations.

[17] This is a bit awkward. The services of someone who helps you to organize your garden are included in the DP, while the services of someone who helps you to organize your finance are not included. This is suggested for pragmatic reasons. It is important that the expenses for the financial product are not included and it is not always easy to distinguish the expenses for the service and the expenses for the financial product.

Finally we have to include import W and export X. So the DP is defined as:

$$Y = H + E + F + G + S + B + X - W$$

To be able to monitor the DP directly from the payments that are made, we have to replace expenses by payments. So, we define $H(t)$ as the payments by households in the past year, as monitored on day t. The same for the other elements of the DP. This leads to the following approximation of the DP:

$$Y(t) = H(t) + E(t) + F(t) + G(t) + S(t) + B(t) + X(t) - W(t)$$

These variables are available for the CB throughout the year, if the payments are labelled sufficiently precise. We could use $D(t) = Y(t)$ then. There may be irregularities, however, in $Y(t)$. For instance because the government does not always make certain important payments at the same date. So, instead of using $Y(t)$ it may be better to use an exponentially smoothed average: $\hat{Y}(t) = \alpha \cdot Y(t) + (1 - \alpha) \cdot \hat{Y}(t-1)$. Another option is to skip $B(t)$ and choose the following approximation:

$$D(t) = Y'(t) = H(t) + E(t) + F(t) + G(t) + S(t) + X(t) - W(t)$$

Or even

$$D(t) = Y"(t) = H(t) + X(t) - W(t).$$

And $Y'(t)$ and $Y''(t)$ can also be smoothed of course.

Instead of $Y(t)$, it is also possible, of course, to use $c \cdot Y(t)$. That is completely equivalent. This makes it possible to switch smoothly from one approximation to another. Suppose at day t we want to switch from $Y(t)$ to $Y'(t)$. Then we define $c \coloneqq Y(t)/Y'(t)$ and we continue with $c \cdot Y'(t)$. Such a switch may be useful if there are some structural changes in the structure of the government and the way the productive government organizations are paid for. Consider for instance the possibility that it is decided that from a certain date onwards, all healthcare is completely free. That may result in some instability of the payments for healthcare. It may be better therefore to exclude healthcare for some time from $D(t)$ and include it again as soon as the situation has stabilized.

We are not going to give one final choice for how to define $D(t)$. The different options have to be explored: their stability, their quality as approximation of $Y(t)$ and the complexity of the labelling that is necessary. We assume here that there is a reasonable possibility.

Labelling

Transaction labelling is necessary to be able to estimate the components of the DP-proxy that is actually used and of potential alternatives. This seems to be a heavy burden, but we have already such a labeling for the execution of the VAT and the payment industry is obliged to monitor all transactions in order to prevent illegal activities, among others white washing.

- Labeling must be easy to do: Anyway, the sender and the receiver should be part of it, as well as their BIC codes. Further it should be close to the existing VAT codes.
- The system must keep fingerprints of all transactions in order to verify payments.
- Everybody should record its own transaction details in order to be able to prove the legality of the payments using the fingerprints in the system.

Appendix 2: Price instability

In the monetary system developed, the amount of money is designed to follow the prices. The prices are ideally exogenous. But in reality there may also be an effect the other way around. Price setting is a matter of individual decisions, but maybe price increases are easier accepted if people know that the average price increases are compensated by more money. In that case the prices are partly endogenous. To explore this we consider the situation with a constant real domestic product. Only the price level is changing and we are going to investigate how the DP linking that we propose in section 4 influences the price level.

Let $p(t)$ be the price level in period t. Assume that $p(0) = 1$ and that the nominal domestic product in period 0 is equal to 1. So, the nominal domestic product in period t is equal to $p(t)$. The price level is assumed to develop according to the following mechanism:

$$\ln p(t) = \ln p(t-1) + s(t) + \alpha(\ln m(t) - \ln m(t-1) \qquad (2.1)$$

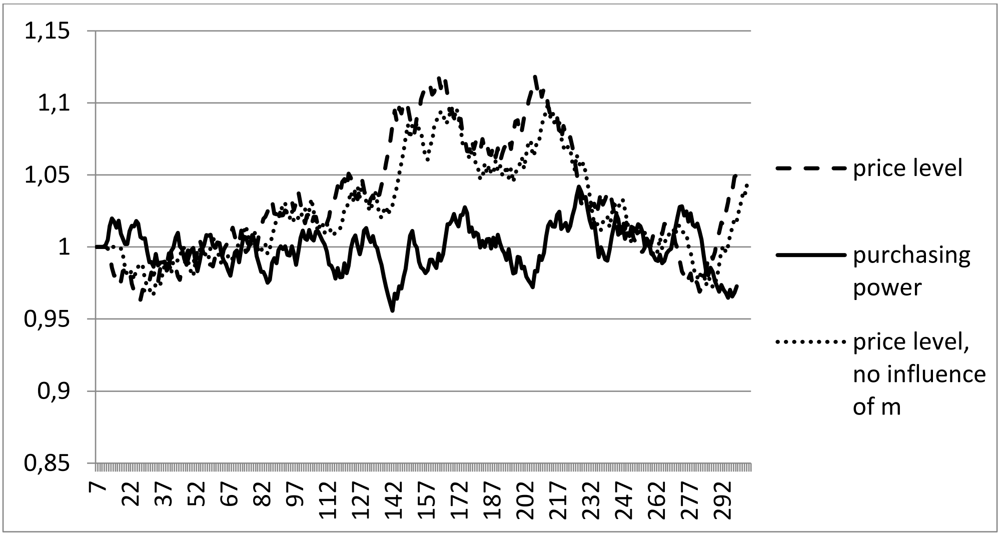
with $m(t)$ the amount of money during period t and $s(t)$ is (independently) uniformly distributed on $[-b, +b]$. If the amount of money has no influence, $\alpha = 0$. If the amount of money is fully reflected in the price level, $\alpha = 1$. We combine this with the assumption that the real domestic product remains constant, 1. For sake of convenience we assume that there are 10 periods per year. Linking the account balances to the domestic product implies:

$$m(t) = m(0) \cdot \{\sum_1^{10} p(t-i) \cdot 1\}/10 \qquad (2.2)$$

So, the balance of an account has grown with a factor $m(t)$ while the prices have grown with a factor $p(t)$. That means that the purchasing power has grown with a factor $m(t)/p(t)$. Because of the delay due to the moving average in formula (2.2), the purchasing power is not completely constant. It is interesting to check now how the prices and the purchasing power develop.

Figures 2.1 gives characteristic results (some realization of the $s(\cdot)$) for the case with $b = 0.01$ and $\alpha = 0.2$. Note that the standard deviation of the $\sum_1^{10} s_{t-i}$ is about equal to 0.02. Such a price level change in a year is considerable indeed. Next to the price level as it develops with influence of the amount of money, we give the price level if there is no influence of the amount of money ($\alpha = 0$).

Figure 2.1: The case $b = 0.01$ and $\alpha = 0.2$



Source: authors' own elaboration

We see how the price level variations are aggravated indeed by the mechanism (1.1). But also that the effect is relatively small for $\alpha = 0.2$. And the stability of the purchasing power is not damaged by it.

Bibliography

Admati A., Hellwig M. (2013), The Bankers New Clothes, Princeton University Press, New York.

Bordo M.D., Levin A.T. (2017), Central Bank Digital Currency and the Future of Monetary Policy, NBER Working Paper Series 23711.

Buiter W.H. (2009), Negative Nominal Interest Rates. Three Ways to Overcome the Zero Lower Bound, “The North American Journal of Economics and Finance”, vol. 20 no. 3, pp. 213–238.

Dyson B., Hodgson G., Van Lerven F. (2016), A Response to Critiques of ‘Full Reserve Banking’, “Cambridge Journal of Economics”, vol. 40, pp. 1351–1361.

ECB (2020), Report on a Digital Euro, https://www.ecb.europa.eu/pub/pdf/other/Report_on_a_digital_euro~4d7268b458.en.pdf [01.09.2021].

Fontana G., Sawyer M. (2016), Full Reserve Banking. More ‘Cranks’ than ‘Brave Heretics’, “Cambridge Journal of Economics”, vol. 40 no. 5, pp. 1333–1350.

Friedman M. (1960), A Program for Monetary Stability, Fordham University Press, New York.

Goodhart Ch.A.E., Jensen M.A. (2015), A Commentary on Patrizio Lainà’s ‘Proposals for Full Reserve Banking: A Historical Survey from David Ricardo to Martin Wolf’, “Economic Thought”, vol. 4 no. 20, pp. 20–31.

Van Hee K., Wijngaard J. (2019), All Attention to Debt Stands in the Way of Improving Money, “ESB”, vol. 104, pp. 251–253.

Van Hee K., Wijngaard J. (2021), A new digital currency system, :Central European Review of Economics and Management”, vol. 5 no. 4, pp. 33-60.

Huber J. (2017), Sovereign Money. Beyond Reserve Banking, Palgrave, Cham.

Jackson A., Dyson B. (2012), Modernising Money. Why Our Monetary System Is Broken and How It Can Be Fixed, Positive Money, London.

Kamstra M., Shiller R. (2008), The Case for Trills. Giving Canadians and Their Pension Funds a Stake in the Wealth of the Nation, “C.D. Howe Institute Commentary”, no. 271, https://www.cdhowe.org/sites/default/files/attachments/research_papers/mixed//commentary_271.pdf [01.09.2021].

Kelton S. (2020), The Deficit Myth. Modern Monetary Theory and How to Build a Better Economy, John Murray, London.

Levin A. (2014), The Design and Communication of Systematic Monetary Policy Strategies, “Journal of Economic Dynamics and Control”, vol. 49(C), pp. 52–69.

Piketty T. (2014), Capital in the Twenty-First Century, Harvard University Press, Cambridge MA.

Roubini N., Mihm S. (2010), Crisis Economics. A Crash Course in the Future of Finance, Penguin Books, London.

Ryan-Collins J., Greenham T., Werner R., Jackson A. (2011), Where Does Money Come from, New Economics Foundation, London.

Stokey N.L. (2002), 'Rules vs Discretion' after Twenty-Five Years, "NBER Macroeconomics Annual", vol. 17.

Sveriges Riksbank (2017), The Riksbank's e-krona project: Report 1, https://www.riksbank.se/globalassets/media/rapporter/e-krona/2017/rapport_ekrona_uppdaterad_170920_eng.pdf [01.09.2021].

Taylor J.B. (1993), Discretion versus Policy Rules in Practice, "Carnegie-Rochester Conference Series on Public Policy", vol. 39, pp. 195–214.

CENTRAL EUROPEAN REVIEW
OF ECONOMICS AND MANAGEMENT

ISSN 2543-9472; eISSN 2544-0365

Vol. 5, No. 4, 96-115, December 2021

www.cerem-review.eu
www.ojs.wsb.wroclaw.pl

Money growth and social stability

Erdem BASCI

TED University, Ankara, Turkey

Sidika BASCI

Ankara Yildirim Beyazit University, Turkey

Tahar GHERBY

EISTI, Cergy, France

Received: 15.07.2021, Revised: 01.11.2021, Accepted: 26.01.2021
doi: http://dx.doi.org/10.29015/cerem.931

Aim: Both the Keynesian and the Fisherian channels of sovereign money growth have slowed down significantly in the decade following the Global Financial Crisis (GFC). Together with the rise of fintech, privately issued unbacked crypto-assets tried to fill this void. The developments have revived the interest on the Central Bank Digital Currency (CBDC) idea and on developing potential channels for future sovereign money growth. The aim of this paper is to compare the Keynesian and Fisherian channels of sovereign money growth regarding their impact on wealth distribution and inflation.

Design / Research Methods: We use a simple monetary model with heterogeneous agents. In our model, the agents are consumers with different spending propensities but with equal initial wealth levels and with exactly the same non-interest incomes over time.

Conclusions / findings: We show that the Keynesian (uniform) money growth channel has a softening effect on the wealth dispersion and thereby, an upward pressure on money velocity. The model implies that the inclusive nature of current post-Covid19 recovery plans may have a desirable impact on social stability. Yet, these plans may turn out to be more inflationary in comparison the post-GFC policies.

Originality / value of the article: This paper shows that heterogeneity of economic agents should not be ignored by post-GFC policy makers and that how new money is created matters in an essential way under heterogeneity of savings behaviour.

Correspondence address: Erdem BASCI, TED University, Ankara, Turkey. E-mail: erdem.basci@tedu.edu.tr. Sidika BASCI, Ankara Yildirim Beyazit University, Turkey. E-mail: sidika.basci@gmail.com. Tahar GHERBI. EISTI, Cergy, France. E-mail: tahar.gherbi@gmail.com.

Implications of the research: The implication for policy makers is that the demand deficiency associated with the fall in money velocity and the worsening of wealth dispersion may be softened by a more inclusive money growth regime, potentially with the practical use of CBDCs. Yet, the extra inflationary impact of such a regime needs to be kept in mind.

Key words: Money Velocity, Money Growth, Heterogeneity, CBDC, Wealth Distribution, Sustainable Development Goals, SDG10, Inequalities, Inflation
JEL: D31, E4, E63

1. Introduction

The growth rate of broad money supply aggregates has been modest over the decade following the Global Financial Crisis (GFC). This coupled with a several decades long fall in the velocity of money (Basci, Gherbi 2020) seems to have led to a demand deficiency era in most G7 countries (Basci, Basci 2021), until very recently. Yet, following the Covid-19 pandemic shock, the nature of the massive expansionary fiscal, monetary and financial sector policies in especially the United States (English et al. 2021; Carroll et al. 2021) have the potential to reverse this trend in low nominal demand growth towards a more inflationary one (Blanchard, 2021; Goodhart 2020; Summers 2021).

The rise of digitalization and the decline of nominal and real interest rates over the last four decades have made it necessary to rethink about the future of macroeconomic policy. The rise of digitalization paves the way for a more inclusive monetary system. The fall in interest rates opens up fiscal room for more expansionary policies. Yet, both of these opportunities require careful analysis and design considerations before taking any concrete policy action. In this paper we demonstrate that 'agent based modelling' (ABM) is a practical modelling tool for that purpose.

The rise of digital technologies in finance (fintech) combined with moderate growth rates in the quantity broad money aggregates in developed countries have paved the way to the development of privately issued unbacked crypto assets. This development has necessitated innovations in public monetary and financial services provided by the sovereigns as well.

On the fintech side, account-based Central Bank Digital Currencies (CBDC) have come up as an innovative idea that would enable equal access of masses to low cost and high quality services offered by sovereign money, simply via their national identification numbers.[1] On the fiscal side the use of 'checks' mailed directly to the home addresses of citizens as part of massive stimulus packages have become more frequent following the Covid-19 pandemic from early 2020 onwards.

Privately issued unbacked crypto assets are by construction both economically and socially unstable.[2] Potentially stable alternatives, the so-called 'stable coins,' have to be backed fully by sovereign money if they really are to be stable. In contrast, national currencies issued by sovereign states have shown success regarding price stability, especially over the last four decades. Yet, implications of sovereign money on social stability has been less explored. The focus of this paper, therefore, will be on sovereign money growth channels and their implications on social stability via wealth dispersion.

In the paper, we construct a heterogeneous agent model where sovereign money can grow in one of two regimes. In the Fisherian regime, money grows proportionally to the nominal interest rate which consist of expected inflation and the real interest rate. In the Keynesian regime, money grows via equally distributed transfers to all citizens.

We find by using a simple heterogeneous agent monetary model that the Keynesian channel of money growth may have desirable effects on wealth dispersion, yet it is more inflationary than the Fisherian alternative.

The paper proceeds as follows. Section 2 presents some stylised facts. Section 3 presents the model and the equations. The analytical steady state solutions for the case of two agents are derived in Section 4. The simulation results with transition dynamics for more than two agents are presented in Section 5. Section 6 concludes with some remarks.

[1] See BIS (2021: Chapter 3) on potential benefits of account based CBDCs. Opportunities for public authorities from fintech like the recently developed fast payments systems are also discussed here. Once the account based CBDCs are fully in place, there will be no further need for mailing checks to imprecise home addresses by the fiscal authority.

[2] In addition to wild fluctuations in their prices, unbacked private crypto assets are prone to cyber-security risks as well as to use in illicit activities. See BIS (2021: Chapter 3) and the references therein.

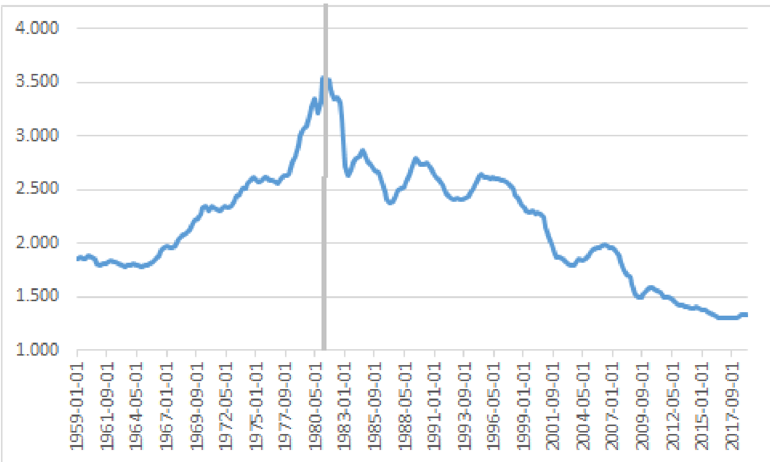
2. Stylized facts

The first stylised fact is the sustained fall in the velocity of circulation of broad money stock during the last four decades. Velocity of money is defined by the below equation:

$$Mv = Py \tag{1}$$

where M is the total amount of money in an economy during a given period, v is the money velocity, P is the price level associated with transactions for the economy during the period and y is the real total income of the economy.

Figure 1. Broad money stock velocity for the U.S.



Source: Federal Reserve Bank of St. Louis, https://fred.stlouisfed.org/
Note: Seasonally adjusted quarterly data for the velocity of the broad U.S. money aggregate MZM .

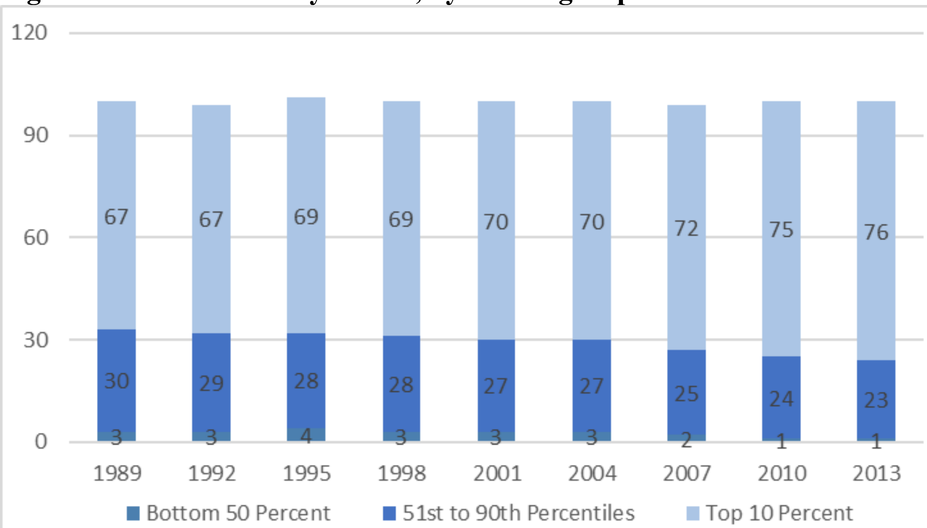
There is a sustained fall in the velocity of U.S. broad money in the recent decades (Figure 1). The structural change is around year 1980, when the Federal Reserve System has started controlling the Federal Funds Rate directly. This was made possible after technological advance in the information and communication technologies, allowing for clearing bank reserves on a daily basis by the Central

Bank. This operational change of making the short term interest rate the main policy instrument of the central bank, coupled with the independence of the Central Bank, opened up a new era of an unprecedented sustained fall in the velocity of broad money.

Basci and Gherbi (2020) attempt to explain such a sustained fall in velocity in a model with consumer heterogeneity. Yet in that paper, there is no money growth assumed and the data before 1980 is not addressed. In this paper we will argue that the inflationary Keynesian monetary growth regime may have led to a relatively more even distribution of money wealth. Following Fisherian decades of money growth therefore was a transition period to a new steady state with much lower velocity, where money has been accumulated in the hands of high savers.

The second stylized fact in line with the above line of reasoning is the sustained widening of the U.S. wealth dispersion after the 1980s.

Figure 2. Shares of family wealth, by wealth group for the U.S.



Source: Congressional Budget Office US, Karamcheva (2016).

In Figure 2 above, the trend in concentration of wealth in the top 10 per cent of the population is evident in the US after the end of the 1980s. This is consistent with the fall in velocity of money, as explained in Basci and Gherbi (2020) in a model without money growth. In the current paper, we will argue that the same dynamics prevail if money growth is proportional (regardless of what the rate of money growth is). This may explain some of the stylised observations in the post 1980 Fisherian era of monetary policy. Such transition dynamics which are sustained over many years are too important to ignore.

3. The model

In our model, the only source of heterogeneity is the savings behaviour of the agents. The agents are consumer-producers with exactly equal initial wealth and equal labour income over time. The wealth can be held in the form of sovereign issued fiat money. We will study two alternative sources of money growth.

In the first case, the stock of money will grow *evenly* via newly produced cash transfers to all agents. The transfers will be equal per capita. We will call this the *Keynesian* channel. The thought experiment is originally due to J.M. Keynes, although the following literature called it 'helicopter money.'[3]

In the second case, the stock of money will grow *proportionally* via newly produced money in the banking system. The transfers will be in the form of interest earned on existing money balances. We will call this the *Fisherian* channel. This can be attributed to the original work of Irving Fisher (Fisher, 1930) who decomposed nominal interest rates into expected inflation and real interest rate components.[4]

We will assume the presence of N agents. M denotes the total amount of money in the economy. $\{M_{1t}, M_{2t}, \ldots, M_{Nt}\}$ is the vector of amounts of money each individual has at time t. $M_t = \sum_{i=1}^{N} M_{it}$ for all t. The budget constraint for agent i at time t is:

[3] See Bernanke (2002) citing both J.M. Keynes and M. Friedman in his seminal speech while using the term 'helicopter money' to mean money financed tax cuts. Recently, some prominent European authors began to use the term 'helicopter money' to mean money financed equal transfers to households. See for example Gali (2020a, 2020b) and Martin et al. (2021).

[4] In 1970s the Keynesian channel of money creation has been more dominant. After 1980, the Fisherian chanel has become more dominant under the guidance of independent central banks. See Jilek and Matusek (2010) and McLeay et al. (2014) for post 1980 channels of money creation in the banking system. Jilek and Matusek (2010: 44) spells out interest rate paid on deposits, as one prominent channel for money growth.

$$M_{i,t+1} = M_{it} + MT_{it} - C_{it} + W_{it}L \tag{2}$$

where MT_{it} is the monetary transfer received at the beginning of time t, W_{it} is the wage rate, L is working time and C_{it} is the consumption level of the i^{th} agent at time t. Since initially, money is distributed equally among the agents in the economy, the initial condition is:

$$M_{i,0} = M_0/N \text{ for all } i \tag{3}$$

We assume that consumption is a linear function of post-transfer money, $PTM_{it} = M_{it} + MT_{it}$ so:

$$C_i(PTM_{i1}) = \gamma_i PTM_{it} \quad 0<\gamma_i<1 \text{ for all } i \tag{4}$$

where γ_i is propensity to spend out of money for agent i. C is the total nominal demand in the economy. $\{C_{1t}, C_{2t}, \ldots, C_{Nt}\}$ is the vector of consumption spending by each individual at time t. $C_t = \sum_{i=1}^{N} C_{it}$ for all t.

The total spending to buy the constant amount of real output, y, determines both the price level at time t, via $p_t = C_t/y$ and the nominal wage income, which is nominal revenue distributed equally across all agents, $W_{it}L = C_t/N$. The gross inflation rate is calculated as usual via, p_{t+1}/p_t.

In both cases, growth rate of total money stock will be taken as the same for comparison purposes. The method of money growth is however different. In the Fisherian case,

$$M_{i,t+1} = M_{it} + rM_{it} - C_{it} + W_{it}L$$

will prevail for all t and for all i, while in the Keynesian case,

$$M_{i,t+1} = M_{it} + rM_t/N - C_{it} + W_{it}L$$

will prevail, where r is the growth rate of total money balances in both cases.

4. Analytical solution for the case of two agents

In this section we will study the steady state money shares and the corresponding velocity of money for the Keynesian and the Fisherian money growth regimes.

Let i=1,2 denote agents 1 and 2. We will assume that, $0 < \gamma_1 < \gamma_2 < 1$. Agent 1, therefore is assumed to be more patient that agent 2.

In the case of the Keynesian money growth regime, new money will be divided equally among the two agents:

$$M_{1,t+1} = M_{1t} + rM_t/2 - C_{1t} + W_{1t}L \tag{5}$$

$$M_{2,t+1} = M_{2t} + rM_t/2 - C_{2t} + W_{2t}L \tag{6}$$

It will be convenient to work with money shares of the two agents for calculating their steady state values. We will denote the post transfer money share of agent *i* by,

$$m_{it} = (M_{it} + \frac{rM_t}{2})/((1+r)M_t).$$

Substituting for consumption values from (4) and wage income values from $W_{it}L = C_t/2$ in (5) and (6) and dividing their both sides by the post transfer total money stock, $(1+r)M_t$ and rearranging, we obtain the two equations for the evolution of money shares:

$$(1+r)m_{1,t+1} = \frac{r}{2} + (1 - \frac{\gamma_1}{2})m_{1t} + \frac{\gamma_2}{2}m_{2t} \tag{7}$$

$$(1+r)m_{2,t+1} = \frac{r}{2} + (1 - \frac{\gamma_2}{2})m_{2t} + \frac{\gamma_1}{2}m_{1t} \tag{8}$$

It is easy to verify that the money shares always add up to one, the above system of equations is stable and the steady state value of the less patient consumer (agent 2), m_{2s} can be calculated as:

$$m_{2s} = \frac{r + \gamma_1}{2r + \gamma_1 + \gamma_2}$$

Taking the derivative with respect to *r* we get:

$$\frac{dm_{2s}}{dr} = \frac{(2r + \gamma_1 + \gamma_2) - 2(r + \gamma_1)}{(2r + \gamma_1 + \gamma_2)^2}$$

or,

$$\frac{dm_{2s}}{dr} = \frac{(\gamma_2 - \gamma_1)}{2r + \gamma_1 + \gamma_2} > 0$$

since $0 < \gamma_1 < \gamma_2 < 1$.

The steady state value of the less patient consumer's money share, therefore is an increasing function of the money growth rate, *r*. Since $m_{1s} + m_{2s} = 1$, the steady state value of high saving consumer is a decreasing function of money growth. Hence a Keynesian inflation has a softening effect on the wealth distribution arising from heterogeneous savings.

The velocity of circulation of post transfer money stock defined through equation (1) can be calculated for the steady state solution as follows.

$$v_t = \frac{Y_t}{(1 + r)M_t} = \frac{C_{1t} + C_{2t}}{(1 + r)M_t}$$

Substituting for respective nominal consumptions from (4) and rearranging for money shares of the two agents, we obtain the velocity in a simplified form:

$$v_t = \gamma_1 m_{1t} + \gamma_2 m_{2t}$$

Using $m_{1t} + m_{2t} = 1$ we obtain,

$$v_t = \gamma_1 + (\gamma_2 - \gamma_1) m_{2t}$$

which holds for the steady state value as well. Substituting for the steady state solution for the money share of the less patient consumer (agent 2) and rearranging, we can solve for the steady state value of velocity in the Keynesian money growth regime.

$$v_s = \gamma_1 + (\gamma_2 - \gamma_1)\frac{r + \gamma_1}{2r + \gamma_1 + \gamma_2}$$

The steady state velocity is an increasing function of the money growth rate, *r* in the Keynesian regime. Therefore the positive distributional effect of inflating the economy this way has a cost of higher inflation in transition to steady state and higher equilibrium prices on the steady state path.

Going through a similar analysis for the Fisherian money growth regime is relatively easier, since the proportional nature of money growth to individual money balances gives rise to a *neutrality* result. Neither the money shares, nor the transition or the steady state velocity of money are affected by the money growth rate, *r,* under the Fisherian regime. In this case $m_{2s} = \gamma_1/(\gamma_1 - \gamma_2)$ regardles of the speed of money growth.

In order to observe the transition dynamics in a more crowded economy, in the next section we will present the simulation results from typical runs of our model with more than two agents under the two distinct regimes of money growth.

5. Simulation results[5]

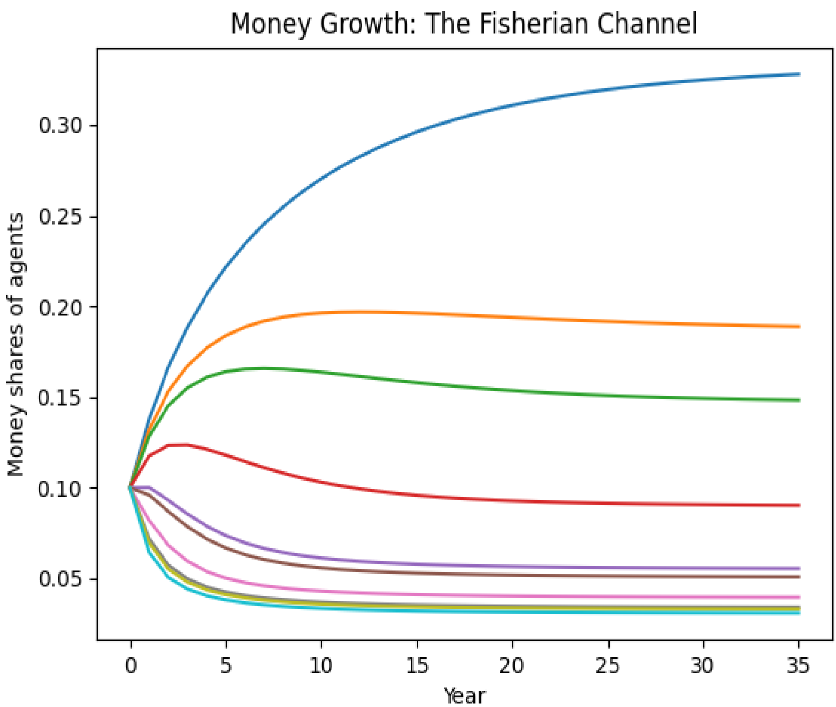
For simplicity of demonstration and without loss of generality, the number of agents (i.e. consumers) in the economy, *N,* is taken as 10. The initial total amount of money in the economy, *M,* is taken as 1000 and by Equation (3), $M_{i0} = 100$ for all i. Therefore, initially all agents have an equal share in liquid assets of 10 per cent. The total real production level, *y,* is taken as 100 real units of consumption goods.

[5] Results are obtained by using a code written for Python and is available upon request from the authors.

The agents are assumed to be heterogeneous and their marginal propensities to consume (MPC) are generated randomly from a uniform distribution between 5 per cent and 95 percent. This is consistent with a very wide range of MPCs reported in the empirical literature (see for example Carroll et al. 2017).

For comparability of the results in all simulations, the seed of the random variable is assigned the same value in all simulations. The lowest MPC value is 0.075 and the highest MPC value is 0.813. The most patient agent therefore spends 7.5 per cent of its post-income monetary wealth, while the least patient one spends 81.3 per cent of its monetary wealth. The later can be thought to represent the 'hand-to-mouth' consumers with very little steady state precautionary money balances in comparison to their income. The rest of the agents have MPC values evenly spread between these two extremes.

Figure 3. Wealth dispersion over agents, Fisherian case



Source: authors' own elaboration

Figure 3 shows the results for the run the simulation with 10 agents and a constant money growth rate of 7 per cent per annum. As described in Section 3, all agents receive an equal amount of wage income, since they are assumed to be homogeneous regarding their skills and preferences for work. Therefore, the only source of inequality in this paper is the heterogeneity in the consumption and saving propensities of the agents.

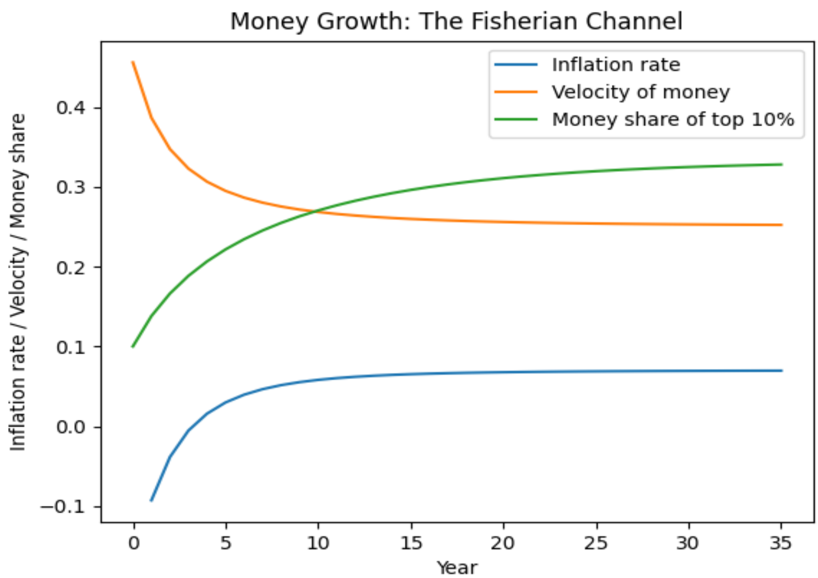
The blue line at top shows the rise of the money share of the most patient agent over the years. In contrast, the green line at the bottom shows the decline in the money share of the least patient agent. In this Fisherian case, money grows solely proportionally to the money balances of each agent (at 7 per cent per annum). Therefore, the dispersion between money shares of the top 10 per cent and the bottom 10 per cent savers is quite remarkable.

The total nominal demand grows significantly below the rate of growth of aggregate broad money, especially in the initial years, because of the high savings of the patient agents. As they accumulate more monetary wealth, and thereby get closer to their desired steady state money-to-income levels, their consumption expenditures increase towards their income levels. The total spending growth also approaches the 7 per cent broad money growth. Hence the inflation rate approaches 7 per cent from below, following initial years with a very *deflationary* bias.

Figure 4 shows the equilibrium path of transition in key macroeconomic variables. The growth rate of broad money is constant at 7 per cent per annum throughout the simulation period. Money grows proportionally to own money balances of each agent, i.e. only the Fisherian channel is activated.

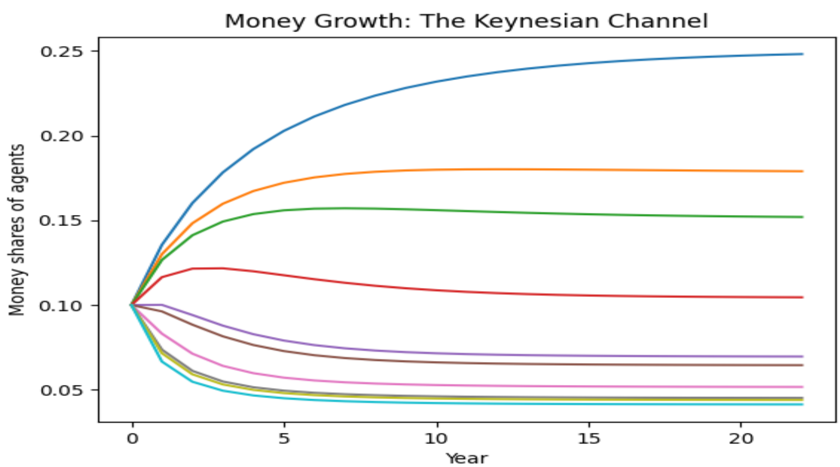
The fall in the velocity of money together with the rise of the share of money holdings of high savers is remarkable. The sharp fall in money velocity, especially in the earlier years, puts a significant amount of deflationary pressure on the inflation rates. Even at a 7 per cent nominal money growth, inflation is pushed into a deeply negative territory in the first year due to a shortfall in aggregate spending. Over time as the wealth distribution approaches a steady state, the inflation rate converges to 7 per cent from below.

Figure 4. Velocity, inflation and wealth share of top savers: Fisherian case



Source: authors' own elaboration

Figure 5. Wealth dispersion over agents: Keynesian case



Source: authors' own elaboration

An alternative way of money growth could potentially soften this impact. If new money were to be distributed equally across all agents in the same society as above, the wealth distribution, the velocity of money and the inflation dynamics could potentially be different.

Figure 5 presents the results of the case where money growth is distributed evenly across agents. We call this the Keynesian channel. First the growth rate of broad money is set to be 7 per cent by the monetary and fiscal authorities and then this amount of new money is deposited to the accounts of each of the 10 agents equally. This exercise is repeated at the beginning of each period.

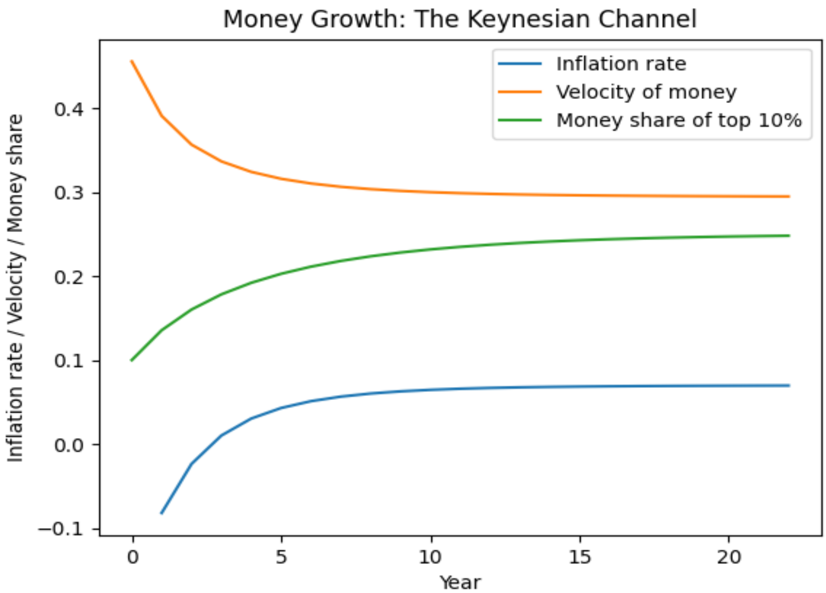
The first observation in Figure 5 is a similar pattern with Figure 3. The wealth dispersion is inevitable because of savings heterogeneity. Yet, the wealth dispersion is reduced, both in transition and in the steady state, due to the nature of transfers in this case. For example, in year 20, the money share of the most patient agent is 26.9 per cent in the Keynesian money growth regime, while it used to be 31.1 per cent in the Fisherian regime.

A similar softening impact may well be expected for the macroeconomic variables like the velocity of money and inflation.

Figure 6 presents the transition paths for velocity and inflation to steady state. Both the initial pace of fall of velocity of money and the shortfall at its steady state value are seen to be more modest in the Keynesian case than in the Fisherian case. Therefore, the deflationary impact on the price inflation rates due to the heterogeneity in savings rates are softer in the initial transition years in the Keynesian case. Yet, eventually inflation again converges to the 7 per cent level in the steady state.

A natural question would be about the impact of different money growth rates under the two different money growth regimes. For that we ran the model numerically under money growth rates ranging from 3 per cent to 30 per cent.

Figure 6. Velocity, inflation and wealth share of top savers: Keynesian case



Source: authors' own elaboration

Table 1. The impact of money growth: the Fisherian channel

Money Growth Rate (%)	Top 10% Money Share in Year 20 (%)	Velocity of Money in Year 0	Velocity of Money in Year 20	Inflation (Geometric Average Annual, %)
3	31.1	0.456	0.256	0.07
4	31.1	0.456	0.256	1.04
7	31.1	0.456	0.256	3.96
15	31.1	0.456	0.256	11.73
30	31.1	0.456	0.256	26.30

Source: authors' own elaboration

Table 1 presents the results for the Fisherian regime. The money growth rates are taken as 3, 4, 7, 15 and 30 per cent in separate simulations with the same (10 agents) artificial societies.

The money share of the top saver rises from an initial value of 10 per cent all the way up to above 30 per cent by year 20, and continues to grow more gradually afterwards. In tandem, the money velocity falls from an initial value of 0.456 to 0.256 in year 20. The fall in velocity keeps average inflation significantly below the money growth rates in the initial 20 years of transition.

One striking observation is the *neutrality* of money velocity and wealth shares visa-vis different money growth rates. The figures for these two variables follow exactly the same time path at all money growth rates. Hence the deflationary bias is also the same. This is due to the proportional nature of money growth in the Fisherian case.

Table 2. The Impact of money growth: the Keynesian channel

Money Growth Rate (%)	Top 10% Money Share in Year 20 (%)	Velocity of Money in Year 0	Velocity of Money in Year 20	Inflation (Geometric Average Annual, %)	Extra Inflation (Geometric Average Annual, %)
3	27.8	0.456	0.275	0.43	0.4
4	26.9	0.456	0.281	1.50	0.5
7	24.7	0.456	0.295	4.70	0.7
15	20.9	0.456	0.323	13.04	1.2
30	17.4	0.456	0.355	28.39	1.6

Source: authors' own elaboration

Table 2 presents the results for the Keynesian regime. For comparability, the money growth rates are taken as 3, 4, 7, 15 and 30 per cent, exactly the same as those in the Fisherian case. The only difference is that here is that new money is distributed evenly across all 10 agents in each period.

As expected, the wealth distribution impact of the Keynesian regime is softer. For a money growth rate of 7 per cent per annum, the money share of the highest saving agent is 26.9 per cent in contrast to 31.1 per cent in the Fisherian case. The fall in velocity and the deflationary bias is softer as well.

A second observation in the Keynesian case is one of *non-neutrality* with regard to different rates of broad money growth. For higher rates of money growth, the wealth distribution impact of heterogeneity is softer. For annual money growth rates of above 15 per cent, the wealth share of the top 10 per cent remains below 20 per cent in contrast to above 30 per cent in the Fisherian case.

Inevitably, this puts an extra inflationary pressure in the transition years. The extra average annual inflation in the first 20 years due to the Keynesian distributional effects can be as high as above 1 percentage points for double digit inflation rates, as seen on the last column of Table 2.

6. Concluding remarks

Technological advances may change the way monetary and fiscal policies are conducted. The information and communication technology (ICT) revolution of the mid 70s changed the way monetary policy is conducted by the central banks. For being able to use short term interest rates as the main policy tool, a central bank had to electronically clear the interbank money market on a daily basis. This was made possible only after sufficient progress in computer technologies.

Switching to interest rates as the main policy instrument was a major structural break in economic history. Together with the central bank independence, direct monetary financing of government deficits have also come to an end. Broad money creation was left to the banking system under the guidance of the central bank in most advanced countries. This had the implication that money creation through the Fisherian channel became more dominant than the Keynesian channel of the 70s.

Likewise, the recent wave of technological revolution in ICT which enable the continuous storage and use of big data has important implications on financial technologies, the so called *fintech*. The central banks faced with an intense completion from private sector companies in issuing their own unbacked currencies, felt the need to innovate and came up with the idea of Central Bank Digital Currency (CBDC). The merits of access by all citizens to ‘account based’ CBDCs is summarised in the 2021 annual report of the Bank for International Settlements (BIS 2021: Chapter 3). This idea will likely trigger a healthy debate on the way monetary and fiscal policies are conducted.

Technological advances may also change the way monetary and fiscal policies are analysed. Heterogeneity has been a technical difficulty that most macroeconomist have avoided over the last four decades and have remained in the convenience of the representative agent paradigm. Yet, in some cases there are important macroeconomic insights to be gained from heterogeneous agent models that are absent in representative agent models (Kirman 1992; Domanski et al. 2016).

Agent Based Modelling (ABM) is one such strong tool of analysis (Arthur 1991). Although in most cases basic economic insights are valid, the experimental and quantitative aspects of ABM have great potential uses to inform and enrich policy design deliberations. ABMs have already been applied to finance (Lebaron 2001) and to macroeconomics (Turrel 2016). The most obvious practical use of ABMs is to study agent heterogeneity and the resulting income and wealth dispersion (Asano et al. 2019). Our simulation model in this paper can be considered as the simple building block of such a sophisticated ABM model. Future versions of our model may incorporate adaptive behaviour of agents, like learning the optimal savings behaviour over time (see for example Basci 1999). Introducing real assets in addition to money and hence real physical investments would be another extension of the current version.

In this paper we have demonstrated by means of a simple monetary model with heterogeneous consumers, the benefits and costs of two alternative money growth regimes, in order to contribute to the recently revived debate on the use of ‘helicopter money’. Our results show that more inclusive ways of money growth (potentially with the use of CBDCs) may have some social stability benefits in addition to some economic stimulus benefits. Yet, the extra inflationary impact of such a regime has to be taken into consideration. The post-pandemic new policy mix needs to be carefully managed if it is to remain both inclusive and non-inflationary.

Bibliography

Arthur W.B. (1991), Designing Economic Agents that Act Like Human Agents. A Behavioural Approach to Bounded Rationality, "American Economic Review", vol. 81 no. 2, pp. 353–359.

Asano Y., Kolp J.J., Heitzig J., Farmer J.D. (2019), Emergent Inequality and Endogenous Dynamics in a Simple Behavioural Economic Model, "INET Oxford Working Paper", no. 2019–11.

Basci E. (1999), Learning by Imitation, "Journal of Economic Dynamics and Control", vol. 25 no. 9, pp. 1569–1585.

Basci S., Gherbi, T. (2020), Demand Deficiency, Money Velocity and Heterogeneity, "Central European Review of Economics and Management", vol. 4 no. 2, pp. 137–153.

Basci E., Basci S. (2021), Demand Deficiency in G7 Countries, "International Econometric Review, Economics of the 21st Century", vol. 13 no. 3, pp. 59-70..

Bernanke B.S. (2002), Deflation: Making Sure "It" Doesn't Happen Here. Remarks before the National Economists Club, Washington, D.C., November 21, https://www.federalreserve.gov/BOARDDOCS/Speeches/2002/20021121/default.htm#f8 [02.12.2021].

BIS (2021), CBDCs: an Opportunity for the Monetary System, Bank for International Settlements Annual Report, Basel, https://www.bis.org/publ/arpdf/ar2021e3.htm [02.12.2021].

Blanchard O. (2021), In Defense of Concerns over the $1.9 Trillion Relief Plan, Peterson Institute for International Economics, February 18, https://www.piie.com/blogs/realtime-economic-issues-watch/defense-concerns-over-19-trillion-relief-plan [02.07.2021].

Carroll C.D., Crawley E., Slacalek J., White M.N. (2021), Modelling the Consumption Response to the CARES Act, "International Journal of Central Banking", vol. 17 no. 1, pp. 107–141.

Carroll C.D., Slacalek J., Tokuoka K., White M.N. (2017), The Distribution of Wealth and the Marginal Propensity to Consume, "Quantitative Economics", vol. 8 no. 3, pp. 977–1020.

Domanski D., Scatigna M., Zabai A. (2016), Wealth Inequality and Monetary Policy, "BIS Quarterly Review", March, pp. 45–64.

English B., Forbes K., Ubide Á (eds.) (2021), Monetary Policy and Central Banking in the Covid Era, CEPR Press, https://voxeu.org/content/monetary-policy-and-central-banking-covid-era [02.12.2021].

Fisher I. (1930), The Theory of Interest, 1st ed., The Macmillan Co., New York.

Galí J. (2020a), The Effects of a Money-Financed Fiscal Stimulus, "Journal of Monetary Economics", vol. 115, pp. 1–19.

Galí J. (2020b), Helicopter Money: The Time is Now", VoxEU.org, March 17, https://voxeu.org/article/helicopter-money-time-now [02.12.2021].

Goodhart Ch. (2020), Inflation after the Pandemic: Theory and Practice, VoxEU, June 13, https://voxeu.org/article/inflation-after-pandemic-theory-and-practice [02.12.2021].

Jilek J., Matousek R. (2010), Money in the Modern World, Peter Lang, Frankfurt.

Karamcheva N. (2016), Trends in Family Wealth, Congressional Budget Office, https://www.cbo.gov/publication/51846 [02.12.2021].

Kirman A.P. (1992), Whom or What Does the Representative Individual Represent?, "Journal of Economic Perspectives", vol. 6 no. 2, pp. 117–136.

Lebaron B. (2001), A Builder's Guide to Agent-Based Financial Markets, ,"Quantitative Finance", vol. 1 no. 2, pp. 254–261.

Martin P., Monnet E., Ragot X., Renault T., Savatier B. (2021), Helicopter Money as a Last Resort Contingent Policy, VoxEU, CEPR, April 5, https://voxeu.org/article/helicopter-money-last-resort-contingent-policy [02.12.2021].

McLeay M., Radia A., Thomas R. (2014), Money Creation in the Modern Economy, "Bank of England Quarterly Bulletin", vol. 54 no. 1, https://www.bankofengland.co.uk/quarterly-bulletin/2014/q1/money-creation-in-the-modern-economy [02.12.2021].

Summers L. (2021), The Biden Stimulus Is Admirably Ambitious. But It Brings Some Big Risks, too. Opinion, The Washington Post, February 7, https://www.washingtonpost.com/opinions/2021/02/04/larry-summers-biden-covid-stimulus/ [02.12.2021].

Turrell A. (2016), Agent-Based Models: Understanding the Economy from Bottom-up, "Bank of England Quarterly Bulletin", vol. Q4, pp. 173–188.

CENTRAL EUROPEAN REVIEW
OF ECONOMICS AND MANAGEMENT

ISSN 2543-9472; eISSN 2544-0365

Vol. 5, No. 4, 117-143, December 2021

www.cerem-review.eu
www.ojs.wsb.wroclaw.pl

Negative interest rates, COVID-19, and the finances of listed euro firms

Henk VON EIJE

University of Groningen, The Netherlands

Received: 13.07.2021, Revised: 27.10.2021, Accepted: 26.11.2021
doi: http://dx.doi.org/10.29015/cerem.930

Aim: The paper measures the impact of negative interest rates on listed firms in the original euro zone countries. It also measures the impact of the first COVID-19 year.

Design / research methods: The paper uses panel data to measure the influence of the short-term ECB deposit rate and the 10-years German bond yield on short-term and long-term firm variables. Cross section fixed effects are applied to first differences and dummy variables. For liquidity and non-liquid assets the effects are also measured for small and large companies, for sectors, and for countries.

Conclusions / findings: Corporate liquidity ratios and creditor ratios decline when short-term ECB-rates fall. If ECB rates are negative, liquidity ratios are further reduced by 0.6 percentage points. Declining long-term German government bond yields increase non-liquid assets, while negative yields boost these assets by 4.5% extra. In the first COVID-19 year, the investments in non-liquid assets were 7.6% smaller, while liquidity ratios increased by 2.3 percentage points.

Originality / value of the article: Papers on the influence of negative interest rates and of COVID-19 on European firms are unavailable. This makes the paper relevant for firm managers and policy makers and a benchmark for future research.

Implications of the research: Because the issues addressed are new, further research is valuable. One may think of comparable studies for different countries. Many other suggestions for further research are given in the conclusions.

Keywords: Negative interest rates, European Central Bank, German government bond yields, short-term firm financing, liquidity ratios, debtor ratios, creditor ratios, dividends, long-term borrowing cash flows, non-liquid investments, corona crisis, COVID-19.
JEL: E22, E31, E32, E58, G31, G35.

Correspondence address: Henk von EIJE, University of Groningen, Nettelbosje 2, 9747 AE Groningen, The Netherlands. E-mail: j.h.von.eije@rug.nl.

1. Introduction

Some financial innovations are man-made, like bitcoin, financial derivatives, and special-purpose acquisition companies (SPACs). Negative interest rates are only partly man-made, because they are set by Central Banks, while they are followed by financial markets.

Until deep in the 20th century it would have been unimaginable that interest rates would be negative.[1] Nevertheless, negative interest rates apply nowadays in major developed countries, like Germany, France, and Japan, but also in smaller ones like Switzerland, The Netherlands, Finland, Sweden, and Denmark. Negative interest rates may be set by the central bank. For example, in Denmark there is already a policy of negative interest rates in effect since 2012 (Krogstrup et al. 2020) and the European Central Bank started with a negative interest rate of -0,1% on its deposit facility in 2014.[2] As a result, also private banks turned to invoke negative interest rates and firms (and later also private customers) were only able to leave their excess liquidity in deposits with banks if they were prepared to pay for it. In the sequel also solvent governments issued long-term debt at low or negative interest rates.[3]

Negative interest rates change the economic environment of firms and investors and may have pervasive effects on them. An analysis of the impact of such negative interest rates on corporate finance and corporate finance policies may thus be truly relevant.[4] In this paper I go into consequences of nominal interest rates for listed

[1] The first instance that I am aware of is Japan, where the T-bill rate became negative at the end of 1998 (Jørgensen, Risberg 2012). That such negative nominal rates may not be that strange for consumers and firms is discussed shortly by Thornton (1999).

[2] https://www.ecb.europa.eu/stats/policy_and_exchange_rates/key_ecb_interest_rates/html/index.en.html [18.06.2021].

[3] The Central Bureau of Statistics (2020) of The Netherlands identified at the end of June 2020 nine European countries for which sovereign debt rates were negative.

[4] There are other important questions related to the impact of low or negative (real) interest rates in economics and finance. For example, how do negative interest rates affect preferences and the discounting anomalies (Frederick et al. 2002)? What can investment institutions do to earn more to keep the spending at the desired level (Perold 2012)? In the same vein: how can pension funds and life insurers keep the value of assets equal to the value of discounted future promised payments (Antolin et al. 2011)? How to cope with risky discounted values for the distant future if interest rates are low (Newell, Pizer 2003), and how to address the negative values arising from the use of the Gordon growth model (Gordon 1959) at negative interest rates?

euro-zone firms. First, I focus on short-term measures, namely liquidity-, debtor- and creditor-ratios and their reactions to ECB rates. Second, I address longer term aspects like cash dividends, long-term borrowing cash flows and non-liquid investments and their sensitivity to long-term interest rates. Besides the impact of interest rates on these finance variables I also study if there is an additional effect when those rates are negative.

While doing so, there was also an opportunity to measure the impact of the corona crisis year 2020 (being the first year with a world-wide pandemic since the Spanish flue). The spread of the corona virus (COVID-19) had far-reaching consequences in many countries. Not only for mortality,[5] long-term illness, and overpopulated hospitals but also because of the pervasive measures taken by the governments in the form of lock downs, social distancing requirements, and economic assistance provided.[6] It is interesting to learn what influence the first year of this world-wide pandemic had on short- and long-term finances of firms.

In section 2, I go into the background of negative interest rates and in section 3, I present the data and the methodology. Section 4 shows the results of cross-sectional fixed effects regressions for short-term financial variables and structural financial variables of the firms. In section 5, I provide more detailed evidence by size, sector, and country for the two most important variables. Finally, section 6 presents the conclusions and gives suggestions for further research.

[5] The World Health Organization reported October 11, 2021 4,842,716 deaths (https://covid19.who.int/).

[6] A survey of the socioeconomic consequences of the corona epidemy, like labor, health, gender, discrimination, the environment, and public policy responses is provided by Brodeur et al. (2021). Donthu and Gustafsson (2020) summarize a special issue of the “Journal of Business Research” on the corona crisis.

2. Negative interest rates

Causes for the negative interest rates are not in all countries completely similar. For many countries, the abundancy of liquidity provided by Central Banks aimed at getting inflation at an adequate level (often assumed to be 2%) contributed to it. Besides this traditional task, a second aim of Central Banks is to assist governments in reducing unemployment by buying longer-term securities in the open market (Quantitative Easing: QE). This may reduce interest rates and stimulate investments. QE may, additionally, also assist local governments in preventing them to become bankrupt. This was relevant for the southern euro-zone countries and for Ireland during the euro-crisis from the end of 2009 until deep in 2012. In these countries sovereign interest rates soared because of bankruptcy fears caused by large government debt ratios. A fourth reason for keeping interest rates low is the wish to fight a possible appreciation of the local currency (Denmark).[7]

The discussion above applies to nominal interest rates. In fact, it may be amazing that the nominal interest rates are negative when there is an extremely large supply of liquidity. Many researchers assume that the abundant liquidity generated by Central Banks may not be withdrawn that quickly when inflation increases above 2% and that it may then result in soaring nominal interest rates. However, even if the nominal rates would rise, real interest rates may still stay negative if the rise in nominal interest rates will lag the rise of actual inflation. For these reasons negative real[8] interest rates may prevail for a long time.[9,10]

---

[7] Of course, a country may also indicate to keep interest rates low for one official reason (fighting unemployment), but also have the side-benefits of fighting appreciation (e.g. Switzerland).

[8] Graphically Borio et al. (2017: 10) show four periods with negative sort-term and long-term real interest rates "globally", though such periods occur in individual countries more often (Borio et al. 2017: 28, 46). From 1870 till now there have been four such periods, namely in World War I, around World War II, around 1975 (only for short-term real rates) and after about 2010 (long-term real rates about after 2015). Borio et al. (2017) also investigate several determinants of real interest rates, and they conclude that not only real factors, like GDP growth, life expectancy, and percentage of dependent population are important explanatory variables, but also monetary policy periods, like the Gold standard period, the Bretton Woods period, and the inflation targeting period.

[9] In a Reuters Poll amongst fixed investment specialists, many of them expect that real rates on government bonds will remain negative the forthcoming year and that pre-corona real sovereign bond returns might not be expected soon (Karunakar 2020).

A major discussion amongst economists is the question whether negative nominal interest rates of a Central bank will be transferred to other sectors in the economy.[11] The investment trap already suggests that lowering interest rates below a certain point will not increase economic activity. Moreover, negative interest rates might reduce the supply of funds to banks thereby diminishing the supply of funds to firms. Finally, bank profits would decline and thereby make it less interesting to lend. In that sense, negative interest rates could be a "black hole", by distorting economic laws. However, others argue that negative interest rates are just "business as usual". In a recent paper Altavilla et al. (online July 1st, 2021) show that negative interest rates in the euro zone did not make monetary policy ineffective. In fact, bank deposits did not decline, also because firms' liquidity increased during the period of negative interest rates. When confronted with negative interest rates, firms do invest more and increase their liquidity balances less. From now on the results of Altavilla et al. (2021) are assumed to hold, meaning that deposit rates will be transferred to bank lending rates.

In this paper, I study the impact of nominal interest rates to see if corporate liquidity holdings indeed decline and non-liquid investments do increase. Table 1 shows the ECB depository rates at the end of the year and the minimum and maximum of the annual 10-years German government bond yields, as well as the average of the two. I use the German government bonds for our calculations of the influence of long-term rates, as their yields are in many euro countries a benchmark for firms, also because they are often used in capital budgeting calculations as approximations of risk-free rates.

---

[10] Schmelzing (2019) even finds that there is a structural decline in real interest rates taking place for more than seven centuries. If this decline continues, negative real interest rates become a phenomenon which with firms (and economists) need to deal with for a long time.

[11] Ulate (2019) finds that at negative rates monetary policy is less effective. Altavilla et al. (2021) find that negative Central Bank interest rates are transmitted to other sectors of the economy. It can, however, be doubted if small firms (and individuals) will ever be paid for borrowing money (Bromley 2020).

Table 1. ECB deposit facility rates at the end of the year and the minimum, maximum and mean ten-year German government bond yields during the year (GGBYs), 2011–2020

1	2	3	4	5
Year	ECB Rate	Minimum GGB Yield	Maximum GGB yield	Mean GGB yield
2011	0.250	1.690	3.497	2.594
2012	0.000	1.162	2.050	1.606
2013	0.000	1.168	2.041	1.605
2014	-0.200	0.540	1.946	1.243
2015	-0.300	0.077	0.990	0.534
2016	-0.400	-0.184	0.629	0.223
2017	-0.400	0.154	0.604	0.379
2018	-0.400	0.220	0.768	0.494
2019	-0.500	-0.718	0.260	-0.229
2020	-0.500	-0.840	-0.188	-0.514

Sources: ECB Rate Is the Deposit Facility Rate at the End of the Year, https://www.ecb.europa.eu/stats/policy_and_exchange_rates/key_ecb_interest_rates/html/index.en.html [18.06.2021]; GGB Yield Is the German 10-years Annual (Minimum, Maximum, and Mean of these two) Government Bond Yield, http://www.worldgovernmentbonds.com/bond-historical-data/germany/10-years/ [18.06.2021].

It proves that the ECB rate was negative for the first time at the end of 2014 and that it stayed negative during the following six years. The minimum German government bond yields followed in 2016 and in 2020 the maximum yield on such bonds even proved to be negative.

Negative interest rates and short-term firm finances. If a deposit with a bank makes losses with negative interest rates, it may not be attractive for firms to hold such deposits. Instead, they might hold cash. At the current small negative interest rates, it is not likely that firms will switch all bank deposits into cash (Jensen, Spange 2015). The prevention of the loss of income via a negative interest-bearing deposit will not outweigh the relatively high costs of holding cash at the firm (or elsewhere in a storage room), while there are in addition high costs in transferring banknotes physically. Nevertheless, there may be marginal effects. Treasury managers may not be willing to accumulate depository holdings further. Instead, they may now accept that more cash is held. In principle, however, these shifts between bank deposits and cash holdings would not necessarily mean that a firm's overall liquidity changes. With excess bank deposits caused by negative interest rates, a firm could of course also try to pay its creditors quicker. Another option to reduce excess bank deposits would be to soften credit policies and thereby increase its accounts receivables. For these reasons, not only the impact of the interest rates on liquidity, but also the impact on debtors and creditors is studied here.

Negative interest rates and long-term firm finances. For the long-term finances of firms, I study the impact of interest rates on cash dividends, the increase in long-term borrowing cash flows,[12] and the investments measured by the increase in the natural logarithm of total assets minus cash and cash equivalents. I assume that these more structural finance characteristics will be influenced most by longer term interest rates, for which I use the mean of the maximum and the minimum of the ten years German government bond yields (Table 1, column 5). For the dividends paid it is not set in advance whether the impact of interest rates will be negative or positive. A larger interest rate may result in more interest income on bank deposits and commercial paper, which might be transferred to investors via additional dividends. However, it may also result in lower dividends if the debt needs more servicing and the higher interest costs make less cash available to investors.

Low or negative interest rates should make the borrowing costs lower and decreased the borrowing cash flows if the firms do not finance themselves with additional cheaper debt. In the latter case, the impact of lower interest rates will be the combined effect of lowering cash flows per unit of debt but of increasing cash flows for more units of debt.

Finally, for investments the relationships are theoretical quite unidirectional. Lower cost of financing (including lower cost do debt) will make it possible for

[12] I study this variable instead of the leverage ratios itself, since then the leverage rate could not be used as an independent variable too, while it is used as an explanatory variable in the other equations. Moreover, an interesting phenomenon of declining and negative interest rates is that the debt servicing outlays may be reduced when the leverage increases. Such a phenomenon may occur with solvent governments (in non-Covod-19 times), and I considered it interesting to see if this also happened to the firms.

firms to invest more. This is also one of the assumptions of Central Banks if they apply QE for getting lower interest rates.

3. Data and methodology

I study the data for listed firms in the EU-15 countries[13] that have the euro as its currency. This means that the United Kingdom (no EU country anymore), Denmark and Sweden are excluded, as they have their own currencies. I focus on listed firms, because these are on average more advanced than non-listed firms and because they may be under more scrutiny of investors. These characteristics imply that these firms may react sharply to changes in the economic environment, the financial sector, and interest rates. Data come from the Orbis database that gives recent data for 10 years, which nicely fits the period around which the interest rates in the euro-zone became negative, as shown in Table 1. I, finally, exclude financial firms (SIC codes 6000-6999) and utilities (SIC codes 4900-4949). This results in 1224 firms in the sample.

Short-term data. I first focus on short-term firm finances, namely on cash and equivalents (liquidity) holdings, the debtors, and the creditors. These data are transformed into ratios by dividing by total assets. Table 2 shows the development of the averages of these ratios between 2011 and 2020.

[13] EU-15 refers to the number of member countries in the European Union prior to the accession of ten additional candidate countries on May 1, 2004.

Table 2. Annual ratios of the main variables and differences between 2011 and 2020

	1	2	3	4	5	6
Year	Liquidity-ratio	Debtor ratio	Creditor ratio	Cash dividend ratio	Increase in long-term borrowing ratio	Non-liquid invest-ments
2011	0.121	0.163	0.120	0.027	-0.014	n.a.
2012	0.120	0.158	0.118	0.026	-0.003	0.044
2013	0.131	0.153	0.118	0.027	-0.005	0.010
2014	0.134	0.147	0.116	0.026	-0.004	0.067
2015	0.134	0.142	0.116	0.026	0.008	0.100
2016	0.129	0.140	0.115	0.024	-0.004	0.102
2017	0.132	0.140	0.117	0.026	-0.001	0.068
2018	0.129	0.134	0.115	0.028	0.001	0.078
2019	0.124	0.120	0.105	0.025	0.007	0.125
2020	0.150	0.107	0.098	0.019	0.011	0.004
# of Obs.	11,039	11,145	11,137	7,858	6,522	9,788
Dif (2019-2012)	0.004	-0.038	-0.013	-0.001	0.010	0.080
PDif (2019-2012)	(0.464)	(0.000)	(0.001)	(0.501)	(0.237)	(0.000)
Dif (2020-2012)	0.030	-0.052	-0.021	-0.007	0.014	-0.041
PDif (2020-2012)	(0.000)	(0.000)	(0.000)	(0.000)	(0.100)	(0.000)

Source: author's own elaboration.
The table presents in columns 1 till 5 the average ratios of Cash and equivalents, Debtors, Creditors, Cash dividends and the Increase in long-term borrowing respectively, all scaled by total assets. Column 6 gives the change in the natural logarithm of the total assets minus cash and cash equivalents. All the variables are presented by Year . The number of observations is calculated over all available years. Dif (2019–2012) presents the difference between 2019 and 2012 and Dif (2020–2012) the difference between 2020 and 2012. Between these differences are the two-sided P-values for the differences based on unequal variances (between parentheses).

The table reveals that the liquidity ratio (column 1) is rather stable over time, but that it increased suddenly in the corona year 2020.[14] This can also be seen from the P-values from the bottom of Table 2. Between 2012 (used as benchmark year,

[14] It should be noted here that the number of observations is not equal in each year. When downloading the data (June 16, 2021) there was a smaller number of firms available for 2020 then for earlier years. This will have biased the results. Nevertheless, for the liquidity ratio it is unlikely that the smaller number of firms will have contributed to the increase, because larger firms generally report earlier and thus arrive earlier in databases, while they also often have lower liquidity ratios.

because all observations were available for all variables for this year) and 2019 there is no significant difference (P value = 0.464). However, between 2012 and 2020 there is (P-value=0.000). Table 2 also reveals that the debtor ratio (column 2) is always larger than the creditor ratio (column 3). This is logical, as the firm adds value to its goods bought, and when one assumes similar payable policies for goods bought and sold, debtor ratios should be larger. Both debtor- and creditor ratios decline over time between 2011 and 2020, which is clear from the highly significant changes between 2012 and 2019/2020. Given the decline in interest rates over the investigated period, it is not strange that creditors are paid faster, the more so when interest rates become negative. At the same time the firm's customers seem to have done the same, as debtor ratios declined even stronger.

Long-term data. The columns 5 till 7 of Table 2 give the development in the longer-term variables. There is hardly any change in the ratio of cash dividends paid (column 4), except for the decline in the last year 2020. Between 2012 and 2019 there was no significant effect (P-value of the difference is 0.501), but between 2012 and 2020 there was (P-value 0.000). The long-term borrowing cash flows (column 5) declined the first years of the observations but increased afterwards. However, the change between 2012 and 2019 and between 2012 and 2020 is not significant. Finally, there seems to be a trending increase in non-liquid investments (column 6) with a significant P-value (of 0.000) for the 8.0% increase, but this trend was broken in the corona year 2020 with a significant decline between 2012 and 2020 of 4.1% (P-value also 0.000). For information on the variables used I refer to Table A1 and for their descriptive statistics to Table A2 in the Appendix.

Methodology. Because the ECB rates and the German government bond yields are declining over time and the dependent and independent variables could trend over time too, I take the first differences per year. These first differences are analyzed with cross section fixed effect regression analyses, with cluster robust standard errors.

The first focal variable is the change in the interest rates (either the ECB deposit facility rate or the German bond yields). The second variable is a dummy, taking the value of 1 if the rate (or yield) is negative, and else zero. The third variable is a dummy variable, which takes the value of 1 in the corona year (2020) and zero in other years. Besides the focal variables, I use four control variables: the change in the natural logarithm of operating revenue “D-LN(OPR)”, the change in the return on assets “D-ROA”, the change in the long-term debt ratio “D-LTDR”, and, finally, the change in the tangible assets ratio “D-TAR”.

I checked for multicollinearity by measuring the correlation coefficients between the independent variables. There was a high correlation (0.782) for the change in the ECB rate and the change in the government bond yield.[15] This is not a problem, because these variables are not used in the same regression equation. Because the other variables have a correlation below a threshold of 0.7, there is no major problem of multicollinearity. I then use a cross-section fixed effects model to estimate the relations.[16]

4. Interest rates and COVID-19 effects

Table 3 shows the relation between the ECB rates, the ECB rates being negative, and the impact of the first corona year on short term finances of the firm. It proves that declining ECB rates reduce both liquidity holdings and creditor ratios significantly, as the sign of ECB rate is positive for those dependent variables.

[15] This is an indication that the short-term ECB rates are indeed (partially) transmitted to other parties in the economy; in this case to the German government and its 10-year bond yields. Similar results are found by Jensen and Spange (2015).

[16] The technique used is state of the art as can also be seen from the recent paper of Altavilla et al. (2021) who use the same technique with addition of time fixed effects. Inclusion of the latter would make interest rate collinear and then these focal effects would disappear from the regression. Therefore, time fixed these were left out. The benefits of cross-section fixed effects are in comparison with OLS less omitted variable bias and, in comparison to a random effects model better consistency. Non-stationarity is already coped with through first differences, so an error correction model is not needed. Because there are no lagged dependent variables included in the regression, Arellano Blundell Bover Bond techniques are not needed.

Table 3. The impact of changes in ECB rates, of negative ECB rates and of the corona year on changes in liquidity variables

	(1)	(2)	(3)
Variables	Liquidity ratio changes D-LIQR	Debtor ratio changes D-DEBTR	Creditor ratio changes D-CREDR
D-ECBR	0.018**	0.006	0.014***
	(0.009)	(0.005)	(0.004)
ECB-	-0.006***	-0.001	-0.001
	(0.002)	(0.001)	(0.001)
CORONA	0.023***	-0.007***	-0.005***
	(0.003)	(0.001)	(0.001)
D-LN(OPR)	-0.024***	0.009***	0.007***
	(0.002)	(0.001)	(0.001)
D-ROA	0.087***	-0.007**	-0.039***
	(0.006)	(0.003)	(0.003)
D-LTDR	-0.001	-0.004	0.010***
	(0.005)	(0.003)	(0.003)
D-TAR	-0.274***	0.006	0.042***
	(0.015)	(0.008)	(0.007)
Constant	0.007***	-0.004***	-0.000
	(0.002)	(0.001)	(0.001)
Obs.	9,705	9,737	9,728
R-squared	0.095	0.014	0.039
Number of Firms	1,215	1,216	1,215

Source: author's own elaboration.
The table shows the cross section fixed effects regression results. All variables are annual changes except for the dummies for the negative ECB interest rates and for the Corona crisis year. The dependent variables are the annual change in liquidity ratios (liquidity divided by total assets) in column 1, the annual change in the ratio of debtors to total assets (column 2) and the annual change in the ratio of creditors to total assets (column 3). The explanatory variables are presented in Appendix A1. Cluster robust standard errors are shown between parentheses below the coefficients. *** p<0.01, ** p<0.05, * p<0.1

The positive sign of ECB rates on the liquidity ratio was not expected, as Shirai and Sugandi (2019) find that there exists in most countries a negative relation between cash holdings in the economy and central bank interest rates. A probable reason for the different result is that I focus on firms, while firms have generally less cash in hand than the public and firms have more cash equivalents, like bank deposits. Because the listed firms are amongst the largest firms in the economy, they react quickly to negative interest rates on their cash equivalents. This means that these firms search for alternative, more profitable investments in the short-term finances. This can for example be done by paying creditors quickly and getting a better reputation with them or by enhancing the reputation with debtors by softening the payment requirements. Of course, such investments can also be done in long-term finances like -as will be seen later- investments in non-liquid assets.

The positive sign for the creditors could be expected. It is an indication that excess liquidity holdings (given declining interest rates) can be reduced by paying creditors faster. Nevertheless, there is no other effect of negative ECB rates per se (ECB-) on the other liquidity measures; neither by increasing the debtor ratios, nor by reducing the creditor ratios.

Finally, the corona crisis increased liquidity ratios significantly, but reduced debtor and creditor ratios. For the liquidity and creditor ratio, these are quite unexpected significant signs, as the corona crisis could require firms to withdraw from their liquidity balances[17] and to slow down paying creditors. That firms' debtors paid less in the first corona year might be expected.[18]

Table 4 shows the relation between the (German) government bond yields and these yields being negative as well as the impact of the first corona year on long-term finances of the firm. The (marginal significant) positive sign of the bond yields on cash dividends, indicates that with such yields declining, also cash dividends decline. A much stronger (negative) significant effect of government bond yields is found for the non-liquid investments of firms. Reduced government bond yields do increase investments.

[17] Table 4 analyzes if there are longer term financing effects of the corona crisis that may have influenced the liquidity ratios, like lower dividends during the corona crisis or less non-cash investments.

[18] The significant coefficients of the control variables will not be discussed here, but generally they have the signs that could be expected.

Table 4. The impact of changes in 10-years German government bond yields, of negative German government bond yields and of the corona year on changes in structural firm variables

	(1)	(2)	(3)
Variables	Cash dividend ratio changes D-CADIR	Increase in long-term borrowing ratio D-LTBCF	Non-liquid investment changes D-LN(NCA)
D-GGBY	0.002*	-0.003	-0.021***
	(0.001)	(0.004)	(0.007)
GGBY-	-0.002	0.008	0.045***
	(0.001)	(0.005)	(0.008)
CORONA	-0.003*	0.004	-0.076***
	(0.002)	(0.007)	(0.011)
D-LN(OPR)	0.002	0.015***	0.283***
	(0.002)	(0.005)	(0.007)
D-ROA	0.053***	0.024**	-0.030
	(0.004)	(0.011)	(0.020)
D-LTDR	-0.004	0.098***	0.099***
	(0.006)	(0.009)	(0.018)
D-TAR	0.032***	-0.099***	-0.017
	(0.010)	(0.029)	(0.049)
Constant	0.000	-0.004*	0.042***
	(0.001)	(0.002)	(0.003)
Obs.	6,613	5,834	9,702
R-squared	0.037	0.028	0.184
Number of Firms	1,000	872	1,215

Source: author's own elaboration.

The table shows the cross section fixed effects regression results. All variables are annual changes except for the dummies for the negative German government bond yields and for the Corona crisis year. The dependent variables are the annual change in cash dividends divided by total assets (column 1), the annual increase in long-term borrowing divided by total assets (column 2) and the annual change in the natural logarithm of non-liquid assets (column 3). The explanatory variables are presented in Appendix A1. Cluster robust standard errors are shown between parentheses below the coefficients. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

If the government bond yield is negative (GGBY-), there is only a significant and strong effect on the non-liquid investments, as these increase by 4.5%. When combining the liquidity holdings results in Table 3 and the non-liquid investment results of Table 4, one may conclude that in the listed euro-zone firms negative (ECB) interest rates make liquidity holdings to decline, while negative long-term government bond yields make non-liquid investments to increase. These results are in line with the findings of Altavilla et al. (2021).[19]

Finally, the corona crisis reduced cash dividends (only marginally significantly so) and the non-liquid investments. Both effects could have contributed to the corona-induced increase in liquidity ratios of Table 3, though the non-liquid investment results are much stronger (namely -7.6%).

5. Effects for size, sector, and country

It is relevant to see if the results differ for small and large firms. I focus on the liquidity ratios and the non-liquid investments because the liquidity holdings are the prime variable to look at for the interest rate sensitivity of the short-term finances of the firm. And the non-liquid investments are likely to be influenced (even targeted so by monetary policies) by the longer-term interest rate changes. Moreover, these variables showed the largest R-squares for the short-term effects (Table 3) and the long-term effects (Table 4).

I measured the median of operating revenue of all observations (547.995 million euros) and then selected firms below and above the median (small and large firms). However, some firms were not always small or large. For that reason, I selected firms that were permanently small during all years, and firms that were permanently large. This procedure makes that there are less observations for the combined small and large firms in Table 5, than the numbers shown for all firms in Tables 3 and 4.

Table 5 presents the results for the permanently small and large firms. It proves that the positive interest rate sensitivity for the liquidity ratios found in Table 3 is caused by the small firms. Large firms do not react significantly with their liquidity holdings to ECB rate changes. This implies that the small firms' treasury managers actively manage their firm's liquidity based on interest rates, while larger firms do

[19] There are no significant effects of interest rates on the increases of long-term debt cash flows; probably because of counteracting effects of lower interest rates and increases in debt. Nevertheless, I consider the signs to be interesting.

not directly do so. Both types of firms, however, reduce their liquidity ratios when the ECB rate becomes negative.

Table 5. Liquidity ratios and investment effects by firm size

	(1)	(2)	(3)	(4)
Variables	Liquidity ratios small firms D-LIQR	Liquidity ratios Large firms D-LIQR	Non-liquid investments small firms D-LN(NCA)	Non-liquid investments large firms D-LN(NCA)
ECBDR / GGBY	0.031*	-0.002	-0.009	-0.015**
	(0.017)	(0.009)	(0.013)	(0.007)
ECB- / GGBY-	-0.006*	-0.005***	0.050***	0.039***
	(0.003)	(0.002)	(0.015)	(0.008)
CORONA	0.020***	0.025***	-0.063***	-0.080***
	(0.005)	(0.003)	(0.020)	(0.011)
D-LN(OPR)	-0.024***	-0.035***	0.261***	0.373***
	(0.003)	(0.005)	(0.010)	(0.016)
D-ROA	0.093***	0.101***	0.033	-0.340***
	(0.009)	(0.009)	(0.030)	(0.029)
D-LTDR	-0.001	0.016	0.093***	0.234***
	(0.007)	(0.011)	(0.024)	(0.034)
D-TAR	-0.291***	-0.235***	0.184**	-0.479***
	(0.023)	(0.022)	(0.075)	(0.066)
Constant	0.008**	0.004**	0.056***	0.026***
	(0.004)	(0.002)	(0.006)	(0.003)
Obs.	4,021	4,160	4,018	4,160
R-squared	0.102	0.103	0.167	0.206
# of firms	531	492	531	492

Source: author's own elaboration.

The table shows the cross section fixed effects regression results for firms that permanently have operating revenues below the median and firms that have them permanently above the median. All variables are annual changes except for the dummies for the negative ECB interest rates (ECB-) used in the liquidity ratio regressions, the negative German government bond yield (GGBY-) used in the non-liquid investments and for the pandemic crisis year (CORONA) used in all four regressions. The dependent variables are the annual change in liquidity ratios (liquidity divided by total assets) in columns 1 and 2, and the annual change in the natural logarithm of non-liquid assets (columns 3 and 4). The explanatory variables are presented in Appendix A1. Cluster robust standard errors are shown between parentheses below the coefficients. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Interestingly, the large firms do react significantly with their non-liquid investments to long-term interest rates, while small firms do not. Large firms invest significantly more if the German government bond yields are declining. Though small firms do not react significantly to changes in long-term bond yields, that behavior changes if those yields are negative. Then they start investing by 5%. In addition, large firms also invest significantly 3.9% more if the long-term bond yields are negative.

Finally, the corona pandemic increased the liquidity ratios for small and large firms significantly, probably related to the concomitant strong decline in non-liquid investments for both size groups.

Table 6 presents the impact for major sectors of Manufacturing and Services, as well as for the remaining (Other) sectors combined. The liquidity ratios of manufacturing firms do not react in any way significantly to the ECB rates. The liquidity holdings in the services sector, however, do react strongly to ECB rates, and decline with smaller ECB rates. To a lesser extent, liquidity ratios in the Other sectors get smaller too when ECB rates diminish. Also, the liquidity ratios in the Services sector react positively to negative ECB rates, while the Manufacturing and the Other sectors do not.

Services sector firms' non-liquid investments do not react to long-term government bond yields per se, but they react strongly when the government bond yields are negative. The firms of the Manufacturing sector increase their investments when government bond yields decline, but they do not show an additional effect of negative government bond yields. The Other sector(s) do react to both the government bond yields per se, as well as to those yields being negative.

Finally, all three major sectors do react significantly to the corona crisis. Liquidity ratios increased and non-liquid investments declined. Both effects were strongest in the services sector.

Table 6. Effects by sector for liquidity ratios and non-liquid investments

	(1)	(2)	(3)	(4)	(5)	(6)
	Liquidity ratio changes D-LIQR			Non-liquid investments changes D-LN(NCA)		
Variables	Manufact.	Services	Other	Manufact.	Services	Other
ECBDR / GGBY	0.004	0.078***	0.035**	-0.028***	-0.002	-0.024**
	(0.012)	(0.025)	(0.017)	(0.009)	(0.020)	(0.012)
ECB- / GGBY-	-0.004	0.020*	0.009	0.017	0.085***	0.064***
	(0.005)	(0.010)	(0.007)	(0.010)	(0.023)	(0.014)
CORONA	0.025***	0.039***	0.022***	-0.065***	-0.100***	-0.070***
	(0.004)	(0.007)	(0.005)	(0.014)	(0.031)	(0.019)
D-LN(OPR)	-0.016***	-0.029***	-0.033***	0.236***	0.390***	0.307***
	(0.003)	(0.006)	(0.003)	(0.009)	(0.023)	(0.010)
D-ROA	0.089***	0.114***	0.034***	-0.092***	-0.119***	0.150***
	(0.010)	(0.011)	(0.012)	(0.031)	(0.039)	(0.037)
D-LTDR	-0.026**	0.015*	0.010	0.215***	0.029	0.176***
	(0.012)	(0.008)	(0.015)	(0.039)	(0.028)	(0.049)
D-TAR	-0.365***	-0.340***	-0.182***	-0.219***	0.041	0.117*
	(0.023)	(0.043)	(0.021)	(0.074)	(0.154)	(0.066)
Constant	0.006***	0.006	0.003	0.035***	0.077***	0.024***
	(0.002)	(0.004)	(0.003)	(0.004)	(0.010)	(0.006)
Obs.	5,042	1,962	2,701	5,042	1,959	2,701
R-squared	0.102	0.125	0.089	0.153	0.167	0.299
# of firms	615	257	343	615	257	343

Source: author's own elaboration.

The table shows cross section fixed effects regression coefficients. The dependent variables are the annual change in liquidity holdings (columns 1 till 3) and annual non-liquid investments (columns 4 till 6). The table distinguishes between manufacturing firms (first SIC codes 2 and 3), service sector firms (first SIC codes 7 and 8), and Other firms (remaining SIC codes exclusive of Financial firms and Utilities). All variables are annual changes except for the dummies for the negative ECB interest rates (ECB-), the negative German government bond yield (GGBY-) and the pandemic crisis year (CORONA). The ECB rate and the negative ECB rate (ECB-) are used in the regressions for the liquidity ratios, and the German government bond yield (GGBY) and that yield being negative on average (GGBY-) are used in the non-liquid investment equations. The other explanatory variables are presented in Appendix A1. Cluster robust standard errors between parentheses are shown below the coefficients. *** p<0.01, ** p<0.05, * p<0.1

Table 7. Effects by country for liquidity ratios and non-liquid investments

	(1)	(2)	(3)	(4)	(5)	(6)
	Liquidity ratio changes D-LIQR			Non-liquid investment changes D-LN(NCA)		
Country	D-ECBR	ECB-	CORONA	D-GGBY	GGBY-	CORONA
Austria	0.073	0.006	0.027*	-0.014	0.027	0.051
	(0.057)	(0.012)	(0.015)	(0.025)	(0.031)	(0.043)
Belgium	-0.031	0.001	0.031**	-0.018	0.052	-0.148***
	(0.044)	(0.009)	(0.014)	(0.032)	(0.038)	(0.053)
Finland	0.079*	-0.016*	0.013	-0.023	0.067**	-0.094**
	(0.045)	(0.009)	(0.012)	(0.025)	(0.030)	(0.040)
France	-0.008	-0.003	0.038***	-0.008	0.029**	-0.078***
	(0.016)	(0.003)	(0.005)	(0.012)	(0.014)	(0.020)
Germany	0.032*	-0.008**	0.013***	-0.020	0.024	-0.076***
	(0.018)	(0.004)	(0.005)	(0.013)	(0.015)	(0.020)
Greece	0.004	-0.011	0.016	0.005	0.100***	-0.072*
	(0.033)	(0.007)	(0.012)	(0.020)	(0.026)	(0.038)
Ireland	0.073	0.006	0.027*	-0.254***	-0.209***	0.037
	(0.057)	(0.012)	(0.015)	(0.052)	(0.060)	(0.077)
Italy	-0.002	-0.000	0.011	-0.013	0.072***	-0.010
	(0.027)	(0.006)	(0.007)	(0.023)	(0.026)	(0.033)
Luxemburg	-0.070*	0.000	0.041***	-0.004	0.033	-0.088*
	(0.041)	(0.009)	(0.012)	(0.031)	(0.034)	(0.045)
Netherlands	0.052	-0.026***	0.041***	-0.045	-0.001	-0.044
	(0.046)	(0.009)	(0.012)	(0.037)	(0.042)	(0.054)
Portugal	0.025	0.006	0.025*	0.000	0.082***	-0.136***
	(0.041)	(0.008)	(0.015)	(0.023)	(0.029)	(0.044)
Spain	0.081**	-0.009	0.013	0.015	0.121***	-0.099***
	(0.032)	(0.007)	(0.009)	(0.023)	(0.027)	(0.035)

Source: author's own elaboration.
The table shows cross section fixed effects regression coefficients. The dependent variables are the annual change in liquidity to assets ratios (columns 1 till 3) and annual non-liquid investments (columns 4 till 6). All variables are annual changes except for the dummies for the negative ECB interest rates (ECB-), the negative German government bond yield (GGBY-) and the pandemic crisis year (CORONA). Column 1 shows the coefficients of the change in the ECB rate on the change in liquidity ratios and column 2 of negative ECB rates on liquidity ratios. Columns 3 and 6 show the impact of the Corona-year on liquidity ratios and non-liquid investments, respectively. Column 4 presents the impact of changes in mean German 10-years government bond yields on non-liquid investments and column 5 of that yield being negative on non-liquid investments. Control variables (like in Tables 3 and 4) were used in the equations but omitted for presentation reasons in this table. Cluster robust standard errors between parentheses are shown below the coefficients. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 7 shows the results for the coefficients of the interest rates and the corona year by country. These coefficients originate from a full fixed effect regression analysis that included the other control variables.

For the liquidity holdings, Germany and Spain show signs of the ECB rate (column 1) that are at least marginally significant and positive, like in the analysis for all countries together. Only for Luxemburg there is a marginally significant negative coefficient. In Finland, Germany, and The Netherlands negative ECB rates (column 2) reduce the liquidity holdings (in line with the results of Table 3). For these countries, my findings confirm the results of Altavilla et al. (2021). However, I do not find such significant negative effects in all countries, which implies that their results are not uniform over the euro-zone. Finally, in eight of the twelve countries studied, the corona year increased the liquidity holdings significantly or marginally so (column 3), namely in Austria, Belgium, Germany, France, Ireland, Luxemburg, The Netherlands, and Portugal (also in line with the results found in Table 3).

For the investments, only one country has a significant effect of the 10-years mean (German) government bond yields (column 4), namely Ireland. That sign is in line with what was expected and with the sign found in Table 4, meaning that a decline in that interest rate increased investments. In that same country, however, there is an unexpected negative effect of the negative 10-years mean (German) government bond yields (column 5) on investments. In six countries the impact of that government bond yield being negative had the expected significant positive sign. This was found for all four South-European countries (Spain, Greece, Italy, and Portugal), as well as for Finland and France. Again, in some countries the results of Altavilla et al. (2021) do hold, but not in all of them. In line with the results in Table 4, the impact of the corona year (column 6) resulted in (marginally) significant negative investments in most countries, namely in Belgium, Denmark, Spain, Finland, France, Greece, Luxemburg, and Portugal.

6. Conclusions

Negative interest rates are a new phenomenon in Europe. In this paper I test if short-term finances and long-term finances of listed firms in the euro zone react to short- or long-term interest changes. In addition, I test if there is an additional effect of such rates being negative. If the structural decline in nominal interest rates prevails, other countries may be confronted with negative rates as well, and firms in other countries can learn from what happened to their counterparts in the euro zone. The major findings are that the liquidity ratios and creditor ratios decline with declining short-term interest rates. Moreover, liquidity ratios show an additional negative effect when the short-term rates are negative. For the long-term variables, the non-liquid investments increase if (German) government bond yields decline and that they get an additional impulse if the long-term yields are negative. The findings of the impact of negative interest rates (yields) on liquidity ratios and on non-liquid investments are in line with the recent findings of Altavilla et al. (2021).

I also measure the impact of the interest rates on liquidity holdings and non-liquid investments for firms with different sizes, for different sectors and for the different countries. Overall, the results are similar, though I neither find sensitivity of liquidity ratios for large firms nor for manufacturing firms. Also, non-liquid investments of small firms and of service firms do not significantly react to long-term German government bond yields. Finally, differences between countries for the interest sensitivity of liquidity ratios and non-liquid investments remain.

For the corona year 2020, non-liquid investments dropped severely, while – despite of the crisis – the liquidity ratios increased significantly. Also, debtor-, creditor- and cash dividend ratios declined during the crisis. Liquidity ratios increased for small and large firms, for the three sectors distinguished, and for most countries significantly during the corona crisis year. Finally non-liquid investments declined for large and small firms, for the three sectors, and for most of the countries in the crisis year.

Because many of the issues addressed here are quite new, further research is valuable. Besides aspects indicated in footnote 4 one might think of the following research on (negative) nominal interest rates on macro-economic and firm variables.

If, for example negative interest rates prevail, will then the negative effect on liquidity ratios pertain, or not? Will then non-liquid investments remain to be increasing, or not? And will the increased level of non-liquid investments caused by negative bond yields also result in additional growth for the firms that invested, or will these investments have been subject to agency costs and not have added value? Moreover, I assumed that the relations would be linear, but Gao et al. (2021) suggest that it may not always be so. Finally, it may also be relevant to see what effects real interest rates have on firm variables.

Further research on the corona crisis will also be interesting. Now the corona virus is still rampaging in many countries and a "fourth wave" happens to occur in the euro countries. When sticking to the findings here, it would be interesting to study why the negative non-liquid investment was less in the corona year in countries like Austria, Ireland, Italy, and The Netherlands? Are these the special types of firms in the country, the government subsidies, or the structure of the economy, or (a combination of these and) other factors. Moreover, firms in disaster-prone countries chose to have less leverage (Elnahas et al. 2018). Are firms in these countries less affected by the corona crisis? Moreover, did firms with large growth potential feel less need to reduce non-liquid investments? And if they kept investing, did they then access long-term borrowing or (seasoned) equity? Finally, did non-listed firms react quite differently to the crises, or not?

For the aftermath of the crisis, it will be interesting to learn what kind of impact the drop in investments in the corona year 2020 has for the growth of the impacted firms and for their countries. And what will the firms do with the liquidity holdings when they experienced a significant increase in the liquidity ratios during the corona crisis? Will the liquidity be used for catching up investments, will it be retrieved for risk reduction or as a buffer for future crises, or will it be paid out?

Appendix

Table A1. Mnemonics, meaning, and sources for the variables used in the regression equations

Mnemonic	Meaning	Source
D-ECBR	The annual change in the ECB deposit facility rate at the end of the year.	Table 1
ECBR-	A dummy variable: 1 in the years that the ECB deposit facility rate is negative; else 0.	Table 1
D-GGBY	The annual change in the mean German 10-years government bond yield.	Table 1
GGBY-	A dummy variable: 1 in the years that the German 10-years mean government bond yield is negative; else 0.	Table 1
D-LIQR	The annual change in Cash and cash equivalents (Liquidity) divided by total assets	Orbis
D-DEBTR	The annual change in Debtors divided by total assets	Orbis
D-CREDR	The annual change in Creditors divided by total assets	Orbis
D-CADIR	The annual change in Cash dividends divided by total assets	Orbis
D-LTBCF	Increase/Decrease in long-term borrowing cash flows	Orbis
D-LN(NCA)	The annual change the natural logarithm of total assets minus cash and equivalents divided by total assets	Orbis
CORONA	A dummy variable, zero in all years, but 1 in 2020	
D-LN(OPR)	The annual change in the natural logarithm of Operating revenue	Orbis
D-ROA	The annual change in Net profits divided by total assets	Orbis
D-LTDR	The annual change in the Long-term debt ratio divided by total assets	Orbis
D-TAR	The annual change in Tangible assets divided by total assets	Orbis

Table A2. Descriptive statistics

Panel A gives information on the ratios (measured to total assets) and the change in the long-term borrowing cash flows and the change in the natural logarithm for the non-liquid assets. Panel B gives the dependent variables used in the regression equation, which are the first annual differences from panel A (except for the increase in long-term borrowing cash flows (D-LTBCF) and the annual change in the natural logarithm of non-liquid total assets (D-LN(NCA)). Panel C provides the independent variables from the regressions. The meaning of the mnemonics is found in Table A1.

Variable	# of Obs.	Mean	Median	Std. dev.	Min	Max
Panel A: Ratios (or changes indicated by the prefix D)						
LIQR	11,039	0.130	0.095	0.129	0.000	1.104
DEBTR	11,145	0.140	0.124	0.105	-0.152	0.880
CREDR	11,137	0.114	0.091	0.093	0.000	0.727
CADIR	7,858	0.025	0.016	0.037	-0.094	0.926
D-LTBCF	6,522	0.000	-0.001	0.137	-4.411	1.590
D-LN(NCA)	9,788	0.069	0.033	0.329	-4.181	9.035
Panel B: Dependent Regression Variables (First annual differences indicated by the prefix D)						
D-LIQR	9,792	0.002	0.001	0.074	-0.918	0.857
D-DEBTR	9,910	-0.006	-0.002	0.040	-0.833	0.512
D-CREDR	9,901	-0.002	-0.001	0.037	-0.574	0.411
D-CADIR	6,669	-0.001	0.000	0.031	-0.890	0.914
D-LTBCF	6,522	0.000	-0.001	0.137	-4.411	1.590
D-LN(NCA)	9,788	0.069	0.033	0.329	-4.181	9.035
Panel C: Independent Regression variables (Dummy variables or first annual differences indicated by the prefix D)						
D-ECBR	11,016	-0.083	-0.100	0.088	-0.250	0.000
ECBR-	12,240	0.700	1.000	0.458	0.000	1.000
D-GGBY	11,016	-0.345	-0.311	0.376	-0.988	0.157
GGBY-	12,240	0.200	0.000	0.400	0.000	1.000
CORONA	12,240	0.100	0.000	0.300	0.000	1.000
D-LN(OPR)	9,858	0.040	0.035	0.403	-8.329	10.007
D-ROA	9,828	0.001	-0.001	0.509	-31.901	31.982
D-LTDR	9,817	0.005	0.000	0.150	-11.899	1.775
D-TAR	9,901	-0.003	-0.001	0.051	-0.934	0.823

Source: author's own elaboration.

Table A3. Correlation coefficients between the independent variables

The meaning of the mnemonics is found in Table A1.

	D-ECBR	ECB-	D-GGBY	GGB-	CORONA	D-LN(OPR)	D-ROA	D-LTDR	D-TAR
D-ECBR	1.000								
ECB-	0.235	1.000							
D-GGBY	0.782	0.194	1.000						
GGB-	0.162	0.270	-0.269	1.000					
CORONA	0.312	0.167	0.046	0.620	1.000				
D-LN(OPR)	-0.022	0.024	-0.001	-0.059	-0.100	1.000			
D-ROA	-0.018	0.011	0.008	-0.041	-0.026	0.097	1.000		
D-LTDR	0.023	0.002	-0.015	0.055	0.027	0.018	-0.301	1.000	
D-TAR	-0.046	-0.022	-0.039	-0.035	-0.074	0.025	-0.069	0.068	1.000

Source: author's own elaboration.

Bibliography

Apergis N., Christou Ch., Gupta R. (2018), Convergence in income inequality. Further evidence from the club clustering methodology across states in the U.S., “International Advances in Economic Research”, vol. 24 no. 2, pp. 147–161.

Altavilla C., Burlon L., Giannetti M., Holton S. (2021), Is There a Zero Lower Bound? The Effects of Negative Policy Rates on Banks and Firms, “Journal of Financial Economics” (2021), https://doi.org/10.1016/j.jfineco.2021.06.032 [01.07.2021].

Antolin P., Schich S. Yermo J. (2011), The Economic Impact of Protracted Low Interest Rates on Pension Funds and Insurance Companies, “OECD Journal: Financial Market Trends”, https://doi.org/10.1787/fmt-2011-5kg55qw0m56l [02.12.2021].

Borio C.E.V., Disyatat P., Juselius M., Rungcharoenkitkul P. (2017) Why So Low for So Long? A Long-Term View of Real Interest Rates, BIS Working Paper No. 685, https://ssrn.com/abstract=3090799 [01.07.2021].

Brodeur A., Gray D., Islam A., Bhuiyan S. (2021), A Literature Review of the Economics of COVID-19, “Journal of Economic Surveys”, vol. 35 no. 4, pp. 1007–1044.

Bromley S. (2020), Negative Interest Rates: Could You Be Paid to Take out a Business Loan?, https://www.simplybusiness.co.uk/knowledge/articles/2020/11/what-are-negative-interest-rates-for-small-business/, November 20 [13.07.2021].

Central Bureau of Statistics (2020), https://www.cbs.nl/nl-nl/longread/diversen/2020/effect-van-de-coronacrisis-op-de-nederlandse-en-europese-overheidsfinancien/rentelasten-blijven-historisch-laag [9.07.2021].

Donthu N., Gustafsson A. (2020), Effects of COVID-19 on Business and Research, “Journal of Business Research”, vol. 117, pp. 284–289, https://doi.org/10.1016/j.jbusres.2020.06.008 [03.12.2021].

Elnahas A., Kim D., Kim I. (2018), Natural Disaster Risk and Corporate Leverage, October 1, http://dx.doi.org/10.2139/ssrn [03.12.2021].
Frederick S., Loewenstein G., O’Donoghue T. (2002), Time Discounting and Time Preference: A Critical Review, “Journal of Economic Literature”, vol. 40 no. 2, pp. 351–401, https://doi.org/10.1257/002205102320161311 [03.12.2021].

Gao X., Whited T.M., Zhang N. (2021), Corporate Money Demand, “The Review of Financial Studies”, vol. 34 no. 4, pp. 1834–1866, https://doi.org/10.1093/rfs/hhaa083 [03.12.2021].

Gordon M.J. (1959), Dividends, Earnings, and Stock Prices, “The Review of Economics and Statistics”, vol. 41 part 1, pp. 99–105.

Jensen C.M., Spange M. (2015), Interest Rate Passthrough and the Demand for Cash at Negative Interest Rates, “Danmarks Nationalbank Monetary Review”, 2nd quarter, pp. 1–12, https://www.nationalbanken.dk/en/publications/Documents/2015/06/Interest%20Rate%20Rass-through%20and%20the%20Demand%20for%20Cash%20at%20Negative%20Interest%20Rates.pdf [03.12.2021].

Jørgensen A., Risbjerg L. (2012), Negative Interest Rates, "Danmarks Nationalbank Monetary Review", 3rd Quarter, Part 1, pp. 59–72, https://www.nationalbanken.dk/en/publications/Documents/2012/10/MON3Q_P1_2012_Negative%20Interest%20Rates.pdf [03.12.2021].

Karunakar R. (2020), Negative Real Yields on Sovereign Debt Here to Stay, https://www.reuters.com/article/us-markets-bonds-poll/negative-real-yields-on-sovereign-debt-here-to-stay-reuters-poll-idINKBN26J00H [09.07.2021].

Krogstrup S., Kuchler A., Spange M. (2020), Negative Interest Rates: The Danish Experience, https://voxeu.org/article/negative-interest-rates-danish-experience [09.07.2021].

Newell R.G., Pizer W.A. (2003), Discounting the Distant Future: How Much Do Uncertain Rates Increase Valuations?, "Journal of Environmental Economics and Management", vol. 46, pp. 52–71, https://doi.org/10.1016/S0095-0696(02)00031-1 [03.12.2021].

Perold A.F. (2012), Negative Real Interest Rates: The Conundrum for Investment and Spending Policies, "Financial Analysts Journal", vol. 68 no. 2, pp. 6–12, https://www.jstor.org/stable/23102596 [03.12.2021].

Schmelzing P. (2019), Eight Centuries of Global Real Interest Rates, R-G, and the 'Suprasecular' Decline, 1311–2018, http://dx.doi.org/10.2139/ssrn.3485734 [03.12.2021].

Shirai S., Sugandi E.A. (2019), Growing Global Demand for Cash?, "International Business Research", vol. 12 no. 12, pp. 74–92, https://doi.org/10.5539/ibr.v12n12p74 [03.12.2021].

Thornton D.L. (1999), Nominal Interest Rates: Less than Zero?, The Federal Reserve Bank of St. Louis, Monetary Trends, https://econpapers.repec.org/scripts/redir.pf?u=https%3A%2F%2Ffiles.stlouisfed.org%2Ffiles%2Fhtdocs%2Fdatatrends%2Fpdfs%2Fmt%2F19990101%2Fcover.pdf;h=repec:fip:fedlmt:y:1999:i:jan [13.07.2021].

Tokic D. (2017), Negative Interest Rates: Causes and Consequences, "Journal of Asset Management", vol. 18, pp. 243–254, https://doi.org/10.1057/s41260-016-0035-2 [03.12.2021].

Ulate M. (2019), Going Negative at the Zero Lower Bound: The Effects of Negative Nominal Interest Rates, Federal Reserve Bank of San Francisco Working Paper 2019–21, https://doi.org/10.24148/wp2019-21 [03.12.2021].