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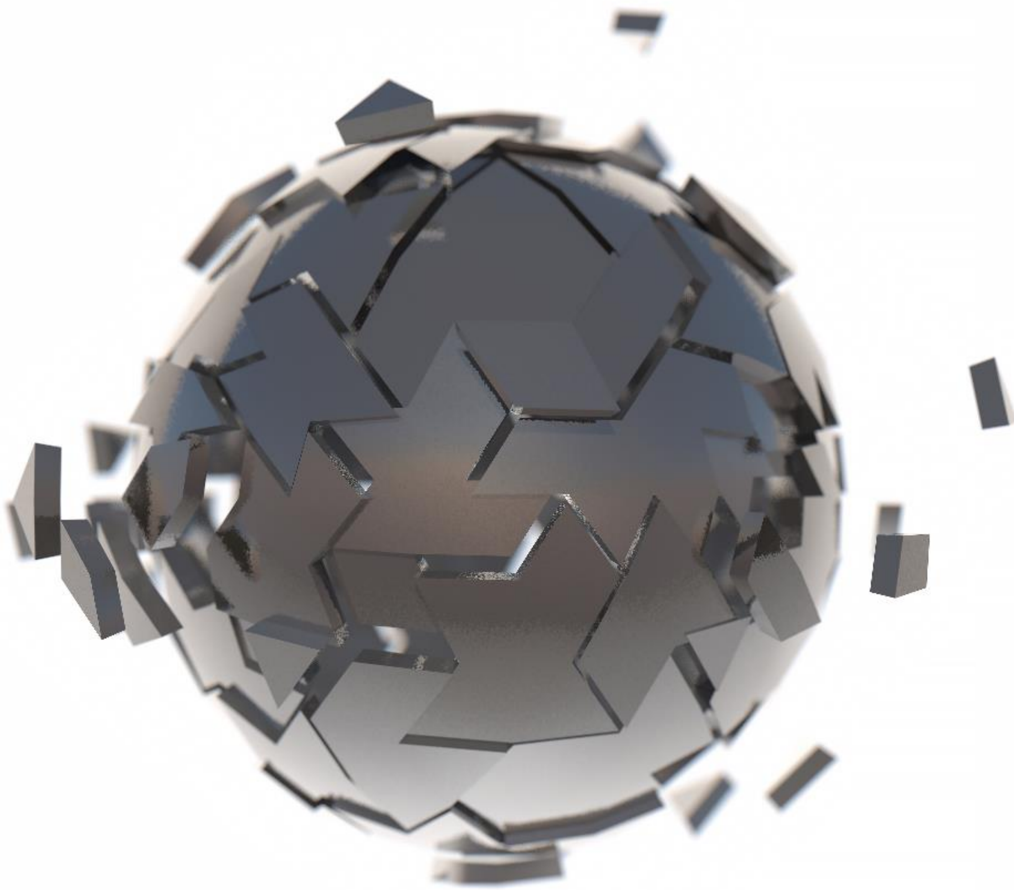

Agent-based modelling for central counterparty clearing risk

Enhancing CCP Resilience, Recovery, and Resolution for financial institutions, exchanges, and policy makers

April, 2020

Executive Summary

Enhancing CCP Resilience, Recovery, and Resolution for financial institutions, exchanges, and policy makers

This paper is intended as a contribution to the debate around how to strengthen risk management processes at central counterparties (CCPs). We present the case for using Agent Based Modelling (ABM) to assess the impact of the various proposals on the table.

One of the consequences of the 2008-2009 financial crisis was a push for far greater use of central clearing. The significant increase in central clearing has itself led to a discussion about how to ensure stability of CCPs. After the default at Nasdaq Clearing AB in September 2018, a large group of sell-side and buy side firms shared perspectives on ways to strengthen the risk management processes at CCPs through a joint publication - *A Path Forward for CCP resilience, Recovery and Resolution*.

We understand that any changes to the CCPs would be of interest to various parties – clearing members (CMs), end users, policy makers, regulators, and the CCPs themselves. At the same time, we believe it is essential for individual CCPs and CMs to understand and analyse their relationships with each other, the dynamics of the CCP environment, and ever-changing market conditions, before proposing and implementing changes. We propose an ABM approach to simulate an artificial CCP environment, allowing the various participants to understand, analyse, and quantify the effects of the proposed changes.

ABM is a bottom-up approach to the modelling of complex and adaptive systems with heterogeneous agents. We model the financial markets through the individual behaviours of the market participants and their interactions with each other, as well as their interactions with the market environment. This way, we are able to model emergent behaviours in the financial markets, which is particularly useful when simulating stressed scenarios or default events.

Our ABM model was designed specifically to examine the effects of the proposed recommendations in the joint publication by the financial institutions. It incorporates three major processes at the CCPs:

- **Market simulation** – This module provides an artificial market environment simulating the real-world financial market. We simulate a CCP market environment comprising one CCP and 60 CMs. As in real life, the CMs have different balance sheet positions and trading behaviours. The evolution of traded asset prices are modelled by the supply and demand from the CMs. The state (balance sheet and trading behaviours) of the CMs can also change as the market environment evolves.
- **Margin call framework** – This module enables the evaluation of the proposed recommendations related to margin requirements at the CCPs. The products in-scope for this model trade on margin. Our ABM models the respective margin calculations and variation margin call processes.
- **Default management framework** – This module is to enable the analysis of various recommendations related to the default management process. When a CM cannot answer margin calls, the default management process at the CCP is triggered. Once triggered, CCPs in the model will close the trade portfolio of the defaulted party, calculate default loss, and mutualise this default loss through the default waterfall.

This ABM model is implemented jointly with Simudyne, a simulation software company, and Cloudera, an enterprise data cloud company. Together, the solution combines a state-of-the-art CCP market model with an easy-to-customise, highly scalable, cloud-enabled platform for market participants to quickly and easily evaluate the implications of any proposed changes to the CCP's risk management frameworks. Our CCP market model also provides additional benefits by enabling users to run an unlimited number of stressed scenarios, thereby extending the analysis to broader topics embedded in the CCP framework such as concentration risk, wrong-way risk, and systemic risk across multiple exchanges to reveal potential hidden exposures.

Contents

CCP Resilience – from One Crisis to the Next

Central Counterparty (CCP) reform has been a major topic of discussion in financial services forums and conferences in recent years. Market participants recognise that CCP processes should be strengthened given the important role they play in the stability of the financial markets. We note that any changes at the CCPs can give rise to unforeseen consequences through network effects and emergent behaviours. Hence, we present the case to analyse and quantify the effects of any potential changes to the current CCP framework through an artificial market environment developed with an Agent-Based Modelling (ABM) approach.

Since the 2008 financial crisis, policy makers and market participants have increasingly relied on central clearing to improve market transparency, mitigate systematic risk and hence make derivatives markets safer. The commitment to central clearing for standardised over-the-counter (OTC) derivative contracts was one of the pillars of the Pittsburgh declaration [1]. The G20 leaders stipulated that all standardised OTC derivatives should be traded on exchanges or electronic trading platforms and cleared through CCPs, and uncleared derivatives should be subject to higher capital requirements and margin levels. These developments led to a significant increase in centralised clearing, especially for interest rate and credit derivatives. In 2009, approximately 24% of OTC interest rate derivatives and 5% of OTC credit derivatives were centrally cleared; but by H1 2019, these levels had risen to approximately 78% and 58% respectively [2].

With rising levels of central clearing, there has been growing concern about the effectiveness of CCP risk management among market participants and policy makers. The level of discussion around these topics intensified following the default event at Nasdaq AB in September 2018. The default of a clearing member (CM) was triggered by a loss on their cleared portfolio due to a 17 standard deviation jump in the European power market. The default led to a loss of 2/3 of the CCP's default fund, equal to 107 million EUR. Since the event, CMs and end users have actively raised concerns around CCP governance, and shared their perspectives on enhancing CCP governance along with risk and default management practices at CCPs.

One recent and notable development in this regard is the paper – "A Path Forward for CCP Resilience, Recovery and Resolution" published and backed by a total of 19[1] major buy-side and sell-side firms' call for regulatory action to make CCPs safer [3]. The paper brings together recommendations to address outstanding issues at the CCPs through enhanced risk management and aligned interests among market participants. The signatories represent the firm-level support of the recommendations and suggest the collaboration of regulators, policy makers and CCPs to help implement the proposed changes described in the paper.

The financial markets are highly complex, so even small changes to the current processes at the CCPs can potentially lead to unforeseen impacts that propagate throughout the markets due to emergent behaviours and other network effects. It is also worth noting that many of the market reforms involve significant costs and risks during the transition state, hence the gains in financial stability should be

1 The paper was originally published and backed at a firm-wide level in October 2019 by Allianz, BlackRock, Citi, Goldman Sachs, JPMorgan Chase & Co., Societe Generale, State Street, T. Rowe Price, and Vanguard. Support for the paper has recently been extended to include ABN AMRO Clearing, Barclays, Deutsche Bank, Commonwealth Bank of Australia, Franklin Templeton, Guardian Life, Ivy Investments, Nordea, TIAA and UBS as of March 2020.

carefully weighed before investing in the reform. These considerations need be carefully analysed by all market players before the changes are implemented at the CCPs.

In addition, we recognise that different stakeholders may have different perspectives on this topic. For example, most CCPs have for-profit structures that do not necessarily contain incentives to implement the suggestions provided by CMs and end-users. Extensive regulatory intervention can also sometimes be counterproductive and impede the ability for CCPs to "evolve" to an ideal state of risk management. However, we do believe the right arrangements and changes will give all parties the incentives and capabilities to ensure effective CCP risk management, serving the interests of the CCPs, CMs and end-users.

Therefore, we have developed an ABM solution that captures the emergent properties of real-world financial markets through simulation. All stakeholders interested in the CCP reform can use this ABM solution to simulate the potential effects of various recommendations. This in turn allows participants to better analyse, compare, and quantify the impact of the suggested changes to the CCP process, and to be better prepared for future changes.

The focus of the remainder of this paper is modelling CCP behaviour. However, it is useful take a moment to also describe the broader vision of our work beyond this paper, namely:

a. The capability to evaluate the recommendations proposed by the 19 financial institutions as well as other potential proposals to the overall CCP risk management framework;
b. The capability for stressed analysis across an unlimited number of scenarios;
c. The capability to do this across CCPs to capture interconnected effects – in other words, the trigger points for contagion effects across CCPs;
d. The capability to extend the model to incorporate other risks inherent in the CCPs, including but not limited to concentration risk, liquidity risk and wrong-way risk.

Applying Agent-Based Modelling to the CCP Challenge

The complex and emergent behaviour of financial markets, especially under stress, has proven difficult to model with traditional mathematical approaches. Traditional models try to capture complex interactions of participants using formulaic approximations of aggregate behaviour, and thereby fail to capture many aspects of the dynamics and emergent behaviours of the markets. Instead, we recommend the use of ABM to realistically simulate the dynamic behaviour of individual participants, avoiding shortcuts, and generating a far richer understanding of possible outcomes.

How to model the real-world financial market?

Financial markets are highly complex systems; attempts to model them by combining equations of micro processes often fail to fully explain macro phenomena. The evolution of the state of the financial markets is not a simple aggregation of the separate actions of market participants, but rather a product of dynamic interactions among all participants in addition to individual actions. As these participants interact and learn over time, behaviours can be seen to emerge in markets.

Traditional mathematical models generally achieve asymptotic consistency and rationality through the repeated use of representative samples. Unfortunately, these models lack the capability to explain such interactions and the capability to model emergent properties of the financial markets, especially behaviours and properties that have not been previously observed.

The intricacies of the financial markets, especially under stressed scenarios and default events, cannot be modelled solely through mathematical derivations. We need to follow the path of each participant and process in the markets to see where it leads. This approach is the essence of agent-based modelling.

What is agent-based modelling?

ABM recreates a complex and adaptive world of heterogeneous agents. The current state behaviour of, and interactions between, these agents is explicitly modelled in the program and can change with time and experience. We allow interactions between these agents, and between the agents and the environment, over time to accumulate to form the patterns observed in the real world.

These properties of ABM are of particular use when modelling stressed scenarios and/or default events. In a stressed environment, the financial markets frequently exhibit some or all of the following phenomena [4]:

- **Emergence:** when system-wide dynamics arise unexpectedly out of the activities of individuals in a way that is not an aggregation of that behaviour.
- **Non-ergodicity**: the environment and participants' behaviour change with time, events and experience.
- **Uncertainty:** the financial markets are capable of producing almost unlimited types of behaviour and results never previously observed.
- **Irreducibility**: the financial markets cannot be reduced to mathematical models that fail to capture dynamic and emergent behaviour. The only way to see where things will go is to "live" through them.

Compared with traditional mathematical models, ABMs take a bottom-up approach to these features of financial markets, simulating individual behaviours and allowing agents to evolve and interact with other agents as well as the environment over time. In Table 1, we compare the ways in which ABM captures these phenomena to the approaches used by traditional equation based models.

Properties	Agent-based models	Traditional mathematical models
Emergence	Captured using the spatio-temporal interactions of heterogeneous agents	Modelled through optimisation
Non-ergodicity	Allow model to have constantly changing states through adaptive agents	Generally assumes an equilibrium state where the odds of things do not change
Uncertainty	Captured using static and dynamic rules	Modelled through representative figures
Irreducibility	Trace out behaviours of the real world through simulations	Modelled through deductive equations

Table 1 Comparison of ABM vs. Traditional mathematical models

Designing the ABM

We have developed an ABM model simulating the CCP risk management framework. The model captures the impacts of changes in CCP resilience, resolution, and recovery processes. The model provides the capability to save, observe, understand and analyse the effects of any potential changes.

Our ABM model simulates an artificial CCP environment in order to generate quantitative insights on the effects of potential changes to CCP policies and protocols, such as the recommendations provided in the "A Path Forward for CCP Resilience, Recovery and Resolution".

There is no one-size-fits-all solution in ABM model design. The key guiding principle of this model is simplicity, with the aim of maximising insight around the key drivers of CCP risks arising in stressed situations. The aim is not to create an exact replica of the real financial markets, but rather build a "fit-for-purpose" model tailored to the task of evaluating the recommendations for CCPs risk management. The focus of our effort is therefore on exploring the essential features and mechanisms of the real-world processes for our purposes of quantifying alternative policies for the CCPs.

In order to maximise flexibility, the model allows the majority of the parameters to be adjusted by the user for each run, enabling analysis and precise quantification of the impact of each and every proposed change. The model records all state changes for each agent and the environment at every time step, as well as associated behaviour and interaction changes for visualisation, analysis, and quantification. The approach ultimately provides the depth of insight required to inform decision making for all relevant parties.

Our ABM model simulates the financial markets in a CCP environment through agents (market participants and the exchanges), each with their own attributes. Each agents will also follow their rules to interact with each other and the environment. The network diagram of these agents are depicted below.

The focus of the model is closely tied to the joint publication of the 19 financial institutions, therefore it is useful to begin by summarising the recommendations proposed by that paper to provide context. The proposed changes can be grouped into the following five main ideas:

1. Product scope for clearing	reconsider the type of products in scope for clearing through CCPs
2. Margin requirements	introduce liquidity and concentration factors in margin calculations
3. Default management process	redesign the default management waterfall and sizing, including auction of the defaulted trades
4. Resolution planning	redesign recapitalization processes and policies
5. CCPs and CMs' capital structure requirements	reconsider capital size and structure requirements for both CCP and its members

Driven by these recommendations and ABM model design principles, our ABM model captures three major processes at the CCPs:

1. **Financial market simulation**: simulates a market environment for different types of CMs and end-users, with evolving states in response to participants' idiosyncratic behaviours and interactions over time.

2. **Margin call framework**: calculates initial margin and variation margin requirements for CMs' portfolios and makes associated margin calls.

3. **Default management framework**: simulates the default management protocols triggered by a CM's default.

1. Financial Market Simulation

The market consists of one CCP and 60 CMs [2] that are represented as "agents" in the model. The clearing firms can buy or sell a number of more or less liquid futures contracts by sending one or more limit orders to the exchange. The model is executed in discrete steps, representing the passage of time. The step length can be adjusted as required (from nanoseconds needed by algorithmic trading to seconds for the purpose of this paper). Each CM can submit a quantified buy or sell order, or can choose not to submit any orders at any step of the simulation. The exchange receives orders from the CMs and matches them

2 As a reference, CME group has 68 CMs as of March 2020

based on a price/time priority algorithm. The exchange also maintains a limit order book containing unexpired partially filled or unfilled orders.

The limit orders sent by the CMs exhibit the following behaviours:

- **Fundamental strategy:** derives a limit price based on deviations from its own model's fundamental price of the traded instrument and the current traded price. The fundamental price also incorporates a jump component representing external market shocks.
- **Momentum strategy:** derives a limit price based on various formulae applied to previous traded prices and the current traded price.
- **Noise:** derives a limit price based on a random walk.

Compared to the fundamental changes in the microstructure of financial markets, the core behavioural features of market participants have not historically changed significantly [5]. Therefore, the design of our model closely follows known "stylised facts" about the markets, inferring the model parameters and setup from empirical studies and historical market data. Consequently, the evolution of traded asset prices is modelled by the supply and demand from CMs. Consistently observed characteristics of the financial markets, such as the fat-tail distribution of returns and volatility clustering, are incorporated into the trading behaviours of the CMs. Model parameter values are calibrated to historical market data for respective futures products.

At the end of each time-step, trades between members and the exchange are cleared and settled. The trade details are recorded and sent to the CMs.

2. Margin call framework

Most products that are centrally cleared trade on margin. For each settled trade, the exchange calculates the initial margin (IM) based on the trade portfolio and its risk position. The trade process is considered complete once the required IM amount is transferred between the specified accounts.

At a specified resettlement frequency (model default is at each time-step), the exchange calculates a variation margin by marking each CM) portfolio and collateral to the market. The exchange will make a margin call when the margin account of the CM falls below the margin account requirements. The CM will then answer the margin call of the exchange by transferring funds into or out of the accounts.

If at the end of any time-step, the CM cannot answer a margin call, i.e. does not have sufficient funds to cover the variation margin requirements, then the CM is considered in default and the default management process is automatically triggered.

3. Default management framework

At each time-step, the exchange calculates the default fund requirements by applying an extreme but plausible (and easily parameterisable) shock to the current portfolio. The default fund is calculated based on a cover "x" model, where the default fund size is calculated as the sum of simultaneous defaults of the largest "x" CMs ranked by portfolio loss. Each CM contributes to the default fund in proportion to its own portfolio and risk position. Note that the exchange will also contribute "y" % of the default fund requirements.

When one or more CM defaults, the default-handling process at the exchange is automatically triggered. The exchange first tries to close the position and calculate the total default loss. The margin account and default fund contribution of the defaulting member(s) are taken first and absorb some portion of the default losses. The exchange then mutualises the remaining loss to the non-defaulted CMs in proportion to their default fund contribution.

Together, the market simulation, margin call, and default management processes will synchronously lead to changes in the states of the CMs and the environment. The CMs and the exchange will then make their own decisions and actions under the different circumstances. By simulating paths of these agents over time, the model captures emergent and non-ergodic properties of the financial markets. This in turn allow us to store, observe, understand, and analyse the effects of any potential changes to these CCP processes.

Implementing the Model

Implementing an ABM model of CCP behaviour, a high-dimensional, bottom-up simulation approach, requires significant computation and memory resources. Partnering with leading technology firms – Simudyne and Cloudera – Deloitte has implemented a flexible and highly scalable end-to-end solution.

Why is ABM gaining traction now?

The last 5 years have witnessed a surge in interest in the use of ABMs to solve real-world problems, together with increased interest by leading universities and research groups around the world. The question is – what is driving this interest? Why ABM and why now?

A key attraction of ABM is its bottom-up approach to simulation. However, such high-dimensional (many agents, many time-steps, many features, complex dynamics) modelling requires significant resources, in terms of CPU/GPU cycles, storage and network bandwidth. The goal is to simulate aggregate behaviour by building a state-space representation of the dynamics and interactions of individuals in real-world environments, and this requires large-scale complex simulations to evaluate behaviour and hence generate valuable insight. Recording data on agent-level and aggregate outcomes at each step of the simulation is also essential to facilitate analysis and quantification of these behaviours. It is only recent improvements in technology in each of compute, storage and networking that these capabilities have become more widely available and cost-effective through platforms like Simudyne and the Cloudera Data Platform (CDP).

The technology enablers of the model

The model is built on the Simudyne platform and runs on Cloudera's CDP. The Simudyne platform provides an easy to use, highly customizable SDK, together with libraries of support functions specifically optimised for ABMs. Architecturally, the Simudyne SDK uses Apache Spark to distribute ABM simulations by performing calculations in parallel across large number of processor nodes. It also has a user-friendly front-end console built into the SDK, which greatly simplifies data and process visualisation. The CDP provides a multi-cloud, hybrid platform delivering maximum flexibility, efficiency and computational performance across any environment - on premise, public or private clouds. Taken together, the combined technologies of Simudyne and Cloudera provide a highly scalable, cloud-enabled simulation environment, enabling seamless scaling to millions of simulations, as well as large storage capability required for making decisions based on deeper insights into the dynamics of the underlying behavioural relationships.

Conclusion

Banks must be able to effectively analyse and understand their bilateral relationships with CCPs. The COVID-19 crisis illustrates the imperative of doing this properly now so that they can be well prepared for the recovery and the next market shock. CCPs and policy makers also need to understand the system-wide dynamics resulting from the unique positions of market participants and their interactions, before proposing and implementing changes.

By using a simulated environment based on ABMs that can both realistically and easily represent the real-world, banks and other market participants can better discuss and test potential policies, processes and strategy changes. Decisions will therefore be based on a greater depth of insight into a wider representation of system dynamics. This is because ABMs more accurately model the emergent (and irrational) behaviour found in the real world.

Working together, Deloitte, Simudyne and Cloudera have developed a CCP/CM modelling approach that combines modelling expertise, a state-of-the-art software platform and cloud scalability. Banks, CCPs, regulators and policymakers can use it to quickly evaluate the implications of the dynamics of complex market environments and situations.

Please contact us today to arrange a demonstration and to learn how to be better prepared and positioned for future changes.

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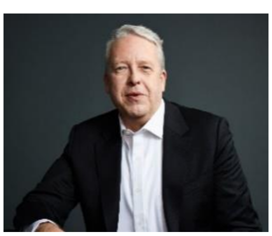

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