Working Paper Series

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Evaluating market risk from leveraged derivative exposures

Abstract

Market participants use leveraged derivatives to gain access to equity market exposure through broker banks. Leverage and interconnectedness via overlapping portfolios of dealer banks can amplify adverse market movements, potentially causing sizeable losses. I propose a model, based on granular data, to simulate losses from a banks' trading book in case of an adverse market scenario. Following a move in asset prices, banks mark their positions and issue margin calls; some (leveraged) counterparties fail to pay their margins, forcing banks to liquidate their positions causing a pressure on asset prices due to market impact. The impact is amplified because of the leverage and when counterparties are exposed to multiple banks over the same underlying. I employ the model to assess current capital and margin rules in covering risks from broker's exposure to highly leveraged clients.

Keywords: EMIR, market risk, leverage, Initial margin, Variation margin

JEL codes: C60, G23, G13, G17.

Non-technical summary

After the global financial crisis, bank stress tests have become a key tool of bank prudential supervision in EU and in other jurisdictions. At the same time, authorities have put a considerable effort to collect daily data on derivatives markets to increase transparency, mitigate systemic risk, and limit market abuse. Yet these two crucial reforms have had limited feedback between each other in prudential sense, with the result that the wide amount of data available on derivatives exposures of banks is not currently utilised in the context of stress test. The main reasons for this gap are the challenges that comes with using such big data, and the model complexity underlying the derivatives market.

Against this background, this paper proposes a model to effectively exploit activity-based data to complement and enrich the picture from supervisory data and measure the market risk from banks' exposures in the derivatives market. The main application of the proposed framework is to challenge banks' self risk assessment in bottom-up stress tests, for which now only limited data is available. In addition, authorities could employ the framework to calibrate macroprudential measures aimed at mitigating the impact of a disorderly liquidations of banks positions.

The proposed model estimates the losses banks will incur would some of their counterparties fail to pay their margins, forcing banks to liquidate their positions. The model considers the potential amplification effect of overlapping exposures across dealer banks by including the market impact of fire sales of hedge by banks.

Simulations focus on equity derivatives market and they show that effects are heterogeneous, with some banks being particularly hit, due their high interconnectedness in the market and high concentration in their exposures.

Introduction

Banks play a central role in the derivatives market, acting as prime brokers, liquidity providers or clearing members. However, other financial institutions are increasingly active and tend to take directional and often leveraged positions. Due to the complexity of the exposure structure, potential spillovers and data limitations which can also restrict modelling perimeter, estimating market risk from derivative exposures for financial stability assessment and in stress tests remains a challenging task.

Recently, the failure of a family office Archegos (see ESMA (2022), SEC (2022)) has triggered renewed regulatory attention to highly leveraged non-banks active in the derivative markets, which pose counterparty risk to prime brokers. In particular, at the end of March 2021, a number of banks started to liquidate billions of dollars' worth of various stocks on positions tied to the total return swaps held by Archegos after it had failed to meet margin calls. This sale caused an additional plunge of around 27% to some of the underlying stocks and the share price of some broker banks themselves declined by around 15 % (CreditSuisse (2021), ESMA (2022), SEC (2022)). Hence, any (long) position that had exposure to the stocks whose price was falling owing to fire sales or stocks of the broker banks were immediately affected and potentially could have also triggered a default on margin requirements. In this particular event, no other cases of unmet margin requirements were recorded; however, the broker banks registered substantial quarterly losses (see Figure 1).
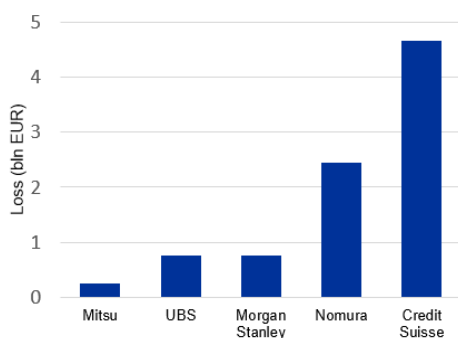

Figure 1: Reported losses of broker banks due to Archegos exposure (Source: ESMA (2022))

I focus on equity derivatives since prime brokerage is almost exclusively limited to this derivative asset class. As of end year 2020, the notional outstanding in this market segment in the Euro Area (EA) totaled EUR 25 trillion, which represents around 10% of the total EA derivatives market in terms of notional. At the same time, elevated periods of volatility and common leverage practices embeds increased exposure to market, liquidity and credit risk for investors and banks providing broker services. Within the equity derivatives, this

paper focuses on the non-centrally cleared OTC[1] equity market segment - equity swaps. The reason for this choice is twofold. Firstly, as these contracts are mostly traded OTC, they are less standardised and allow clients to potentially increase exposure beyond their liquidity capacity across multiple dealer banks, such as in the case of Archegos. This type of synthetic prime financing, where broker banks only pay-out the return (also negative) on stock performance and receive an agreed rate in exchange, offer benefits to both parties: in some jurisdictions clients do not need to disclose their exposures to the banks, while brokers enjoy a more favorable regulatory treatment in comparison to a traditional prime financing (ESMA (2022)). Secondly, other types of contracts present either additional modelling complexity, e.g. futures require modelling clearing network, default fund contributions and collateral transformation channels, or, as in the case of options, do not entail a liability for the buyer, typically a non-bank financial institution or a corporate. In the latter case the bank would not be exposed to the type of risk I am trying to capture with the model.

The modelling approach in this paper complements and could enrich the modelling of market risk in standard banking stress tests. Derivative exposures and, in general, the bank's trading book is subject to market risk capital requirements. During the EBA 2021 stress test, a third and largest (36.58bn EUR or 31%) of total market risk impact (118bn EUR in the first year of adverse scenario) was estimated to originate from Net trading income (NTI) and 17bn EUR of which were from financial assets and liabilities in the trading book. However, the estimate is based on the static balance sheet assumption and mostly relying on bank submitted data to the standardized templates (see EBA (2020, 2021)). Under the current setup of EBA stress-testing (EBA (2020)) banks, on a highest group consolidated level, are requested to provide supervisors with their projected losses that would occur under an adverse scenario – a bottom-up estimate. The supervisor, on the other hand, may employ a top-down[2] and horizontal peer comparison approaches to challenge the bank's beliefs. For market risk exposures, the stress test covers full revaluation of various accounting items in the balance sheet (such as items held for trading, hedging or other comprehensive income), CCR[3] and CVA[4] provisions, revaluation of liquidity reserves and projection of client revenues. While some aggregate information on the composition of the trading book would be available in the provided templates, the type of concentrated derivative exposures, such as stemming from prime brokerage business, and potential further spillovers cannot be addressed as it requires additional and highly granular data set that would contain details

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[1]Over-the-Counter
[2]A high-level assessment of overall exposures using internally developed models
[3]Counterparty Credit Risk
[4]Credit Valuation Adjustment

on contract characteristics.

Against this background, I propose a model to simulate losses from the derivatives trading book in an adverse scenario, that can be used to challenge banks bottom-up estimates and to enhance market risk treatment in stress tests. In short, I focus on losses in the trading book from leveraged equity derivatives and related margin calls, by utilising granular transaction data on euro area investors' derivatives positions. The model considers the potential amplification effect of overlapping exposures across dealer banks by including the market impact of fire sales of hedge by banks. In addition, the model also speaks to (synthetic) leverage and liquidity risk in the financial system and in non-banks. Thus, it can be utilized more generally for financial stability risk assessment and enhancing the macroprudential framework for non-banks. This approach has several advantages. Firstly, it considers explicitly the interaction between the banking system with its counterparties via an OTC market, which is currently only partially considered in stress testing. Secondly, it highlights the importance of overlapping exposures and how these can create spillover in the market, thus amplifying individual losses. Thirdly, the approach is consistent with existing methodologies to assess current capital and margin rules.

This paper contributes to a number of streams of literature. One category is related to the use of micro-data to conduct stress test. Sydow et al. (2021) shows how the combined endogenous reaction of banks and investment funds to an exogenous shock can amplify or dampen losses to the financial system compared to results from single-sector stress testing models. Fukker et al. (2022) study how overlapping portfolios provide a channel for financial contagion induced by the market price impact of asset deleveraging. Bardoscia et al. (2019b) analyse the network of exposures constructed by using the UK trade repository data and study how liquidity shocks related to variation margins propagate across the network and translate into payment deficiencies across different derivative markets. They find that in extreme theoretical scenarios where liquidity buffers are small, a handful of institutions may experience significant spillover effects due to the directionality of their portfolios. Similar findings are shown in Jukonis et al. (2022a), who assess whether the current levels of funds' holdings of cash and other highly liquid assets would be adequate to meet variation margin calls on derivatives under a range of stress scenarios. The work of Jukonis and Thorin (2022b) relate to the methodologies employed in the EBA stress test (EBA (2020)) and how can micro-data be used in calibrating challenger views for assessing the non-linear equity derivative exposures. Next, it also contributes to a growing body of research using TR[5] data

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[5]Trade repository

such as Abad et al. (2016), Bank of England (2018), Bardoscia et al. (2019a), Duffie et al. (2015), FSB (2018), Hau et al. (2019), Jensen and Achord (2019).

Other closely related are the studies by Fricke (2021) and Molestina Vivar et al. (2020) on synthetic leverage among funds. The former proposes a new measure of synthetic leverage and finds that synthetically leveraged funds tend to underperform and display higher levels of fragility while the latter demonstrates that outflows are larger during stressed periods and after bad performance compared with unleveraged funds. The work of Aramonte et al. (2021) describes a framework for the key channels of systemic-risk propagation in the presence of NBFIs[6] through margin requirements - leverage enables greater leverage, and spikes in margins can lead to system-wide deleveraging (see also Schrimpf et al. (2020)).

The rest of the paper is organised as follows. Section 1 describes the data employed and provides some stylised fact on the equity derivatives market. Section 2 introduces the model set up and Section 3 describes the results of the simulations. Sections 4 concludes.

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[6]Non-bank financial intermediaries

1 Equity derivatives market: stylised facts

In this section I introduce the data that is employed throughout the paper, and describe how the sample is constructed. Further, I present some stylised facts on the equity derivatives market, clarifying how investors can build synthetic leverage by entering equity swaps.

1.1 Sample definition

The results presented in this paper are based on granular transaction-by-transaction EMIR data on derivatives. EMIR data have been reported by counterparties resident in the EU since February 2014 and include more than 120 data fields for each individual derivative transaction. I employ a sub-sample of the data set restricted to the trades reported by counterparties located in the euro area (data which is available at the ECB). I use the set of paired and deduplicated transactions in the trade state reports as defined in Perez-Duarte and Skrzypczynski (2019). This is further enriched with data from the ECB's Centralised Securities Database (CSDB) on characteristics of individual securities and information from Anna Derivatives Service Bureau (AnnaDSB) on characteristics of individual derivative contracts.

From the EMIR data, I retrieve the derivatives representing equity asset class and with underlying an equity instrument traded by euro area investors. The data set is highly granular and complex, thus I performed extensive data manipulation and cleaning. Despite this processing, the final data are still subject to some quality limitations. Most results presented in this paper are based on a cleaned sub-sample using the reference date of 31 December 2020 to be able to compare it to EU-wide banking stress test templates, but also a longer time series is considered to gauge the market structure. In general, the results of this paper fall into a sample period that starts at Q4-2019 and ends in Q4-2021. When selecting the sample from EMIR, I identify contracts by a number of criteria - the reporting of contract type by the counterparties and its characteristics (maturity date, execution date, payment frequencies, underlying reference rate, underlying security ISIN, etc), classification of financial instrument (CFI) code, product ISIN as issued by AnnaDSB. In addition, I also use fields that relate to collateral - Variation and Initial margins (VM and IM, respectively) and overcollateralization. It is important to note that EMIR reporting does not allow to identify the type collateral that is posted, but only it's value. However, according to ISDA (2022) survey, the regulatory IM collected by 20 largest market participants included 5.5% of cash, 73.6% of government securities and 20.9% of other securities at year-end 2021. While cash is more widely used for VM - the same firms reported receiving 43.8% of cash, 17.9% government securities and 38.2% other securities to cover VM calls (same source).

Furthermore, I source the month end market prices of the underlying instruments using CSDB database. To identify the trades conducted by euro area banks and their subsidiaries, I filter the EMIR data based on the list of banks directly supervised by the SSM[7]. All subsidiaries of the parent bank, together with the parent bank itself, are considered as one entity when computing or aggregating the exposures. This approach is in-line with the EBA stress-test requirements where banks submit their reports based on the highest level of consolidation. In addition, I drop transactions that are marked as intragroup and create additional flags if the direct or ultimate parent of both reporting sides are the same or have any subordinated relationship. This identification is done with the help of GLEIF database. Finally, I employ the classification from (Lenoci and Letizia, 2021) to identify the sector of the counterparty.

1.2   Market overview

The EA equity derivatives market is smaller in terms of notional than other segments, but its higher volatility embeds higher exposure to market risk for investors. This translates in high margin requirements, especially in times of market turmoil, see e.g. Jukonis et al. (2022a), and can lead to higher credit risk, especially for banks providing broker service to investors. This justifies looking in more detail at this segment.

As of end year 2020, the notional outstanding in this market totalled EUR 25 trillion, which represents around 10% of the EA derivatives market in terms of notional (see Figure 2). A significant part of the market - EUR 10 trillion notional outstanding - is represented by Delta-1 derivatives, i.e. contracts that have no optionality, hence give investors the same exposure as they would own the underlying asset. These are futures, which are standardised, traded on exchanges (ETD) and cleared; and swaps, forwards and contracts-for-differences (CFDS), which are traded OTC and typically not cleared. While options represent the bulk of the total outstanding notional, they do not entail a liability for the buyer, in this context typically a non-bank financial institution or a corporate. Hence the bank would not be exposed to the type of risk I am trying to capture with the model, i.e. the client defaulting on the margin account and thus triggering unwinding of the hedge by the bank.

Euro area banks play a crucial role in the market, owing to their activities of market makers, and brokers in the OTC segment. Overall, 8 out of 10 EUR trillion of notional outstanding sees a euro area bank as one of the counterparty in Delta-1 equity derivatives (as reported by all euro area banks in the ECB EMIR sample). This figure includes both cleared and non-cleared market segments and in case of the former, banks enjoy the almost exclusive

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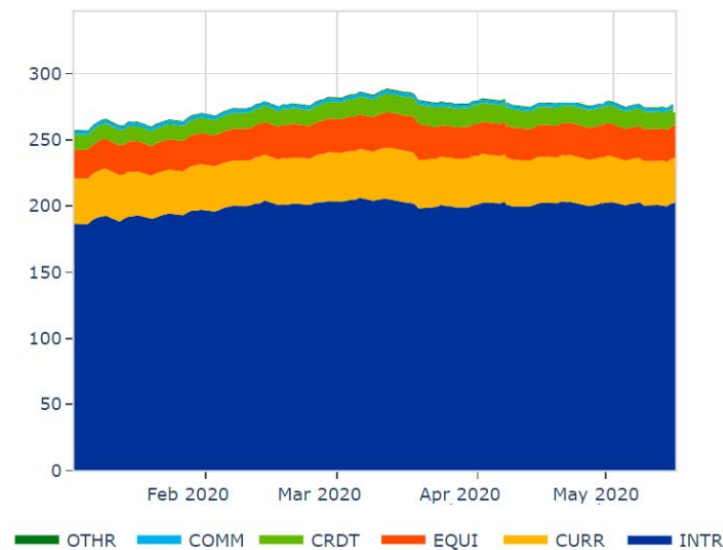[7]https://www.bankingsupervision.europa.eu/banking/list/html/index.en.html

Figure 2: Derivatives market overview. Amounts are expressed in EUR trillion. (Source: EMIR data available to the ECB. Reporting includes all transactions where at least one counterparty is from euro area or where an underlying security is from euro area. For aggregation, paired transactions in the trade state reports are used (as in Perez-Duarte and Skrzypczynski (2019)) in order to avoid double counting.)

status of being clearing members with the central counterparties (CCPs) and intermediating the trades. As for swaps, banks trade with investors from the financial and non-financial sectors, with EA investment funds being increasingly more active (around 25% yearly increase in outstanding notional in Q2021) and with the exposures being mainly concentrated in funds from three countries - see left panel in Figure 3. Banks acting as dealers typically hedge their position in these contracts in two ways:

- Buy/Sell underlying stock
- Buy/sell Opposite swap (futures) for non-index (index) underlying.

This is evident when splitting individual banks' portfolios by the side they take in the contract (long or short), with major banks having fairly balanced positions. The same picture emerges when looking into the templates reported by banks for the EU-wide banking stress test[8]. For this purpose I utilised the templates for *Full revaluation accounting items*, where banks report instruments held for trading (HfT) and their related economic hedges. In making this comparison, I assume that all equity derivatives reported in EMIR belong the the HfT portfolio - while this assumption could be strong for certain asset classes, notably interest rate derivative, as they can be used to hedge the banking book, this seems more reasonable when dealing with equity instruments, which seldom are reported as part of other

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[8]See https://www.eba.europa.eu/risk-analysis-and-data/eu-wide-stress-testing

accounting portfolios. Focusing on the equity instruments, it is important to note that for the stress test, banks have to report not only their derivatives positions, but also their exposures via linear equity instruments (i.e. holding of stocks) - these are reported as *L1* instrument - which give a measure of the hedge. Further, templates include a breakdown for cleared instruments, which allow to map *L2 cleared* as equity futures and *L2 other* and *L3* as equity swaps and CFDS.
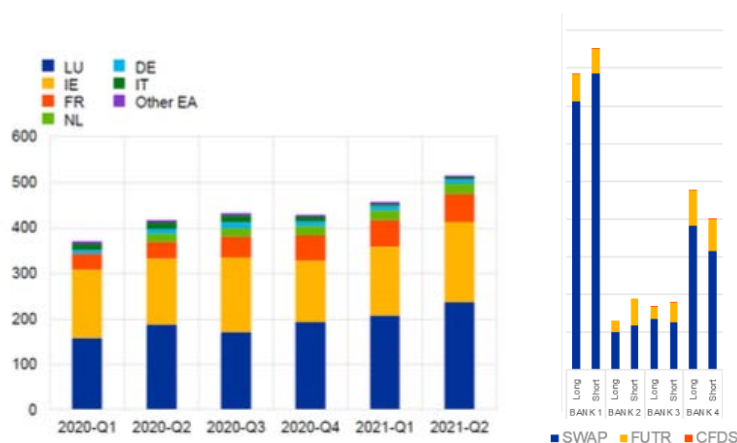

Figure 3: EA bank role in the equity derivatives market. Left panel: EA fund exposure in the equity swap (aggregate of all types, i.e. total return, variance, dividend, etc.) derivatives market. Amounts are expressed in EUR billion. (Source: EMIR data available to the ECB) Right panel: A snippet of bank positions in equity derivatives, by side. Banks selected based on 2021 EBA Stress Test data submissions. The full data and amounts are not shown for confidentiality reasons. (Source: 2021 EBA Stress test data)

The collected and reconciled data (a snippet is shown on the right panel of Figure 3) shows that equity swaps have the largest notional exposure among Delta-1 derivatives traded by sample banks by far. On the other hand, while futures also have some leverage arrangements, they require modelling clearing network, default fund contributions and collateral transformation channels which are out of scope of this study. Hence the paper will focus only on equity swaps.

1.3   Equity swaps in more detail

An equity swap is conceptually very similar to the more commonly used interest rate swap, i.e. two counterparties accepts to exchange payments at predefined dates, each indexing a certain rate. In an equity swap the buyer gets a cash flow related to equity stock/index performance and pays a reference rate (e.g. EURIBOR) on the notional. Depending on the type of swap, the performance of the stock can measured in several ways, including difference in stock price, dividend rate, volatility, variance, or total return (return on stock

plus dividend payouts). Notably, buyer's cash flows can be negative depending on underlying performance.

Despite being part of the non-cleared market segment and traded OTC, equity swaps are typically fully collateralized and require both, initial and variation margin, which is a usual practice among broker banks rather than a regulatory constraint.[9] Variation margin (VM) covers changes in the contract value, while initial margin (IM) is required at execution and constitute the margin account. Similarly to most contracts, which require initial margin to reflect the potential loss over 2 to 10 days in a tail event, depending on broker agreement, the initial margin for equity swaps can be static or dynamic and reflects the tail risk of the overall portfolio. For a non-model based IM, EMIR allows 15 % flat rate for equity derivatives[10] which is applicable to a total portfolio notional. This standard schedule was slightly adjusted to take into account net-to-gross ratio, which is applicable to netting sets (see Annex IV of EU2016/2251 (2016)).

1.4 Leveraged trading and overlapping portfolios

The fact that equity swaps are traded on margin accounts makes these instruments very appealing for clients that aim to build synthetic leverage. By entering an equity swap, clients obtain synthetic exposure to the underlying stocks without owning them. This exposure is leveraged as clients pay only a fraction of the notional value into the margin account (see Figure 4 for a schematic representation). However, not all equity swap positions found in the EMIR data can be attributed to synthetic leverage. To assess the leverage of market participants (non-banks), the derivative (synthetic) positions would need to be linked with on-balance sheet positions to see how derivatives positions are used - to gain synthetic exposure or to hedge. For hedging purposes, market participants (bank clients) would need to *sell* equity swap contracts in order to have a delta neutral exposure against their stock holdings and the market value of their derivative exposures would increase (rather than decrease) in case of falling stock prices, which would not result in an additional liquidity pressure. This paper emphasizes the opposite situation - when market participants use brokerage services to *buy* the equity swap contracts, this way obtaining the synthetic exposure.

In general, clients need to replenish their margin account when market moves against them, by using either cash or HQLA securities. Depending on broker agreement, positions

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[9]For market participants (financial counterparties and non-financial counterparties that exceed the clearing threshold pursuant to Article 4a or 10 of EMIR) with a nominal volume of non-centrally cleared OTC derivatives of more than € 3 billion at group level, the obligation to exchange initial and variation margins started on 4 February 2017. The requirement to exchange initial margins will apply to counterparties with an aggregate average notional amount exceeding EUR 8 bln starting 1st Sep 2022, current threshold is EUR 50 bln.

[10]The rate varies per asset class, for Interest rate derivatives it is between 1% to 4%, Credit 2% to 10% (in both cases depending on the maturity of the contracts), 10% for Commodities and 6% for FX.
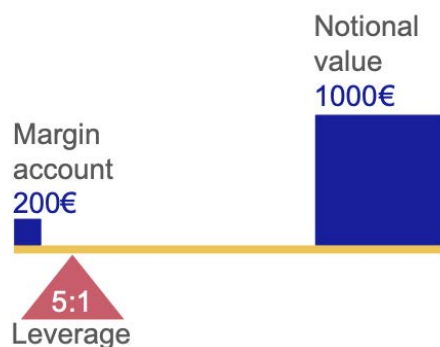
Figure 4: Schematic representation of leveraged margin account

can be one-way collateralised, i.e., only client pays, but not the dealer bank. Importantly, the amount to be paid in the margin account depends on the whole notional amount of the contract so also a relatively modest market movement can generate a material margin call, depending on the leverage. For investors with low liquid holdings, timing is crucial to allow for collateral transformation, as failing to meet the call in a timely manner (typically one day) can cause the position to be partially or entirely liquidated. Empirical observations from EMIR data suggest that the leverage of investors in the euro area varies by sector but on average is around 5 : 1. This is shown in Figure 5 as the ratio between the initial margin received by the broker against the underlying notional (i.e. 1/Leverage) on each derivative portfolio traded by the counterparties of various sectors.
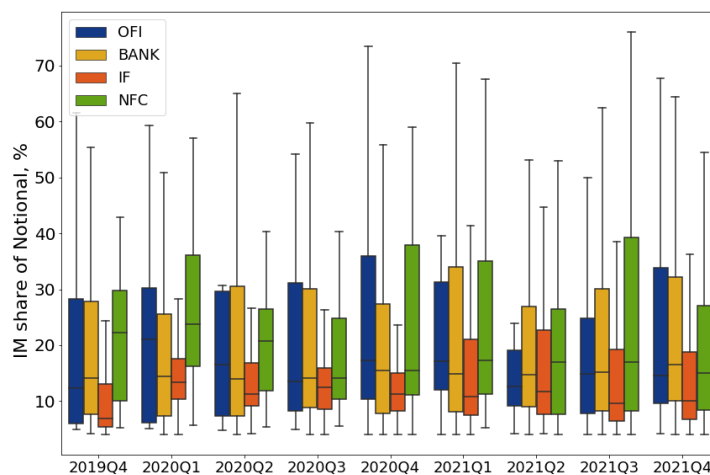

Figure 5: Leverage in non-cleared equity derivative market embedded in portfolios held by different sectors (Source: EMIR data available to the ECB). How to read the chart: for example, 20% means 5:1 leverage, so for a counterparty to have exposure of EUR 1000 to a certain security, it needs to post EUR 200 in the margin account.

An investor may also seek to build its leveraged portfolios across multiple dealers banks,

e.g. to overcome limits imposed by each bank on the size of the portfolio. While banks should in theory be aware of exposures towards other dealers, the level of disclosure is unclear and recent evidence, see e.g. Branzoli et al. (2021), shows that the market is still very opaque. In addition, EMIR data allows only partial view of the exposure (limited to EU or EA) and granular data sharing across jurisdictions would need to be set up to identify leveraged portfolios across multiple dealer banks. Nevertheless, despite limitations, granular data still allows identifying the concentration in certain stocks by the same counterparty via different broker banks (Figure 6). In such configuration, in the case of adverse market movement a counterparty will receive several concurrent margin calls. Failure to meet such margin calls will prompt the banks to unwind their hedge, potentially causing fire sales of the underlying stock.
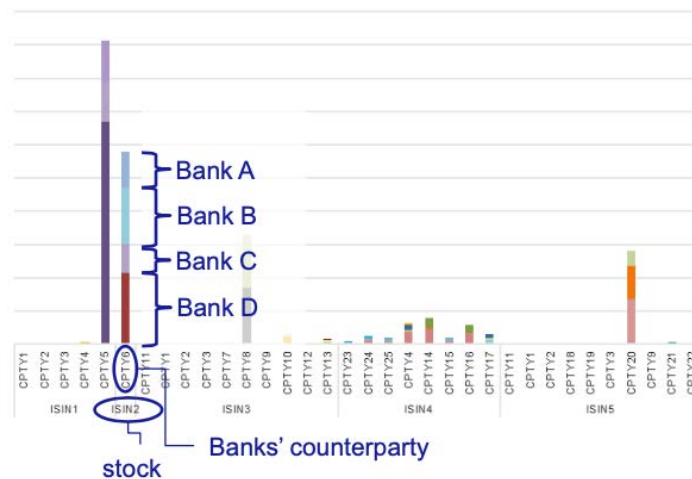

Figure 6: Portfolio overlap among EA banks - selected example. ISIN refers to an underlying security of equity swap. Data shows that some counterparties have long exposures of the same underlying across multiple dealers.

2 Model

This section describes the model I developed to measure the market risk from banks' portfolio in the equity derivatives market. In a nutshell, the model simulates several clients defaulting on their margin calls following a market shock, to which banks react by liquidating, in part or in total, the hedge, to keep their exposure delta neutral. When several banks trade simultaneously on the same underlying, due to overlapping portfolio, the market impact generates extra losses on their HfT portfolios, hence impacting the bank profit via the net trading income (NTI).

Each run of the simulation uses as starting point the portfolios reported at end year 2020, by $d \in D$ dealer banks with their clients $k \in K$ and consists of the following steps:

i. The equity market suffers an exogenous shock u on prices S of each underlying μ in the sample:

$$S_{t+1}^{\mu} = S_t^{\mu} \times (1 + u^{\mu}) \quad \forall \mu \tag{1}$$

The shocks are calibrated to be within range of those applied in the last EU-wide banking stress test where they depend on the geography and are within the interval $[-0.64, -0.32]$ (relative change in stock price, %), see (EBA, 2020). In the model, assuming an overall adverse scenario, for each individual stock μ a shock u is drawn from a uniform distribution $\mathcal{U}(-0.55, -45)$, with shocks being uncorrelated across stocks.[11]

ii. Each bank d marks its positions on equity swaps and calculate margin requirements (VM) for its clients k.

$$VM_{d,k}^{\mu} = VM(S_{t+1}^{\mu}, S_0^{\mu}, Q_{d,k}^{\mu}) = [\Delta MtM_{t+1}(S_{t+1}^{\mu}, S_0^{\mu}, Q_{d,k}^{\mu})]^+ \tag{2}$$

where

$$MtM_t(S_t^{\mu}, S_0^{\mu}, Q_{d,k}^{\mu}) = w((L(0, \delta) + r)N\delta - Q_{d,k}^{\mu}(S_t^{\mu} - S_0^{\mu})) \tag{3}$$

where S_0 is the underlying stock price at contract trade date, $Q_{d,k}$ is the quantity of underlying stock/contracts between bank d and client k and $N = Q_{d,k} \times S_0$ denotes underlying notional amount. $L(0, \delta)$ is the reference rate that remunerates floating rate leg (such as EURIBOR, LIBOR, etc), r is a spread and δ denotes the length of the contract in years. The specification (3) refers to the so called *bullet swap* where cash flows are exchanged on a single date. It is straightforward to generalise this formula for the case with more resetting dates and cash flows. In addition, an equivalent formulation is when return is expressed in relative and not absolute terms. In this case equity leg would be $(S_t^{\mu} - S_0^{\mu})/S_0^{\mu} \times N$. Finally $w \in \{-1, 1\}$ denotes the side that the bank takes in the contract, with $w = 1$ being *short* (in which case it would *sell* the contract by paying out the stock performance and receiving fixed rate on notional).

When repricing the contracts, all contracts that have more than one cash flow reset

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[11]The range of impacts is within the bounds of market risk scenario for equities as defined EU-wide banking stress test. This scenario of static shocks is calibrated based on a multivariate copula approach which already embeds a historical correlation structure (for details see Rancoita and Ojea Ferreiro (2019))

date and maturity longer than 1 year were valued as 1 year bullet swaps[12]. Since the current architecture of EMIR reporting does not allow to consistently identify the spread r, it was set at 2%.

The total margin call from bank d to client k is the sum across the entire portfolio:

$$VM_{d,k} = \sum_\mu VM^\mu_{d,k} \qquad (4)$$

while client k needs to meet margin calls for a total amount given by

$$VM_k = \sum_d VM_{d,k} \qquad (5)$$

iii. With probability p_s a client k fails to meet a fraction θ_s of the new margin call VM_k. I assume both p and θ depend only the sector $s = s(k)$ of the client, hence all dealers of a defaulting investor are impacted proportionally to their exposure, i.e. all banks are treated equally by the debtor. I define the set of defaulting clients as $\bar{K}$.

iv. When considering the loss, I distinguish 2 cases - full and partial liquidation. In the first case the amount of stock sold is equal to $Q^\mu_{d,k}$. In the second case, banks liquidate part of their hedges and sell an amount of stock X such that:

$$VM(S^\mu_{t+1}, S^\mu_0, Q^\mu_{d,k} - X^\mu_{d,k}) = \theta_{s(k)} VM(S^\mu_{t+1}, S^\mu_0, Q^\mu_{d,k}). \qquad (6)$$

The amount $X^\mu_{d,k}$ can be approximated by

$$X^\mu_{d,k} \approx \min\left(Q^\mu_{d,k}, \left(Q^\mu_{d,k} - \frac{\theta_{s(k)} VM^\mu_{d,k} + MtM_t(S^\mu_t, S^\mu_0, Q^\mu_{d,k})}{S^\mu_0(1+r) - S^\mu_{t+1}}\right)^+\right) \qquad (7)$$

which is obtained by simply substituting (3) into (6), setting $L(0, \delta) = 0$ (which is not unrealistic assumption given the current low rate environment) and solving for X. Clearly, if $X^\mu_{d,k} = Q^\mu_{d,k}$, the position is fully sold.

v. Price impact for stock μ, denoted as P^μ, applies to securities being liquidated, which suppresses realisation values for dealers and increases marked losses in the balance sheet. The impact is based on Fukker et al. (2022), where it is derived by applying a quantile regression for securities at *ISIN* level. One of the main advantages of this approach is the inclusion of the system-level return as a main component in security-level price changes defined for different security buckets, this way solving a high degree of

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[12]Note that $\delta \leq 1$ in all cases.

sensitivity to potential outliers. In addition, it allows to obtain a concave representation with a full distribution of impacts for each security. Nevertheless, the technique employed here is heavily data dependent and relies on a number of sources which often can be scarce or not available. The missing cases are handled by averaging and projecting the impacts based on geographical, sector and capitalization level. The impact on indices is aggregated based on geographical criteria by computing the average impact. Alternative modelling approaches could include linear (Kyle (1985)), square-root (Bouchaud et al. (2009)) or other concave (Bouchaud et al. (2009), Tóth et al. (2011)) representations that would offer a relatively more flexible and less data dependant inference. However, this does not offer the benefits of a quantile regression approach that allows to repeat the impact assessment for the full distribution which is necessary in modelling fire sales dynamics with deleveraging pressures and assessing policy implications on controlled liquidation.

Importantly, when computing the price impact, the volumes sold by each bank connected to the defaulting clients are considered jointly, also those not located in the euro area. In this way the model captures the loss amplification due to overlapping portfolios across dealers banks, and partially the cross-border contagion. The exposure to non-EA dealers is available only when the client is domiciled in the EA, due to its reporting obligation. Similarly, by considering all clients of EA dealer bank is possible to capture also those located outside EA, and gain additional insight on the potential contagion. This is is one the advantage of using an activity based dataset as opposed to supervisory data alone, as it allow to overcome, at least in part, the limit imposed by jurisdictions and supervisory perimeters.

vi. Banks recognise the loss. Losses can stem from both types of hedging, i.e. when the dealer bank holds the underlying stock referenced on defaulted contracts, or it entered another derivatives contract in the opposite direction[13]. If banks initially fully hedged by holding a stock at price S_0, the loss due to liquidation (denoted as LL - *Liquidation Loss*) is recognised in the profit and loss (PnL) statement via the NTI, and it is given by:

$$LL_d^\mu = \sum_{k \in \bar{K}} X_{d,k}^\mu (S_{t+1}^\mu - S_0^\mu) < 0 \, . \tag{8}$$

On the other hand, if banks hedge fully by taking opposite trade (in which case they

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[13]While excluded from the sample, it is important to note that the return on securities as offered by prime brokers often includes performance of basket of securities.

do not own the physical stock, but only exchange opposite financial cash flows), the reduction of short position, would create a mismatch between the hedge legs, and the loss would materialise in the PnL of their balance sheet (where the sum of long position is restricted to related hedges):

$$HL_d^\mu = \sum_{k \in \bar{K}} MtM_{t+1}^{\text{short}}(P^\mu S_{t+1}^\mu, S_0^\mu, Q_{d,k}^\mu - X_{d,k}^\mu) + \sum_{k \notin \bar{K}} MtM_{t+1}^{\text{long}}(P^\mu S_{t+1}^\mu, S_0^\mu, Q_{d,k}^\mu) < 0\,.$$

(9)

The total loss depends on how the banks built the hedge for each underlying and the decision to unwind one or both hedges in case $\theta < 1$, which is an information difficult to reconstruct from the datasets employed here. Further, a bank can decide to use a different but correlated stock to hedge one exposure, e.g. if the exact hedge is not available or illiquid. However, EMIR data do not indicate the purpose of a trade or what accounting category it is assigned to. To partially overcome this shortcoming, if one indicates with $\alpha_\mu \in [0,1]$ the fraction of exposure in equity μ hedged via holding the stock itself, the total loss for the bank can be approximated by the following:

$$L_d = \sum_\mu \alpha_\mu LL_d^\mu + (1 - \alpha_\mu) HL_d^\mu\,.$$

(10)

In case of full liquidation and due to leveraged margin account, the broker would keep a fraction (or full amount, depending on a loss) of posted initial margin. In particular, the loss in NTI will be adjusted net of received collateral, indicated as $IM_{d,k}^\mu$ (Initial Margin).

$$\hat{LL}_d^\mu = \sum_{k \in \bar{K}} (Q_{d,k}^\mu (S_0^\mu - S_{t+1}^\mu) - IM_{t,d,k}^\mu)^+$$

(11)

Based on the empirical observation from Figure 5, it is assumed that Initial Margin account is always at 20% of the maximum between underlying notional and current market value of the position, i.e.

$$IM_{t,n,k}^\mu = 20\% \times \max(N_{n,k}^\mu, MtM_t(S_t^\mu, S_0^\mu, Q_{n,k}^\mu))$$

(12)

In terms of stress test templates, such loss would need be compared to that reported in the *Full revaluation* table, as *Total impact HfT* for linear equity instruments and related derivatives under the category *HfT and their related economic hedges*.

vii. Finally, I define a metric for loss amplification by

$$LA = \frac{\sum_d L_d}{\sum_d \sum_{k \in \bar{K}} \theta_{s(k)} VM_k} \tag{13}$$

where L_d is defined in Eq. (10).

The advantages of this set up are several. Fist, it allows to enhance the quality assurance process during the stress test with granular data and challenge bank's potential capital depletion in the integrated system of exposures and beyond the self risk assessment. Secondly, it provides a background for further integration to the more general system-wide stress testing framework such as Sydow et al. (2021) where banks would be interconnected beyond investment funds.

3 Results

This section presents the results of the simulations, where the model is run with different set of values for the parameters θ_s and p_s. Each simulation comprises 10000 runs with 75 banks and results in two distributions of losses for dealers, LL_d and HL_d. The results will show 1% quantile and mean of these loss distributions across banks. As mentioned in Section 2, it is difficult, with the data at hand, to have the precise composition of the dealers' hedge, so both LL_d and HL_d are reported separately. While model outcomes are available at bank level, here I present distributions across all banks to preserve confidentiality.

Subsection 3.1 presents the results for the case in which bank fully liquidate their hedge in response to the missed margin call. Here only p_s will vary.

Subsection 3.2 considers partial liquidation in which banks can decide to keep the position open in case of missed margin call by the client. This means both θ_s and p_s can vary.

Subsection 3.3 maps the results to actual observed losses of banks during the Archegos incident and market risk impact during the EBA stress test.

3.1 Full liquidation

Figure 7 shows results for full liquidation for a different set of default probabilities across sectors. In particular, x-axis shows a pair of default probabilities (PDs) assigned for counterparties from certain sectors during each simulation run. The first entry in the pair indicates the PD of a counterparty that is classified either *Non-financial, Pension fund, Insurance company* or *Other* (not including *Investment fund* or *OFI*), while the second entry applies

to a counterparty labelled *Investment fund* or OFI^{1415}.

Results suggest, and as can be observed by consistent outliers in the boxplot distributions, that the losses are concentrated on large banks which have also significantly larger positions. The most adverse case is for the 1% quantile and PD set $(0.07, 0.09)$ where the losses for biggest dealers in NTI range from around EUR -1 bln to EUR -2.4 bln and from EUR -0.8 bln to EUR -4 bln due to the mismatch between hedge positions. Hedge loss is somewhat larger than the liquidation loss (NTI) in all considered cases and this difference is precisely the price impact after the initial sell-off amplified by the interconnection between clients and brokers. The dealer is left with partially hedged position which it needs to mark against the prevailing adverse market prices. In turn, it is affected by the common fire sale from all involved banks that close positions with a defaulted counterparty.
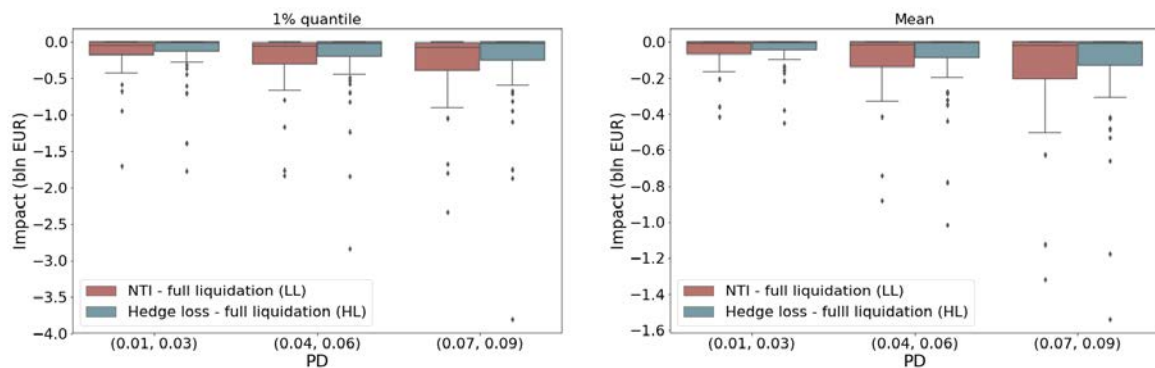
Figure 7: Bank losses due to full liquidation. Each box plot shows distributions of 1 % quantile (left panel) and mean (right panel) losses for each bank due to fire sale and hedge accounting.

3.2 Partial liquidation

Figure 8 shows results for the case of partial liquidation. The parameter θ is shown on the x-axis and varies between 0 and 0.8. The default probabilities were fixed at $(0.07, 0.09)$ for all counterparty sector cases as described in the previous section.

When $\theta = 0$ results are comparable to the case of full liquidation. This observation suggests that it could be beneficial to design policies that would force controlled liquidation in case of large mutual losses across banks on certain securities. In particular, already in the case when $\theta = 0.4$ the losses are approximately cut by half. However, this requires a more careful study of potential permanent or transient price impact behaviour.

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[14] Other Financial Intermediary

[15] For example, for a pair $(0.07, 0.09)$, at each simulation run, the probability to default for a counterparty representing *Non-financial, Pension fund, Insurance company* or *Other* (not including *Investment fund* or *OFI*) sectors is 7%. Similarly, the probability to default for a counterparty which is an *Investment fund* or *OFI* is 9%.
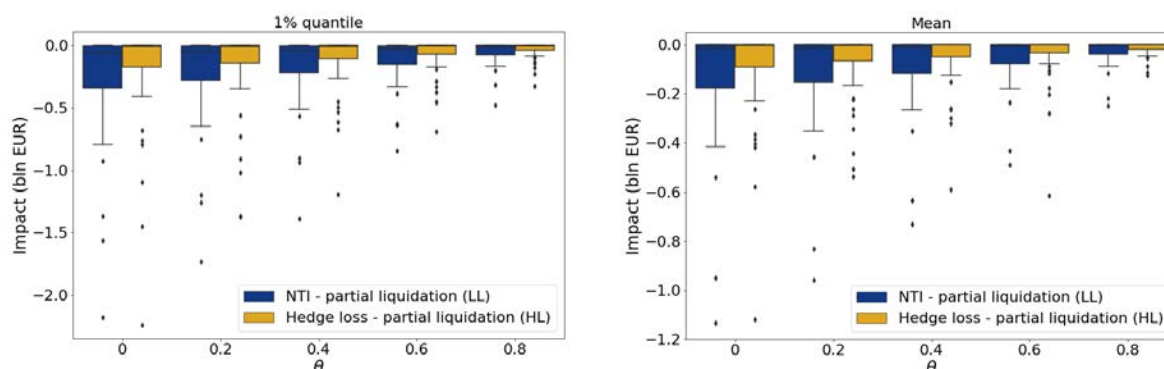
Figure 8: Bank losses due to partial liquidation. Each box plot shows distributions of 1 % quantile (left panel) and mean (right panel) losses for each bank due to fire sale and hedge accounting.

3.3 Impact materiality

As it can be observed in Figure 1, the total impact during the Archegos incident for the involved banks amounted to around EUR 10 bln and ranged from EUR 0.3 bln to EUR 4.7 bln. In this case, banks fully unloaded their securities which were used for hedging the equity swap exposures. In the model setup that is described in this paper, this is illustrated in Figure 7 and is labeled as *NTI - full liquidation*. The fire-sale from involved banks in Archegos case caused an additional plunge of around 27 % to some of the underlying stocks and the share price of some broker banks themselves declined by around 15 % (CreditSuisse (2021), ESMA (2022), SEC (2022)). However, when a partial liquidation is employed, losses are substantially reduced as is shown in Figure 8. Here θ illustrates the fraction of position that is not sold immediately and this approach can be used to find optimal liquidation strategy with least market and price impact.

As observed by ESMA (2022), due to some difference in disclosure and reporting regulations of that time between EU and non-EU jurisdictions, Archegos had less opportunities to build these positions with dealers from EA. Consequently, similar practice would be also applicable to other clients that want to enter similar type of contracts. Hence one would expect that within the EA there is less space for this type of scenario to materialize. Nevertheless, results show that losses across dealer banks are still material while the data available to the ECB gives only a partial picture. The 2021 EBA stress test estimates that the total impact to market risk segment from NTI was around EUR 36.58 bln (EBA (2021)). However, some of the losses in the trading book might not be marked as this type of assessment does not utilize granular data and assumes a static balance sheet. Hence, the model described here could be used to enrich the market risk assessment during the bank stress tests also from a

system perspective.

4   Conclusions

This paper introduces a model to estimate market risk for bank' derivatives exposures in an adverse scenario.

The proposed model utilises granular transaction data on euro area investors' derivatives positions, and it allows to estimate the losses banks will incur would some of their counterparties fail to pay their margins, forcing banks to liquidate their positions. The model considers the potential amplification effect of overlapping exposures across dealer banks by including the market impact of fire sales of hedge by banks. Simulations show that effects are heterogeneous, with some banks being particularly hit, due their high interconnectedness in the market and high concentration in their exposures.

Despite the high level of insights that this framework provides, it still bears some limitations. Firstly, the framework is data and computational intensive, primarily for the need to filter and reprice thousands of exposures and for the simulation setup. Secondly, the computation of the actual loss depends on the exact composition of the hedge, which is not considered here. Finally, a more accurate probability of default for clients would be based on their individual liquidity holdings, rather than their sector. While the framework is flexible enough to accommodate certain improvements, and could be further extended to capture other market segments (e.g. FX, interest rate), granular data sharing across jurisdictions (EU and non-EU) would need to be set up to identify leveraged portfolios across multiple dealer banks and to better capture the price impact effect. In fact, one goal of the OTC derivatives reform was to make the market more transparent but individual regulators continue to have limited view on this global market.

In the model setup the losses for banks with largest concentration of equity swap exposures range from around EUR -1 bln to EUR -2.4 bln in a full liquidation scenario (losses during the Archegos incident for the involved banks ranged from EUR 0.3 bln to EUR 4.7 bln and totalled around EUR 10 bln). In addition, the 2021 EBA stress test estimates that the total impact to market risk segment from NTI was around EUR 36.58 bln (EBA (2021)). However, some of the losses in the trading book might not be marked as this type of assessment does not utilize granular data. Hence, the model described here could be used to enrich the market risk assessment during the bank stress tests also from a system perspective.

In addition, this approach could potentially be used to calibrate macroprudential measures in case of severe market turmoil, to mitigate the effect of a disorderly liquidation of their hedge by affected dealers. One such measure could consider a controlled liquidation, where,

following the default of an interconnected clients, the hedges against its positions are pooled together and liquidated in smaller tranches, hence reducing the overall market impact and removing first-move advantage among dealers in need to re-balance their positions. Another measure could envisage limits on the leverage of investors, which decline with the size of the exposures, taking into account the overlaps among dealers over the same counterparties and underlying.

Finally, although the model presented here is bank-centered, it also speaks to (synthetic) leverage and liquidity risk in the financial system and in non-banks. This sector has grown in size over the last decades and still lacks a comprehensive macroprudential policy framework. Developing and enhancing such a framework would in turn limit the counterparty risk for banks.

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