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Repo Markets, Collateral Re-use and Systemic Fragility. A Literature Review

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Repo Markets, Collateral Re-use and Systemic Fragility. A Literature Review

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ABSTRACT

In the Aftermath of the 2007-09 financial crisis, repurchase agreement (repo) markets were generally considered to be partly responsible for the crisis. Ten years afterwards, strongly reformed repo markets are far from being dead, as in the US, or even more lively than ever, as in Europe. Over these years, researchers have questioned the capability of repo markets to insulate the financial system from systemic risk. The use of collateral has been a centrepiece of the debate: while used to secure repo transactions, it connects credit and securities' markets, potentially increasing opaqueness and contagion risk. In addition, when the so-called *re-use* is allowed, the same collateral can back simultaneously multiple transactions, potentially increasing interconnection and leverage. This work analyses the recent literature on repo markets, focusing on the re-use of collateral and its repercussions on financial stability. While there is a relatively rich literature on the overall modelling of the repo markets in general, collateral re-use can benefit from further research. The first set of literature analysed in this work regards the legal framework and the statistical quantification of collateral re-use. A systematic review is then devoted to recent works, both theoretical and empirical, modelling and investigating the relationship between repo market, collateral re-use and financial stability. The identification of less explored areas worth studying more in detail concludes the work.

Keywords: repo markets, collateral re-use, rehypothecation, systemic risk

JEL codes: E58, G01, G21, G23

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The 2007-2009 global financial crisis persuaded regulators and academicians of the manifold imbalances and risks, also for the financial stability, accumulated in the repo markets (especially in the US) during the run-up of the crisis. Repo contracts, thanks to the presence of a security exchanged between two counterparties as collateral, can be clearly considered a secured (and therefore safer) loan. The crisis unveiled the possibility of strains, dry-ups and runs in this safer market. On top of that, the expansion of the repo markets in the pre-crisis years proved to be capable to usher in insolvencies involving large areas of the banking industry and threatening an impairment of the financial system as a whole.

On the one side, the expansion of the repo markets in the pre-crisis years was linked to a more general tendency of the financial system to escape regulatory requirements and limitations, operating outside of the regulated environment and building up a "shadow banking sector". The repo markets were employed as the marketplace to intermediate funds outside of the banking industry among institutional investors such as money market or speculative funds, securities dealer and other financial intermediaries. In conjunction with the use as collateral of synthetic financial products such as Residential Mortgage-Backed Securities (RMBS), the repo markets became the protagonist, during the pre-crisis years, of the expansion of the overall leverage of the financial system outside of the monitoring eyes of the regulators and supervisory authorities. As indicated also by the Financial Stability Board (2013), the crisis showed that the repo markets needed reform to prevent the build up of the next crisis.

On the other side, during the financial crisis the repo markets showed that, despite being secured, repo transactions allow for malfunctioning similar to those taking place in the unsecured lending markets. As noted by Gorton and Metric (2012) the design of the repo markets provides only limited resilience in front of sudden shocks. Following shocks modifying expectations on limited parts of the economy (such as, for instance, the real estate sector) distrust can spread producing a general preference for safe assets which leads to refuse entire categories of securities as collateral. Haircuts on the provided collateral can limit significantly the borrowing capacities of the counterparties, inducing the necessity of financing through assets' sales, with the consequences of sharp falls in securities' prices. Despite the presence of collateral, riskier counterparties can also be excluded from the market, leading to liquidity shortages and defaults.

Despite its vulnerabilities and the challenges posed for financial stability, the repo markets also served as stabilising factor for the money markets in general and for the financing of banks and financial institutions in particular. As made visible by the aggregate figures of the ECB Survey on Money Markets (2015) and also verified in the micro-data by Di Filippo, Ranaldo and Wrampelmeyer (2016), during the financial crisis the euro area financial industry experienced a large substitution between unsecured and secured lending. While unsecured financing dryed-up both for the riskier counterparties and for the longer maturities, the repo market provided a valid substituting channel for the satisfaction of banks' liquidity needs. Also thanks to the specific euro area setting, where Central Counterparties (CCPs) are the most commonly intermediary of repo transactions, repos have ensured a stable, though capital intensive and short term, source of

financing especially for the most distressed segments of the euro area financial sector.

Against the backdrop of this apparent contradiction, this paper analyses the recent contributions in the economic analysis of repo markets and collateral re-use with a special attention to their link to the build-up of vulnerabilities in the financial system. One of the purposes is to find in the available literature indications on what to expect from present and future repo markets and on how to best design repo markets in order to make them more resilient. Looking forward to a path of normalisation in the years to come, both in the overall level of risk of single market participants and in the macro conditions, the economic modelling of the interaction between the secured funding and the other sources of funding can help understanding the developments in the funding structures. Looking at the availability of high-quality collateral, and having in mind the important flows of securities in direction of the central banks having taken place in the past years, the assessment of the implications of specialness and re-use can help in informing the policy making process. Recent modifications of the regulatory environment, in particular the provisions of the EU Securities financing transactions (SFTR) Regulation 2015/2365, stimulate a keen attention on the economic interpretation of the collateral re-use mechanism in the repo markets.

The work is structured as follows. The first section will introduce the definition of repo and will explore the legal basis and regulatory limits for collateral re-use in the different jurisdictions. The second section is devoted to the statistical assessment and quantification of collateral re-use. The different statistical approaches are compared, illustrating advantages and challenges of the different methods, with particular attention to the use of granular data. The third section offers a review of the literature dealing with the problem of repo markets' vulnerability. The review illustrates the five broad categories of destabilising factors identified by the recent literature in the repo markets. The fourth section focuses on the literature explicitly dealing with collateral re-use. Also in this case, the analysed contributions are broadly classified in four categories, according to the modelling technique adopted and to identified effects of re-use on the financial system as a whole. The fifth section illustrates the conclusions of the work.

I. Legal background

According to ICMA 2019, a repurchase agreement (repo) is a transaction in which:

> (...) one party sells an asset (usually fixed-income securities) to another party at one price and commits to repurchase the same or another part of the same asset from the second party at a different price at a future date or (in the case of an open repo) on demand (ICMA 2019).

The price agreed for the transaction consists in the difference between the selling price and the repurchase price for the involved security. The price can incorporate a remuneration for either the provider of the security or the provider of funds, depending on the purpose of the transaction: cash lending or securities lending (in this last case: trades involving 'specials' in the sense of Duffie 1996).

The rationale for engaging in repos is mainly related to the secured nature of the transaction: in case of counterparty insolvency, any potential loss is mitigated by the right of the non-defaulting party to withhold the cash or the security initially provided by the defaulted counterparty and meant to be reverted at maturity.

Normally, repos take place around the world in accordance to a set of standard rules. One popular standard documentation for repos is represented by the International Capital Market Association (ICMA) Global Master Repurchase Agreement (GMRA) (see ICMA 2011). Another important reference documentation is represented by the International Securities Lending Association (ISLA) Global Master Securities Lending Agreement (GMSLA), which is coordinated with the aforementioned ICMA GMRA, given the partially overlapping nature of the involved transactions (see ISLA 2010). Both sets of documentation clearly state some fundamental characteristics of the repo (and securities lending) contracts: (i) when reverting the initial transaction the exchanged security can also be different but *equivalent* to the original; (ii) in case of default, a non-defaulting party having entered a repo contracts is exempt from the so-called *automatic stay* (for the United States, automatic stay is defined by the U.S.C., chapter 11, § 541), having the right to establish a balance between the fair value of the outstanding obligations of the two parties having entered the repo contract and to confine the residual credit/debit obligation to that balance.

Implicit in the reported contractual documentation is an extremely important aspect of the repo transactions: the collateral purchased in the spot transaction changes ownership and can be further used in subsequent analogous transactions until due for repurchase by the original seller. While sometimes called *re-hypothecation* or *re-pledging* in analogy to the derivatives market (also see Monnet 2011 for the discussion of re-hypothecation in the derivatives market), the most proper definition of this procedure in the repo market is *re-use* (see ICMA 2019), meaning with it:

> (...) the onward outright sale of collateral by a repo buyer to a third party in the cash market (ICMA 2019).

Interestingly, in the European Union, with the purpose of facilitating cross-border repo activity and ensuring the enforceability of repo contracts in the single market, the Directive 2002/47/EC on "Financial collateral arrangements" sets out and protects the right of *re-use* for the security buyer having entered a repo contract, explicitly excluding the possibility that a repo might be *re-characterised* by courts as non-automatic stay exempt transactions.

The legal framework of the United States departs from the one described so far for two key aspects: on the one hand the transfer of the legal title involved in the standard repo contracts is weaker and more controversial than in the EU, on the other hand some securities financing transactions are subject to limitations regarding the extent the pledged assets can be re-used (by the broker-dealer bank). Regarding the first aspect, Comotto 2014 clarifies that:

> Under the law of New York, which is the predominant jurisdiction in the US, the transfer of title to collateral is not legally robust. In the event of a repo seller becoming

insolvent, there is a material risk that the rights of the buyer to liquidate collateral could be successfully challenged in court (Comotto 2014).

For this reason, in the US framework repos have to explicitly contain a right of collateral re-use in order to produce effects equivalent to the ones described above for the EU framework. In addition, the US regulation explicitly sets a threshold for the re-use of collateral by broker-dealer banks. The limit is set out in the SEC Rule 15c3-3 of the Securities Exchange Act of 1934 regarding "Customer protection – reserves and custody of securities". The provisions of the SEC Rule 15c3-3 are aimed at avoiding that broker-dealers finance their own activities using securities owned by the clients. More in detail the rule defines as "margin securities" those clients' securities held by the broker-dealer bank as pledge against a margin debit. The rule sets a limit of 140% for the re-use by the broker-dealer bank of such securities. While not directly affecting repo chains extensions, the SEC Rule 15c3-3 reduces the extent in which the primary source of collateral (that is to say customer's or hedge fund's assets, see Singh and Aitken 2009 for reference) can be re-used by broker-dealer banks in their own business, capping in some way the *collateral multiplier* produced at system level (see Singh and Aitken 2010, p. 4 note 3, regarding the exclusion of repos from the provisions on the 140% re-use limit).

Some important regulatory changes have taken place, in particular in the EU, following the Financial Stability Board (FSB) recommendations for the "Strengthening Oversight and Regulation of Shadow Banking - Policy Framework for Addressing Shadow Banking Risks in Securities Lending and Repos" (see FSB 2013). In a report published in the August 2013, the FSB explicitly identified the repo markets as a potential source of instability for the financial system. In addition, the FSB directly pointed to the re-use of collateral involved in repo transactions as a source of potential vulnerability for the financial system. The ensuing recommendations have substantiated, among others, in the Regulation (EU) 2015/2365 on "Transparency of securities financing transactions and of reuse and amending Regulation (EU) No 648/2012".

EU Securities financing transactions (SFTR) Regulation 2015/2365 directly addresses repo collateral re-use in several way. Firstly, it defines a family of financial transactions to be treated in a similar way under the Regulation: the "securities financing transaction" (SFTs). Under SFTs, the Regulation counts: (i) repos, (ii) securities and commodities lending, (iii) buy-sell back transaction and (iv) margin lending transaction. By including margin lending transactions among STFs, the defined framework straddles both repo contracts and derivative contracts, covering a wider area than the discussed SEC Rule 15c3-3. Secondly it foresees restrictions for the re-use of collateral involved in the SFTs. Namely it introduces (i) disclosure obligations, in order to make sure customers entering such transactions might be adequately informed about the re-use of the delivered collateral and (ii) the necessity of collecting an explicit expression of consent from the customer in order to proceed to the re-use (see for reference, Allen and Overy 2015 and Deloitte 2017) . Additionally, the Regulation establishes a reporting obligation for the institutions entering into SFTs transactions in a way similar to the provisions of Regulation (EU) No 648/2012 on "OTC derivatives, central counterparties and trade repositories" (EMIR).

Additional limitations to the re-use of third party collateral are specified by the Markets in Financial Instruments (MiFID II) - Directive 2014/65/EU. It mainly sets out disclosing obligations and transparency duties for the intermediaries engaging in customers' collateral re-use . In addition, title transfer financial collateral arrangements, preluding to re-use, have to be appropriate to the relationship with the clients. Finally, Directive 2014/91/EU forbids the re-use of collateral by custodians of the holdings of harmonised investment funds (UCITS) (see FSB 2017a).

While largely more liberalised than the US collateral market, the EU legal framework inclines towards an increased level of monitoring on the re-use of collateral also as regards collateral exchanged for repo and securities lending transactions. According to Fuhrer et al. (2015), Switzerland can be considered a jurisdiction where both technological infrastructures and regulatory environment interpose no obstacle to a potentially unlimited re-use of collateral involved in repo transactions:

> The CHF repo market qualifies for a thorough analysis of the re-use of collateral as the re-use is not restricted, neither technically, legally nor economically (Fuhrer et al. 2015).

As noted by the authors, the possibility of fully leveraging the potential offered by the securities made available as collateral by the entered securities financing transactions also depend on the availability of an efficient and interconnected system of trading, clearing and settlement. In the Swiss case, an electronic gross settlement system for cash transactions (SIC) and the electronic Swiss Securities Settlement System (SECOM) ensures a efficient re-use of the received collateral. In addition the absence of haircut, extends the collateral multiplier potential.

Table I. Repo collateral re-use: comparison across jurisdictions

Jurisdiction	Limitations	Legal source and references
USA	140% of customers' debit balance	See Singh and Aitken 2009
EU	Transparency obligations	See FSB 2013
Switzerland	Absolutely no limitation	See Fuhrer et al. 2015
Rest of the world	Generally no limitation	See Singh and Aitken 2009

II. Quantification of re-use

The statistical quantification of collateral re-use represents one of the key information for the understanding of the implication of collateral circulation in banking and shadow-banking activities. Consequently, it has attracted the interest of both institutions and researchers. The re-use of collateral is particularly difficult to measure for several reasons. Firstly, when based on re-hypothecation rights, re-use is captured by off-balance sheet entries in financial reporting, for which a low level

of detail is normally available (for a discussion of the topic within the US jurisdiction, see Singh and Aitken 2010). Secondly, when re-used, securities coming from different sources (including own securities) are typically confused together, making an attempt to disentangle them difficult even for the intermediary entering the trading itself, that might not be able to find any indication of the source of the collateral in its information and trading systems (see, for a discussion of market practices, FSB 2017b, p. 4). In the following, four families of methods documented in the literature will be analysed and assessed from the point of view of specific advantages and drawbacks.

A. Balance sheet approach

An influential approach to the quantification of collateral re-use is defined in several works by Manmohan Singh and James Aitken. The approach defined by the two authors is based on the analysis of (i) off-balance sheet items reported in their financial statements by the most important broker-dealer banks and (ii) industry-level figures regarding the asset under management and leverage levels of hedge funds. The pivotal element of the analysis consists in the 10-Q and 10-K reports (that is the financial statements produced by US listed firms with quarterly and yearly frequency, respectively) made publicly available by the leading broker-dealer banks. In these reports, US listed banks disclose the fair value of the collateral received that they can repledge, typically with the indication of the amount effectively repledged (see Singh and Aitken 2010). Equivalent formulations can be also found in the balance sheets and annual reports of European banks. For instance, in the following financial reports of European banks the following formulation can be found:

> The fair value of financial instruments given as collateral or transferred under repurchase agreements by the Group that the beneficiary is authorised to sell or reuse as collateral amounted to EUR 396,876 million at 31 December 2018 (EUR 408,380 million at 1 January 2018) (BNP Paribas 2018, p. 106).

> The fair value of collateral received for which the Bank has a right to sell on or pledge even where the provider does not default, mainly consisting of repo transactions and securities lending transactions, was as follows: Total received collateral 71,903 million, of which sold or repledged 57,045 million (Commerzbank Group 2018, p. 230).

> Obtained collaterals which are permitted to be sold or repledged [*in table: 41,280 million, of which repledged or sold 22,641 million*] (Nordea Group 2018, p. 170) .

The identified fair value of collateral received for which banks have a right to sell or repledge can be aggregated at system level by summing the individual figures for the notably most important financial institutions engaging in the broker-dealer activity. The obtained aggregated amount represents a measure of the employed collateral, including the repetitions determined by repo chains. According to the authors, an aggregation of a limited number of international institutions can

represent a good approximation of the global figure. In Singh and Aitken (2009) the authors limit themselves to the four biggest American broker-dealers for a monitoring of the evolution of the aggregate figure for the United States. In Singh and Aitken (2010) the five biggest European broker-dealer are added to the dataset to obtain a more encompassing figure, while in Singh (2011) also Nomura is added to the analysis in order to cover for Japan.

The second crucial element in the approach employed by Singh and Aitken is the quantification of the "source collateral" underlying the collateral received identified with the above described procedure. The underlying assumption is that broker-dealer banks make extensive use in their own trading of collateral posted by hedge-funds searching for loans aimed at financing leveraged financial operations. Estimating source collateral underlying re-use by broker-dealer banks makes it possible to formulate a "churning factor" for collateral which is a proper measure of re-use. In Singh and Aitken (2010) the churning factor is so defined:

$$\text{churning factor of collateral} = \frac{\gamma \sum_{b=1}^{B} \alpha_b}{\sum_{h=1}^{H} \beta_h} \tag{1}$$

where γ measures the share of third party (hedge fund industry) collateral to the overall "collateral received" figure; b are the B broker-dealer banks for which the "collateral received" (α) is estimated on the basis of financial statement data and h are the H hedge-funds contributing to the industry level figure on "source collateral" (β) from hedge funds.

In Singh (2011) the ratio of total collateral received and primary sources of collateral is defined as "velocity of collateral" making explicit the link between fluctuations in re-use (and balance sheet size of key intermediaries more in general) and monetary policy already analysed by Adrian and Shin (2009) and Adrian and Shin (2011).

The balance sheet approach to the estimate of collateral re-use proposed by Singh and Aitken has many advantages. Relying on public data, such as financial statements of listed firms and public reports by financial intermediaries' associations, allows for the construction of indicators comparable across studies. It is a relatively simple approach, easy to update at regular time intervals and can adapt to the need of a continuous monitoring activity by producing in an inexpensive way a relatively long time series of collateral velocity estimations (as demonstrated by Singh and Alam 2018). The main drawback of the approach consists in the degree of approximation of the obtained figure. Apart from the approximations determined by the use of financial data referred to a sub-sample of the population of intermediaries, a key estimate determining a high level of approximation is that of γ, which directly drives the estimate of the "collateral velocity".

B. Survey data approach

ESRB (2014) proposes an alternative approach to the quantification of repo collateral re-use based on data gathered via a survey. The ESRB analysis represents an attempt to contribute to the reduction of the "SFT data gaps" identified by the FSB "Policy Framework for Addressing Shadow Banking Risks in Securities Lending and Repos" (see FSB 2013). The ESRB study was published

in parallel with the European Commission regulatory proposal that preluded the introduction of the Securities financing transactions (SFTR) - Regulation 2015/2365 in the European Union, that is aimed at granting the European bodies with a timely and highly granular dataset regarding STFs.

Being designed *ad-hoc* for the study of use and re-use of collateral by systemic financial intermediaries, the survey presented in the ESRB study is highly targeted and granular. The survey refers to February 2013 and the sample includes the 38 major banks and the 13 most important agent lenders in Europe, covering a high share (60%) of the European banking system total assets and an even higher share of the European repo market (more than 90%). The granularity of the information collected by the ESRB survey is elevated: each participant to the survey was asked, among others, to report its activity in terms of collateral inflows and outflows by instrument type (what kind of SFT channels the collateral: reverse repos, securities lending, OTC derivatives trading, margin lending...), collateral type and type of counterparty.

The descriptive evidences collected through this survey by the ESRB are particularly useful for the understanding of the repo SFTs markets in Europe. Among others, the survey identifies (i) the marked predominance of repos and securities lending among the other STFs instruments (close to 90% of the total SFTs); (ii) the very high proportion of reusable collateral over the total received collateral (close to 95%); (iii) the high proportion of debt financial instruments over the total received collateral (higher than 80%).

Despite the difficulties encountered in gathering the information on re-use (see ESRB 2014, p. 4), the ESRB analysis can leverage the granularity of the information available to improve the collateral re-use metric proposed by Singh and Aitken (2010). The improvements move along three main lines: (i) the inclusion in the "primary collateral" aggregate of the collateral received from all sources (not only hedge funds); (ii) the use in the numerator of the collateral posted and not the collateral received; (iii) exploit the granular information to gather a more precise estimation of the γ coefficient (the share of third party collateral to the overall "collateral received" figure). Along the defined lines, the γ coefficient is re-estimated as:

$$\gamma = \frac{\textit{collateral receivable and reusable}}{\textit{collateral receivable and reusable} + \textit{own unencumbered assets}} \tag{2}$$

making possible a more precise definition of the collateral re-use factor:

$$\text{collateral re-use factor} = \frac{\gamma' \sum_{b=1}^{B} \alpha'_b}{\sum_{b=1}^{B} \beta'_b} \tag{3}$$

where γ' is the more precisely estimated share of third party collateral to the overall "collateral posted" figure; b are the B intermediaries for which the "collateral posted" (α') and the "collateral received" (β') figures are summed.

The estimate produced by the ESRB study for the collateral re-use factor is pretty much in line with the estimate available in Singh and Alam (2018) for the collateral velocity and equal to 2. Apart from a more precise estimate of the collateral re-use factor (or multiplier), the results

presented by the ESRB study provide a wide ranging picture of the SFTs market in Europe.

An approach similar to the one adopted by ESRB (2014) can be found in a study published by the Reserve Bank of Australia (RBA) in the late 2014 (see Cheung et al. 2015) where the results of a survey including information on collateral re-use are presented. With respect to ESRB (2014), the Cheung et al. study is more focused on the imbalances between supply and demand of high quality collateral and on collateral shortage and less on the collateral re-use itself.

The Cheung et al. study is based on a survey collecting information referred to the June 2014 and including in the sample the twenty largest securities dealer banks in the jurisdiction. Also in this case the information provided by the respondent intermediaries is relatively granular, including information on both incoming and outgoing collateral flows, counterparty and instrument types.

The estimate of the collateral *rate of re-use* in the Cheung et al. study is relatively more approximate than the one produced in ESRB (2014). The authors rely on two pivotal information: (i) an overall estimate of the collateral owned and pledged by banks and institutional investors and (ii) the sum of the amount of collateral that the respondents have reported as re-used. The *rate of re-use* can be then simply obtained as:

$$rate\ of\ re\text{-}use = \frac{collateral\ owned\ and\ used\ +\ collateral\ re\text{-}used}{collateral\ re\text{-}used} \tag{4}$$

The estimate of the collateral *rate of re-use* provided by Cheung et al. (equal to 1.6) is more approximated than the one produced in ESRB (2014), indicating that a quantification of repo collateral re-use based on survey data needs to be underpinned by a collection of very granular and specific information in order to significantly improve the precision of the estimates in comparison to the balance sheet approach. In conclusion, the main advantage of the estimations made on the basis of surveys over the ones based on publicly available data is that survey data can be explicitly designed to capture targeted information on SFTs. On the other hand a survey is clearly a more expensive tool that, in addition, renders the reproduction and the cross-check of the obtained results by other authors more difficult.

C. Commercial granular data approach

In Ferrari et al. (2017) the estimation of collateral re-use is performed on the basis of highly granular (transaction by transaction) data obtained from the commercial data provider ICAP RepoFundsRate (RFR), which includes information on repo transactions executed on the two CCP-based electronic trading platforms BrokerTec and MTS. The data employed by the authors cover the period March 2013 - September 2015 and refer to seven euro area countries (Austria, Belgium, Finland, France, Germany, Italy an the Netherlands).

The general challenge posed by the estimation of collateral re-use on the basis of transaction by transaction data is the necessity to identify transactions (links) that configure re-use. This matching exercise can either be directed on characteristics of the transaction itself or on characteristics of the intermediaries (nodes) connected by the transaction. In the case of Ferrari et al. (2017), the

authors have opted for a simple matching technique based on the nature of the connected nodes in the network: each transaction connecting two intermediaries qualified as broker is labelled as "collateral re-use" transaction. This makes possible to compute a:

$$broker\text{-}to\text{-}broker\ activity = \frac{broker\ quantity\ on\ loan}{lendable\ quantity} \tag{5}$$

The above defined metric "broker-to-broker activity" is employed by the authors as proxy for the "collateral re-use" on the basis of several reasons mainly related to the European legal framework that makes the re-use by intermediaries qualified as brokers far more likely than in the case of any other financial intermediary. "Broker-to-broker activity" proxies re-use in a different way than in the previous studies: it tells us how larger than 1 is the "churning factor of collateral". A "broker-to-broker activity" bigger than 100% provides us with the indication that a certain security is re-used more than once. The figures provided in this study are not comparable with the ones exposed for the previous studies, because Ferrari et al. (2017) provide averages over the "broker-to-broker activity" ratio computed over each single security in the dataset. This procedure does not take into account the outstanding amounts of each security, making a comparison with the above reported figures arduous.

In conclusion, very granular datasets provided by commercial data provider can be sourced in order to compute estimations of repo collateral re-use. Transaction by transaction data requires an extensive and elaborated treatment before any metric can be produced. One of the main advantages of this approach is that aggregate re-use figures can be analysed in detail, potentially at transaction level, allowing for an investigation of determinants and effects of this activity.

D. Proprietary granular data approach

The work of Fuhrer et al. (2015) relies on proprietary data available to the Swiss National Bank. In order to study the circulation of collateral in the Swiss financial system, the authors source two main data sets: (i) data obtained from the most used repo trading platform for transactions in Swiss franks (Eurex repo trading platform); (ii) data sourced from the Swiss securities settlement system (SECOM). The two information combined (using a transaction key as link) provide a transaction-by-transaction dataset containing a precise identification of: (i) parties involved in the transaction; (ii) maturity structure; (iii) collateral basket involved and (iv) delivered collateral included market value.

As it is normally the case with transaction-by-transaction datasets, the quantification of collateral re-use is mediated by the preliminary identification of collateral chains within the overall network structure defined by the original dataset. The matching procedure adopted by the authors aims at identifying collateral chains by selecting couples of transactions with the following characteristics:

- identical securities (ISINs) are used in both transactions (initial and re-use);

- the collateral provider in the second transaction (re-use) is the same as the collateral taker in the first transaction (initial);

- the repurchase date of the second transaction (re-use) is not later than the repurchase date of the first transaction (initial)

[...] - as soon as the collateral value of the initial transaction is used up by re-use transactions, possible subsequent re-use transactions are no longer flagged as re-use transactions

(Fuhrer et al. 2015, pp. 6-7).

Having applied the described method, the authors are in the position of identifying initial and subsequent links in the collateral chains, gauging not only the proportion of transactions leading to re-use but also the repo chains' length. The average length of repo chains in the Swiss frank repo market is estimated as equal to 4. In line with Bottazzi et al. (2012), the authors define two different metrics for re-use that exploit the granularity of the available data. The first metric is a re-use rate (rr) that can be used both at system and at intermediary level:

$$rr = \frac{\sum_{n=1}^{N} d_n c_n}{\sum_{n=1}^{N} c_n} \tag{6}$$

where c_n denotes the value of the collateral used in transaction n and d_n is a dummy variable that takes value 1 in case the transaction is identified as "collateral re-use transaction" and 0 otherwise. The second metric is the collateral multiplier (m) which is defined slightly modifying the re-use rate formula and introducing as denominator the market value of the I securities available for repos in the reference market (s_i):

$$m = 1 + \frac{\sum_{n=1}^{N} d_n c_n}{\sum_{i=1}^{I} s_i} \tag{7}$$

The authors estimate a value for the metric m that oscillates between a maxim of 1.2 at the end of 2007 to a minimum close to 1 during 2011. These estimates are consistently lower than the ones produced in the studies referring to the global and to the euro area financial industries by Singh et al. (2018) and ESRB (2014) among others. Fuhrer et al. (2015) note that the lower values could be determined by the particularly limited scope of the study (only Swiss frank denominated transactions) that focuses on a sub-segment of the financial network that could be characterised by a limited activity of broker-dealer banks. In addition, the matching procedure instrumental for the repo collateral re-use estimation heavily relies on the availability in the dataset of all possible links (the transactions) departing from each node (the intermediaries) in the collateral re-use network. Transactions taking place over alternative channels or platforms cannot therefore be considered. This problem, which can be considered a general problem of the "granular data" approach, can possibly bring to an underestimation of the collateral re-use.

A series of reports published over an extended period of time by the Financial Stability Board

(FSB) illustrates the detailed architecture of a data collection mainly focussed on STFs and based on granular proprietary data gathered by national institutions. The FSB report "Strengthening Oversight and Regulation of Shadow banking" (FSB 2013) identified two main risks for financial stability stemming from repo chains and collateral reuse - namely: (i) opacity and uncertainty undermining intermediaries credibility in times of crisis and (ii) contagion risk - and advocated for the introduction of a regular data collection process aimed at the monitoring of these risks. The project of a global data collection is exposed in FSB (2015), where two tiers for the data collection are identified: (i) a national aggregator, which collects and elaborates data reported by the intermediaries included in the reporting population, and (ii) a global aggregator, which collects and elaborates data provided by the national aggregators.

The work of the FSB is strictly connected, in the EU legal environment, to the Securities financing transactions Regulation (SFTR) - Reg. 2015/2365. By directly engaging in the formulation of indicators of collateral re-use and collateral multiplier (in particular in FSB 2016 and FSB 2017b), despite not providing empirical results and estimation, it prefigures possible concrete uses of the SFTs data collected according to the SFTR. Addressing the question on how to quantify the amount of reused collateral, the FSB identifies three approaches:

$$collateral_{reused} = collateral_{posted} - collateral_{own,encumbered} \tag{8}$$

$$collateral_{reused} = \frac{collateral_{received,\ eligible\ for\ reuse}}{collateral_{received,\ eligible\ for\ reuse} + collateral_{own}} collateral_{posted} \tag{9}$$

$$collateral_{reused} = \min(collateral_{received}, collateral_{posted}) \tag{10}$$

FSB defines (8) as exact metric, (9) as approximate metric and (10) as indirect approximate metric. Interestingly FSB (2017b), commenting on the results of the public consultation regarding "Non-Cash Collateral Re-Use. Measure and Metrics", concludes:

> Although each measure of collateral re-use has some benefits, the responses received on the February 2016 report suggested that market practice is generally aligned with the assumptions behind the approximate measure (i.e. the second measure). For example, market participants do not generally distinguish between own securities or securities originating from another collateralised transaction when posting collateral. Respondents also highlighted that it would be extremely difficult to extract the information needed to compute the exact measure and indicated that the indirect approximate measure may lead to over-estimating collateral re-use. (FSB 2017b, p. 4).

The re-use data aggregated at the desired level (jurisdiction, instrument type, global...) can be employed to assess re-use rates and collateral multipliers. Among the metrics identified by FSB (2017b) are particularly relevant for this study:

$$reuse_{rate} = \frac{collateral_{reused}}{collateral_{received,\ eligible\ for\ reuse}} \tag{11}$$

$$reuse_{share} = \frac{collateral_{reused}}{collateral_{posted}} \tag{12}$$

$$multiplier = 1 + \frac{collateral_{reused}}{assets_{total}} \tag{13}$$

Interestingly, the metrics defined by the FSB for the quantification of collateral reuse and multiplier are very close to the ones already introduced when discussing Fuhrer et al. (2015). Similarly, several common challenges are faced in both studies. When using granular proprietary data for the quantification of collateral re-use and multiplier, two aspects appear as particularly challenging: (i) the disentangling of own and third party collateral employed in secured financing by an intermediary; (ii) the identification of the proper denominator for the definition of the collateral multiplier. The complexity of the granular proprietary data collection and elaboration is more than compensated by the elevated degree of flexibility and timeliness offered by it.

III. Modelling repo market's fragility

Before inquiring the literature concerning the economic analysis of collateral re-use, the following paragraphs will deal, more generally, with repo market's fragility. The focus of this work is the literature dealing with collateral re-use in connection with systemic fragility. The proper backdrop for the analysis of models explicitly dealing with re-use is represented by those works that introduce the main mechanisms and channels that can explain fragility in the repo market in general. Another reason for investigating the literature on fragility in the repo market is that models involving re-use are in some cases extensions of models not featuring re-use.

In the following paragraphs, some reference works on repo market's fragility will be presented proposing a loose taxonomy. The analysed papers will be classified in five categories, corresponding to the key mechanisms adopted in models and analysis for explaining how repo market can dry-up or collapse ushering in financial instability (a similar attempt of literature review focused on repo and financial stability can be found, among others, in Corradin et al. 2017).

A. Repo runs (coordination failure)

The analysis and models commented in the following paragraph represent a first category of works, which is identified by the following characteristic: They all identify the fragility of the repo market in its vulnerability to runs similar to those referred to in the banking economic literature (see, among others, Bryant 1980, Diamond and Dybvig 1983, and Allen and Gale 1998).

Table II. Repo collateral re-use: comparison across quantification approaches

Approach	Pros	Cons	Re-use measures	Quantification
Balance sheet data	Simple, quick, inexpensive	High approximation	*velocity* (or *churning factor*) $= \frac{\gamma \sum_{b=1}^{B} \alpha_b}{\sum_{h=1}^{H} \beta_h}$ (Singh and Aitken 2010)	*velocity*=4 in Singh and Aitken (2010) (global level - end 2007); *velocity*=3, 2.4 (end 2007, 2010) in Singh (2011); *velocity*=2 (end 2017) in Singh (2018)
Survey data	Versatile, precise, flexible	Expensive, difficult to repeat and reproduce	*re-use factor* $= \frac{\gamma' \sum_{b=1}^{B} \alpha'_b}{\sum_{b=1}^{B} \beta'_b}$ (ESRB 2014)	*re-use factor*=2 (EU level - Feb. 2013) in ESRB (2014); *rate of re-use*=1.6 (Australia - June 2013) in Cheung et al. (2015)
Trns. by trns. commercial data	Extremely detailed	Opaque, costly and approximate matching	*broker-to-broker as proxy of re-use* $= \frac{\textit{broker quantity on loan}}{\textit{lendable quantity}}$ (Ferrari et al. 2017)	*broker-to-broker as proxy of re-use* comprised between 0% and 107% (euro area level - 2013-15) in Ferrari et al. (2017)
Trns. by trns. proprietary data	Extremely detailed, multiple metrics, high frequency	Opaque, matching necessary, underestim. due to missing links	$rr = \frac{\sum_{n=1}^{N} d_n c_n}{\sum_{n=1}^{N} c_n}$ and $m = 1 + \frac{\sum_{n=1}^{N} d_n c_n}{\sum_{i=1}^{I} s_i}$ (Fuhrer et al. 2015) $rr = \frac{collateral_{reused}}{collateral_{received}}$ and $m = 1 + \frac{collateral_{reused}}{assets_{total}}$ (FSB 2017b)	$0.02 < rr < 0.2$ (Swiss frank repo market 2007-08) and $1 < m < 1.2$ (Swiss frank repo market 2006-12) in Fuhrer et al. (2015)

"Securitized banking and the run on repo" by Gorton and Metrick (2012) investigates, by means of descriptive evidence and empirical analysis, what the authors define the "run on repo" having taken place at the onset of the financial crisis (2007-2008). The authors clarify that the concept of "run on repo" refers to the steep increase in haircuts for securities related to the residential mortgage securitization industry (such as residential mortgage-backed securities - RMBS, credit default swap collateralized debt obligations - CDO or collateralized loans obligations - CLO). The increase in the margins required for utilising a certain security in a repurchase agreement corresponds to a run because it produces the same effects: due to higher margins, the liquidity constrained agent (the borrower) is provided with less credit for the same amount of collateral posted in the transaction. Provided the limitation in securities in the balance sheet of the borrowers which can be used for repo transactions, and the possibility that margins reach 100%, the margin increase produces in the secured segment the same consequence of a run in the unsecured segment: the impossibility for the borrower to roll-over its debt and, consequently a bankruptcy due to illiquidity.

The work of Gorton and Metrick provides first a representation of the "securitized banking system", which the authors consider having been the leading business model for several dealer

banks in the US in the years preceding the financial crisis. The "securitized banking system" is a business model in which banks make profits by originating, collateralising and distributing structured products based on the loans extended (directly or indirectly). In this business model, the balance sheet becomes a temporary station for the loans generated by the banks, which are destined to be packaged in the form of debt securities and distributed across the financial system, or employed as collateral in repo transactions *vis-a-vis* liquidity rich institutional investors.

Using a unique dataset collecting credit and repo spreads regarding a representative set of US based financial institutions, the authors decompose the evolution of credit spreads, repo spreads and margins during the crisis in some of their determinants. The first indicator been tested is the ABX index, which is an index capturing the evolution of house prices in the US. Despite the close link between house price evolution and value of the structured products used as collateral by some institutions during the financial crisis, the authors find little or no correlation between the ABX index and the evolutions in spreads and margins. On the contrary, the Libor-OIS spread shows a significant correlation with the spreads and margins. This finding suggests that, despite the automatic stay exemption, which entails that the lender of a repo transaction can satisfy himself with the collateral in case of insolvency of the counterparty, the counterparty risk has represented one of the most relevant determinants of the distress in the repo market during the financial crisis.

In Martin, Skeie and von Thadden (2010) the runs on repo markets are further characterised, from a theoretical point of view, as a coordination problem similar to the classic Diamond and Dybvig (1983) model. The authors provide a full account of the similarities between repo markets and unsecured markets, showing that the existence of collateral is not a *panacea* against runs and crises. The most important reasons for the fragility of the repo contracts are to be found in the underlying maturity transformation performed by the repo counterparties: very short term funding, typically overnight, is exchanged against a long term security. Despite being securities far more liquid and marketable financial instruments than loans, they open up several spots of vulnerability. In the first place, they can possess a different value for the lender and for the borrower (the original owner of the collateral is the one that is able to extract the greatest value from the collateral itself). In the second place, in order to transform securities in cash, investment has either to be brought to maturity or securities have to be liquidated in the financial market. In the first case, liquidity is necessary to buy time until the long term investment matures, in the second case, "cash-in-the-market" pricing limit recovery rate of liquidations.

The model proposed by the authors is dynamic, with rationale expectations and foresees multiple equilibria. The model is strictly linked to Diamond Dybvig (1983) and Qi (1994) models. This family of models identifies the conditions for multiple equilibria in the financial system. The "good" equilibrium is an equilibrium in which there is no run and all agents behave according to their ex-ante foreseeable liquidity needs. The "bad" equilibrium is the run equilibrium, that is the equilibrium in which investors irrespective of their kind, act as impatient ones and require the liquidation of their investments.

More in detail, the model proposed by Martin, Skeie and von Thadden is an infinite time

economy with two kind of agents. The first kind of agents is a continuum of virtually immortal dealers, which are endowed with some own funds and are able to make profitable investments. The second kind of agents is a continuum of investors that are generated at the beginning of every period and live for three periods. The investors can be impatient (consume in time 2) or patient (consume in time 3), but only learn their type in time 2. Leverage and intermediation are generated endogenously in the model: dealers have limited resources and can make profits in borrowing from the investors and making profitable investments in the long term technology (securities). The long term investment, the securities, are used as collateral in the financing transactions *vis-a-vis* the investors, providing a modelling of a simple repo market. The authors assume a reduced utility for the investor of holding the security. This is the key for the vulnerability of the modelled repo market: as soon as the investor perceives the possibility of an insolvency in time 2 of the dealer, they prefer to run, in order to avoid being left with the security.

Given the characteristics of the model, the authors cannot conclude with forecasts of the runs, but can indicate conditions and thresholds for the possibility of the runs themselves. A first indication is that one of the fragility of the repo markets consists in the fact that some of the main actors (among which the money market funds and the securities' dealers) typically do not have access to the central bank discount liquidity provision facilities (discount window or marginal refinancing operations). A lender of last resort for the non-bank institutional investors reduces or cancels the possibility of run on the repo markets. The authors identify also thresholds in terms of liquidity and solvency that enable the forestalling of runs: dealers having sufficient profitability perspectives and sufficient liquidity to respond to abnormally high liquidation requests on the second period are able to survive until the last period and avoid defaulting.

Kuong (2015) introduces an alternative representation of fragility in the repo markets by modelling it in the absence of exogenous shocks. The setting presented by the author features three different types of specialised financial agents: a continuum of financial firms (which can be interpreted as hedge funds or dealer banks), a continuum of creditors (which can be interpreted as commercial banks or other institutional investors) and a representative buyer in the financial markets (which could be interpreted as a money market or a pension fund). Roles and specialisation are assumed to be given. In Kuong's model there are different sources of uncertainty: the firms exclusively have profitable investment opportunities, whose return is stochastic. After having been financed by their creditors, firms engage in their investment opportunity with a non-observable degree of effort, which gives rise to risk-taking incentives and moral-hazard on the side of the firms. Finally, since the collateral buyer in the financial markets is financially constrained, the risk of cash-in-the-market pricing in case of massive liquidation of collateral on the wake of insolvencies can be ex ante assessed.

In Kuong's model, fragility in the repo markets arises as a consequence of a lack of coordination between firms and creditors in the setting of margins and in the choice of the risk to be taken in the selected investment strategy. The failure in coordinating between these two categories of agents ensues from the anticipation of fire sales and materialises via two main channels. The first

channel is the risk-taking channel. This channel translates the anticipation of fire sales into lower incentive for the firms to put effort in the investment project, which determines a higher number of defaults and the triggering of fire sales. On the other hand, a margin channel drives a similar process, in which higher margins reduce the viability of the safe investment strategy for the firms and facilitate the materialisation of the feared fire sales of collateral in the financial markets. Note that Kuong's model, representing fragility as a product of coexisting rational expectations multiple equilibria, enables the identification of factors underlying the materialisation of repo market crises, but does not provide with the possibility of effectively determining whether the crisis outcome will materialise.

B. Costly information and declining collateral quality

A second thread of literature relates the fragility of the repo market with the opacity of the collateral utilised in the transactions, which renders information on its quality costly. Costly information opens the doors to information asymmetries and market collapses.

The work of Gorton and Ordoñez (2014) sets out to deal with the problem of modelling a crisis in the secured lending segment that is spurred by a small shock, that does not necessarily threatens the economy in others states of the world. The underlying idea is that the crisis is more dependent on internal endogenous developments than on the effect of exogenous shocks. Differently from other approaches (for instance, Geanakoplos 2009), the authors do not rely on the heterogeneity of the economic agents to explain the build-up of the leverage. Instead, they model an economy where the verification of the asset quality is costly and, as a consequence, it is not performed over extended periods of time, bringing as a consequence a "blissful ignorance" about the fundamentals of the collateral used in the transactions, which is abruptly interrupted by sudden exogenous shocks motivating a research for information on collateral and a sudden breakdown of the economy.

In Gorton and Ordoñez (2014) the economy is modelled in the form of overlapping generations. Every agent lives two periods and is born as household and lives its last period as firm. Households are endowed with cash and firms with land and managerial skills (to be employed in production together with cash - these two are the only production inputs). Firms are willing to sell or pledge their land in order to get the cash necessary to perform the production. Since cash is non-storable, households are willing to be counterparties in the transaction in order to have the land necessary to get money when they will be firms in the second period. Though not all land is good (not all land is valuable), the equilibrium that is established in absence of shocks is an equilibrium where all firms can finance their production process and first best optimum is progressively reached. In presence of a shock that produces the knowledge that some land has lost value, agents are motivated to scrutiny the quality of the assets pledged. This produces a crisis which is more violent, the longer the preceding period of information insensitiveness.

Thanks to the technical solutions adopted, the authors are able to capture some important characteristics of the contagion channels in the secured markets. First, fragility is created by the limited incentive to the scrutiny and verification of the collateral fundamental value. During

extended periods of financial ease, collateral tends to decrease in quality, while agents in possess of good collateral implicitly subsidise agents holding bad collateral. This equilibrium becomes always more stretched as long as leverage increases together with ignorance about fundamental values. A flight to quality process ensuing bad news spreading in the economy over the fundamental values of the assets can produce a contagion dynamic and an overall loss in welfare.

C. Margin/leverage cycles

Geanakoplos (2009) models fragility in the repo markets explicitly excluding the two approaches introduced in the previous two sub-sections. In fact, his modelling choices are selected in order to reflect the experience gathered during past financial crises (in particular the great financial crisis of 2007-09) and the author considers asymmetric information (more generally issues related to the development of information) and coordination failures not to be credible explanations for the crisis' build up and unfolding. Geanakoplos leverages own past works (in particular Geanakoplos 1997 and Geanakoplos 2003) to build up a comprehensive framework where instability in the repo markets (and more generally in the secured finance markets) is explained by the recurrent build up of leverage: the "leverage cycles". The author's modelling of leverage cycles is consistent with the empirical investigations triggered by the great financial crisis on the connections between leverage in banks' balance sheet and liquidity distress in times of crisis (see Adrian and Shin 2008). It also applies to both the financial sector and secured finance backing non-financial investments (see Geanakoplos and Zame 2014 for a general equilibrium extension).

In Geanakoplos (2009) the modelling of secured lending fragility is performed by introducing heterogeneity in the beliefs of the agents and by making margins and leverage possibilities endogenous to the model. The economic puzzle behind Geanakoplos work is the fact that the financial crisis was originated by a relatively small amount of impaired financial products and an even smaller amount of reasonably expected (and realised) losses on those products. One of the main aims of the work is to explain how in an asset backed financial intermediation system a small amount of losses can be able to trigger wide ranging effects in the economy.

The model proposed by Geanakoplos is a three periods' economy that relies on a continuum of utility maximising agents, endowed with both cash and assets. The assets are characterised by a stochastic return in the last period of the economy (either high or low). Investors differ in their beliefs on the probability of the high return. The higher their expectation of a high return of the asset, the greater their willingness to borrow money to buy it. Allowing lending across agents, in equilibrium, most optimistic agents are heavily indebted. Pessimistic agents are not willing to buy the asset and prefer to lend cash to optimistic agents. Incoming bad news on the return of the asset make the lenders demand more collateral, which causes the default of the most optimistic agents. The decrease in asset prices are bigger than expected because, with sufficient default levels, there is not anymore a sufficient number of optimistic agents capable of substituting the defaulted ones: as the crisis unfolds, the average belief on the returns of the asset necessarily decreases.

Geanakoplos' model is particularly remarkable, because does not rely on informational asym-

metries for explaining the possibility of contagion in the markets following fire sales of collateral on the wake of a shock. Turbulence in a limited part of the financial system can extend to other seemingly unrelated sectors of the economy and eventually generate a financial crisis even without assuming that mistrust increases among investors. In this case, the vector of contagion in the financial distress encountered by a few "top" investors, whose optimistic attitude is the main cause of the price rises before the crisis. This feature of the model is even more important considering the application of the model to the secured lending, where the monitoring of the counterparty is by construction less compelling than in the unsecured lending. Eventually, in the secured lending, is the collateral and its quality that makes the difference.

D. Margin/leverage spirals

Brunnermeier (2009) introduces a fourth literature thread where the repo market microstructure is explicitly analysed and its component are used to model repo market's vulnerability. Similarly to Geanakoplos (2009), in order to identify the vulnerable spots in the repo markets, Brunnermeier concentrates its analysis on the connection between leverage and liquidity. More in particular, Brunnermeier analyses in detail the financial turmoils of 2007-08 and the amplification mechanisms having determined its transition into a full fledged financial crisis.

At first, as it is also made clear in Hartmann and Smets (2018) with regard to the euro area, the financial turmoils of 2007-08 were identified by most analysts and institutions as a liquidity crisis, affecting a limited area of the financial system, to be addressed by an extraordinary provision of liquidity targeted at financial institutions. Brunnermeier (2009) describes the main features of the reinforcing spirals having made possible the transition from the financial turmoils to the financial crisis.

The first of these economic mechanisms relates to the "borrowers' balance sheet effects" and the consequent "liquidity spirals". Prices in the financial markets are strictly related to the activity of leveraged financial institutions specialised in the securities' intermediation. These intermediaries provide liquidity to the financial markets by means of their trading activity ("market liquidity" in the sense defined in Kyle 1985). Being leveraged, the activity of these intermediaries is strictly linked to their capability of financing themselves in the repo markets (by pledging or borrowing securities for their trading). The degree of leverage allowed by market conditions to this kind of institutions is defined by Brunnermeier as "funding liquidity". Funding liquidity is strictly related to the "safety buffers" requested by financing banks to the leveraged investors (mainly: margins and haircuts). The higher the risk-aversion of financing banks (higher margins and haircuts), the lower the leverage attainable by leveraged investors and therefore lower the funding liquidity.

Brunnermeier (2009) identifies three further reinforcing mechanisms. Firstly, a liquidity spiral is reinforced by a "lending channel". Financing banks, observing the liquidity distress encountered in the market, anticipate liquidity distress for their own investment projects and adopt a strategy of precautionary liquidity hoarding. Liquidity hoarding further deteriorates liquidity conditions in the market and produces aggregate negative externalities and allocation inefficiencies. Secondly,

first-come, first-served rules both with regards to banks and other financial intermediaries are able to reinforce liquidity spirals by forcing fire sales of assets by liquidity constrained agents facing a run on their liabilities. Lastly, the network structure of the financial system, featuring bilateral interconnections at multiple levels, increases opaqueness and prompts distrust among financial intermediaries.

The model prefigured in Brunnermeier (2009) is explicitly developed in Brunnermeier and Pedersen (2009). The model features three types of "specialised" agents. The first type of agents consists in "customers". Customers are agents interested in buying or selling securities in the financial market, and represent the source for price imbalance in the market, since they forward their orders to the markets in an imbalanced way and in different time periods. The "temporary order imbalance" generated by the customers' "sequential market access" is the rationale for the activity of the second type of agents: the "speculators". Speculators smooth price fluctuations by matching the customers' orders. Speculators are knowledgeable of the markets and are aware that customers' orders bring the securities' prices away from fundamentals. The profitable arbitrage activity motivates speculators' intervention in the market and provide the market with the necessary "market liquidity". Being leveraged agents, speculators need external capital in order to perform their activities. The "funding liquidity" for the speculators is provided by financiers (banks). Financiers set the margins requested to the speculators, implicitly limiting the speculators' leverage (their "funding liquidity") on the basis of historic information gathered from the market and in order to control their value at risk (VaR).

Brunnermeier and Pedersen (2009) model addresses the following apparent paradox: liquidity driven fire sales move prices downwards, away from fair value, making a long position on the affected security safer and not riskier (upward movements are made more likely). The informed financier should react to liquidity driven fire sales by easing the margins on the affected securities and not by tightening them (as it happens in the reality). In their model, Brunnermeier and Pedersen show that in presence of "informed financiers" margins are stabilising: the lower the price of the security affected by liquidity driven fire sales, the lower the margin for the speculators (who are then able to mitigate the price fluctuation by means of their trading activity). On the contrary, when financiers are "uninformed", margins are increasing in historical price volatility and market illiquidity can increase margins. Increased margins reduce speculators' "funding liquidity", forcing them to exit positions in order for them to control leverage. Fire sales increase, in turn, historical volatility, forcing financiers to tighten margins further generating a "liquidity spiral".

In Brunnermeier and Pedersen (2009) several stylised facts about the unfolding of financial turmoils into a financial crisis are reproduced and analysed. The sudden liquidity dry-ups that affect repo markets is traced back to (i) leveraged activity of speculators, (ii) margin spirals taking place in presence of (iii) imperfectly informed financiers. Interestingly, dry-ups can affect areas of the financial system apparently distant from the one giving birth to the distress (the sub-prime mortgage sector in the 2007-09 crisis): leveraged speculators can be affected by market illiquidity in one sector and reverberate its negative effects in other sectors by means of the "funding liquidity"

mechanism. Historical volatility of the financial markets is able to capture fragility because it is computed using the same inputs that are factored in by financiers when defining margins. A flight to quality dynamic can then be easily explained as a flight to asset types that (for whatever reason, typically because related with government guarantees) tend to be less volatile and then less vulnerable to liquidity spirals.

A series of works can usefully complement the illustration of Brunnermeier and Pedersen (2009) contributions by providing both empirical and theoretical extensions. Of particular importance in the following works is the interplay between different money market segments: unsecured financing, secured (repo) financing and short term securities market. Substitution between sources of financing provide robustness to the financial system, while crises can take place only when liquidity spirals affect all financing channels.

Using a unique transaction-by-transaction dataset, Mancini, Ranaldo Wrampelmeyer (2016) provide an in-depth description and analysis of the euro area repo market. The analysis stretches over the period 2006-2013 and is mainly based on data from the Eurex repo market (but also makes use of MTS and LCH data). Exploiting the heterogeneity both in the time dimension and in the nationality of the collateral employed in the transactions, the authors can conclude that the secured financing has represented a stabilising factor for the euro area financial system during the crisis years. The repo market in the euro area both before and during the crisis has been dominated by banks.

Substitution between unsecured and secured interbank financing has been one of the main factor underlying the great expansion of the euro area repo market during the financial crisis. Thanks to its capability of mitigating credit risk the secured market has served as backstop to the liquidity dry-up taking place in the euro area capital markets in the aftermath of the financial crisis. In the years following the sovereign debt crisis of 2010, the heterogeneity among rating in sovereign debt securities employed as collateral has produced a fragmentation in the secured capital markets. The interest of repo transactions has increasingly depended on the rating of the underlying security. Some sovereign debt bonds, issued by the worst rated euro area governments, have been de facto excluded from the repo market.

Despite fragmentation, the authors find that secured lending has effectively contained the adverse consequences of liquidity dry-ups. Reforms on the side of the prudential regulations on banks has provided an incentive for banks to use Central Counterparties (CCPs) for their secured lending activity.

While contagion across agents is a feature of most models looking into the problem of runs and fire sales, in Ranaldo, Rupprecht and Wrampelmeyer (2016) we can find an encompassing theoretical account of the contagion dynamics that can be at work across money market segments (secured and unsecured). The main model motivation is to go beyond a segment by segment approach to money market dry-ups and to take into account simultaneously multiple funding sources, in the awareness that as long as there is the possibility of substituting funding sources, insolvencies due to liquidity crises may hardly appear. As predicted in Freixas, Laeven and Peydro (2015), Ranaldo,

Rupprecht and Wrampelmeyer indicate that a liquidity spiral has to take place simultaneously in three different markets, the securities market (for the sale of the assets), the unsecured market and the secured market. For a distressed bank, constraints come in contemporaneously in all the three markets via: a) higher interest rates (or complete dry-up) in the unsecured funding market, b) higher haircuts and consequently capital constraints in the secured lending market and c) fire sale losses in the securities market.

The model proposed by Ranaldo, Rupprecht and Wrampelmeyer is quite articulated. The economy lasts 4 periods (from period 0 to period 3) and there are three types of agents: customers, banks in surplus of liquidity (lenders) and banks short of liquidity (borrowers). Agents can at each period exchange a risky security. Crisis in the financial intermediaries is brought about by a fundamental shock. This shock can be translated in a funding crisis, as in Brunnermeier and Pedersen (2009), only if the financial institution is constrained in funding in both the secured and in the unsecured market. If the shock is sufficiently violent and hits in a material way the capital of the bank, than a spiral both in the secured and in the unsecured lending can arise. This spiral cannot be solved by the sale of the asset as the agent incurs in a "cash-in-the-market" pricing situation.

The fragility of the financial intermediary in the middle of a liquidity spiral crucially depends on the leverage levels existing in the periods before the spiral. In fact, the model shows that the greater the leverage the more severe the consequences of the shock and the risk of defaulting. The model also enables the authors to identify a time varying optimal level of leverage. This optimal leverage is, a bit counterintuitively, lower in the good times and higher in the times of financial difficulties. This has to be linked to the effects of the shocks: they typically hit the capital, inducing an automatic increase in the leverage. This consideration also provides an important policy indication: strict and rigid limitations of banks' leverage levels may cause unintended fire sales for banks hit by a shock, producing the effect of liquidity spiral.

Di Filippo, Ranaldo and Wrampelmeyer (2016) provide further empirical indications in the direction of a close link and interaction between the secured and the unsecured funding. An analysis of both the secured and the unsecured segments in the euro area money markets provides the authors with results that partially corroborate the most popular theories regarding the liquidity crises. In particular the authors find that banks that experience downgrading are more likely to substitute unsecured funding, where they face tighter conditions, with secured funding, an instrument where collateral mitigate credit risk. On the contrary, the authors do not find evidence of liquidity hoarding by liquidity-rich banks, made with the intention of gaining market shares and increasing profits, like the one theorised by Acharya, Gromb and Yorulmazer (2012).

The authors use a rich dataset made up of overnight transactions both from the TARGET2 platform, for the information regarding the unsecured segment, and from the Eurex Repo trading platform, for the analysis of the secured segment. In the case of the TARGET2 data, the construction of the dataset relies on a well-established procedure for the matching between the two legs of the transaction (the flow of money from the lender to the borrower on the settlement date and

the opposite flow from the borrower to the lender at maturity). In the case of the secured lending, only transactions with underlying generic collateral are analysed in order to avoid the effect of specialness in the analysis. The authors model unsecured and secured lending both separately and in conjunction (utilising the share of unsecured borrowing on total borrowing). In order to take into consideration the effect of borrowing from the central bank, the study is completed with a case study exploiting the structure of the main refinancing operations.

The authors are able to conclude that banks that undergo a downgrading are more prone to liquidity hoarding and tend to diminish the unsecured lending in favour of safer collateralised lending. As for the borrowing, a distress inducing a downgrade entails a deterioration of the price conditions for the unsecured borrowing. Though, as long as the bank controls safe assets that can be employed in repo transactions, this negative effect can be counterbalanced by an increase in the secured lending. The authors also find that the regulatory innovations introduced by Basel III, like the Liquidity Coverage Ratio, go into the direction of granting an access to the secured funding channel, which represents a guarantee of liquidity for the banks involved by distress episodes.

E. Collateral scarcity

A fifth literature thread identifies "collateral scarcity" as a possible driver of vulnerability for the repo markets. Concerns regarding scarcity preexist the 2007-09 financial crisis. The CGFS (2001) report documents how, well before the crisis, regulatory and supervisory institutions identified an increasing trend in the demand for high quality collateral not necessarily matched by an increased corresponding supply. The mentioned CGFS report focuses on the increased use of collateral as "risk mitigation tool". The Committee identifies several root causes for this increase: (i) the developments having taken place in the financial industry and concerning the risk management techniques and tools, including the expansion of the trading in derivatives; (ii) the rapid rise of the repo contracts as source of secured finance. The production of securities susceptible to be considered high quality collateral is particularly difficult for the financial sector (and the private sector in general). In the absence of a sufficient provision of high quality collateral, markets could react by (i) migrating to less liquid and riskier collateral or by (ii) segmenting and tending to exclude agents that for institutional or economic reasons do not possess collateral of sufficient quality.

The regulatory reforms introduced in the aftermath of the global financial crisis have contributed to increase the concerns regarding the availability of collateral. The CGFS (2013) report highlights in particular how the introduction of the "liquidity coverage ratio" under Basel III increases the demand for high-quality liquid assets (HQLA), forcing banks to keep a relevant portion of their HQLA unencumbered in order to possibly face shocks in liquidity needs. Another source of additional pressure on collateral availability consists in the reforms in the derivatives' trading regulations, imposing an overall increase in quantity and quality of the collateral available backing both OTC and centrally cleared transactions, and introducing restrictions on the collateral re-use activity and, consequently, on its liquidity easing function. Solvency II has also increased insurance companies' appetite for high quality securities.

Central banks themselves, during the crisis, have affected the high quality collateral availability in the market. This effect of monetary policy measures on scarcity is mainly mediated by the "assets purchase programs" enacted in the different jurisdictions (in different ways) during the crisis. In Benoît Cœuré (2017), the effects of ECB asset purchase program (APP), and more in particular of the public sector purchase program (PSPP), are assessed. In the speech, while making clear that the effects of regulatory and monetary policy measures are difficult to disentangle, the scarcity in the short-term maturities of the German Bund is identified and traced back to the interplay of supply constraints and institutional and market settings. Similarly, D'Amico et al. (2014), examining the special collateral repo market in the United States, are able to identify a "scarcity channel" of the Federal Reserve quantitative easing program (QE), linking QE related asset purchases to the drops in repo rate and to the increases in market prices for the affected securities. In Caballero (2006) the problem of securities and collateral scarcity is presented as having a global scale and as being linked to global imbalances: disproportions between demand and supply, in a globalised economy, are interpreted as being at the core of financial bubbles and other vulnerabilities in the financial markets.

Heider and Hoerova (2009) provide a theoretical framework for assessing the effects of scarcity on the financial system's resilience. The authors model the interbank market in the spirit of Diamond and Dybvig (1983) and Bhattacharya and Gale (1987), where the key mechanisms at work are the unobservable (and non-contractible) liquidity shocks affecting the banks' depositors and the trade off, faced by the bank, between liquidity and returns. In the model by Heider and Hoerova (2009) a continuum of banks, trading in perfect competition, maximise returns over a timespan of three periods. In the first period banks collect deposits and invest in three possible assets: an illiquid asset, a risk-free liquid asset and a bond. In the second period: (i) liquidity shocks are realised and (ii) trading in the unsecured and secured market takes place to satisfy financial constraints. In the last period returns from assets are collected and transactions are reverted.

Heider and Hoerova (2009) can derive from their model several important conclusion regarding availability of safe assets to be used as collateral and the vulnerability of the financial system. The first implication is the decoupling of secured and unsecured interbank rates following the onset of the financial turmoils and the consequent increase in bad loans. The connection between secured and unsecured capital markets is represented by the safe assets' price, which become more and more demanded (and expensive) in times of deteriorating credit quality. The sensitivity of government bond price to credit risk is increasing in the scarcity in the supply of the bond itself in the financial system. In conclusion, tight funding conditions in the unsecured interbank market can propagate to the secured market, making overall financing problematic for intermediaries. This contagion mechanism between secured and unsecured interbank credit market is amplified by collateral scarcity, which contributes to the overall vulnerability to crises of the financial system.

The imperfect substitution as collateral between privately-created safe assets and government debt is at the basis of the analysis in Gorton and Ordoñez (2013). The authors extend the model elaborated for "Collateral Crises" (see Gorton and Ordoñez 2014) in order to identify a channel for

crises which is related to the scarcity of proper high quality collateral in the financial system. The authors advocate a special role for the government debt in the secured financial transactions. In periods of lower than optimal availability of government debt to be employed for the collateralisation of repo contracts, the private sector produce imperfect surrogates, among others in the form of asset-backed securities. The capacity of privately-created safe assets to sustain secured finance, while sufficient in normal times, proves inadequate in front of a financial crisis, that erodes value to privately-created safe assets. For the authors the different role played in times of crises by government debt and privately-created safe assets shows that the Ricardian Equivalence between postponed taxation (public debt) and direct taxation does not hold.

The model used by the authors extends the overlapping generations setting already defined in Gorton and Ordoñez (2014). In that paper, land was used as collateral and costly verification rendered scrutiny of the land's quality sub-optimal for agents in normal times. The extension is obtained by the authors by introducing a further endowment for the agents in the form of bond and taxation. Abundance of government bonds mitigates the market disruptions induced in the model by a crisis: the difficulty in collateralising financial transactions. This result produces several important conclusions: the first result being that the decline in output in times of crisis is lower when a larger amount of government bonds are in the system. The second result is that the lower the probability of a crisis, the bigger the buffer effect produced by the circulation in the economy of government debt. This second result is to be linked to the consideration that "flight to quality" effects tend to tighten funding conditions in the secured market via the price effects on safe assets.

Table III. Summary of the modelling of repo market's fragility

Approach	Main channels	Selected works
Runs and coordination failure	Runs take place by means of not rolled-over positions, via increases in haircut and margins or via fire sales that depress asset pricing. Multiple equilibria models	Gorton and Metrick (2012), Martin et al. (2010), Kuong (2015)
Costly information	Opacity in collateral and costly information lead to bubble build-up	Gorton and Ordoñez (2014)
Margin/leverage cycles	Heterogeneity in beliefs leads to overly extended leverage and exposes to sudden dry-ups and fire sales	Geanakoplos (2009)
Margin/leverage spirals	Models with market microstructure. Key role played by leveraged market makers providing liquidity to securities markets	Brunnermeier (2009), Brunnermeier and Pedersen (2009), Mancini et al. (2016), Ranaldo et al. (2016), Di Filippo et al. (2016)
Collateral scarcity	Scarcity of high quality collateral amplifies repercussions of shocks	CGFS (2001), CGFS (2013), Heider and Hoerova (2009), Gorton and Ordoñez (2013)

IV. Re-use and financial stability

This last section aims at presenting and analysing works that directly address the economic mechanisms involved in the collateral re-use. Some of the selected works focus on the economic rationale for collateral re-use and on the market microstructure made possible by it. Several works directly address the channels through which collateral re-use can possibly affect financial stability. Some other works explore the relationship between collateral re-use and macro economic dynamics. In all cases, the presented works offer methodological and technical solutions for the modelling of re-use and for the assessment of its interactions with the rest of the financial system (or with the entire economy).

Also in this last section, the analysed works are classified on the basis of a loose taxonomy. Works are grouped mainly taking into account similarities in the approach adopted for the collateral re-use modelling. Interestingly, not all the main channels identified in the previous section and linking repo transactions and systemic fragility feature in the below discussed works, hinting at the further

space for future contribution available on the topic.

A. Re-use, liquidity, and leverage

Bottazzi et al. (2012) provide a model in which repo transactions and collateral re-use arise as instruments for the build-up of *leveraged* and *short* positions in the financial markets. In Bottazzi et al. (2012), agents are heterogeneous in consumption preferences and therefore they are willing to build *long* or *short* positions on securities in order to better fit their preferences for a particular consumption stream. The possibility of transferring consumption from a period to the other thanks to the trading of securities is limited by the key constraint of the paper: the physical possession of the securities, which the authors identify as the *box constraint*. Provided that agents attach a value to the physical possession of the securities, which goes beyond its fundamentals, repo chains arise in equilibrium as means for leveraging up positions without violating the *box constraint*. Similarly, as in the usual financial markets microstructure, agents use repos and repo chains in order to finance short selling without violating the *box constraint*.

The repo-chains model by Bottazzi et al. (2012) is constructed as a general equilibrium model with incomplete markets (GEI, see for reference Geanakoplos 1990). Beside endowments of good and real securities, the authors introduce the possibility for agents to enter repo transactions with each other in order to exchange securities beyond the limits imposed by physical possession. The presence of a lower bound to the selling of securities (the physical availability of the security itself) generates a "shadow value" for the security. The securities' "shadow value" affects the conditions at which financial transactions take place: securities are valued beyond fundamental value and repo transactions for the exchange of collateral for short selling purposes are justified. Under the assumption of limited re-use possibilities (e.g.: segregated collateral), the model provides an equilibrium in which agents enter leveraged positions and create repo-chains.

The model elaborated by Bottazzi et al. (2012) obtains equilibrium repo chains without assuming a particular market micro structure. Repo contracts and repo chains are motivated by the liquidity premium attached to physical possession of securities. The model can thus introduce specialness in repo contracts: repo contracts entered with the aim of obtaining a security (and not the cash) can be traded at special (low, in comparison to general collateral repos) rates. Institutional arrangements differentiating the re-use constraints affecting the agents are also shown to give rise, in equilibrium, to intermediate agents (dealers) that have liquidity gains linked to haircut spreads. The recursive nature of repo chains can potentially give rise to highly leveraged positions opening up to financial stability risks. The possibility of failures and default are not directly dealt with by the authors, but hinted at as further extension of their analysis.

Similarly to Bottazzi et al. (2012), also Maurin (2015) provides a general equilibrium model for collateral re-use (defined as *rehypothcation* in his paper). In Maurin (2015) repo contracts arise because of limited commitment problems, which affect both cash lenders and collateral lenders: both category of agents can face (symmetric) scenarios in which losses are incurred in case the repo transaction is not reverted at maturity. This "double-sided commitment problem" affecting the

repo markets is used by Maurin (2015) to directly investigate the vulnerability of these markets in case collateral re-use gives rise to overextended repo chains and the connected exaggerated leverage.

The model by Maurin (2015) is similar to the general equilibrium model with incomplete markets (GEI) introduced by Bottazzi et al. (2012) and is presented as an extension of Geanakoplos (1997). The economy is a two-periods exchange economy, where a set of heterogeneous agents is endowed with a good for consumption in each period, can trade their holdings of a security entitling to a share of Lucas tree, and face uncertainty about the state of the world in the last period. Agents trade the security and enter repo contracts in order to achieve risk sharing and consumption smoothing, being their preferences over consumption in the different periods heterogeneous. Similarly to Bottazzi et al. 2012, agents face a "box constraint", forcing to securities borrowing for the purpose of short selling and providing an additional "shadow value" to scarce collateral.

In Maurin 2015, collateral re-use produces welfare gains only in a setting with incomplete markets and decentralised trading. Even when trading is decentralised, some securities are missing and re-use increases welfare by freeing up more collateral for financing purposes, welfare gains associated with collateral re-use are lower than the ones associated with alternative leveraging techniques (such as the "pyramiding"). The main drawback of the collateral re-use arrangement is identified by the author in the unsecured nature of the securities' lender exposure: differently from the cash lender, his claim on the security could remain unsatisfied in the event of a "failure" to deliver back at maturity (on the side of the security borrower) despite the cash collateral acquired at repo settlement. This feature of repo contracts including collateral re-use rights opens up to vulnerability in the repo markets: extended repo chains increase the likelihood that a race for collateral due to unexpected changes in preferences or to market conditions or an opportunistic failure to return collateral on the side of a large market player may cause a domino effect in which repo transactions simultaneously fail at maturity with complex consequences for the financial system.

In Gottardi, Maurin and Monnet (2017) some important questions regarding the repo markets are dealt with. The authors propose a model able to provide insight on the following topics: i) the rationale for employing repo transactions for lending and borrowing; ii) the rationale for the re-use of the collateral employed in repo transactions and iii) the rationale for the intermediation of dealers. The authors' model allows for repo contract characteristics to arise endogenously in the economy. Differently from previous works, repo contracts are a consequence of aversion to risk, rather than a tool to overcome asymmetric information. The re-use of collateral is explicitly modelled and an account of its benefits and risk is provided.

The authors' model consists in a three periods economy, where two categories of risk-averse agents are endowed with either money or asset and money. The agent endowed with asset is the natural borrower, the agent without asset is the natural lender. The asset's return is stochastic and only known in the second period, generating uncertainty about the consumption in the third period for the asset's holder. The agents are not committed to complying with their obligations and this gives rise to the necessity of secured lending among them.

Firstly, the authors analyse the equilibrium properties of haircuts and liquidity premia. Consistently with empirical evidence, haircuts are related to counterparty's riskiness. Haircuts also increase in the riskiness of collateral. Bad collateral obtains less liquidity premium than good collateral, because of its distribution in the interbank system. Secondly, the authors provide an account of the re-use of collateral: the re-use of collateral produces a collateral chain and, hence, a collateral multiplier. Re-use of collateral is explained as a product of scarcity: re-use is seen as a tool to increase market liquidity. Moreover, the services connected to the collateral management provide a rationale for the existence of intermediaries between natural lenders and natural borrowers in the repo market.

B. Repo chains, specialised intermediaries, and contagion

Infante 2015 models repo chains and collateral re-use with the explicit purpose of reconciling two distinct empirical evidences made available by the financial crisis. On the one hand Gorton and Metric (2012) identified in the increase in bilateral margins the driver of the repo run spiral triggering the financial crisis. On the other hand, Krishnamurthy et al. (2014) produced diverging conclusions with respect to Gorton and Metric (2012), with particular respect to the size of the fraction of short term secured market affected by the "repo run" and on the haircuts applied, which in their analysis did not move much during the crisis. Infante 2015 approaches the problem adopting a point of view similar to Copeland et al. 2014, where the discrepancy is traced back to differences in try-party and bilateral repo markets, referring to the fact that the latter have been more severely hit during the crisis.

The model proposed by Infante 2015 is a lean model allowing for repo chains and featuring three agents: an optimistic hedge fund, a risk averse money market fund and a dealer bank intermediating between the two. The essential form of a repo market and its underlying financing and trading motives are assumed as given: the hedge fund is willing to buy in the market a security on the basis of an optimistic subjective probability distribution of its returns. The hedge fund, though endowed with a certain amount of own funds, can leverage its expected profits by entering a repo transaction with the dealer bank, allowing for a leveraged long exposure towards the security market. The money market fund has a clear incentive to enter the repo transaction: a return is generated on the (otherwise unproductive) cash via the repo rate. The incentive for the intermediation by the dealer bank are interesting and recall the works of Bottazzi et al. 2012 and Maurin 2015: through a spread in the margins applied to the hedge fund (higher) and the money market fund (lower) the dealer bank obtains a seemingly risk-free liquidity excess ("liquidity windfall") ready to be employed in other (profitable) banking activities.

Infante 2015 directly addresses the insolvency problem and the critical role played by the insolvency arrangements involved in the repo market. The arrangements in case of insolvency are assumed to be favourable to the dealer bank: in case of counterparty defaults, the dealer bank is entitled to full recourse. In case of default on the side of the dealer bank, no recourse is allowed and the lenders have to satisfy themselves with the provided collateral. The possibility of losses in

case of dealer's default are left open only for the hedge fund, which internalises the possibility of an opportunistic failure on the side of the dealer bank in case of security returns exceeding the value of the repo principal amount. The money market fund, on the contrary, completely insulates itself form the dealer bank and, in case of its default, can satisfy itself entirely by selling the security employed as collateral in the market.

The described setting allows Infante 2015 to exclude that the repo contract between money market fund and dealer bank can be affected by changes in creditworthiness regarding the latter. In this way the author is able to reconcile the empirical evidence regarding the relatively stable tri-party repo rates and margins during the crisis: where the transaction is properly insulated from counterparty risk, vulnerability are more difficultly triggered. The defined problem is presented as a Nash bargaining problem between dealer bank. The possible equilibria of the problem allow the author to discuss the effect of an increase in the dealer bank's probability of default and of an increase in correlation between default risk and security returns. Infante 2015 shows that, given the bargaining nature of the transaction and the dependence of the conditions on the two counterparties' respective market power: (i) higher margins in the bilateral market can be both linked to a relatively high creditworthiness of the dealer bank or to a relatively high correlation between the dealer bank's default probability and the security's returns; (ii) an increase in the dealer bank's probability of default not correlated with security returns determines a decrease in repo margins.

Eren 2014 models repo chain and collateral re-use adopting a simple three agents and two periods model similar to the one used by Infante 2015, but reaching different conclusions. In Eren 2014, in fact, market distress and the consequent liquidity drought are *per se* sufficient reasons for increase in repo margins and the triggering of what Gorton and Metric (2012) would define a repo run. While not directly addressing the question of contagion in the repo markets, Eren's model defines the condition for dealer banks' insolvencies and provides an outline for an analysis of the interactions between immediate liquidity needs and profitability of repo trnsactions for the dealer bank.

Similarly to Infante 2015, also in Eren 2014 the market micro structure is assumed as given. A risk neutral profit maximiser hedge fund is offered a profitable investment opportunity in the first period. Cash surplus deriving from a "cash investor" are channelled to the hedge fund via a dealer bank, intermediating between the two. The cash investor is assumed to have no bargaining power in its relationship with the dealer bank: repos between dealer bank and cash investor are remunerated at risk-free rate and entail no haircut. In Eren 2014 the dealer bank has the necessity to finance a liquidity shortfall in the first period: the necessary liquidity is sourced from the usual haircut spread between the two repos (the one with the hedge fund and the one with the cash investor). In addition, the dealer bank is able to internalise the hedge fun problem entirely: the hedge fund's response to the dealer bank's take-it-or-leave-it offers is anticipated by the dealer bank itself in the form of a participation constraint.

In a baseline model in which the only financing channel for the dealer bank is the repo contract

with the cash investor, the author identifies two possible regimes for the dealer bank intermediation. In normal times, abundant liquidity makes it possible for the bank to apply lower haircuts to the hedge fund while maximising its profits. Better liquidity conditions for the dealer bank, makes it also possible for it to charge higher interest rates to the hedge fund, improving the profitability of the intermediation business. In crisis times, when the cash investor's liquidity is limited (in comparison to the dealer bank's financing needs) the dealer bank is forced to require higher margin (to produce the necessary margin spread) and charge lower repo rates. Extremely negative liquidity conditions can cause the dealer bank to being unable to finance its liquidity needs and become insolvent.

C. Re-use, inflation, and liquidity

Andolfatto et al. (2017) propose a model in which repo contracts and collateral re-use are analysed in a dynamic setting. The model built by the authors is a dynamic general equilibrium monetary model reminiscent of Lagos and Wright (2005) and Geromichalos and Herrenbrueck (2017). Despite not providing a direct analysis of the effects of collateral re-use on financial stability, Andolfatto et al. (2017) propose a detail analysis of the welfare implications of the regulatory tools presently available in the United States for disciplining the collateral re-use. In addition, the authors directly tackle the issue of the relationship between money circulation, monetary policy and collateral re-use. In fact, the authors assess the beneficial effects of collateral re-use in improving risk-sharing and liquidity provision against several inflation levels, establishing a relationship between inflation and welfare gains of collateral re-use.

The model defined by Andolfatto et al. (2017) consists in an infinite and discrete time economy, populated by two types of agents, *investors* and *workers*, having heterogeneous preferences over a single good provide by both the worker's activity and by a Lucas tree. Investors, who are endowed with both cash and a property title (a security) for the Lucas tree's end-of-period production, experience a liquidity shock that differentiate the usability of the security as a mean of payment among them: half of them, in fact, are randomly selected not to be able to use the security as a mean of payment. The described setting allows the authors to capture the trade-off between securities and cash: while cash is preferable in a cash-only market, its face value is eroded by inflation, making the relatively more illiquid asset preferable in markets where both means of payment are accepted.

In the environment defined by Andolfatto et al. (2017), repo contracts arise naturally as risk-sharing instruments between different investors, subject to heterogeneous liquidity shocks. Re-use and repo chains arise when repo contracts also involve the workers. In this contexts the authors can analyse in detail the welfare gains implied by collateral re-uses in several regulatory and monetary policy environments. In particular the authors can examine the differentiated effects of the SEC rule 15c3-3 and the Dodd-Frank Act, Title VII, Section 724 provisions. SEC rule 15c3-3, by limiting the amount of re-usable securities to a multiple of the cash lending involved in the margin, shows to be beneficial for welfare improvements, in particular because it creates a *regulatory premium for cash* that counterbalances the elevated preference for securities characterising the unregulated setting. On the contrary the Dodd-Frank Act, Title VII, Section 724 provisions, by introducing a

segregation (a non re-usability) of a share of the securities used as guarantee, is found to have no welfare benefits, being unable to stimulate ex-ante the demand for cash.

Andolfatto et al. (2017) also analyse the interaction between collateral re-use and inflation. In the setting defined by the authors, repo contracts and re-use are instruments the agents use in order to (partially) avoid the hidden tax on cash implied by inflation. In this setting, collateral is effectively used as a mean of payment and substitute cash for a share of market participants. The authors find that the welfare gains of the substitution between security and money as mean of payment is increasing in the inflation levels. The authors' analysis implies that, together with the prudential and macro-prudential tools available to the regulators (such as the SEC rule 15c3-3 or the Dodd-Frank Act, Title VII, Section 724 provisions), monetary policy can be a driver for the increase or for the containment of the collateral re-use activity.

D. Re-use, leverage, and volatility

The implications for financial stability of collateral re-use and the policy measures to prevent systemic risk are extensively analysed in Brumm et al. 2018. By means of the analysis of an exchange economy with repo contracts and collateral re-use, the authors are able to identify a non-monotone effect on welfare of the increase in collateral re-use. In their model, in fact, the risk sharing possibilities made available by collateral re-use prove beneficial and welfare increasing for agents with heterogeneous risk-aversion. Nonetheless, the agents' heterogeneous beliefs (some are optimist and some pessimist) leads to sub-optimal allocations of assets, especially in the presence of high levels of collateral re-use. The authors can therefore identify an optimal level of collateral re-use, depending on the overall conditions of the economy, which justifies both a regulatory intervention limiting the collateral re-use and provides at the same time a policy indication in the direction of an intermediate optimal level of this kind of activity.

A simple two-periods model, featuring one good and two agents introduces the authors' analysis. While endowment in the first period is certain, the one in the second period is uncertain. Similarly to Andolfatto et al. (2017), agents can trade their endowment in the security entitling to a share of the production of a Lucas tree. In the presence of heterogeneity in the risk aversion of the two agents (one is risk neutral and the other risk averse) and subjective beliefs significantly distant from the true probabilities of the uncertain states of nature, the authors can prove that an incomplete markets equilibrium with re-use can be welfare improving with respect an Arrow-Debreu equilibrium. Nonetheless, moderate levels of re-use usher in welfare optimum by allowing for both a moderate level of risk sharing and a limited distortion due to incorrect beliefs.

The two-period model is extended by the authors to an infinite-horizon economy. Differently from the two-periods model, the infinite-horizon model features shocks in all periods following the first one and the heterogeneous beliefs of the two agents is described by different transition matrices of the Markov process governing the exogenous shocks in the economy. Similarly to the two-periods economy, the dynamic model identifies the leverage increase produced by higher re-use rates. The additional effects of re-use captured in the dynamic setting are those related to wealth distribution

and price volatility. By increasing the overall leverage levels in the economy, high collateral re-use rates are strictly connected to increased effects of the "economic cycle" (in this case: the dynamic in the exogenous shocks) on the different categories of agents: booms favour wealth transfer benefiting risk prone agents, crises favour risk-averse agents. Collateral re-use also affects assets' volatility, which is found to be monotonically increasing in the re-use rate.

Brumm et al. 2018 analysis succeeds in providing an encompassing framework in which to analyse both the benefits and the risks entailed by repo markets and collateral re-use. One of the main merits of the work is to identify a non-monotone relationship between collateral re-use and welfare. This result provides awareness for the policy making process and provides a rationale for the existence of alternative regulatory approaches on this topic in different jurisdictions. The result is mainly obtained by identifying several contradicting driving forces. On the one hand, in line with most of the literature on collateral re-use, this is shown to have beneficial effects on risk sharing *via* its liquidity provision. On the other hand, increased leverage, "pro-cyclicality" and assets' prices volatility counterbalance the collateral re-use benefits and motivate the preference for an intermediate level of collateral re-use.

Table IV. Summary for re-use and financial stability

Approach	Main channels	Selected works
Re-use, liquidity and leverage	Re-use alleviates liquidity constraints and increases leverage. GEI models	Bottazzi et al. (2012), Maurin (2015), Gottardi et al. (2017)
Repo chains and specialized intermediaries	Simple chains with market microstructure. Defaults and domino effects integrated in the models	Infante (2015), Eren (2014)
Re-use, inflation and liquidity	Monetary models: re-use as mean to avoid inflation-related costs	Andolfatto et al. (2017)
Re-use, leverage and volatility	Leverage and price volatility as effects of collateral re-use in economy with agents with heterogeneous beliefs	Brumm et al. (2018)

V. Conclusions

The academic literature on collateral re-use and its effects on financial stability is relatively young. The present work aims at introducing to this new literature thread by exploring, and relating one to the other, some of the most significant contributions in this field. In addition, this works aims at analysing two strands of adjacent literature. On the one hand the literature introducing to the legal framework governing the repo transactions in general and the collateral re-use in particular, on the other hand the statistical literature focusing on the quantification of

this type of activity. In particular, the analysis of the statistical literature provides insights on the possibilities opened to the empirical economic analysis by the different available datasets and by the datasets that the most recent regulatory initiatives will make available in the future.

With the relevant exception of the United States, the legal framework for repo contracts and collateral re-use appears to be relatively stable across jurisdictions. On the contrary, estimates of the amount of collateral effectively re-used, and of the connected *collateral multiplier* significantly vary across countries. This work indicates that the source of the discrepancy can be found in both the reference market itself, where the role of some key players (money market funds, hedge funds, or dealer banks) can be more or less pronounced, and in the quantification methodology adopted. Comparisons in the estimates produced for the same jurisdictions, employing different methodologies, indicate that estimates based on transaction by transaction data tend to provide lower figures than estimates based on aggregate data. While being more accurate and rich in information, investigations based on granular data face severe limitations with special reference to scope limitations in the underlying data and matching methodologies adopted for the reconstruction of repo chains.

The analysis of the available literature addressing the vulnerability of repo markets allows to identify five main channels through which repo markets can destabilise the financial system. One first literature stream theorise that repo markets can be affected by coordination problems, leading to runs similar to the runs of unsecured deposits. A second family of models identifies in the information-sensitive nature of collateral the vulnerability of repo markets. Leverage cycles are at the core of a third strand of literature, identifying in the excessive leverage the main drawback of secured finance. Margin spirals and volatility are shown by a fourth strand of literature to threaten the stability and resilience to shocks of repo markets. A last literature thread relates the fragility of the repo markets to the scarcity of suitable assets to be used as collateral. Some of the mentioned channels do not feature in any available model of collateral re-use and repo chains, which encourages an extension of the theoretical literature in this last field.

Only a limited set of studies directly models and analyses collateral re-use and only a more limited subset accounts for its links and effects on financial stability. The amplifying role played by collateral re-use for both liquidity provision and leverage is at the centre of a first set of works. A second set of works focuses on the typical microstructure of the repo market (featuring a dealer bank intermediating securities and funds between "natural" cash holders and "natural" security holders), highlighting the possibility of contagion entailed by the re-use of collateral along repo chains. A third set of works extends the analysis of the implications of repo chains to a dynamic setting directly addressing the topic of the optimal regulation of collateral re-use. While offering an analysis of a wide range of key areas, the available literature on collateral re-use can benefit from contributions directed at analysing more closely the microstructure of the repo market while producing a welfare optimality assessment directed at guiding the policy making process.

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