4 September 2023
ESMA50-524821-2800

ESMA Working Paper No. 2, 2023

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Abstract

Despite substantial regulatory reforms, US and EU money market funds (MMFs) experienced severe stress in March 2020. Funds investing in private assets such as EU Low Volatility Net Asset Value (LVNAV) MMFs faced acute challenges to meet regulatory requirements while facing high redemptions. Such funds must maintain their mark-to-market net asset value (NAV) within 20 basis points of a constant net asset value and must maintain a 30% share of assets that mature within one week. We develop a stylized model to show that under certain conditions related to outflows and the market liquidity of their assets, LVNAVs may face difficulties in fulfilling both regulatory constraints at the same time. We calibrate our model to EU and US data and evaluate different regulatory reforms. Removing the use of amortised cost has the largest positive effect in terms of resilience, while higher liquidity requirements have more limited effects, Improving the market liquidity of the assets MMFs invest in would substantially improve the resilience of MMFs. Introducing countercyclical liquidity buffers would also enhance their resilience, especially when the assets eligible to meet liquidity requirements are more liquid than the rest of the portfolio, and the effect is larger than increasing liquidity requirements. Overall, we find that, based on our market impact estimates, the NAV constraint is generally the binding one.

JEL Classifications: G01, G23, G28

Keywords: Money Market Funds, Regulation, Runs, Systemic risk

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* The views expressed are those of the authors only and should not be reported as reflecting the views of the European Securities and Markets Authority, the European Systemic Risk Board and its members, or any institution the authors may be affiliated with. Any errors or omissions are the responsibility of the authors. The authors would like to thank Serge Desrolles, Jennifer Eliott, Daniel Hiltgen, Antoine Martin, Patrick McCabe, Jose-Luis Peydró, Richard Portes, Jay Surti and seminar participants at the Autorite des Marches Financiers, Banque de France, Bank of England, European Commission, European Securities and Markets Authority, European Systemic Risk Board, Federal Reserve Board, Federal Reserve Bank of New York, International Monetary Fund, 2022 MNB-OMFIF financial stability conference, Securities and Exchange Commission and UK Financial Conduct Authority.

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Non-technical summary

Money market funds (MMFs) offer daily redemptions to investors while investing in short-term fixed income assets such as Commercial Paper (CP) or Certificate of Deposits (CDs) issued by financial institutions. Over time, MMFs have become key intermediaries in the financial system most notably on the short-term funding markets. Investors tend to treat MMF shares like deposits or a cash-like instrument and use them as short-term cash management vehicles. MMF vulnerabilities emerge from their liquidity and maturity transformation activities: they offer daily redemptions to investors while investing in instruments of longer maturity and of varying degrees of liquidity.

Despite substantial regulatory reforms after the Global Financial Crisis of 2007-2008, US and EU MMFs exposed to private debt experienced acute challenges during the COVID-19 crisis in March 2020. MMFs faced large redemptions from investors while short-term markets froze, resulting in liquidity issues for MMFs and the intervention of central banks to provide a backstop.

This paper provides a framework to assess MMFs resilience and shows that the maximum redemptions a MMF can face depends on regulatory constraints and asset liquidity. We use detailed portfolio data for a sample of 78 US and EU MMFs with USD 1,353bn in assets to assess each individual fund resilience. The maximum redemptions a fund can face ranges between 40% and 80% of the net asset value.

We use our model to assess the impact of regulatory reforms such as an increase in liquidity requirements, changes to the allowed price deviation for MMFs using amortised cost or requirements to invest in more liquid assets. Overall, we find that removing the use of amortised cost has the largest positive effect in terms of resilience, while higher liquidity requirements have more limited effects.

This paper complements existing literature in three ways. First, we model how the interaction between regulatory requirements, asset liquidity and investor redemptions determine the resilience of MMFs. Second, we show how to measure the resilience of MMFs and how the maximum level of redemption a fund can withstand can be heterogenous across EU and US MMFs. Finally, we provide a quantitative assessment of regulatory reforms on MMF resilience.

1 Introduction

Money market funds (MMFs) exposed to private sector debt offer daily redemptions to investors while investing in short-term fixed income assets such as Commercial Paper (CP) or Certificate of Deposits (CDs) issued by financial institutions. Over time, MMFs have become key intermediaries in the financial system most notably on the short-term funding markets. Investors tend to treat MMF shares like deposits or a cash-like instrument and use them as short-term cash management vehicles. MMF vulnerabilities emerge from their liquidity and maturity transformation activities: they offer daily redemptions to investors while investing in instruments of longer maturity and of varying degrees of liquidity. MMFs are used by institutional investors as cash management vehicles, which implies that large redemptions can occur in case of a sudden spike in liquidity demand from investors or if concerns about the MMF itself arise (FSB, 2021a).

In the aftermath of the Global Financial Crisis of 2007-2008, important regulatory reforms took place in the US and the EU to reduce vulnerabilities and increase the resilience of MMFs. Those reforms included the introduction of minimum weekly liquid assets requirements and additional measures on the use of amortised cost valuation for MMFs exposed to the private sector. US institutional Prime MMFs were forced to move to mark-to-market while in the EU, Low Volatility Net Asset Value MMFs were allowed to keep using amortised cost valuation for short-term assets, provided that the deviation between the mark-to-market and the amortised cost valuation of the MMF portfolio remains below 20 basis points.

Despite those substantial reforms, MMFs exposed to private sector debt experienced an acute stress in March 2020 such that for the second time in less than 15 years the sector required external intervention, with central banks in the EU and the US providing support to short-term funding markets where MMFs operate. Following these events, policymakers have proposed a series of additional regulatory reforms to make MMFs more resilient (FSB, 2021b, ESMA, 2022, SEC, 2021).

In that context, how can MMFs be made more resilient? What are the specific measures that could improve the most the resilience of MMFs and what are the trade-offs between improving individual fund resilience while maintaining MMF central role in short-term funding markets?

In this paper, we outline a model to assess MMFs resilience, defined as the maximum amount of redemptions a fund could face without breaching regulatory requirements. In that set-up, the resilience of a MMF can be thought as the result of an optimisation problem under constraints, where the manager choses a liquidation strategy subject to liquidity and price deviation requirements. We then calibrate the model to assess EU and US MMFs resilience in February 2020, right before the COVID-19 acute stress. We then assess the impact of a range of regulatory reforms on the resilience of MMFs using an analytical and a simulation approaches.

We show that MMF resilience depends on the calibration of regulatory requirements (such as minimum liquidity thresholds) as well as the liquidity of the assets MMF invest in, which is challenging to assess for short-term funding markets. Using detailed portfolio data on 78 EU and US MMFs with USD 1,353bn in assets we find that levels of resilience vary by funds, ranging from 40% of net asset value up to 80%, reflecting initial levels of liquid assets and different regulatory constraints in terms of price deviation. Regarding regulatory reforms, we show that increasing liquidity requirements has a limited impact on resilience, while removing the use of amortised cost would greatly improve the resilience of MMFs using this valuation method. Other measures such as introducing countercyclical liquidity buffers or improving the liquidity of underlying markets would also have a significant impact on MMF resilience.

Our paper contributes to different strands of the literature on vulnerabilities related to non-banks and MMFs in particular. On the theoretical side, Diamond and Dybvig (1983), Chen et al. (2010) show how runs can arise from liquidity transformation performed by financial institutions. Hanson et al. (2015) compare the asset/liability structure of banks and market-based intermediaries (such as hedge funds or MMFs) and find that shadow banking creates negative externalities as the social costs of fire sales by non-banks exceed the private costs. Using comparative statics, the authors discuss how changes in the money premium for safe claims and the strength of fire-sale effects drive the trade-off between traditional banks and shadow banks. Our key contribution to this strand of literature is to model how the interaction between regulatory requirements, asset liquidity and investor redemptions determines the resilience of MMFs.

On the empirical side, Bouveret et al. (2022) review risks related to MMFs across the world since their inception in 1972. They show that liquidity transformation and sudden changes in investors' perceptions of the funds' ability to convert fund shares into cash make them prone to runs. In addition, the global pattern of runs and crises indicates that MMF vulnerabilities are not unique to a particular set of governing arrangements. Several papers have covered the run on MMFs observed during the Global Financial Crisis of 2007-2008 (Pedersen (2009), Gorton and Metrick (2012), Chernenko and Sunderam (2014), Ivashina et al. (2015)) and sponsor support provided to MMFs in the US (McCabe (2010)) and in Europe (Bengtsson (2013), Ansidei et al. (2014)). More recently, several papers have focused on the role of investors and the link between run risk and liquidity requirements during the acute stress of March 2020. ESRB (2021) reviews the different vulnerabilities faced by EU MMFs and how they materialised during the COVID-19 crisis. Li et al. (2021) show that US prime MMFs which are more likely to use fees and gates (due to lower liquid assets) experienced higher outflows than MMFs with higher liquidity buffers. Using data on US and European MMFs, Cipriani and La Spada (2020) document that runs were more severe for MMFs offered to institutional investors and at risk of imposing fees or gates due to the breach of regulatory requirements. Dunne and Giuliana (2021) find that EU LVNAVs experienced larger outflows than other EU MMFs not subject to fees and gates and that LVNAVs with lower WLAs saw larger outflows (as the use of fees and gates became more likely). Consistent with those results, Darpeix (2021) shows that for French MMFs not subject to fees and gates, liquidity levels did not play a role in the intensity of redemptions. Avalos and Xia (2021) find that MMFs serving large institutional investors had large outflows irrespective of their liquidity levels, while the liquidity of the funds was more relevant for small institutional investors. Our findings show how to measure the resilience of MMFs and how the maximum level of redemption a fund can withstand can be heterogenous across EU and US MMFs. We also contribute to the literature by providing estimates of asset liquidity for short-term funding markets, which is very challenging due to data gaps.

Finally, our results contribute to the discussion on regulatory reforms. McCabe et al. (2013) suggest introducing ‘minimum balance at risk’ — a fraction of MMF shares which would be redeemable only with a delay — to reduce first-mover advantage for MMFs investors. McCabe et al. (2013), Cipriani et al. (2014) and Hanson et al. (2015) analyse risks related to the link between redemption gates, liquidity fees and liquidity requirements, posing that such arrangement might result in pre-emptive runs, also documented by Li et al. (2021). To the best of our knowledge, our paper is the first to quantify the effects of different regulatory reforms on MMFs resilience.

The remainder of the paper is as follows: Section 2 provides information on MMF regulatory reforms and challenges faced by fund during the COVID-19 stress period in March 2020, section 3 outlines a stylized model to illustrate how liquidity risk can crystallize for MMFs and what role regulatory requirements play; Section 4 applies the model to data on European MMFs; Section 5 discusses coordination failures and Section 6 concludes.

2. MMF Regulatory reforms and the Covid-19 stress

2.1 The regulatory environment for MMFs in the US and the EU

A range of regulatory reforms have taken place in the US and in the EU in the aftermath of the GFC, following work by IOSCO (2012) and the FSB (2012).

In the US, the Securities and Exchange Commission (SEC) adopted a set of reforms in 2010 and 2014 (SEC, 2010; 2014b), which - among others - require MMFs to hold minimum levels of daily and Weekly Liquid Assets (WLA). In addition, Prime Institutional funds, which invest mainly in private securities such as CDs and CPs and which are targeted at institutional investors, were required to convert from a constant net asset value (using amortized cost) to floating net asset value (mark-to-market, also called variable net asset value, VNAV). The new rules also enabled Prime MMFs to suspend redemptions or use fees if WLAs were to fall below 30% of total fund assets.

In the EU, the regulatory reform has been achieved through the Money Market Fund Regulation (MMFR), which entered into force in 2019. The MMFR introduced a wide range of provisions including reporting and stress testing requirements and prohibited sponsor support. The MMFR also created new types of MMFs, resulting in different types of EU MMFs. Under the MMFR, MMFs are either short-term MMFs or standard MMFs depending on the maturity of their portfolio and the pricing of their shares. Short-term MMFs are either (i) public debt net constant value funds (CNAVs), which invest almost exclusively in government instruments, (ii) VNAVs, which invest in private assets and use mark-to-market valuation for their shares, or (iii) LVNAVs which are permitted to maintain a constant net asset value and invest in private instruments. While LVNAVs use a constant NAV, they also have to mark-to-market their NAV (sometimes called 'shadow NAV'). If the deviation between the constant NAV and the mark-to-market NAV is higher than 20 basis points, LVNAVs must use the mark-to-market NAV to determine the cash to be received by redeeming investors. Finally, if WLAs fall below the 30% requirement and daily outflows are higher than 10% of assets, LVNAVs have to consider imposing fees and redemption gates to investors[5].

As of end-2022, EU MMFs amounted to EUR 1,510bn in assets. LVNAVs account for 48% of the sector, followed by VNAVs (41%), while CNAVs play a small role (11%) due to the low interest rate environment. More than half of EU MMFs are in foreign currencies, with USD accounting for 34% of NAV and GBP for 21%, while EUR MMFs represent 44% (ESMA, 2023). Given the dominant role played by private sector MMFs in the EU, and LVNAV in particular, the focus of this article is on this type of MMFs.

2.2 Stress faced by EU and US private-debt MMFs during the Covid-19 crisis

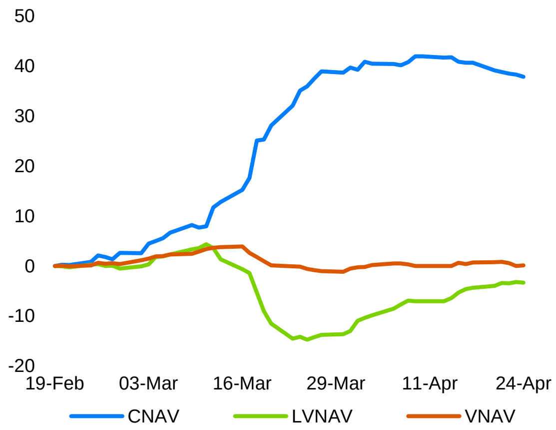
In March 2020, at the onset of the COVID-19 crisis, MMFs experienced massive redemptions from investors. In the EU and the US, MMFs investing in private short-term assets saw outflows of up to 20% of their net asset value in less than two weeks (FSB (2021a)). Faced with redemption levels that were higher than those observed during the Global Financial Crisis of 2007-2008 (Investment Company Institute (2020)), US and EU MMFs had to dispose of assets to raise cash in order to meet investor withdrawals.

In the EU, LVNAVs MMFs faced a substantial challenge. While they could in principle sell their most liquid assets to raise cash quickly, doing so would put them at risk of breaching their WLA requirements. This in turn would likely lead to further redemptions as investors would pre-emptively run to avoid being subject to fees and gates (Cipriani et al., 2014). Alternatively, LVNAVs could try to sell less liquid assets, but as private money markets froze in March, any

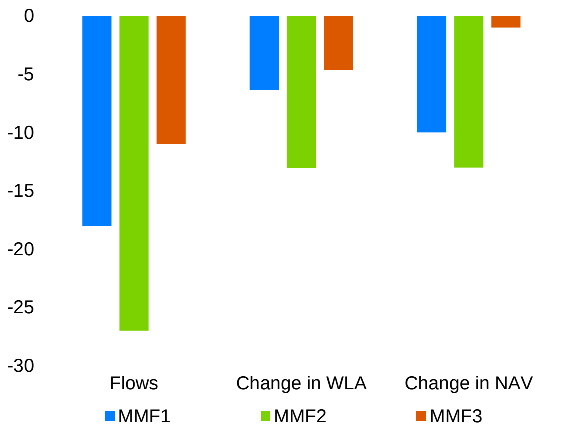
5 This provision is different from US rules, where fees and gates have to be considered when WLAs fall below 30% irrespective of daily outflows.

such sale would entail large discounts. These trading losses would then be reflected in a large deviation between the mark-to-market NAV and the constant NAV, which could in turn potentially force the MMF to switch to floating NAV and thus trigger further outflows from investors. Figure 1 (right) illustrates the trade-offs by looking at three EU USD LVNAVs. Each of those funds faced large outflows in the week of 25 March, ranging from 11% to 27%. To cope with the redemptions, managers had to use part of their WLA, resulting in a decline in their level (green bar), and sell some of their assets at a discount, leading to wide NAV deviation (red bar).

Figure 1: Cumulative flows during the Covid-19 crisis (left) and weekly flows and changes in WLA and NAV deviations for three LVNAVs (right)



Note: Cumulative flow into EU MMFs, % of NAV.
Sources: Morningstar, Refinitiv Lipper, Crane, ESMA.



Note: 7D net flows in % of assets and weekly change in WLA (in pp) and NAV deviation (in bps) as of 25 March 2020.
Source: Crane.

In some cases, MMFs were close to breaching their regulatory liquidity requirements, and had to accept significant discounts on their asset sales, resulting in large deviations between the mark-to-market NAV and the constant net value for LVNAVs (ESMA (2020b)).

To safeguard financial stability, the Federal Reserve and the European Central Bank intervened to support money markets and MMFs. Overall, no MMFs had to introduce redemption fees, gates or even fully suspend redemptions during the market turmoil.

In contrast to the Global Financial Crisis, the acute stress faced by MMFs in 2020 was almost entirely tied to liquidity risk. ESMA (2021) show that non-public debt MMFs are subject to three reinforcing vulnerabilities on their asset side. First, VNAVs and LVNAVs (and Prime MMFs in the US) have a large footprint in the market they invest in. They are estimated to hold more than 50% of CPs and CDs issued by financial institutions. Second, MMFs have a very high portfolio overlap: they share common exposures to identical issuers and similar assets. Finally, the liquidity of the markets they are exposed to is very limited. Secondary market activity is subdued due to the buy-and-hold nature of the investors, and dealers have limited incentives to make markets.

3 A model of liquidity risk and regulatory requirements for MMFs

We introduce a stylized model to illustrate how liquidity risk can crystallize for MMFs and what role regulatory requirements play. We focus on a two-period model without uncertainty. The model is focused on short-term horizons (from one day to one week).

The model is developed along the line of a reverse stress testing approach. The objective is to estimate the resilience of MMFs by measuring the maximum amount of redemptions a LVNAV could face without breaching any of its two regulatory constraints (NAV deviation or liquidity requirements).

3.1 Notation and setting

We consider an MMF, whose portfolio at time t consists of cash (deposits), denoted by a_0 and N different money market instruments, denoted $a_i \geq 0$ (in monetary units) which mature in T_i calendar days for $1 \leq T_i \leq \mathrm{N}$ (with $T_0 = 0$ as deposits are redeemable immediately). When the point in time is clear, or not relevant, we will use simple notations a_i instead of $a_{i,t}$. The total value of the MMF's holdings at time t is $V_t = \sum_{i=0}^{\mathrm{N}} a_i$.

The MMF is subject to several constraints:

Regulatory constraint on weekly liquidity: At all times, the portfolio must contain a share of at least $p_w = 30\%$ of assets that mature within 7 days or less.

Regulatory constraint on maximum Net Asset Value (NAV) deviation: The MMF's Net Asset Value computed using mark-to-market valuation shall not vary by more than $\upsilon = 20$ basis points from the NAV calculated using amortized cost valuation.

Investor redemptions: The MMF must (either have or) be able to raise enough cash to reimburse its redeeming investors who want to step out of the fund. We denote the total amount of investor redemptions by R, which needs to be met one day after having been requested.

We assume that the fund fulfils all constraints at time t and will now translate these into our model.

Weekly liquidity: First, we set a Boolean for the *weekly* liquidity constraint, ω_i^w , which is equal to 1 if and only if T_i is smaller than 7 days and 0 otherwise[6]. In particular, we thus have $\omega_0^w = 1$ for deposits. At time t the fund fulfils this constraint, such that the sum of the weekly liquid assets $V^W = \sum_{i=0}^{\mathrm{N}} \omega_i^w a_i \geq p_w V_t$.

Investor redemptions: If a redemption $R > a_0$ occurs, the MMF's cash holdings are insufficient to meet all investor demands and the MMF needs to sell some of its assets to meet the redemptions. The MMF will choose a proportion $\gamma_i \in [0,1]$ to be sold of each asset i ($1 \leq i \leq \mathrm{N}$) such that $\sum_{i=0}^{\mathrm{N}} \gamma_i a_i \geq R$.

The sale of a volume $\gamma_i a_i$ may depress the price of asset i, which is modelled by a nonincreasing **price impact function** ψ_i satisfying $\psi_i(0) = 1$ and $\psi_i(q) \geq 0$ for every volume of sales $q \geq 0$. If the MMF sells a quantity q of the asset i in the market during the time interval $[t, t+1)$, the final value it receives at $t+1$ is $\gamma_i a_i \, \psi_i(q) \leq \gamma_i a_i$. As the deposit, a_0 is already in cash, there is no price impact, and we have $\psi_0(q) = 1$ for all $q \geq 0$[7].

NAV deviation: There are different ways to value the portfolio of assets at t + 1, after the sales have occurred, as discussed in appendix 1. Using the amortized cost approach, the value of MMF's holdings s given by the value of the remaining assets in the portfolio:

$$V(\gamma) := \sum_{i=0}^{\mathrm{N}} a_i (1 - \gamma_i),$$

as if the impact factor due to the sale of $\sum_{i=0}^{\mathrm{N}} \gamma_i a_i$ did not have any effect on the price of the assets remaining in the portfolio. We can define for each of these values the portion concerning only short maturity (weekly) assets V^W as:

$$V^W(\gamma) := \sum_{i=0}^{\mathrm{N}} \omega_i^w a_i (1 - \gamma_i)$$

If the MMF faces total redemption R by its investors, it will seek to meet the redemptions, fulfil its two other regulatory constraints (WLA and NAV deviation) and minimise the losses due to sales, expressed as the difference between its original portfolio and the post-sale portfolio value. This can be formulated as an optimization problem in which the fund searches for the optimal vector $\gamma_i \in [0,1]^N$ that minimises its loss L and fulfils all constraints. The loss depends

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6 For LVNAVs, WLA may also include government assets with a residual maturity of up to 190 days, which are not considered here.

7 We shall assume for simplicity that the liquidated quantity q is in fact $\gamma_i a_i$, as if the money market fund were the only actor in the market. Would the money market fund have an estimate of the quantity q_i' of asset i sold by the other actors in [t, t + 1), it could use $\gamma_i a_i \psi_i(q_i' + \gamma_i a_i)$ for an estimation of the cash amount generated by asset i; our model can easily be adapted to this more general situation at the cost of more tedious notation.

on the regulatory requirements of the weekly liquid assets, p_w, and the maximum allowed NAV deviation, υ. We get:

$$L(p_w, \upsilon, R) \coloneqq min \sum_{i=0}^{N} a_i - V(\gamma)$$

$$\text{s.t } V^W(\gamma) \geq p_w V(\gamma)$$

$$\sum_{i=0}^{N} \gamma_i a_i \, \psi_i(\gamma_i a_i) \geq R$$

$$\frac{\sum_{i=0}^{\mathrm{N}} \gamma_i a_i \, (1 - \psi_i(\gamma_i a_i))}{\sum_{i=0}^{\mathrm{N}} a_i \, (1 - \gamma_i)} \leq \upsilon$$

$$1 \geq \gamma_i \geq 0 \;\; \text{for all } i,$$

or equivalently,

$$\sum_{i=0}^{N} a_i - L(p_w, \upsilon, R) \coloneqq max \; V(\gamma)$$

$$\text{s.t } V^W(\gamma) \geq p_w V(\gamma)$$

$$\sum_{i=0}^{N} \gamma_i a_i \, \psi_i(\gamma_i a_i) \geq R$$

$$\sum_{i=0}^{\mathrm{N}} \gamma_i a_i \, (1 - \psi_i(\gamma_i a_i)) \leq \upsilon \sum_{i=0}^{\mathrm{N}} a_i \, (1 - \gamma_i)$$

$$1 \geq \gamma_i \geq 0 \;\; \text{for all } i,$$

where the first constraint is the liquid assets constraint, the second one is the redemption constraint and the third one is the NAV deviation constraint. The fourth constraint simply bounds the proportion of sales to a number between 0 and 100% for every asset. Note that the value *V* is decreasing in every component of γ; hence, if every constraint is satisfied with $\gamma = 0$ except for the redemption constraint, the optimum is $\gamma = 0$ if $R \leq 0$, a case that we shall evidently disregard. We use the shorthand notation $\mathbb{1}$ for the all-one *N*-dimensional vector, and we define the function $\Gamma(\gamma) := \sum_{i=0}^{N} \gamma_i a_i \, \psi_i(\gamma_i a_i)$, which is separable and decreasing. Also, $\gamma \longmapsto a^T\gamma - \Gamma(\gamma)$ increases with γ. Finally, Γ is concave if $\psi_1, \ldots, \psi_N$ are concave functions.

Lemma 1. *Suppose that the optimization problem is feasible, that* $R > 0$*, and that the functions* $q \longmapsto q\psi_i(q)$ *are increasing for every* $N \geq i \geq 1$ *. Then* $R = \Gamma(\gamma)$ *for the optimal* γ*.*

Lemma 1 implies that if the fund is required to sell assets in order to meet all redemptions R, it will only sell the minimum needed, and never more, in order to meet R. A fortiori, this also implies that for $\mathrm{R} \leq a_0$ where the MMF can meet all redemptions using available cash, it will choose to do so and not sell any assets.

3.2 Maximum level of redemptions

Let us study the feasibility of this optimization problem. To this end we will determine for every pair p_w in $[0,1]$ and v in $[0, \infty)$ the largest level of redemptions, $R_{max}(p_w, v)$, that the MMF can meet while still complying with its regulatory constraints. We are thus interested in the feasible set of the above optimization problem and consider the following secondary problem:

$$max\ R$$

$$\text{s.t } V^W(\gamma) \geq p_w V(\gamma)$$

$$\Gamma(\gamma) \geq R$$

$$a^T\gamma - \Gamma(\gamma) \leq v a^T(1-\gamma)$$

$$1 \geq \gamma_i \geq 0 \ \text{ for all } i.$$

Under the assumption that the functions $q \longmapsto q\psi_i(q)$ are increasing for every $N \geq i \geq 1$, the above lemma asserts that the optimal R equals $\Gamma(\gamma^f)$ for the optimal γ^f of the above problem, so we can simplify it to:

$$max\ \Gamma(\gamma)$$

$$\text{s.t } V^W(\gamma) \geq p_w V(\gamma)$$

$$a^T\gamma - \Gamma(\gamma) \leq v a^T(1-\gamma) \tag{1}$$

$$1 \geq \gamma_i \geq 0 \ \text{ for all } i.$$

Observe also that $a^T\gamma - \Gamma(\gamma)$ increases with γ_i if ψ_i is a convex function. Indeed,

$$\frac{\partial\left(a^T\gamma - \Gamma(\gamma)\right)}{\partial\gamma_i} = a_i - a_i\left(\psi_i(a_i\gamma_i) - a_i\gamma_i\psi_i'(a_i\gamma_i)\right)$$

$$\frac{\partial\left(a^T\gamma-\Gamma(\gamma)\right)}{\partial\gamma_i}=a_i\left(\psi_i(0)-\psi_i(a_i\gamma_i)-\psi_i'(a_i\gamma_i)(a_i\gamma_i-0)\right)\geq 0$$

3.3 A simplified model for intuition

The above optimization problem can be completely solved in closed form in the following setting:

1. Every asset included in the weekly liquid asset a_i for which $\omega_i^w=1$ is subject to a constant price impact $\psi_i(q)$ equal to a constant $c_W\leq 1$ independent of the sales volume $0\leq q\leq\infty$.
2. Deposits a_0 have no price impact ($\psi_i(a_0)=1$).
3. For all other assets a_i which are not WLAs ($\omega_i^w=0$), the price impact $\psi_i(q)\equiv c_Y$ for all $0\leq q\leq\infty$.

Not only do those three assumptions make (1) linear, but they also allow us to obtain some separability property, which we can exploit to convert (1) into a simple 2-dimensional optimization problem. For the sake of notational simplicity, we write $I_w:=\{i:\omega_i^w=1\}$ and $I_Y:=\{i:\omega_i^w=0\}$. The function $\Gamma(\gamma)$ becomes $\Gamma(\gamma)=c_W\sum_{i\in I_w}a_i\gamma_i+c_Y\sum_{i\in I_Y}a_i\gamma_i$ and the function $V^W(\gamma)$ becomes $\sum_{i\in I_w}a_i-\sum_{i\in I_w}a_i\gamma_i$. Let us define

$$T_W(\gamma):=\sum_{i\in I_w}a_i\gamma_i,$$

the amortized cost value of the short-term assets the MMF has to liquidate, which ignores the trading costs due to the price impact. We define also

$$T_Y(\gamma):=\sum_{i\in I_Y}a_i\gamma_i.$$

Note that, by separability, T_W can take any value between 0 and

$$T_W,max\coloneqq\sum_{i\in I_w}a_i$$

by a proper adjustment of γ. Similarly, T_Y ranges in $[0,T_Y,max]$ with

$$T_Y,max\coloneqq\sum_{i\in I_Y}a_i.$$

The optimization problem now becomes:

$$R_{max}(p_w,\upsilon)=max(c_WT_W+c_YT_Y)\qquad(2)$$

$$\text{s.t } (1 - p_w)T_W - p_w T_Y \leq (1 - p_w)T_{W,max} - p_w T_{Y,max}$$

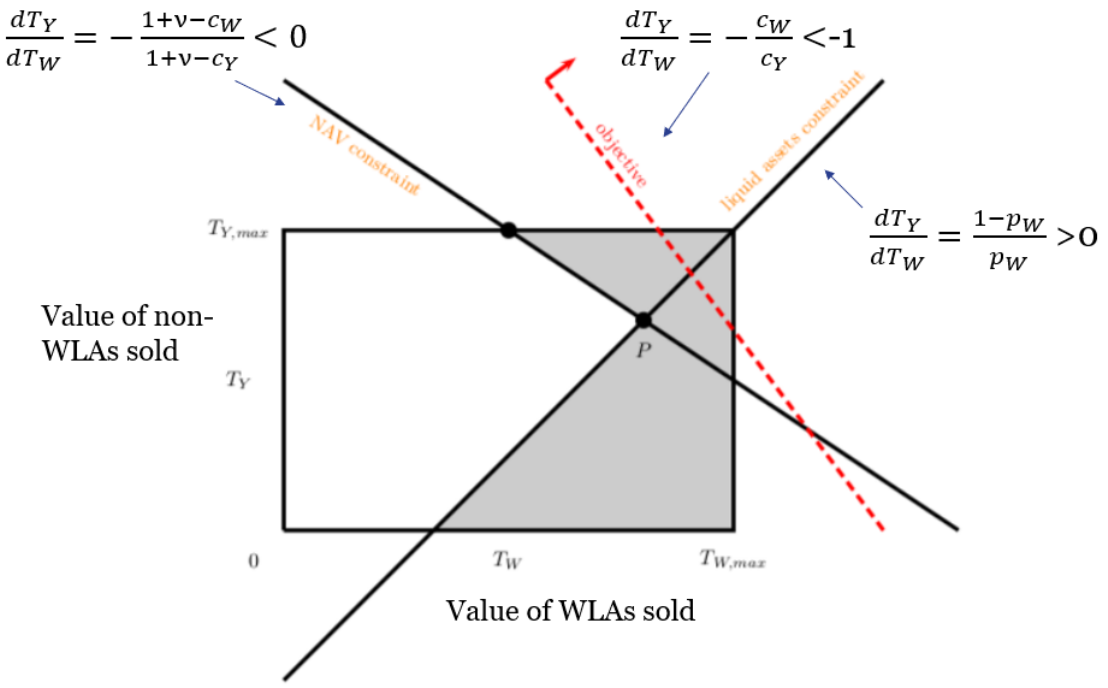
$$(1 + \upsilon - c_W)T_W + (1 + \upsilon - c_Y)T_Y \leq \upsilon\left(T_{W,max} + T_{Y,max}\right)$$

$$T_{W,max} \geq T_W \geq 0,\ T_{Y,max} \geq T_Y \geq 0.$$

The assumption that the liquid assets constraint is valid at time t, that is, for $\gamma \equiv 0$ translates into the inequality $T_{W,max} \geq p_W\left(T_{W,max} + T_{Y,max}\right)$. The solution of this optimization problem can be easily found as a function of the parameters p_W and υ using some elementary linear algebra and geometric principles. Three distinct situations can occur. There are three cases, depending on combinations of the parameters. Case 1 discussed below is the most relevant one from a practical perspective and we thus relegate the discussion of the two other cases to appendix 1.

Case 1. Assume first that assets counting as weekly liquid assets have a lower price impact than other assets $c_W \geq c_Y$ with $c_Y < 1$ a graphical representation of this situation is provided in Figure 2. The point $\left(T_{W,max}, T_{Y,max}\right)$ does not satisfy the NAV constraint: the sale of a large volume of assets would result in trading losses that would cause the mark-to-market NAV to deviate more than allowed. Since this point $\left(T_{W,max}, T_{Y,max}\right)$ satisfies the liquid assets constraint with equality, the point P where both the NAV constraint and the liquid assets constraint are tight lies in the rectangle $\left[0, T_{W,max}\right] \times \left[0, T_{Y,max}\right]$. Note that the slope of the objective is smaller than −1, while the slope of the NAV constraint is larger than −1 because $c_W \geq c_Y$.

Figure 2: First case: the price impact for short-term assets is less severe than for longer term assets



Note: The rectangle shows the combination of WLA and non-WLA sales. WLAs are shown on the x-axis and non-WLAs on the y-axis. The two black lines show the regulatory constraints on NAV deviation and WLAs. The red dotted line is the objective function.

Source: Authors' calculations

Therefore, the optimal value of the problem is attained at the point P, where the value of the objective function is

$$R_{max}(p_w, \upsilon) = \frac{\begin{pmatrix} c_W \\ c_Y \end{pmatrix}^T \begin{pmatrix} 1+\upsilon-c_Y & p_w \\ -1-\upsilon+c_W & 1-p_w \end{pmatrix} \begin{pmatrix} (1-p_w)T_{W,max} - p_w T_{Y,max} \\ \upsilon\left(T_{W,max} + T_{Y,max}\right) \end{pmatrix}}{(1-p_w)(1+\upsilon-c_Y) + p_w(1+\upsilon-c_W)}$$

$$= \frac{\begin{pmatrix} c_W \\ c_Y \end{pmatrix}^T \begin{pmatrix} (1-c_Y)\left((1-p_w)T_{W,max} - p_w T_{Y,max}\right) + \upsilon T_{W,max} \\ (c_W - 1)\left((1-p_w)T_{W,max} - p_w T_{Y,max}\right) + \upsilon T_{Y,max} \end{pmatrix}}{1+\upsilon-(1-p_w)c_Y - p_w c_W}$$

$$= \frac{(c_W - c_Y)\Big((1-p_w)T_{W,max} - p_w T_{Y,max}\Big) + \upsilon\big(c_W T_{W,max} + c_Y T_{Y,max}\big)}{1+\upsilon-(1-p_w)c_Y - p_w c_W} \qquad (3)$$

We also obtain the optimal sales of WLA T_W^* and non WLA T_Y^*:

$$T_W^* = \frac{(1-c_Y)((1-p_W)T_{W,max} - p_W T_{Y,max}) + \nu T_{W,max}}{1+\nu-(1-p_W)c_Y - p_W c_W}$$

$$T_Y^* = \frac{(c_W-1)((1-p_W)T_{W,max} - p_W T_{Y,max}) + \nu T_{Y,max}}{1+\nu-(1-p_W)c_Y - p_W c_W}$$

Observe in particular that $\lim_{\upsilon\to\infty} R_{max}(p_w,\upsilon) = c_W T_{W,max} + c_Y T_{Y,max}$ [8].

From this explicit solution, we can compute the sensitivity of R_{max} to the parameters p_w and υ, and also to the price impact c_W, c_Y and to the ratio $r := \frac{T_{W,max}}{(T_{W,max}+T_{Y,max})}$ that the Money Market Fund has selected. Since, when everything else is fixed, the optimal R_{max} is an affine function of the ratio r, we can compute immediately that

$$\frac{\partial R_{max}}{\partial r} = \big(T_{W,max} + T_{Y,max}\big)\cdot\frac{(c_W - c_Y)(1+\upsilon)}{1+\upsilon-(1-p_w)c_Y - p_w c_W}$$

Next, note that the numerator and the denominator are both affine functions of p_w if everything else is fixed. They present the same property for υ, c_W , and c_Y; hence, the partial derivative of R_{max} with respect to any of these four variables, say x is of the form $\partial R_{max}/\partial x = A/(Bx+C)^2$

for a (possibly negative) constant A, and for

$$Bx + C = 1+\upsilon-(1-p_w)c_Y - p_w c_W \ .$$

Comparative statics. We can compute explicitly the sensitivity of R_{max} , to regulatory constraints related to WLA requirements p_w, NAV deviation υ, to the total quantity of liquid assets $T_{W,max}$ as well as to liquidity conditions in money markets c_W and c_Y.

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[8] Using the calibration presented in 4.2, this implies that R_{max} for VNAVs (or US Prime institutional funds) would be very high, around 90%. Given that both types of funds experienced extreme stress in March 2020, two factors could be at play. First, in a liquidity crisis, the price impact could be substantially larger than in our calibration and/or some MMFs might be unable to dispose of some assets due to limited willingness or ability by dealers to buy the CP and CDs (FSB, 2021b). Second, even though VNAVs are not subject to regulatory constraints for their NAV, investor behaviour might result in additional constraints for managers. For example, investors might not be willing to face say a 50 bps decline in their NAV and as a result MMF managers are subject to an implicit behavioural constraint expressed through limits on their NAV change (rather than deviation).

$$\frac{\partial R_{max}}{\partial p_w} = (c_Y - c_W)(1+\upsilon)\frac{\left((1-c_W)T_{W,max} + (1-c_Y)T_{Y,max}\right)}{\left(1+\upsilon - c_Y + p_w(c_Y - c_W)\right)^2} \leq 0$$

$$\frac{\partial R_{max}}{\partial \upsilon} = (c_Y + (c_W - c_Y)p_w)\frac{\left((1-c_W)T_{W,max} + (1-c_Y)T_{Y,max}\right)}{\left(1+\upsilon - c_Y + p_w(c_Y - c_W)\right)^2} > 0$$

$$\frac{\partial R_{max}}{\partial T_{W,max}} = \frac{(c_W - c_Y)(1-p_w) + \upsilon c_W}{1+\upsilon - (1-p_w)c_Y - p_w c_W} > 0$$

$$\frac{\partial R_{max}}{\partial c_W} = (1+\upsilon)\cdot\frac{\upsilon T_{W,max} + (1-c_Y)\left((1-p_w)T_{W,max} - p_w T_{Y,max}\right)}{\left(1+\upsilon - c_Y + p_w(c_Y - c_W)\right)^2} > 0$$

$$\frac{\partial R_{max}}{\partial c_Y} = (1+\upsilon)\cdot\frac{\upsilon T_{Y,max} - (1-c_W)\left((1-p_w)T_{W,max} - p_w T_{Y,max}\right)}{\left(1+\upsilon - c_Y + p_w(c_Y - c_W)\right)^2}$$

The first equation shows that increasing WLA requirements for a given level of initial WLA holdings decreases R_{max} since the MMF has less ‘excess’ WLA to liquidate in case of redemptions.

The second equation indicates that increasing the NAV deviation leads to a higher R_{max} since the NAV constraint is looser, allowing the fund to sell more assets at a discount without breaching the NAV requirement.

The third equation states that an increase in initial levels of WLA holdings leads to higher R_{max} since the fund has a larger pool of liquid assets (‘excess’ WLA) to sell.

The fourth equation relates R_{max} to the liquidity of WLAs. If the liquidity of WLA increases, the discount for asset sales is lower, hence allowing the MMF to face a larger amount of redemptions and hence a higher R_{max}.

The sign of this last derivative is a priori not clear: the factor $\left((1-p_w)T_{W,max} - p_w T_{Y,max}\right)$ is the excess by which the liquid asset constraint is satisfied at time t, so $(1-c_W)\left((1-p_w)T_{W,max} - p_w T_{Y,max}\right)$ is the trading loss when liquidating the excess of short-maturity assets. For R_{max} to increase with respect to the price impact c_Y, this trading loss must be smaller than $\upsilon T_{Y,max}$. In other words, if the trading loss for liquidating ‘excess’ WLAs is less than the allowed price deviation multiplied by the stock of non-WLAs, then an increase in the liquidity of the less liquid assets would improve R_{max}.

Such formulas can then be used to assess the impact of regulatory reforms (or change to the liquidity of money markets) on the resilience of MMFs, measured by the maximum amount of redemption a fund could face while complying with regulatory requirements as discussed in section 5.

4 Empirical analysis

In this section we use the stylized model developed in section 2 in order to estimate the resilience of MMFs. For the empirical analysis, detailed data on the portfolio composition of funds are needed, as well as information on the potential price impacts of sales of instruments held by MMFs.

4.1 Portfolio data

We apply the model outlined in the previous section on a sample of large EU LVNAVs. We retrieve full portfolio holdings data for 14 EU LVNAV USD MMFs, totalling USD 277 billion as of end-February 2020 from a commercial data provider (Crane)[9]. Table 1 provides an overview of the size and WLA of the fourteen MMFs. We use end-February data so as to look at portfolio exposures before the COVID-19 crisis. The data covers 2,061 holdings, corresponding to 1,755 different CUSIPs, issued by 139 different issuers.

Table 1
Size and WLAs of EU MMFs in the sample

MMF ID	Assets (USD bn)	WLAs
MMF 1	0.8	40%
MMF 2	58.9	51%
MMF 3	1.0	39%
MMF 4	7.2	42%
MMF 5	9.4	43%
MMF 6	2.9	40%
MMF 7	60.2	44%
MMF 8	7.8	42%
MMF 9	83.4	37%
MMF 10	2.1	48%
MMF 11	14.7	51%
MMF 12	3.6	48%
MMF 13	23.2	46%
MMF 14	2.0	33%
Total	227.2	44%

Note: Data for February 2020.
Sources: Crane, Authors' calculations.

[9] Our initial dataset extracted from Crane contains 20 LVNAV USD MMFs, of which we remove four because their reported WLA is below 30%; one MMF reports WLA of 96%, which appears to be a data quality issue and a sixth MMF is removed as it is not domiciled in the EU but in the Cayman Islands and hence not subject to EU regulations.

For each instrument, Crane data provides a range of fields (name of the holding, issuer and issuer type, maturity date, coupon, amount, country of the issuer and credit rating). We classify the assets into four categories: The first asset type is labelled “Commercial Paper” and includes short-term instruments issued by non-government entities (Asset-Backed Commercial Paper, Financial Company Commercial Paper, Non-Financial Company Commercial Paper and Certificate of Deposits). The second type labelled “Deposits”, includes non-negotiable time deposits, Government Agency Repurchase agreements (repo), Treasury repo and Other repo. The third type, called “Government Debt”, is comprised of government-related instruments such as Treasury Debt and Government Agency Debt. The fourth type includes the remaining instruments (longer term assets such as Other instrument and Other Note and Investment Company, i.e. funds’ shares), which we shall label “Other”.

For each MMF we derive a range of portfolio measures. First, we obtain the portfolio composition by asset type (Commercial Paper, deposits, repo etc.) and maturity buckets (below 3M, between 3 and 6M, between 6M and one year and above one year). Then, we compute the level of weekly liquid assets (WLA) for each fund. WLAs are comprised of all instruments with a maturity less or equal to 5 business days and all government-related instruments with a residual maturity less or equal to 190 days. According to the EU MMFR, such government-related assets can be included up to 17.5 percentage points of WLA for LVNAVs.

We extend the analysis to US Prime MMFs (retail and institutional funds) since they tend to invest in similar assets and are also subject to a 30% WLA constraint. However, there are two important differences between EU LVNAVs and US Prime MMFs. First, US Prime retail MMFs are subject to a NAV deviation constraint of 50 basis points (against 20 basis points for LVNAVs). Second, US Prime institutional MMFs have a floating NAV, and are as such not directly subject to a NAV deviation constraint. Nevertheless, almost all US Prime institutional MMFs have AAA money market funds ratings from CRAs[10] and, as a result, are subject to an indirect NAV deviation constraint of 25 basis points, since some CRAs do not allow AAA MMFs to have a NAV deviation above this threshold (Standard and Poor’s, 2020). In addition, institutional investors might redeem if the NAV of the MMFs they invest in would fluctuate substantially[11].

10 Generally money market fund ratings seek to assess the ability of funds to preserve capital and maintain liquidity to investors (ESMA, 2021).

11 Baklanova et al. (2021) report that during the acute stress of March 2020, the largest NAV deviation experienced by a US Prime institutional MMF was 24 basis points. However, the authors note that this MMF did not experience large outflows (less than 0.1% of assets during that week).

Overall, our sample includes 25 US Prime Retail and 39 US Prime institutional MMFs with total assets of respectively USD 472bn and USD 604bn as of end-February 2020, based on Crane data. We use a similar approach as for EU LVNAVs to derive a range of portfolio measures.

4.2 Calibration of liquidity discounts

In order to estimate the maximum amount of redemption an MMF can meet, price impact measures are required. It is extremely challenging to find data on liquidity in private money markets such as CP and CD, let alone estimate the hypothetical impact of distressed liquidations (FSB, 2021b; ESRB, 2021).

On the one hand, there is very limited trading activity since most investors are buy-and-hold given the short maturity of the instruments. On the other hand, dealers have limited incentives to make markets due to a combination of regulatory constraints (Liquidity Coverage Ratio), risk limits and structural features of the CP market (instruments are issued in CP program with a limited number of dealer banks, banks not participating in the program have little to no incentives to make markets due to commercial and credit risk reasons, see Abate (2020)). Finally, trading of short-term debt instruments is mainly done over-the-counter rather on trading platforms, resulting in limited transparency on secondary markets.

For those reasons, we rely on estimates to calibrate the price impact measures and perform a sensitivity analysis on this parameter in our simulations. We calibrate the price impact measures based on the liquidity stress test parameters used by ESMA (ESMA (2020a)[12]). For each asset class and time bucket, the liquidity is determined by the liquidity discount factor used in the ESMA stress test, split by maturity bucket. The liquidity of asset i belonging to the maturity bucket t is equal to one minus the liquidity discount factor for this asset and maturity bucket:

$$c_{i,t} = 1 - LDF_{i,t}$$

The more liquid the asset, the lower the liquidity discount factor and hence our liquidity measure will be closer to 1. In that setting, the price impact is constant and each MMF faces the same liquidity discount irrespective of sales of other MMFs (or any other investor exposed to the same assets). Therefore, joint liquidation costs are not considered (beside the liquidity discount). An alternative could be to modify liquidity discount factors based on sales from other

12 Every year, ESMA, in cooperation with the European Systemic Risk Board (ESRB), designs scenario for MMF stress tests and its different components (interest rate and credit spread shocks, redemption shocks etc.). MMF managers have then to report the results of the stress tests to National Competent Authorities and ESMA.

MMFs: funds trying to sell the same instrument at the same time would face higher liquidity discounts than other MMFs[13].

We assume that time deposits and repo do not have a price impact, resulting in a liquidity discount factor of zero and a liquidity of $c_{i,t} = 1$ for those two assets.

We apply two approaches when calibrating the model. In a simplified application of the model, we decompose the portfolio of MMFs into two assets classes: WLAs with a liquidity of $c_W = 0.998$, and non-WLAs with a liquidity of $c_Y = 0.995$ (based on a liquidity discount factor of 43bps for A-rated 3M corporate bonds)[14]. The liquidity c_W is calibrated based on the average of the liquidity discount factors for sovereign bonds below 3 months (ranging from 0.05% for France to 0.47% for Italy) and the liquidity discount factors for repo and deposits (equal to zero). For non-WLAs, the liquidity c_Y is derived from the liquidity discount factors for A-rated corporate bonds with a residual maturity between 3 and 6 months for CP and CDs (which is approximately 0.6%, see ESMA (2020a) for details). We call this approach the 'analytical approach' since it relies on closed-form formulas derived in section 3.

We also use a second approach, where MMFs invest in a range of asset classes, depending on the type of instrument, issuer and maturity. This approach provides a better depiction of the portfolio exposures of each fund, but the formulas are less explicit and hence more difficult to interpret. We use numerical methods to solve the optimization problem for each MMF, and label this approach the 'simulation' approach. For sovereign and corporate instruments, the liquidity discounts are taken from tables 2 and 3 from the appendix for the ESMA guidelines, using credit ratings and residual maturity. The liquidity discount factors are shown in Table 2.

[13] Appendix 2 provides more information on alternative ways to calibrate the price impact factor.

[14] Using data covering the Global Financial Crisis, SEC (2014) estimates that average spreads amounted to more than 125bps for lower rated securities and close to 80bps for higher rated bonds maturing within 120 days, see appendix 2 for details.

Table 2

Liquidity discount factors by asset class and maturity buckets (in %)

			Deposits and repo				
			0				
			Money market instruments				
	3M	6M	1Y	1.5Y		2Y	
			Sovereign bonds				
AAA	0.05	0.09	0.18	0.19		0.20	
AA	0.07	0.18	0.32	0.42		0.53	
A	0.13	0.25	0.70	0.72		0.75	
BBB	0.47	0.55	0.70	0.72		0.75	
Below BBB or unrated	0.61	0.72	0.82	0.94		0.98	
			Short-term private debt securities (CPs, CDs, etc.)				
AAA	0.15	0.28	0.56	0.60		0.64	
AA	0.23	0.56	1.02	1.35		1.69	
A	0.43	0.79	2.24	2.32		2.40	
BBB	1.50	1.77	2.24	2.32		2.40	
Below BBB or unrated	1.96	2.30	2.91	2.95	2.99	1.96	2.30

Source: ESMA (2020a).

4.3 Maximum level of redemptions

Let us study the feasibility of our optimization problem when the price impacts are of the form

$\psi_i(q) = c_i$ for every $0 < q \leq 1$ and every asset i. While this more general setting cannot be solved explicitly, we can easily solve it numerically as it yields a simple linear optimization problem, since $\Gamma(\gamma) = \sum_{i=0}^{N} a_i c_i \gamma_i \; = \sum_{i=0}^{N} b_i \gamma_i$ with $b_i := \; a_i c_i$ is a linear function:

$$\max b^T a$$

$$\text{s.t } V^W(\gamma) \geq p_w V(\gamma)$$

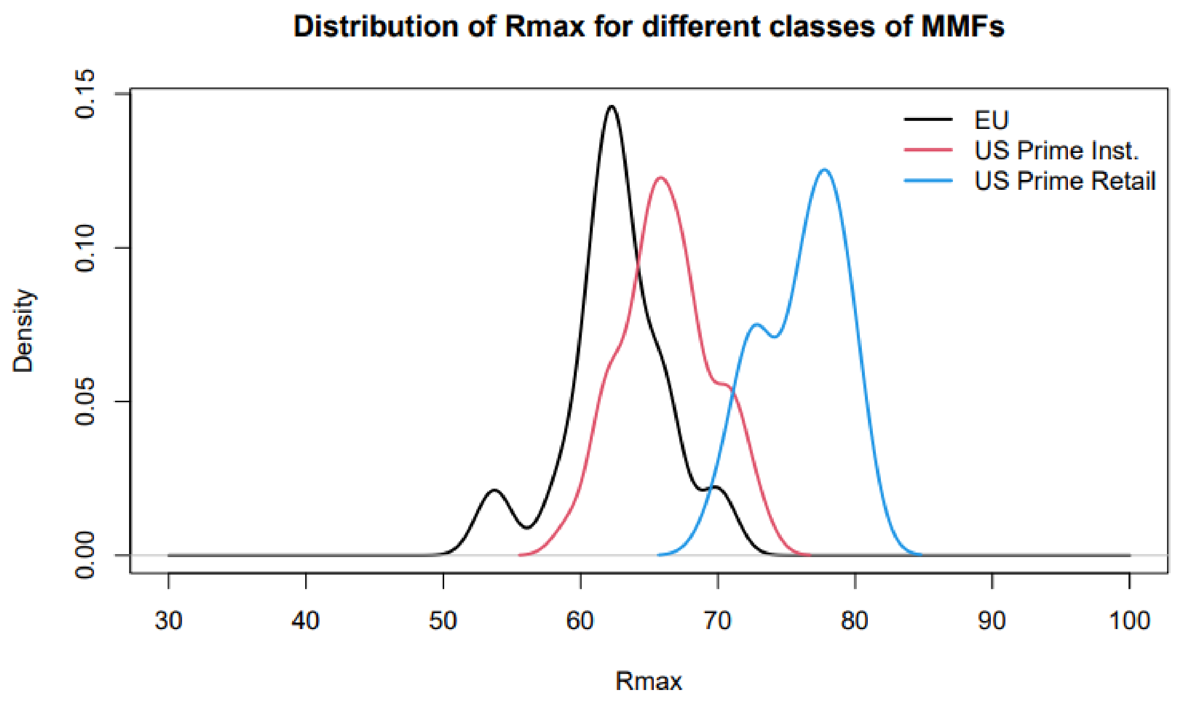
$$(a - b)^T \gamma \leq \upsilon a^T (1 - \gamma) \tag{4}$$

$$1 \geq \gamma_i \geq 0 \;\; \text{for all } i$$

We resolve the optimization problem for each of the funds and for each regulatory type (EU LVNAV, US Prime Retail and US Prime Institutional) in our sample to derive the maximum amount of redemptions they can face using the simulation approach. For each fund we use the calculated WLA, the portfolio composition and the liquidity discount factors from Table 2 to derive R_{max}.

Figure 3 shows that R_{max} ranges from around 40% to up to 70% of NAV[15] for EU LVNAVs, while for US Prime retail R_{max} ranges from 65% to 80% and for US Prime Institutional from 55% to 75%.

Figure 3: Distribution of maximum redemptions (R_{max})



Note: Kernel density of R_{max} for US Prime and EU USD LVNAVs. X-axis indicates the maximum redemptions in % of NAV, y-axis shows the frequency.

Sources: Crane, Authors' calculations.

The higher values of R_{max} for US funds reflect mainly the larger NAV deviation allowed, as US and EU funds are otherwise quite similar in terms of portfolio characteristics[16].

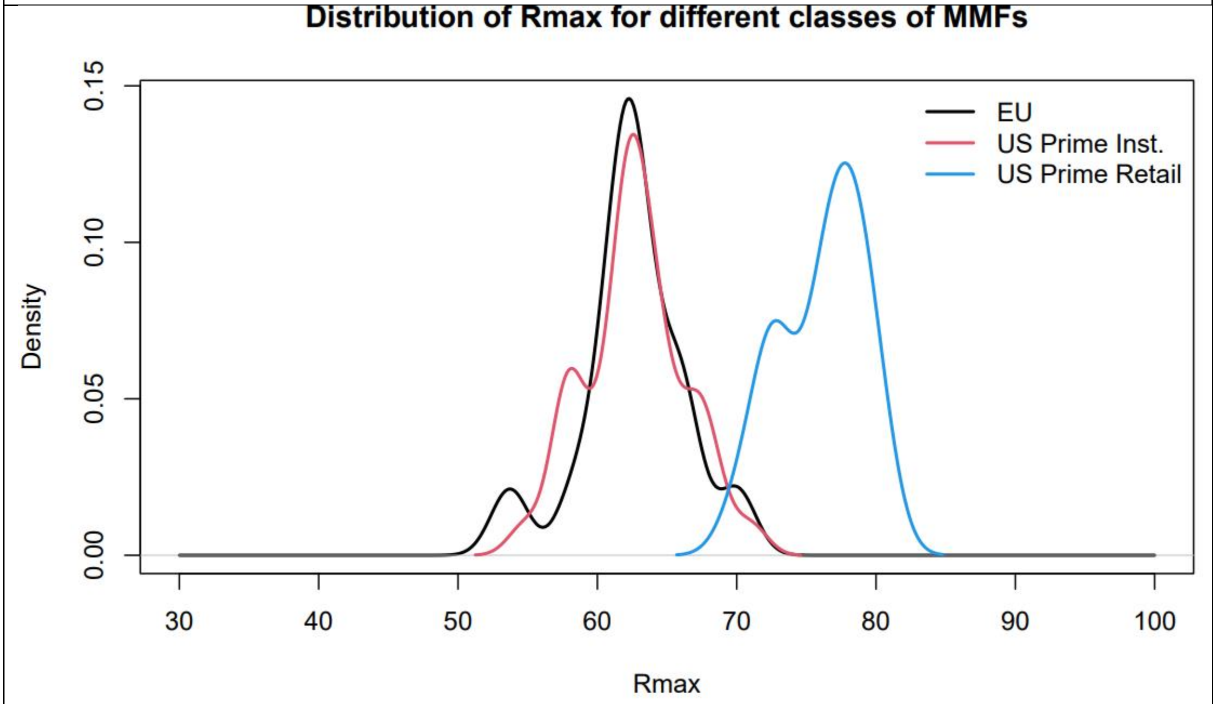
[15] The results are also consistent with reverse stress test results provided by EU MMFs as part of the MMFR reporting requirements.

[16] The portfolio similarity of EU USD LVNAVs and US Prime MMFs is further confirmed by the analysis done by ESMA (2021) which finds a high degree of similarity across those funds.

To illustrate this we change the NAV deviation constraint to 20 basis points for US Prime institutional funds, so that they are subject to a similar constraint as EU LVNAVs.

Figure 4 shows that in that case, the distribution of R_{max} for US Prime institutional MMFs and US LVNAVs are fairly similar, implying that different regulatory parameters rather than portfolio allocation by managers explain the differences.

Figure 4: Distribution of maximum redemptions (R_{max}) with same NAV constraint for LVNAVs and US Prime institutional funds

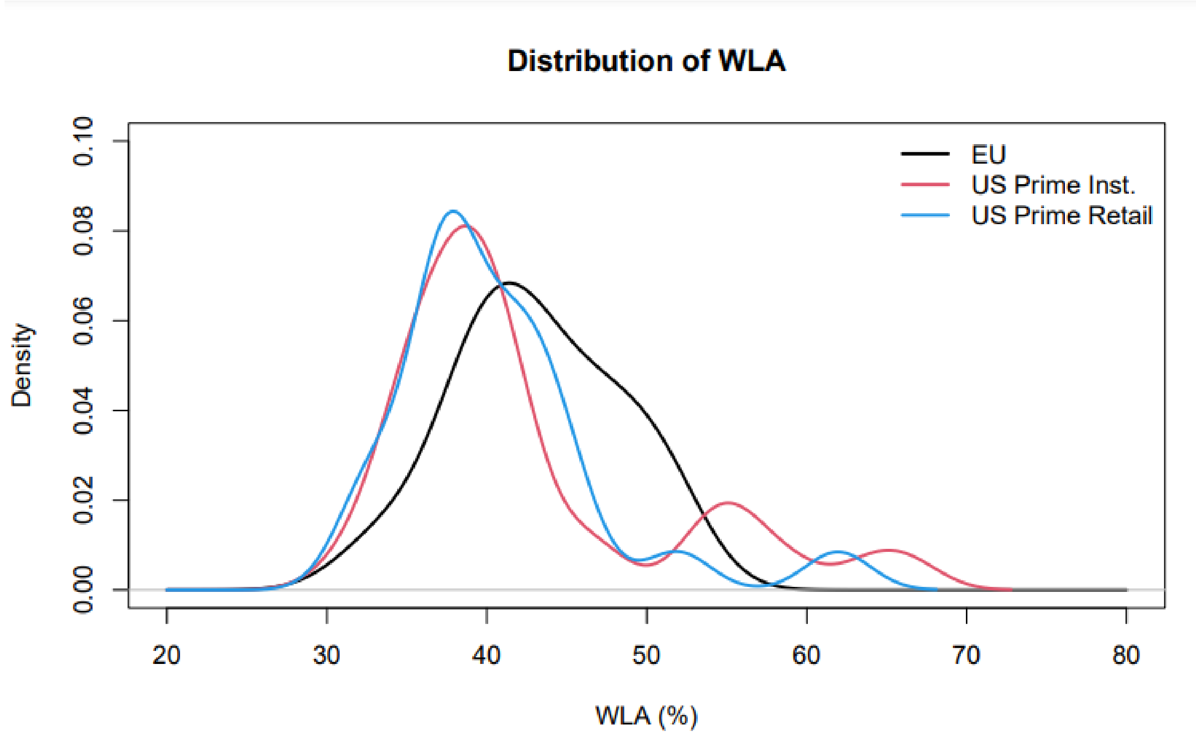


Note: Kernel density of R_{max} for US Prime and EU USD LVNAVs. X-axis indicates the maximum redemptions in % of NAV, y-axis shows the frequency.

Sources: Crane, Authors' calculations.

In the US, the distribution of WLAs across Prime institutional and Prime Retail MMFs is fairly similar (Figure 5), while EU MMFs tend to have WLAs clustered around 40%.

Figure 5: Distribution of WLAs across MMF types



Note: Kernel density of WLAs for US Prime and EU USD LVNAVs. X-axis indicates the WLAs in % of NAV, y-axis shows the frequency.

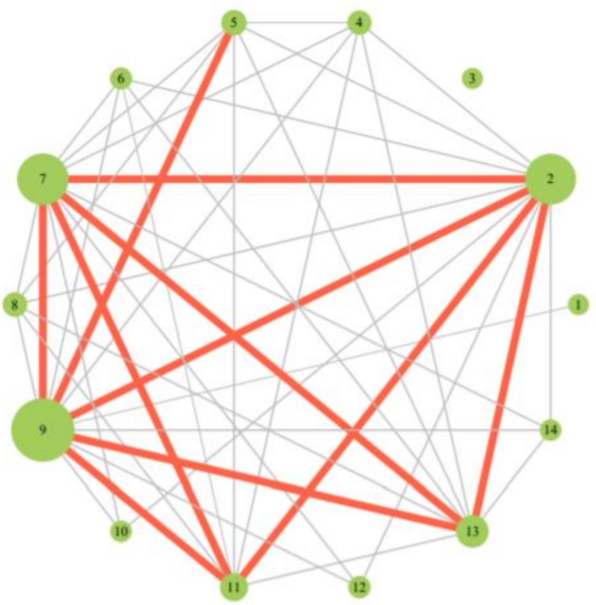
Sources: Crane, Authors' calculations.

4.4 Systemic considerations

Portfolio similarity

The previous analysis has modelled the optimal liquidation strategy of MMFs in isolation: each MMF choses its optimal liquidation strategy independently of other MMFs. In practice, since MMFs are characterized by a high degree of portfolio overlap, simultaneous sales can occur (Georg et al., 2020; ESMA, 2021; ESRB, 2021). While the investigation of coordination failures is beyond the scope of this analysis, Figure 6 illustrates that five out of the fourteen EU LVNAV MMFs have considerable similarity in their portfolio holdings (using the same approach as in Cont and Schaanning (2017)). Consequently, if one of those funds were to engage in a fire sale, the mark-to-market losses could spill over to other funds (Cont and Wagalath (2016)).

Figure 6: Portfolio similarity



Note: Each node is an MMF, whose area is based on its relative size based on NAV. Edges show the portfolio similarity, with wider links (in red) indicating high portfolio similarity.

Sources: Crane, Authors' calculations.

System-wide stress testing

We investigate the issue of coordination failure by assuming that all MMFs are subject to a redemption shock of 20% of NAV in a stylized two-asset case. We assume that each MMF reacts by selling a proportional share of WLAs and non-WLA to maintain the structure of its portfolio (vertical slicing).

Formally, the sale of WLAs is equal to:

$$T_W^* = \frac{R}{c_W} \cdot \frac{T_{W,max}}{(T_{W,max} + T_{Y,max})}$$

And the sale of non-WLAs:

$$T_Y^* = \frac{R}{c_Y} \cdot \frac{T_{Y,max}}{\left(T_{W,max} + T_{Y,max}\right)}$$

These assumptions imply that the share of WLAs remains constant once the redemptions are met.

Based on our sample of 14 EU USD MMFs, the redemptions would amount USD 55.4 billion. The MMFs would sell around USD 24.3 billion of WLAs and USD 31.4 billion of non-WLAs. As a result of the sales, the mark-to-market NAV of the MMFs would deviate from the amortised cost NAV by around 14 basis points, remaining below the 20 basis points collar for LVNAVs.

Using the portfolio composition for each MMF, the sales of assets can then be further decomposed. Within WLAs, the termination of reverse repo and the withdrawal from bank deposits would amount to around USD 11.6 billion, and sales of weekly maturing CP and CDs would amount to USD 11 billion, while the sale of other WLAs (sovereign bonds with a residual maturity lower than 190 days or other weekly maturing assets) would be around USD 1.7 billion. For non-WLAs, the bulk of the sales would be made of CP and CDs at around USD 26.5 billion and around USD 4.7 billion of other bonds. Overall the sales of short-term instruments such as CP and CDs would amount to close to USD 38 billion. To put those numbers in perspective, PWG (2020) estimates that during the two weeks of acute stress in March 2020, US Prime MMFs reduced their holdings of CP by USD 35 billion, and that this reduction in exposures to CP markets contributed to the worsening of conditions in short-term funding markets.

5 Potential implications for MMF regulation

Following the events of March 2020, there has been a range of proposals to reform MMFs. In the US, the President Working Group released a report in December 2020 outlining possible reforms (President Working Group (2020)). In the EU, ESMA published a Report proposing potential regulatory reforms (ESMA, 2022). and the ESRB issued a set of policy recommendations to improve the resilience of MMFs (ESRB, 2022). At the international level, the Financial Stability Board is also expected to publish soon a Consultation Report with proposals to improve the resilience of MMFs (FSB, 2021a). In that context, the model can be used to assess potential regulatory reforms to MMFs and see which type of reforms could have the larger impact in enhancing the resilience of MMFs. In particular, the model can be used to assess reforms targeted at the asset side of MMFs.

In this section, we perform comparative statics of different reform options in order to evaluate their impact on the resilience of MMFs. To this end, we use the analytical formulas developed in the preceding sections (‘analytical results’).

In the following, regulatory reforms affect MMFs by changing the parameters of the regulatory constraints (WLA and NAV deviation) and/or by changing the liquidity of assets held by MMFs. Since our model focuses on the liquidation of assets, it does not include portfolio allocation consideration related to the relative returns of WLA and non-WLA. Since MMFs are subject to stringent regulations on the credit quality and the maturity of the assets they invest in, there are limited trade-offs in terms of risky assets and potential portfolio reallocation.

Focusing on the asset side of MMFs, we analyse the impact of different reforms, which include (i) relaxing the NAV deviation, (ii) increasing liquidity requirements, (ii) using countercyclical liquidity buffers, (iii) and improving the liquidity of money markets MMFs invest in.

We estimate the impact of reforms on two MMFs: one “low WLA” MMFs, which holds 33% of WLA ($T_{W,max}^{Low} = 33\%$) and one “high WLA” fund with WLAs equal to the maximum of the sector, as shown in Table 1 ($T_{W,max}^{Rep} = 51\%$). In the analytical case, those two MMFs would have initial R_{max} of respectively $R_{max}^{Low} = 34\%$ for the ‘low WLA’ fund and $R_{max}^{High} = 43\%$ for the ‘high WLA’ fund. Using numerical simulations and a more granular analysis of their portfolio, their initial R_{max} are respectively $R_{max}^{Low} = 59\%$ for the ‘low WLA’ fund and $R_{max}^{High} = 64\%$ for the ‘high WLA’ fund[17].

5.1 Relaxing the NAV deviation constraint

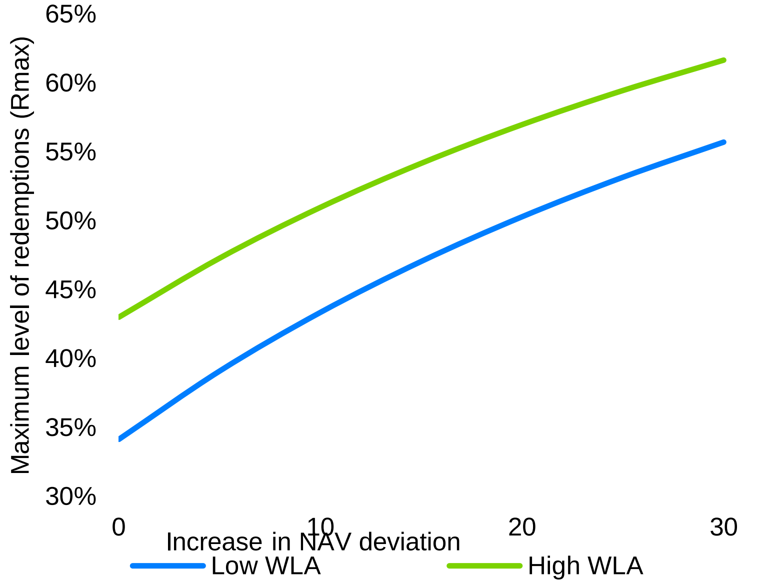
A reform option could be to increase the NAV deviation for LVNAVs. Given their exposure to private assets with limited liquidity, in times of stress the 20bps collar could potentially be breached and the LVNAV would have to pay redemptions using a floating net asset value (instead of a constant net asset value).

In our setting, increasing the NAV deviation has a very large impact[18]. Changing the collar from 20 to 40 bps would results in an improvement of R_{max} by around 15 percentage points in the analytical case for the ‘low WLA’ fund and the ‘high WLA’ fund (Figure 7).

17 The differences between the R_{max} in the analytical and numerical cases can be explained by higher liquidity of assets when using granular data. For example, $c_W = 0.998$ in the analytical case compared with , $c_W = 0.999$ in the numerical simulations. Similarly, $c_Y = 0.995$ in the analytical case compared to $c_Y = 0.997$ using more granular data. If one uses the liquidity measures from granular portfolio information, R_{max}^{Low} would increase to 49% for the low WLAs MMF (against 34% initially) and R_{max}^{High} to 56% (against 43% initially).

18 The large impact of relaxing the NAV constraint is related to the initial values of the NAV deviation. One can show that the increase in R_{max} is a decreasing function of the initial NAV deviation.

Figure 7: Relaxing the NAV constraint increases the maximum level of redemptions substantially (analytical approach)

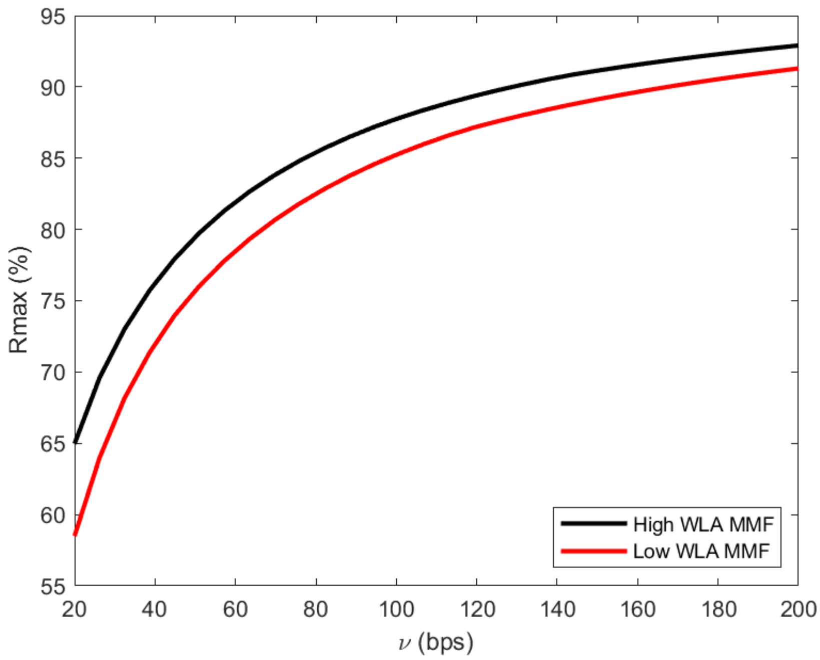


Note: Maximum level of redemptions for a LVNAV MMF as a function of the increase in the NAV collar (in bps).
Sources: Authors' calculations

Simulation results. We use the numerical simulation method to assess the impact of an increase in the NAV deviation on representative MMFs. Such an approach complements the analytical results since the simulation takes into account more granularity regarding the liquidity of the asset classes MMFs invest in[19]. As shown in Figure 7, the results are qualitatively similar to the analytical approach: R_{max} increases with the rise in ν. When the NAV deviation increases by 20bps to 40bps, R_{max} improves by more than 10 percentage points for the 'low WLA' and the high 'WLA' MMF (Figure 8).

[19] Appendix 3 provides further results obtained using the numerical simulation approach for the different reforms analysed in section 5.

Figure 8 : Relaxing the NAV constraint increases the maximum level of redemptions substantially (simulation approach)



Note: Maximum amounts of redemptions R_{max} in % of NAV as a function of the NAV deviation ν in basis points.

Source: Authors' calculations.

However, increasing the collar could also have some unintended consequences. By allowing larger deviations, such a reform could create an expectation among investors that LVNAVs are more stable than they actually are. In addition, the change in the NAV collar might be subject to external constraints related to CRAs. For some CRAs, a AAAmmf-rated fund using amortized cost cannot have a NAV deviation above 25bps before being downgraded (Standard and Poor's, 2020)[20]. Given the reliance of institutional investors on MMF ratings, such downgrade would likely trigger large outflows.

[20] CRAs provide temporary relief ('cure period'), usually around 5 day, during which the MMF can have a NAV deviation above the threshold without being downgraded.

More importantly, the model shows that at the limit, if LVNAVs would move to a floating NAV, then the NAV constraint would vanish and MMFs remain only subject to the WLA constraint.

5.2 Increasing liquidity requirements

One reform consists in increasing WLA requirements to reduce liquidity transformation performed by MMFs. If the regulatory level of WLA is increased, then the MMF will have more liquid assets it could sell to meet redemptions. In addition, since the portfolio of the MMF will be more liquid, the NAV deviation constraint will be less binding as more liquid assets have a lower price discount than other assets.

However, an increase in WLA (p_w) has always a negative impact in our model since it mechanically reduces the 'excess WLA' available for sale. To address this issue, we model this reform as an increase in p_w , the minimum level of WLA, and an equivalent increase in $T_{W,max}$, the initial holdings of weekly liquid assets. We assume the fund keeps its excess liquidity buffer constant compared to the baseline scenario[21] : $T_{W,max} - p_w = b_0$ where $b_0 = 5\%$ based on the calibration for the low WLA MMF.

Analytical results. Increasing the WLA requirements would have similar effects on both types of MMFs. If p_w were to be set 10 percentage points higher, it would allow the 'low WLA' MMF to meet 36% of redemptions against 34% in the baseline (status quo). Overall, the increase in resilience is relatively moderate: a 20 percentage point increase would only result in an increase of R_{max} by 4 point to 39% (Figure 9).

For the 'high WLA' fund, R_{max} would increase by around 2 percentage point if WLAs were to be 10 percentage point higher. This result is not surprising since using the sensitivity formulas, the marginal impact on R_{max} is relatively small.

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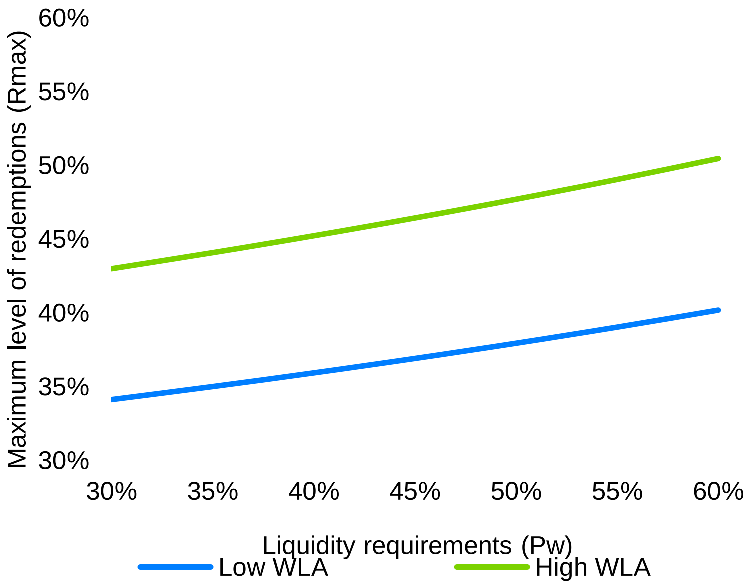
21 Other assumptions could be used. For example, one could assume that the excess liquidity remains constant as ratio of the WLA constraint rather than in absolute. While it is straightforward to model those variants, one would need to justify such assumption based on MMF managers' behaviour.

Figure 9: Increasing the weekly liquid asset requirement only moderately improves R_{max}



Note: Maximum level of redemptions for a LVNAV MMF as a function of weekly liquid assets requirements.
Sources: Authors' calculations

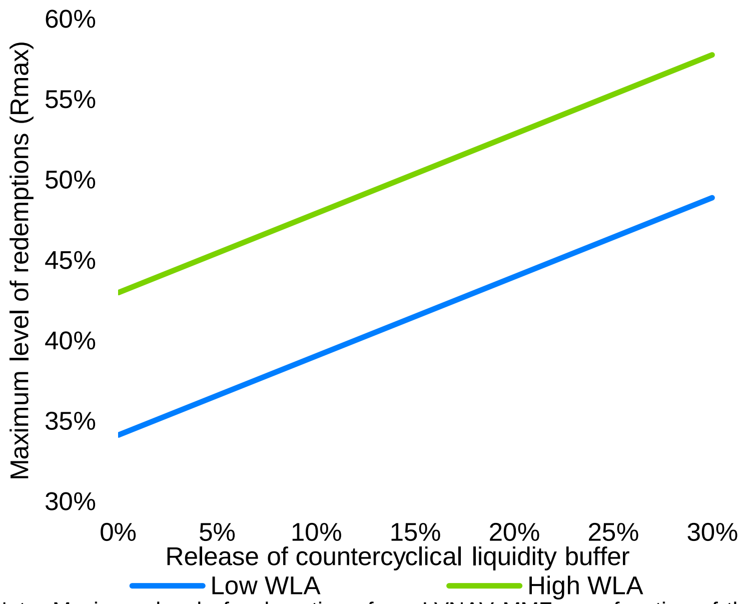
5.3 Countercyclical liquidity buffers

Recent proposals around countercyclical liquidity requirements (such as ECB (2021)) — where WLA thresholds would be relaxed during stress periods to allow MMFs to use their buffers to meet redemptions — can also be analysed using our framework. During stress periods, Authorities would release a portion of the liquidity buffers which could then be used by MMFs without leading to a regulatory breach. In our set-up we can assess the effect of this reform by estimating the impact on R_{max} of changes to the WLA constraint.

We do the estimation in two steps: first we assume that p_w is increased during normal times by a quantity ρ representing the countercyclical liquidity buffers, and $T_{W,max}$ increases by the same amount, as done in the previous subsection. Then during stress periods, Authorities release fully the liquidity buffer, which mechanically improves the excess liquidity of the MMF $(T_{W,max} - p_{w,stress})$.

Analytical results. This measure has a relatively high impact on the resilience of MMFs: in the analytical case, the release of a countercyclical liquidity buffer of 10 percentage points increases R_{max} by 5 points (Figure 10). This effect is twice as large as the previous one. This outcome is driven by the fact that the release of the countercyclical liquidity buffer immediately improves the liquidity profile of the fund. For the ‘high WLA’ fund, the impact is broadly similar: a 5 percentage point increase in R_{max} for a countercyclical liquidity buffer of 10 percentage points.

Figure 10: Introducing countercyclical liquidity buffers



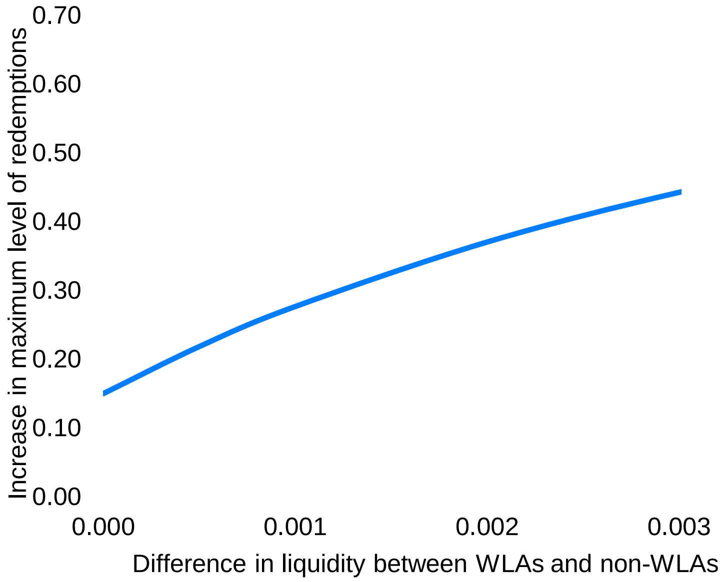
Note: Maximum level of redemptions for a LVNAV MMF as a function of the countercyclical liquidity buffer.
Sources: Authors' calculations

The relatively large effect of the CCLB is proportional to the relative liquidity of the WLAs compared to the non WLAs. The effect of the CCLB is given by:

$$\frac{\partial R_{max}}{\partial T_{W,max}} = \frac{(c_W - c_Y)(1 - p_w) + \upsilon c_W}{1 + \upsilon - (1 - p_w)c_Y - p_w c_W} > 0$$

In our application, WLAs are more liquid than non-WLAs ($(c_W - c_Y) = 0.003$), resulting in a large effect: an increase in R_{max} of more than four percentage points for a CCLB of 10 percentage points. If the liquidity of WLAs would be closer to that of non-WLAs ($(c_W - c_Y) = 0.001$), the effect of a CCLB of 10 percentage points would be smaller, with an increase in R_{max} of only 2.7 percentage points (Figure 11). This indicates that CCLB would be more effective the larger the difference in liquidity between WLAs and non-WLAs.

Figure 11: Sensitivity of the CCLB to the relative liquidity of WLAs and non-WLAs



Note: Sensitivity of Rmax to the relative liquidity of WLAs compared with non-WLAs
Sources: Authors' calculations

5.4 Requiring more liquid holdings, improving the liquidity of money markets and providing liquidity support

Three different reforms seeking to improve the liquidity of MMFs can also be analysed by changing the value of the liquidity discount c_W or c_Y.

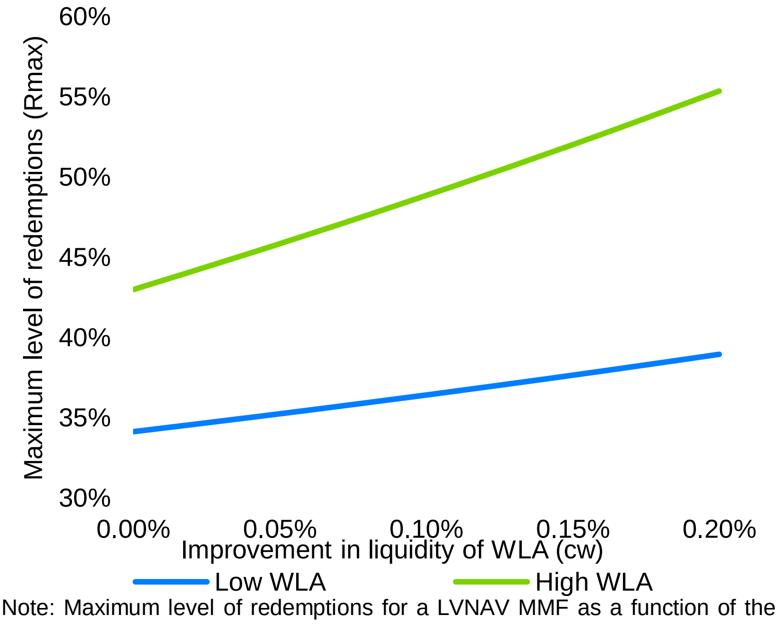
The first one consists in requiring MMFs to hold a share of very liquid assets in their portfolio, such as short-term sovereign debt, which is generally considered more liquid than CP (ECB, 2021a, 2021b). Under the current framework, the definition of WLA does not make a distinction between a CP maturing in 5 days and a short-term Treasury bill maturing in 5 days, although the latter is more liquid. By requiring MMFs to hold sovereign debt, such a measure would facilitate the ability of MMFs to dispose of WLAs to meet redemptions and therefore increase the resilience of the MMF.

More structural reforms could also be contemplated in our model. The COVID-19 crisis has shown that the limited liquidity of CP and CD market was one of the main challenges for MMFs. One reform could seek to improve the functioning and liquidity of money markets. This would encompass a range of reforms related to market structure and transparency, as well as reforms related to incentives for dealers to provide liquidity in time of stress.

The improvement in liquidity of money markets could also come from other sources, including external support from the MMF sponsor, a liquidity exchange bank, or central banks. Any liquidity backstop that would result in improving the ability of funds to dispose of their assets in stress periods would increase the resilience of MMFs. The nature of this backstop is important as well. For example, sponsor support is prohibited in the EU because it could create contagion channels between the MMFs and the banking group it might belong to, as evidenced during the Global Financial Crisis. The expectation of central bank support could also create moral hazard issues, as MMF managers might take more risks and investors might consider MMFs even more cash-like due to the existence of a public backstop.

Analytical results. In our model, improving the liquidity of money markets has a very large effect on MMF resilience. The effect is higher for MMFs with high WLAs (which have higher exposures to the assets that have become more liquid) than low WLA MMF. For example, for the 'low WLA' fund, improving the liquidity discount by 0.1 percentage point (increasing c_W by 0.1%) would improve R_{max} by around 2.5 percentage point. For the 'high WLA' fund the impact would be larger with an increase in R_{max} of around 6 percentage points (Figure 12).

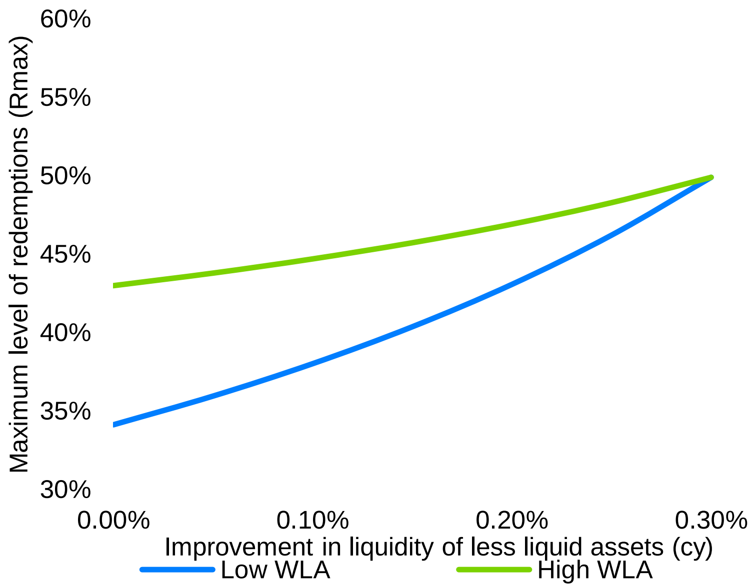
Figure 12: Improving the liquidity of WLAs has differentiated impact on funds.



Note: Maximum level of redemptions for a LVNAV MMF as a function of the liquidity discount factor of WLAs
Sources: Authors' calculations

Relatedly, reducing the liquidity discount of the less liquid assets (increasing c_Y by 0.1%) would improve R_{max} by 4 percentage points for the 'low WLA' and slightly less than 2 percentage points for the 'high WLA' fund (Figure 13). The higher impact of c_Y compared with c_W for the 'low WLA' fund is due to the relatively high share of non-WLA assets held by the MMF. If $T_{W,max}$ were to be equal to 50% (corresponding to the 'high WLA' case), higher liquidity of WLAs would have a larger impact than higher liquidity of other assets.

Figure 13: Improving the liquidity of non-WLAs has a differentiated impact on funds.



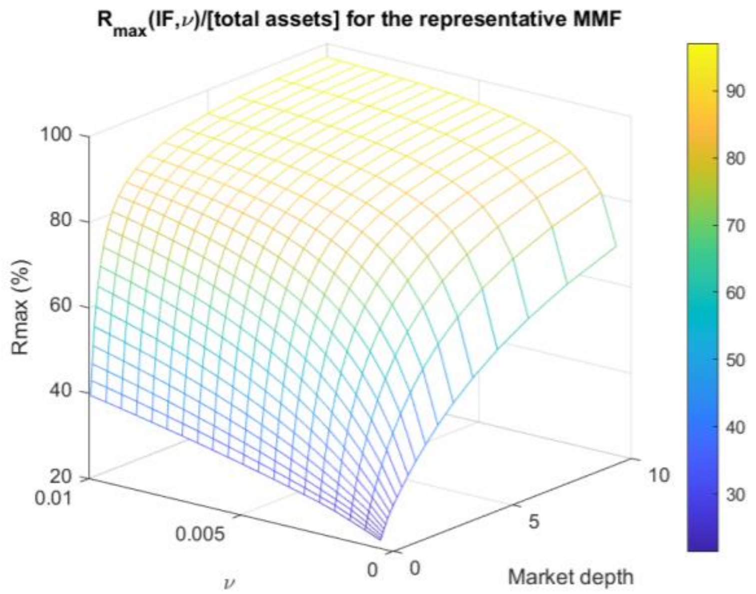
Note: Maximum level of redemptions for a LVNAV MMF as a function of the liquidity discount factor of non-WLAs
Sources: Authors' calculations

It is possible to use the numerical simulations on a representative MMF (with WLAs equal to 44%, the average of the sector) to highlight the importance of the price impact, or market depth (liquidity), of the MMF's holdings.

In Figure 14, R_{max} increases from around 50% to 87% when the market depth increases by a factor 10 (i.e. price impacts become smaller). Conversely, if market depth is reduced by a factor 10 and price impacts thus increase by a factor 10, R_{max} decreases from 50% to 15% or 25% depending on whether the low WLA MMF or the representative MMF is considered. Any policy that increases the market depth of the assets and thus improves the liquidity discount will have a very large influence on the NAV constraint and thus allow for a larger maximum redemption, R_{max}. Conversely, any measures that reduce liquidity also reduce the maximum level of redemptions.

Figure 14 illustrates how the two most important constraints/parameters, the NAV deviation and the market depth respectively, interact: A low (severe) NAV constraint combined with illiquid assets (low market depth) leads to the worst R_{max} outcomes, while liquid markets and lax NAV constraints allow almost 100% of funds to be redeemed.

Figure 14: The maximum level of redemptions is most sensitive to the market depth and the NAV constraint



Note: The chart shows the maximum level of redemptions (y-axis) as a function of NAV deviation (x-axis) and market depth (z-axis),

Sources: Crane, Authors' calculations.

5.5 Decouple the activation of fees and gates from the breach of the WLA requirement

Another reform, which has been suggested by several market participants, consists in removing the link between the breach of the WLA limit and the use of fees and gates (FSB, 2021b). The breach of the WLA limit would not directly trigger any effect, unlike with current regulations where the MMF has to consider using fees and gates when the threshold is breached. In our framework, removing the link would not have a direct impact since the WLA constraint would remain. The most likely impact of such measure would be to reduce the incentives for pre-emptive runs by investors. Since our model focuses on the asset side of MMFs, such effects are not captured.

6 Discussion and macroprudential considerations

6.1 Macroprudential considerations

The previous results show how policy options for MMF reform can have a different impact on the resilience of MMFs. On the one hand, the different regulatory reforms considered seek to improve the resilience of individual MMFs, from a microprudential standpoint. By reducing the fragility of individual entities, those reforms make MMFs more stable and mitigate the risks of destabilising effects of large redemptions. However, microprudential measures can have macrofinancial consequences (Freixas et al., 2015).

MMFs exposed to the private sector are characterised by a very high market footprint (e.g. they hold a substantial share of short-term debt issued by financial institutions), high portfolio overlap and the private markets they invest in tend to have very limited liquidity (buy and hold investors, trading mainly over-the-counter etc.). In that context, microprudential measures might not factor in negative externalities related to the collective behaviour of MMFs or the impact of portfolio reallocation one short-term funding markets.

For example, higher liquidity requirements will reduce the risk of fire sales of less liquid assets during stress periods, improving financial system resilience. At the same time, such a measure entails that MMFs will reduce funding provided to financial institutions by shifting either to sovereign instruments or to very short-dated CPs and CDs. While good for the liquidity of MMFs and for financial stability during stress (by reducing the risk of fire sales of the less liquid assets), such measure implies that banks might face more challenges in obtaining funding in short-term markets and might face higher roll-over risk as MMFs might only be willing to purchase short-dated instruments. Therefore, improvements in the resilience of MMF and short-term funding markets during stress period might come with higher funding costs for banks during normal times and higher refinancing risks.

Forcing LVNAVs to move to floating NAV would improve the resilience of MMFs and might also result in more short-term funding to banks (since the NAV constraint would no longer exist, allowing MMFs to invest in instrument with higher price risk). At the same time, by moving to mark-to-market of MMF shares, such move would reduce the cash-like features of MMFs (FSB, 2021b) and might result in a shift to cash management alternatives (bank deposits or public debt MMFs).

Other regulatory reforms considered are more macroprudential in nature. Countercyclical liquidity buffers for example would be activated by a macroprudential authority and hence would provide relief to the overall sector in times of stress —provided that MMFs actually use the regulatory relief and that stigma effects are not significant—. Since such measure would only be used during stress period, its impact on the baseline would be low. Relatedly providing liquidity support to short-term funding markets would also improve the resilience during stress periods without significantly affecting the baseline.

More structural reforms aimed at improving the functioning of short-term funding markets would also improve financial stability while coming with little trade-offs, provided that such reforms can be carried out.

6.2 Use, limits and possible extension of the model

The framework outlined in this paper can be used by Authorities to assess the relative impact of a different combinations of regulatory options. For such an assessment to be performed, one needs to calibrate the model on the actual holdings of MMFs, which are available to Authorities through regulatory reporting requirements, as well as to calibrate the price impact of asset sales for MMFs. Since markets for CDs and CPs have limited transparency, it might be challenging to obtain precise estimates of the price impact, especially when the volume of asset sales is high.

This challenge partly reflects the nature of CP and CD market: given the very short duration of those instruments, investors follow mainly a buy-and-hold strategy. In normal times, sales are infrequent and MMFs can usually source liquidity by selling the instruments to dealers or to the issuer (although neither the dealer nor the issuer have any obligation to provide liquidity in secondary markets).

Given the uncertainty, a range of estimates can be used for the price impact. Some recent proposals aimed at improving transparency to market participants and Authorities in those markets, which could help address the issue around data gaps.

One additional complication is that the events of March 2020 have shown that when the volumes of sales is high, dealers are unable to provide liquidity and secondary markets can shut down. While this effect is not modelled here, one extension would be to set a limit on the amount of possible sales by type of instruments which would constitute an additional constraint. Such addition yields some challenges, as MMF managers would also need to form expectations about the behaviour of other MMFs.

Another limit to our approach is that this paper focuses exclusively on the asset side of MMFs. The drivers of investors' redemptions are not modelled, yet redemptions might change as the result of asset liquidation of the MMF, possibly increasing further the pressure on MMFs. Since the model has a short-time horizon, such aspects are outside of the scope of this paper. Relatedly, we do not consider the impact of the reforms on the viability of MMFs or on the use of MMFs by investors.

The framework outline in this paper can also be used to perform reverse stress testing, e.g. estimating the size of the shocks above which MMFs would not be able to comply with regulations. This can be done at the individual fund level (for supervisory purposes for example) but also at sector-wide level. The model can be used to estimate what would be the liquidation of assets performed by MMFs to meet a given amount of redemptions and assess whether short-term markets would be able to absorb such amounts of sales.

The analysis can also be extended to other type of open-ended funds. Since investors flows tend to be related to past performance, large changes in NAV are likely to lead to redemptions. Therefore, the NAV constraint can be used to model behavioural factors (rather than regulatory requirements) from investors. Relatedly, while open-ended funds do not have liquidity requirements, managers might want to maintain some levels of highly liquid assets in their portfolio, which could be modelled through the WLA constraint.

7 Conclusion

We have shown how the use of amortised cost and liquidity requirements can create challenges for MMFs exposed to instruments with limited liquidity. In particular, in times of stress, MMFs face difficulties in selling assets to meet redemptions while complying with regulatory requirements. Using data on EU LVNAV MMFs and US Prime MMFs, we use our model to assess the impact of policy reform on the resilience of MMFs. Overall, we find that changing required liquidity requirements has limited effects on the resilience of funds. In contrast, increasing the NAV deviation and at the limit removing the use of amortised cost have a large effect on the maximum amount of redemptions a fund can meet. Relatedly, introducing countercyclical liquidity buffers can foster resilience by providing additional flexibility to MMFs in times of stress. Finally, improving the liquidity of underlying markets has also a significant impact on the resilience of MMFs. The framework outlined in this paper can be used by Authorities when considering regulatory options for MMFs.

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Appendix 1: Mathematical proofs

1 Proofs

Lemma 2. *Suppose that the optimization problem is feasible, that $R > 0$, and that the functions $q \longmapsto q\psi_i(q)$ are increasing for every $1 \leq i \leq N$. Then $R = \Gamma(\gamma)$ for the optimal γ.*

Proof. The condition ensures that $\gamma \longmapsto q\Gamma(\gamma)$ is an increasing function in each component γ_i of γ. Assume that $R < \Gamma(\gamma)$ for the optimal γ, which cannot be the null, as $R > 0$. Since V is decreasing on every component of γ while Γ is increasing, let us study the effect of diminishing a positive component γ_j for which $\omega_j^W = 1$ on these constraints.

The liquid assets constraint can be written as $\sum_{i=1}^{\mathrm{N}}(\omega_i^W - p_W)\, \upsilon_i(\gamma_i) \geq 0$ for some decreasing functions υ_i; decreasing γ_j increases the right-hand side, and this constraint would not be tight. The NAV constraint reads $\upsilon a^T 1 \geq (1+\upsilon)a^T\gamma - \Gamma(\gamma)$. As the right-hand side decreases when γ_j decreases, this constraint cannot be tight either. Hence, as $\Gamma(\gamma) > R$, we must have $\gamma_j = 0$ for every j with $\omega_j^W = 1$. Since the Money Market Fund's portfolio is feasible in t, we have

$$(1-p_W)V^W(0) \geq p_W\big(V(0) - V^W(0)\big) = p_W \sum\{\upsilon_i(0)\colon \omega_i^W = 0\} \geq p_W \sum\{\upsilon_i(\gamma_i)\colon \omega_i^W = 0\},$$

where the second inequality comes from the monotonicity of υ_i . Thus, the liquid assets constraint is satisfied, and decreasing some $\gamma_j > 0$ and for some j with $\omega_j^W = 0$ decreases further the right-hand side. As seen above, decreasing γ_j looses the NAV constraint. Therefore, we can increase the value of the objective function slightly without harming the feasibility of the problem: γ cannot be an optimum. This contradiction refutes the possibility that $\Gamma(\gamma) > R$.

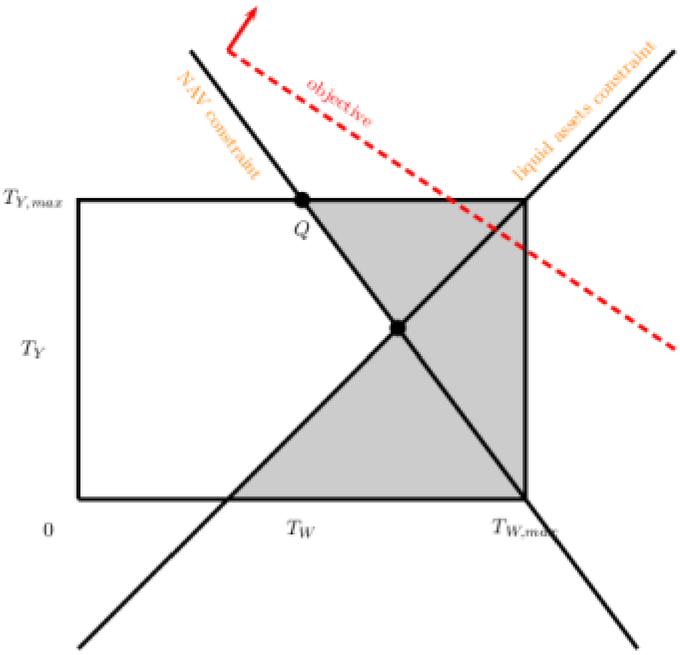
2 Two further cases

Case 2. The second case happens when $c_W < c_Y$ and $\upsilon T_{W,max} \geq (1 - c_Y)T_{Y,max}$, so that the NAV constraint is satisfied in case of full liquidation of the longer term $(T_W, T_Y) = \left(0, T_{Y,max}\right)$, i.e., when selling every longer-term asset and none of the short-term ones is permitted without violating the NAV constraint. Then the slope of the objective function is larger than the slope of the NAV constraint, and the optimum is now reached in the point Q, where the NAV is tight while $T_Y = T_{Y,max}$ (see Figure A1.1). We can easily compute the coordinates of the point Q, and thus the optimal value

$$R_{max}(p_W, \upsilon) = c_W \frac{\upsilon T_{W,max}(c_Y - 1)T_{Y,max}}{1 + \upsilon - c_W} + c_Y T_{Y,max}$$

$$= \frac{c_W(\upsilon - 1)T_{W,max} + c_Y T_{Y,max}(\upsilon + 1)T_{Y,max}}{1 + \upsilon - c_W}$$

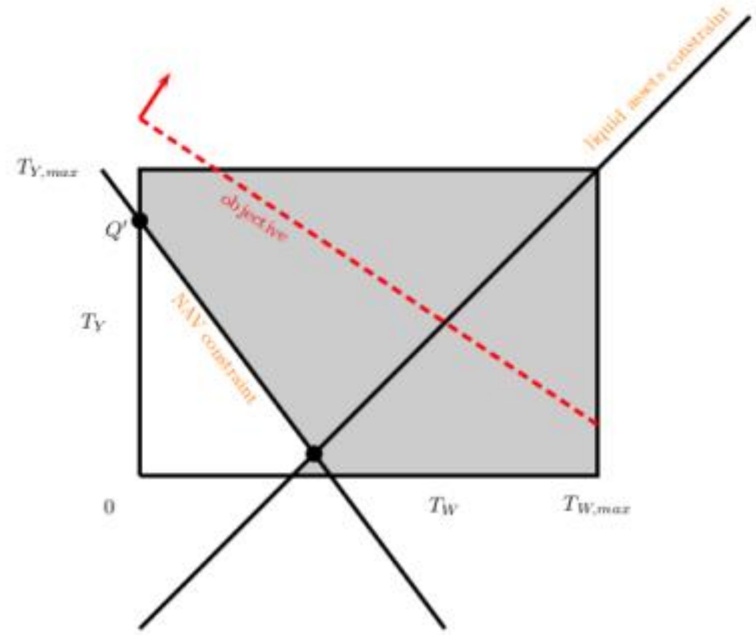
Figure A1.1: Second case



Case 3. The third case happens when $c_W < c_Y$and v$\upsilon T_{W,max} < (1 - c_Y)T_{Y,max}$. There, the point $(T_W, T_Y) = \left(0, T_{Y,max}\right)$ is no longer feasible, and the largest value for R is attained when we liquidate as much as possible of the longer-term assets to satisfy the NAV constraint tightly (see Figure A1.2, point Q'). This yields:

$$R_{max}(p_W, \upsilon) = \frac{c_Y \upsilon\left(T_{W,max} + T_{Y,max}\right)}{1 + \upsilon - c_Y}$$

Figure A1.2: Third case



3 Valuation of MMF shares

In the baseline model, the MMF values its assets as:

$$V(\gamma) := \sum_{i=0}^{\mathrm{N}} a_i(1-\gamma_i)$$

This implies that the price impact has no permanent effect on the asset price.

The alternative viewpoint is to consider that the price impact of the sales is also reflected on the remaining assets held by the fund via mark-to-market accounting, so that the value of the portfolio at $t+1$ is

$$V(\gamma) := \sum_{i=0}^{\mathrm{N}} a_i(1-\gamma_i)\,\psi_i(\gamma_i a_i)$$

A third option is to inly consider effectively realized losses from price impacts on the portion of assets sold, but that mark-to-market losses are not reflected on the remaining assets on the balance sheet. In that case, the value of the portfolio is given by:

$$V(\gamma) := \sum_{i=0}^{\mathrm{N}} a_i(1-\gamma_i) - \sum_{i=0}^{\mathrm{N}} a_i\gamma_i\left(1-\psi_i(\gamma_i a_i)\right)$$

Appendix 2: Calibration of liquidity discount factors

The liquidity discount factors used in the model are based on the liquidity stress test parameters provided in ESMA (2020a). The parameters are based on estimations of liquidity discount factors on sovereign and corporate bonds with different residual maturities.

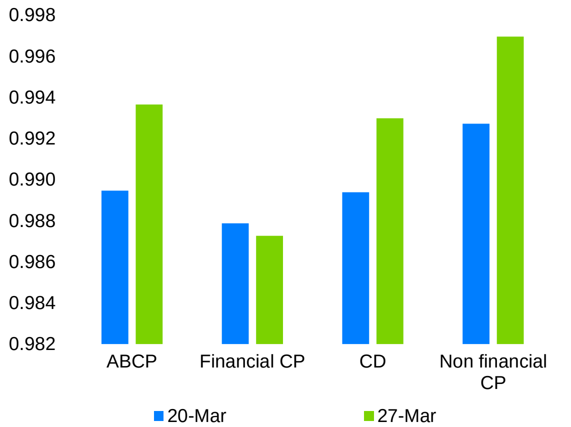
Due to data gaps, data on CP and CD was not used to estimate the discounts. As a result, the discount factors might differ, since the relative liquidity of corporate bonds and CP and CDs might be different, including in period of stress. In the two-asset application, we use $c_W = 0.998$ and $c_Y = 0.995$.

Given the uncertainty around the price impact measure, for illustrative purposes, we look at three other ways to calibrate them.

First, we use weekly data on portfolio holdings from a few MMFs which report the face value and the mark-to-market value of their assets during the month of March 2020. For the main asset classes they invest in (ABCP, financial and corporate CP, and CDs), we compute for each holding and fund the ratio between the mark-to-market value and the face value of the holding and assume that the change in value reflects mainly liquidity risk (rather than credit risk). Chart A2.1 shows that using this proxy, the price impact measure would be between $c_Y = 0.989$ and $c_Y = 0.995$, when taking the lowest observed values for the ratio across asset classes. Using the average value of the ratio would yield $c_Y = 0.999$ which does not seem realistic.

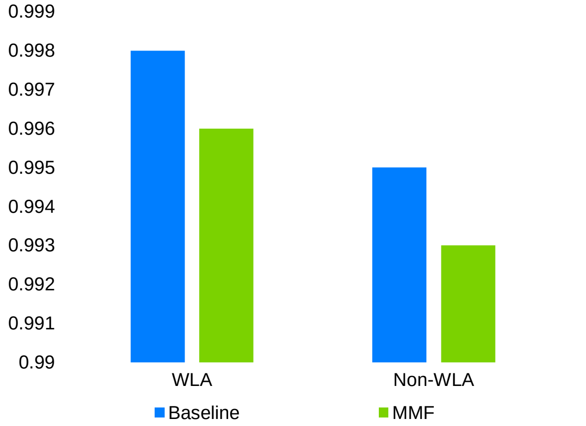
Second, we use data from one MMF which provides detailed portfolio and liquidity information on a daily basis. For this MMF, we take a snapshot of outflows, NAV deviation and WLAs over two periods: between 11 and 18 March 2020 and between 13 and 20 March 2020. For example, we observe that outflows reached 32% between 13 and 20 March 2020 and over the same period its NAV deviation increased by 15 basis points and its WLAs declined by 13 percentage points. Using similar measures for the 11-18 March 2020 period it is then possible to calculate the price impacts c_W and c_Y that would be consistent with the observed change in WLA and NAV deviation. Using this approach we get $c_W = 0.996$ and $c_Y = 0.993$, which are even lower than our baseline estimates (Chart A2.2). In addition, this approach only uses sales from this MMF to estimate the price impact while simultaneous sales from other MMFs are ignored, although they would drive down the price impact even further.

Chart A2.1: Proxies for liquidity risk



Note: Minimum ratio of mark-to-market value of instruments to principal value for a sample of 12 EU USD LVNAVs.
Sources: Crane, Authors' calculations.

Chart A2.2: Calibrating the data based on one MMF flows, change in WLA and NAV



Note: Estimated price impact measures..
Sources: Crane, Authors' calculations.

Third, a few publications provide estimates of liquidation costs which can be used to benchmark our estimates.

SEC (2014a) provides estimates of liquidation costs using actual trade data before and during the Global Financial Crisis using data covering the January 2008- December 2009 period. Using TRACE reporting system, it estimates the average spread on Tier 1 securities (bonds rated AA- or above) and Tier 2 securities (from A+ to A-) for bonds maturing within 120 days and with a trade size of at least USD 100,000.

Between January and September 2008, the average spread amounts to 25 basis points for Tier 1 and Tier 2 securities (implying $c_{All} = 0.9975$). During the acute crisis period (September 12 to October 20), the average spread is estimated at around 78bps for Tier 1 and 127bps for Tier 2 securities (implying $c_{Tier\ 1} = 0.9922$ and $c_{Tier\ 2} = 0.9873$)[22]. Over the post-crisis period, the average spread is 33bps for Tier 1 instruments and 28bps for Tier 2 (implying $c_{Tier\ 1} = 0.9967$ and $c_{Tier\ 2} = 0.9972$).

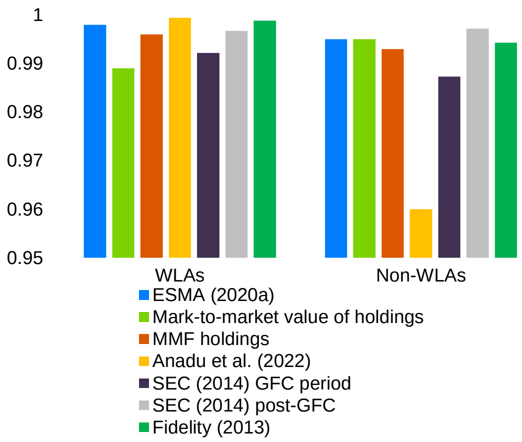
Fidelity (2013) estimates that during the GFC, the average spread on private short-term instruments sold by its Prime MMFs was 12 basis points and the maximum spread was 57 basis points (which would yield respectively $c_Y = 0.9988$ and $c_Y = 0.9943$).

[22] Fidelity (2013) estimates that during the GFC, the average spread on private short-term instruments sold by its Prime MMFs was 12 basis points and the maximum spread was 57 basis points (which would yield respectively $c_Y = 0.9988$ and $c_Y = 0.9943$).

More recently, Anadu et al. (2022) estimate price impacts on short-term markets using information from Exchange Traded Funds (ETFs) tracking short-term indices. Market liquidity of short-term sovereign and corporate bonds instruments is indirectly measured using the ETF premium/discount (which represents the difference between the end-of-day net asset value of the ETF and the intraday value of the shares on secondary markets). The authors find that short-term ETFs tracking sovereign instruments had discounts ranging between 0.01% and 0.11%, while ETFs tracking short-term private debt had discounts ranging from 1% to 7%. Using the average of these ranges for the liquidity discounts of WLAs (c_W) — assuming that only sovereign instruments are WLAs — and non-WLAs (c_Y) would yield $c_W = 0.9994$ and $c_Y = 0.9600$.

Table A2.1 and Chart A2.3 provide a comparison of the different estimates. Estimates for the liquidity discount on WLAs range between 0.9890 to 0.9988 while estimates for non-WLAs range between 0.9873 and 0.9972. Overall, the estimates used in the paper are in line with those alternative sources.

Chart A2.3: Liquidity discounts



Note: Liquidity discounts on WLAs and non-WLAs.
Sources: Fidelity (2013), SEC (2014), ESMA (2020a), Anadu et al. (2022)

Table A2.1

Liquidity discounts

Asset class	WLAs (c_W)	Non-WLAs (c_Y)	Time period
ESMA (2020a)	0.9980	0.9950	Before 2020
Mark-to-market value of holdings	0.9890	0.9950	March 2020
MMF holdings	0.9960	0.9930	March 2020
Anadu et al. (2022)	0.9994	0.9600	March 2020
SEC (2014) GFC period	0.9922	0.9873	Jan. Sep. 2008
SEC (2014) post-GFC	0.9967	0.9972	Oct.2008 -Dec. 2009
Fidelity (2013)	0.9988	0.9943	Sep. 2008

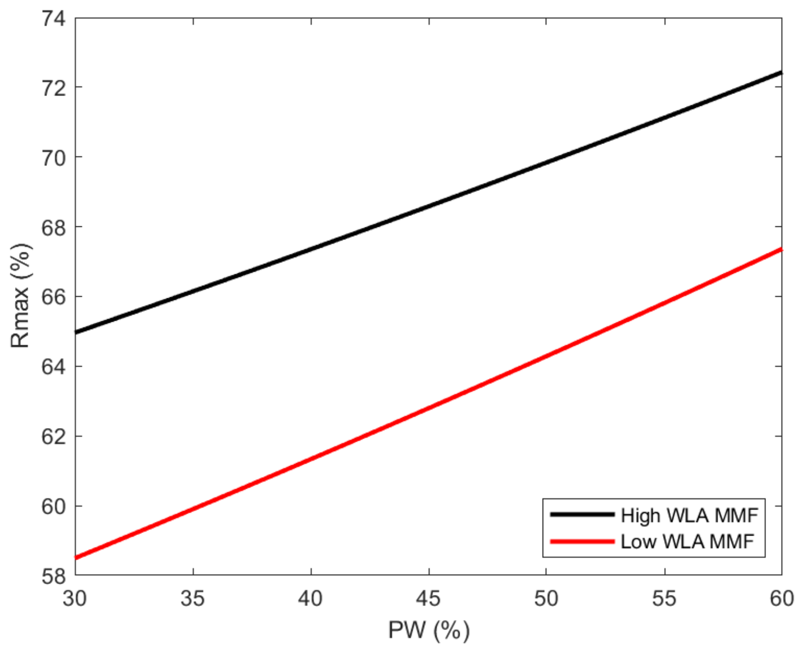
Appendix 3: Numerical simulations for regulatory reforms

This appendix provides further results related to regulatory reforms using numerical simulations with multiple asset classes. We use 9 asset classes as in section 5.2: one asset class with no price impact (deposits and repo) and then two groups of assets (sovereign instruments and short-term private debt securities) classified in 4 maturity buckets as in Table 2.

Increasing liquidity buffers

Chart A3.1 below shows the change in R_{max} when the WLA constraint (p_w) and the corresponding initial holdings of WLAs ($T_{W,max}$) are increased. A 10 percentage point increase in p_w results in an improvement of R_{max} by around 3 percentage points for each MMF.

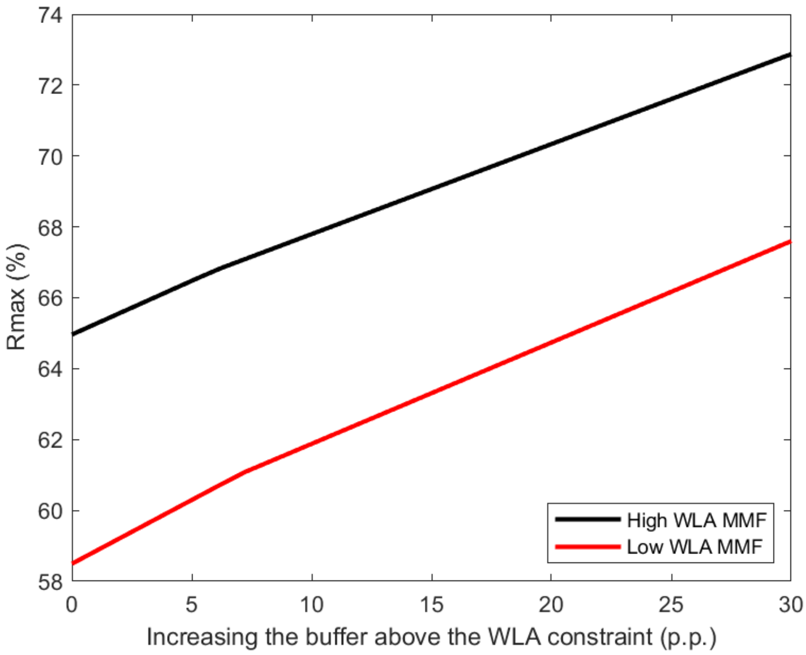
Chart A3.1 Higher liquidity buffers



Countercyclical liquidity buffer

The chart below shows the increase in R_{max} when CCLB are used. A CCLB of 10 percentage point (where p_w would initially be equal to 40% and then be lowered to 30%), would improve R_{max} by around 3.5 percentage points for both types of MMFs (Chart A3.1). Unlike in the analytical case, the improvement in R_{max} compared to the previous case of an increase in p_w is quantitatively small. This is because the relative liquidity of WLAs to non-WLAs $(c_W - c_Y)$ is smaller than in the analytical case as discussed in section 4.3.

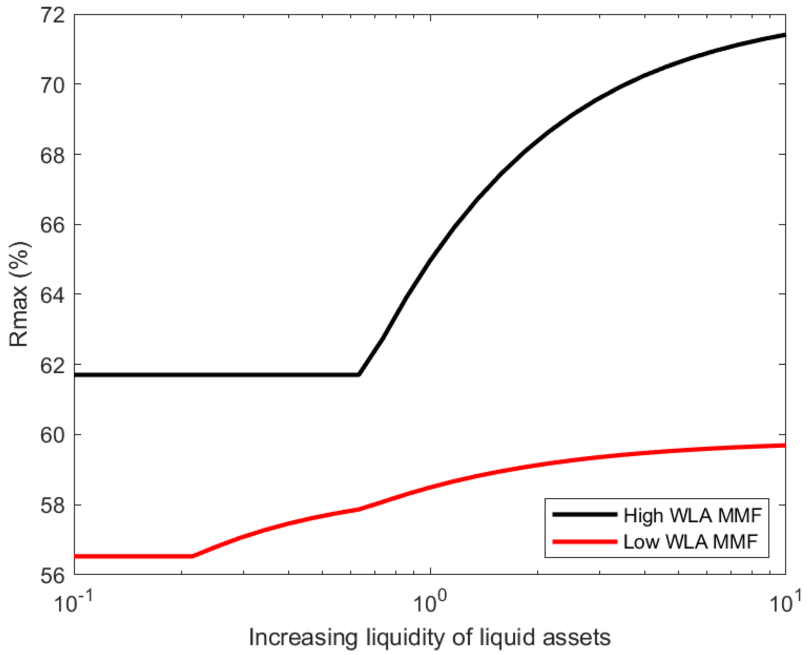
Chart A3.2 Countercyclical liquidity buffers



Changing the liquidity of WLAs

The chart below shows the increase in R_{max} when the liquidity of WLAs c_W changes. When the liquidity deteriorates, R_{max} declines up to a certain point where WLAs cannot be sold without breaching the NAV deviation. When the liquidity of WLAs improve, R_{max} increases for both MMFs with a larger effect for the 'high WLA' fund as in the analytical case.

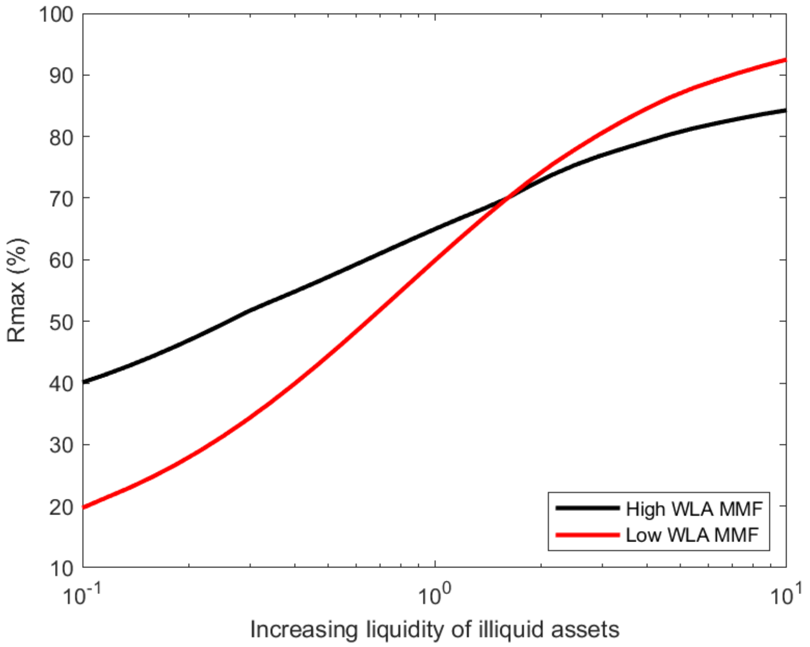
Chart A3.3 Improving the liquidity of WLAs c_W



Changing the liquidity of non-WLAs

The chart below shows the increase in R_{max} when the liquidity of non-WLAs c_Y changes. The impact of changes in liquidity are higher for the 'low WLA' fund since it holds more of the assets whose liquidity is affected.

Chart A3.3 Improving the liquidity of non-WLAs c_y



Overall, the numerical simulations provide qualitatively similar estimates of regulatory reforms than the analytical results.

ESMA Working Paper, No. 2, 2023
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Authorisation: This Working Paper has been approved for publication by the Selection Committee and reviewed by the Scientific Committee of ESMA.

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