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Market liquidity, closeout procedures and initial margin for CCPs

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Abstract

Closeout procedures enable central counterparties (CCPs) to respond to events that challenge the continuity of their normal operations, most frequently triggered by the default of one or more clearing members. The procedures ensure the regularity of the settlement process through the prudent and orderly closeout of the defaulter's portfolio. Traditional approaches to CCPs' margin requirements typically assume a simple closeout profile, and do not account for the '*real-life*' constraints embedded on the management of a default. The paper proposes an approach of evaluating how distinct closeout strategies may expose a CCP to different sets of risk and costs, and consequently could impact the sufficiency of financial resources to cover its risk exposure to a default. The approach is based on a counterfactual simulation, and evaluates a full spectrum of hedging strategies in an exploratory and *model-free* manner, deriving *endogenous* and market-dependent risk metrics. Using the trade repository data available to the Bank (as a result of EMIR reporting) on over-the-counter (OTC) interest rate swaps (IRS) and ten years (ie 2005 to 2015) of information on related market risk factors, the paper derives empirically an efficient hedging strategy that minimizes the CCP's risk exposure to a defaulting clearing member. Endogenous trade-off structures between total risk (market risk plus funding needs) and transaction costs are also established, with marginal sensitivities to individual components of the hedging strategy determined.

Key words: CCPs, market liquidity, closeout procedures, initial margin.

JEL classification: C61, G20, G28, G32.

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I - INTRODUCTION

One of the main objectives of central counterparty risk management is to ensure the CCP's ability to meet its financial obligations in a timely and orderly fashion even when one or more participants default simultaneously. As emphasized in CPSS/IOSCO (2012), rules and procedures to manage a participant's default must not only protect the CCP, but also avoid market disruptions that eventually could propagate to the real economy.[1] The rules and procedures must include provisions for managing and closing out the defaulters' positions in a prudent and orderly manner, enhancing the resilience of CCPs and reducing systemic risk. Financial resources available for managing such defaults, collected in the form of collateral requirements (e.g. margin requirements), must be defined accordingly, supporting well-organized closeout processes until exposures have been properly wound down.

CCP margin models typically reflect the worst possible losses of a portfolio between two points in time (e.g. EMIR specifies 2-days and 5-days time horizons for exchange-traded and OTC instruments respectively), implicitly assuming a static closeout strategy, executed at a defined point of time.[2] In reality however, the margin model should recognize the dynamics of the closeout process, where a set of actions is carried out in a time continuum (i.e. several points in time) subject to a number of real-life market constraints. As argued by Vicente *et al.* (2015), these constraints may relate to settlement procedures of each individual contract, trading costs associated with the market architecture in which closeout occurs, and funding needs arising from the liquidation process. Similarly, EMIR states that a "*CCP shall adopt models and parameters in setting its margin requirements that capture risk characteristics of the product cleared and take into account the interval between margin collections, market liquidity and possibility of changes over the duration of the transaction*" (EMIR, 2012, article 41).

However, modelling risks and costs associated with closeout mechanisms, and more broadly default management procedures (DMP), poses a number of challenges. First, there is a complex set of interactions between the execution of closeout procedures and market behaviour at the time of default. Potential losses may arise exogenously and endogenously to the CCP's actions. Credit exposure and liquidity risk from the defaulter's portfolio may build up as market prices vary while the CCP organizes itself to start the default management procedures.[3] Equally, the default declaration and follow-up actions by the CCP endogenize how losses accumulate from that point onwards, with distinct implementations of the closeout strategies exposing the CCP to different sets of risk and liquidation costs.[4] Further difficulties emerge from the diverse organization, function and design of CCPs, commonly with niche-specific clearing markets and different business models.

[1] Differently from other financial institutions, where one of the main sources of contagion derives from deleveraging, for CCPs it is their ability to properly function in the case risks materialize that avoids propagation of shocks to financial intermediation and economic growth.

[2] Regulation (EU) N^{o} 648/2012 of the European Parliament and Council, 4 July 2012, on OTC derivatives, central counterparties and trade repositories. Commonly known as European Market Infrastructure Regulation, EMIR.

[3] Some time may have elapsed between the payment failure and the identification of a default, given that the CCP needs to differentiate temporary operational failures from permanent insolvency of participants. See Annex I for details.

[4] Additional financial pressures and volatility may derive from the default signalling to the market and the representativeness of the defaulter, potentially impacting liquidity and market concentration.

Consequently, there is no unique risk modelling framework and default management procedures that apply uniformly to all CCPs.[5]

The objective of the paper is to assess how distinct configurations of default management procedures may expose a CCP to different sets of potential losses. The focus is on the impact of the hedging design into the risk metrics to be collateralized, identifying sensitivities to components of the strategy determination, and the existence of an efficient hedging configuration that minimizes market risk, funding needs, and transactional costs associated with the closeout of defaulter's portfolio. From a regulatory perspective, the paper seeks to contribute towards the enhancement of CCPs' resilience. In particular, the paper's proposals could: (i) assist CCPs to design hedging procedures, evaluating a full spectrum of possible outcomes arising from the implementation of DMP[6]; (ii) serve as a complementary tool to test the sufficiency of the resources to manage a default, introducing more realistic assumptions when calculating potential losses from hedging procedures, and; (iii) support CCPs in enhancing their risk management frameworks, proposing a segregation of market risk from funding needs derived from the closeout of the defaulter's portfolio.

As an experimental case for the methodological approach and data used, the present assessment focuses on the Interest Rate Swap (IRS) OTC market, benefiting from the rich and highly granular derivatives trade repository data available to the Bank as a result of EMIR reporting. Moreover, the paper examines hedging strategies and transaction costs on OTC markets, a relatively more scarce literature when compared with exchanged traded derivatives (ETD) and products such as equities and futures contracts. Using a non-parametric historical simulation for 10 years of data (i.e. 2005 to 2015), the paper derives empirically an endogenous trade-off structure between the CCP's risk exposure to a specific clearing member (market risk plus funding needs) and the transaction costs incurred when hedging its portfolio. A hedging strategy formed by a limited number of instruments is found to minimise the total risk, suggesting that a macro-hedge might be an efficient option for the considered portfolio when transaction costs are taken into account. Similarly, marginal sensitivities to hedging components (i.e. the number of contracts used and the timing of the trades) demonstrate the costs of departing from this efficient hedging configuration. When performing the above calculations, profit and losses (PnL) are assessed using full-revaluation and decreasing time to maturity during the DMP, while hedge ratios are estimated directly from past observed transactions.[7]

The remainder of the paper is organized as follows. Section II briefly discusses the CCPs' risk models and their relationship with of default management procedures. Section III presents the paper's approach to evaluating hedging strategies. Section IV displays the empirical results for an experimental case, and Final Remarks concludes the paper.

[5] Regulation, EMIR (2012) and CPSS/IOSCO (2012), recognizes the current structure of the market and accounts for the interaction sensibly, observing its existence without prescribing how CCPs should transpose default procedures into margin charges.

[6] Commonly closeout procedures, and more broadly DMP, are assessed via fire-drills. Although a valuable tool to test processes and evaluate closeout costs, the exercise renders only singular point estimation.

[7] The adjustment is identical to including the roll-yield when trading futures contracts, see Alexander *et al.* (2013) for more details.

II – STANDARD RISK MODELS AND DEFAULT MANAGEMENT PROCEDURES

A large portion of current CCPs' risk models defines margin metrics using fundamentals of a value at risk approach, *VaR*.[8] One of its most appealing attributes is the ability to express the aggregate market risk of a given portfolio with just a single number that represents the potential financial loss for a given confidence level. This single risk metric can be easily translated into a margin requirement. Despite differences in the way future states of the world are represented and risk calculated, the equivalence of *VaR* type metrics and margin requirements have become common practice among CCPs. The metric represents a loss in market value relative to the whole portfolio at some pre-defined moment in the future (i.e. a fixed holding period). It depicts the same portfolio at two different moments (today and future) and then calculates the difference in terms of market value. Transposed to the CCP world, the difference aims to measure the potential loss incurred from the last time the portfolio was marked-to-market until all positions are closed out.

The standard value at risk models rest on the assumption that all defaulter's positions would be closed out at a single point in time, and in the same static market scenario.[9] Typically, these models assume that a portfolio settles at mid-prices (e.g. end-of-day prices), with the underlying premise that markets are able to absorb unlimited volumes, without extra charges as size of trades grows. CCPs have prudently recognized the limitations of this set of assumptions and have enhanced existing models to account for uncovered risks. Bid-ask spread charges were introduced to cope with the market liquidity risk.[10] Similarly, concentration thresholds were established, with additional margin calls to portfolios exceeding pre-defined limits.[11] Existing holding periods were increasingly checked against the size of the portfolios and market turnover measurements.[12] Whenever appropriate, risks associated with wrong-way risk, jump-to-default, etc. were modelled and incorporated into the risk framework.

Amending traditional risk models to encompass an augmenting number of identified risk sources did not come without challenges. The new features were commonly developed exogenously to the core model, in the form of risk add-ons.[13] As such, these modelling frameworks achieved new levels of complexity, with increasing number of inputs (e.g. stress scenarios, market prices, parameters, and so on) and components (e.g. liquidity add-on, concentration add-on, and so on) to be simultaneously managed. In configuring these "piecewise risk models", extra care had to be devoted to guarantee that components were coherently introduced into the structure. Otherwise, undesirable consequences such as discontinuity of the risk metrics, misspecification of the

[8] The value at risk approach, *VaR*, was introduced in the early 1990s by J.P. Morgan with the publication of the RiskMetrics technical document. An overview of *VaR* can be found in Duffie and Pan (1997), and classical references in Jorion (2003, 2007).

[9] In a relevant fraction of cases the market risk of collateral is assessed externally to margin models, in a non-aggregated basis. In this sense, closeout assumptions governing positions and collateral may be distinct, adding another layer of complexity.

[10] See Bangia *et al.* (2002), Angelidis and Benos (2006), and references therein, for methods to incorporate liquidity risk into standard *VaR* models.

[11] Concentration and market liquidity are interconnected types of risk, and to some extent regarded as two different instances of the same phenomenon. In this sense, unique charges accounting for these risks may be found in the industry.

[12] In some circumstances CCPs rely on minimum standards established by regulation (e.g. EMIR defines 2 days holding period for exchange traded derivatives and 5 days for over-the-counter).

[13] Risk model add-ons are usually characterised by one or a combination of the following attributes: i) *scope* – designed to mitigate sources of risk other than market risk (e.g. concentration, liquidity, wrong-way risk, etc.); ii) *independency* – independent from other parts of the model in terms of methodology and calculus processing; iii) *additivity* – generate additive risk figures, which are aggregated across different component charges to form a final margin call; iv) *consistency* – do not have market inputs (e.g. asset prices, yield curves, etc.) consistent with other parts of the model.

compounded effects, and biased measurements would emerge. The predictability of untreated biases may not be easily determined, depending on the portfolio under consideration and the point at which the risk function is assessed (e.g. size and direction of the stress shocks).

However, one of the largest issues over these emerging frameworks rests on the narrow relationship between the mechanics of the adjusted risk models and the actual procedures to manage a default. DMP should ensure the regularity of the settlement process, mitigating losses to the CCP itself, to the other non-defaulting clearing members and to the market as a whole. Collateral collected by the CCP, largely in the form of margin calls (variation and initial margin), should be sufficient to support these procedures, paying for the hedging trades and costs associated with the liquidation (e.g. auction) of the defaulter's portfolio. If the CCP is unable to meet its financial obligations in a timely and orderly fashion, recovery and resolution measures may be triggered. Therefore, CCP risk models should have the ability to operate under equivalent mechanisms of those expected for the closeout procedures, sharing premises that would render compatible model forecasts and CCP's actions during the DMP. In particular, risk model assumptions should be evaluated against the CCP's capacity of reliably executing them during default management procedures.

III - CLOSEOUT PROCEDURES: HEDGING DESIGN

Closeout procedures perform an essential role in the sustainability of CCPs, emerging as the principal DMP action to resume normal operations after the default of one or more clearing members. Distinct closeout strategies expose the CCP to different sets of risks and costs, with the main ones being market risk, funding needs (liquidation risk) and transaction costs (market liquidity costs). The configuration of the closeout components (i.e. splitting, hedging, and liquidation) defines the trade-offs across these risks, and CCPs typically use the closeout procedures to adjust the level of exposure to them. For the purposes of the present analysis, special attention is devoted to the hedging process, although splitting and liquidation also influence the outcome of the default management.[14] Hedging can be broadly defined as the trading process that the CCP uses to neutralize its risk exposure to the defaulters' portfolio.[15] In particular, hedging alleviates cash-flow pressures arising from variation margin and/or settlement obligations, while reducing net exposures (consequently, the expected value of the portfolio and its volatility) and assuaging bid-ask spreads at the liquidation stage.[16]

The impact of hedging strategies, and more broadly DMP, on risks and transaction costs is commonly assessed via fire-drill exercises running either on a regular basis (i.e. yearly or semi-annually), or when a new product/significant model change is introduced to the service. The relevance of such exercises is extensive, ranging from operational testing of systems to risk assessment of the resilience of the CCP. Nonetheless, besides being costly, the tests usually render only one point estimation, and little information is obtained on sensitivities to hedging components. Therefore, the proposal is to evaluate a full spectrum of possible outcomes for different hedging

[14] In particular, different splitting configurations constrain the set of potential trading strategies to be pursued during the hedging phase. Likewise, liquidation performance determines the necessity of further recovery interventions.
[15] In contrast to splitting and liquidation, the efficiency of the hedging process can be more easily assessed measuring its impact over market risk, funding needs, and transaction costs.
[16] There are a number of other legal and operational aspects associated with the hedging process that are not discussed in the paper but that have an important role when designing the strategies. Access https://jenner.com/lehman, volume 5, page 1871 onwards, for an example of those regarding the Lehman Brothers Holding Inc. case.

strategies, and to assess how individual components of the hedge may affect potential losses during the DMP. The results could be used to calibrate existing risk metrics, and the amount of resources necessary to manage a default. Current back-tests of risk models focus primarily on market risk, with simple closeout assumptions to calculate realized losses (see Section II). The proposed framework aims to offer a mechanism to measure "hidden" risks that would arise if the CCP is not able to close out the portfolio under the unique static scenario considered in these exercises.[17]

Hedging Strategy

In order to formally characterize the hedging process, assume the original defaulter's portfolio given by $\mathbf{Q}_0 = [Q_1 \ Q_2 \dots Q_I]$, in which Q_i represents the quantity of the i-th instrument.[18] Define $\mathbf{Q} = \left[Q_{1,1} \ Q_{1,2} \ \dots \ Q_{N,H-1} \ Q_{N,H}\right]$ the portfolio composed of the hedging trades, in which $Q_{n,h}$ expresses the quantity of the hedge executed with the n-th instrument at the h-th period of the closeout horizon.[19] In the present analysis, the hedging strategy $\mathbf{Q}$ is defined under three dimensions, the set of different instruments to trade, the timing of the trades, and the quantity used in each trade. Specifically,

- *Set of instruments* ($\mathbf{N}$). Hedging strategies can be designed in a highly specialized fashion (perfect hedge) in which each instrument of the portfolio is hedged with the exact opposite trade. In this case, the number of trades to be accomplished depends on the number of distinct instruments in the portfolio. Alternatively, hedging could be performed on the portfolio as a whole, following a macro-hedge strategy based on a small number of instruments;
- *Timing of the trades* ($\mathbf{T}$). A hedging strategy also depends on the moment when trades are executed on the market. If the time to absorb a price dislocation generated by a trade is high, one strategy would be to spread trades as far as possible. Alternatively, one could simply place trades all together, with minimum time intervals between operations;[20]
- *Quantity of the trades* ($\mathbf{Q}$). Additionally to the definition of instruments to be traded, the amount of each operation also needs to be specified. Trades could be done at the average trading quantities for each instrument. Alternatively, the entire outstanding notional of a contract could be hedged in one single operation.

Although presented sequentially, these dimensions are commonly defined conjointly. Therefore, a hedging strategy should be interpreted as a dynamic process, executed discretely in a continuous time horizon.

[17] After the 2009 crisis much has been written about model risk, see Danielsson *et al.* (2014) and references therein. However, equally important are the empirical metrics against which these models assessed, and how well they express reality.

[18] For more standardized contracts (e.g. ETD), Q represents the number of contracts, while for OTC trades it expresses the notional amount.

[19] N expresses the total number of trades on hedging process, defined within the set of available instruments $\mathbf{N} = \{1,2,\dots,N\}$. H expresses the last period of the closeout horizon, defined by $\mathbf{H} = \{1,2,\dots,H\}$. If $Q_{n,h} = 0$, $n \in \mathbf{N}$ and $h \in \mathbf{H}$, it implies that n-th instrument is not used at the h-th period.

[20] The set $\mathbf{T}$ is defined as $\mathbf{T} = \{T+1,\dots,T+h,\dots,T+H\}$, and $T+0$ represents the point in time in which the portfolio is last marked-to-market before the default.

Hedging Metrics

Hedging strategies are assessed by measuring the impact on metrics relating to market risk, funding needs, and the total amount of transaction costs incurred when executing the hedging trades. Such metrics are based on the marked-to-market value (MtM) of the original defaulter's portfolio, as well as its expanded version after hedging trades have been introduced. The segregation of the market risk and funding needs is based on the work of Vicente *et al.* (2015), and an adapted version of the concepts of permanent loss (PL) and transient loss (TL). The permanent loss is defined as the portfolio's change in market value from the last mark-to-market assessment ($T+0$) and the final point in time of the closeout horizon ($T+H$). Specifically,

$$PL = min\left(\sum_{h=1}^{H} \Delta MtM_h, 0\right), \tag{1}$$

in which $\Delta MtM_h = \mathbf{Q}_0 \cdot (\mathbf{MtM}_h - \mathbf{MtM}_{h-1}) + \sum_{j=1}^{h} \mathbf{Q}_j \cdot (\mathbf{MtM}_h - \mathbf{MtM}_{h-1})$;[21] $\mathbf{Q}_h$ is the vector composed of the hedging quantities at the h-th period of the closeout horizon; and $\mathbf{MtM}_h$ represents the vector of unitary market values of the contracts at the h-th period. Similarly, the transient loss is defined as the worst accumulated loss exceeding PL incurred during the closeout horizon. Specifically,

$$TL = min(LN - PL, 0), \tag{2}$$

in which

$$LN = min\left(\Delta MtM_1, \sum_{h=1}^{2} \Delta MtM_h, \dots, \sum_{h=1}^{H} \Delta MtM_h, 0\right). \tag{3}$$

Although distinct, permanent and transient losses represent complementary concepts. As positions are hedged, exposure is modified, and consequently the risk profile of the portfolio changes dynamically. Excluding operational charges, daily modifications in the market value of contracts that pay variation margin represent financial obligations of members, generating potential liquidity needs for the CCP during the closeout period.[22] Transient loss focuses on these temporary obligations that must be fulfilled to ensure continuity of the CCP's activities. Additional liquidity pressures could arise from the closeout process itself, with the cost of hedging having to be paid for. However, these costs are excluded from the definition of liquidity need, being considered separately as a new concept (see below the definition of transaction costs).

The extension of permanent and transient loss into risk metrics (i.e., market risk and funding needs) is done by generalising the above definitions as functions of different market scenarios (i.e. price realisations). Under distinct representations of the potential future states of the world (e.g., historical simulation, parametric statistics, Monte Carlo, etc.) many realisations of the two loss metrics could be inferred. The market risk and funding needs metrics are respectively defined considering the minimum values of the permanent and transient loss under these distinct scenarios (other forms of summarization could have been selected, e.g. percentile, expected shortfall, etc.). In particular,

[21] The first term on the right hand-side of the equality represents the change in value of the original portfolio from $h-1$ to h, while the second expresses the equivalent change for the sum of all hedging trades accumulated until the h-th period.

[22] In some cases, the assessment of variation margin (VM) incorporates additional adjustments to the market value of the contracts such that VM is not simply the difference between the market value today and yesterday, $MtM_h - MtM_{h-1}$.

$$MR = -\min_{s \in \mathbf{S}} PL_s \text{ and } FN = -\min_{s \in \mathbf{S}} TL_s, \tag{4}$$

in which MR and FN are respectively the market risk and funding need of the portfolio; PL_s and TL_s are respectively permanent and transient loss assessed at the s-th scenario; and $\mathbf{S}$ represents the set of the CCP's margin scenarios. The sum of market risk and funding needs, assessed under a unique worst-case-scenario, represents the total risk of the portfolio, TR.

Hedging strategies can be an efficient mechanism to mitigate the above risks, nonetheless they may result in substantial transaction costs. Trading environments exert a relevant effect on these costs, impacting price formation and discovery process.[23] Trading in standardized contracts, quoted on exchanges, commonly benefit from a central limit order book, with negotiated prices and offers symmetrically disclosed to participants. Hedging in these environments tends to be less expensive, as market frictions are less severe. By contrast, contracts with bespoke clauses typically entail trading relationships that assume the form of dealer-to-dealer or dealer-to-customer bilateral arrangement.[24] Therefore, price formation depends on the network established among participants, with demand and supply not transparently available to the market (it needs to be induced from interactions with dealers). In addition to information asymmetry and inventory holding premium, search costs for investors and bargaining power for dealers are relevant aspects in the determination of OTC prices at decentralized markets.[25] These frictions can make the price formation opaque, creating extra costs on trading.

Excluding fees, taxes and other operational charges, transaction costs are typically measured as the market dislocation of a price from its "fundamental value" or market expected value. Similarly to the variation margin assessment at CCPs, the premise considered is that end-of-day (EOD) quotes represent market average expectations for the underlying risk factors (i.e., yield curves, spot rates, etc.). As trades move away from these average quotes, financial obligations arise in favour and against the counterparties.[26] Therefore, the transaction cost of a new hedging trade can be approximated by its EOD MtM, on the day of the trade, correcting for any up-front payment embedded into the contract that would render its value different from zero at inception.[27] Specifically,

$$TC = -min\left(\sum_{h=1}^{H} \mathbf{Q}_h \cdot \mathbf{1}_h \cdot (\mathbf{MtM}_h - \mathbf{PUF}_h)\, , 0\right), \tag{5}$$

in which TC is the total transaction cost for a specific hedging strategy; $\mathbf{PUF}_h$ is the vector of unitary payment up-fronts for the hedging trades at h-th period, positive if paid out and negative if received; and $\mathbf{1}_h$ is the diagonal matrix containing the indicator function $1_{\{h=h_n\}}$ that assumes value 1 when the h-th period is equal to the period in which the n-th hedge trade was first executed (i.e. at

[23] For the effects of transaction costs on prices and trading volumes see Constantinides (1986), Michaely and Vila (1996), Barclay *et al.* (1998), Vayanos (1998), Amihud *et al.* (2006), Corwin and Schultz (2012), among others.
[24] Further particularities are added when brokers/intermediaries have to be accessed first.
[25] See pioneering work of Garman (1976) as well as Amihud and Mendelson (1980) on inventories, and Duffie *et al*. (2005) as well as Feldhütter (2012) and references therein for search costs.
[26] Ideally, transaction costs should be measured continuously during the day to incorporate any dislocation on fundamental values. Empirically, these dislocations would impact the absolute magnitude of the costs, having to be exchanged between counterparties in a similar manner to the variation margin. Therefore, the proposed definition of transaction cost focuses on the total cost of the hedge, taking into account spreads and potential intraday dislocations.
[27] CCPs commonly consider transaction costs through market liquidity surveys, price-elasticity estimates, and limits to daily trading (e.g. 20% of weighted average trading volume).

inception), h_n. Under the assumptions considered, the higher these costs, the lower would be the value of the trade when marked-to-market at the average curves of the end-of-day.

Hedging Process

Hedging processes are usually designed and implemented by a default management group (DMG), comprised of experienced traders that determine suitable hedging transactions on the behalf of the CCP. The assembling of the group envisions aligning incentives among stakeholders, the CCP and clearing members. Nonetheless, the use of DMG is also an important way of circumventing market frictions. During the execution of the default procedures, each clearing member represented on the DMG may be allocated a fraction of the defaulter's portfolio. Using current expertise and networks from trading desks, dealers seek among their counterparties the best executing quotes to hedge outstanding positions. Search costs and bargaining powers tend to be mitigated, as these dealing networks are already established. Positive effects may also spill over, alleviating other frictions, as clearing members involved in the closeout process approach markets in an organized and decentralized way.

In order to emulate actions implemented by the DMG and to consider the effects of the closeout process, a counterfactual approach is proposed to measure the impact of different hedging strategies on a hypothetical defaulting portfolio.[28] Contractual characteristics of the hedging trades (e.g. fixed rate, coupon frequency, maturity, etc.) for the defaulter's portfolio are selected from actual cleared contracts of non-defaulting clearing members (i.e., the members that would participate on the DMG). Different configurations of a hedging strategy are assessed considering many possible combinations of $\mathbf{N}$, $\mathbf{T}$ and $\mathbf{Q}$. Specifically, these strategies are defined using the following rationale:

- the set of instruments, $\mathbf{N}$, is represented by the instruments within a maturity silo.[29] The hedging strategy starts considering the most liquid maturity silo, according to open-interest volumes, and all hedges are performed using trades within this silo, $\mathbf{N}=\{\mathbf{N_1}\}$. In a second iteration, the first and second most liquid maturity silos are used, $\mathbf{N}=\{\mathbf{N_1}, \mathbf{N_2}\}$. The number of silos increases progressively, until all silos become available for hedging, $\mathbf{N}=\{\mathbf{N_1}, \mathbf{N_2}, \dots, \mathbf{N}_{N_s}\}$;[30]
- the timing of the trades, $\mathbf{T}$, is expressed by the different days of the closeout horizon when the hedging process can be implemented. The algorithm starts allowing for hedging trades during all days of the closeout horizon, $\mathbf{T}=\{T+1, \dots, T+H\}$, reducing sequentially from $\mathbf{T}=\{T+2, \dots, T+H\}$ to $\mathbf{T}=\{T+H\}$;[31]
- the quantity of the trades, $\mathbf{Q}$, is characterized by the notional amount of each hedging contract. For each combination of $\mathbf{N}$ and $\mathbf{T}$ defined previously, the notional amounts of the hedging trades are determined endogenously by a neutralization algorithm that aims to

[28] As discussed on Section IV, different approaches could be used to select the clearing member to hypothetically default (e.g., initial margin, stress losses over initial margin, etc.). Similarly, more than one portfolio could be assessed, resembling a "cover N" approach currently used by CCPs.
[29] Maturity silo refers to a group of contracts formed of all trades with similar time to maturity at a particular reference date, represented by $\mathbf{N}_n$.
[30] When $N_s = 0$, no hedging is considered.
[31] Let T_1represent the first day when hedging process starts. Rebalancing the hedging strategy after T_1 is not considered at this initial static framework.

reduce the basis point value (DV01) of the portfolio using the contracts with the smallest transaction costs.[32]

When sampling the contractual characteristics for the hedging strategies some boundary conditions may apply. First, original trades between non-defaulting and defaulting clearing members could be discarded from the available set of hedging trades. Second, restrictions could be introduced to limit hedging to a fraction of what is observed in the market. If current volumes from the DMG members are not sufficient to provide a full hedge, then the defaulter's portfolio would remain partially unhedged. Finally, selected trades should be risk reducing, not increasing the net exposure of the defaulter's portfolio.

For different configurations of $\mathbf{N}$, $\mathbf{T}$ and $\mathbf{Q}$, measurements of market risk, funding needs, and transaction costs are calculated. C*eteris paribus* other factors, transaction costs are expected to increase with the number of maturity silos, along with the accuracy of the hedging process. Lengthier execution periods may expose the portfolio to more market risk, although they may reduce pressures over the price-resiliency.[33] The simulation approach allows explicit quantification of such effects under the set of assumptions previously defined. In addition to the measurement of individual sensitivities to $\mathbf{N}$, $\mathbf{T}$ and $\mathbf{Q}$, the approach also sheds light on the determination of an efficient hedging strategy. Ultimately, a particular set of $\mathbf{N}$, $\mathbf{T}$ and $\mathbf{Q}$ could be established to minimize the incurred risk and costs for the specific portfolio under consideration.

Specific operational features of CCPs and/or different hypotheses about market conditions could render distinct structures for the simulation approach. However, the basic objective of the approach is to replicate conditions that the actual trades faced on the market, and to a certain extent, to recreate the market structure based on a counterfactual design of the history. In this structure, market pressures that may alter the behaviour of transaction costs are endogenously incorporated into the exercise.[34] The approach also does not make use of more sophisticated statistical modelling assumptions, focusing only on the descriptive and exploratory performance of distinct hedging strategies. The counterfactual design is able to emulate as many different market conditions as necessary, replaying history or assessing forward-looking hypothetical scenarios. Therefore, not only sensitivities to distinct hedging strategies may be measured, but also how these sensitivities may vary under different market conditions.

IV – EMPIRICAL ANALYSIS

Data and Method

As an experimental case for the methodological approach adopted and data analysed, the present study focuses on the Interest Rate Swap OTC market. The data in use forms a unique and little explored set of OTC transactions for GBP denominated Plain Vanilla IRS, reported to Trade Repositories (TR) as part of the EMIR trade reporting requirement. Under EMIR, all derivatives transactions undertaken by EU counterparties since August 2012 (or open at that point) have to be reported by the following business day to a TR. The Bank has access to information on trades in

[32] See Annex II for details.
[33] The term price-resiliency is used loosely to refer to the speed with which prices recover from an uninformative shock. See Kyle (1985) for a precise definition of the concept and Almgren (2003) for a theoretical model of the impact of the speed of trading over liquidity risk and traded prices.
[34] See Feldhütter (2012) for a discussion on selling pressures and market frictions.

which at least one of the counterparties is a UK entity, which are cleared by a UK CCP, or which have a UK underlying. For the present study, all the outstanding trades from a subset of European TRs as of 15 January 2015, as well as those executed between 16 and 22 January 2015, are considered.[35] Data is provided on a trade-by-trade level, containing precise details about the contracts attributes (e.g. fixed rate, maturity, coupon frequency, etc.) and counterparty information (e.g. beneficiary, legal entity identifier, etc.).[36] The use of the data is subject to a process of data cleansing (e.g. duplicated fields, erroneous recording, etc.) and standardization (e.g. day-count convention, payment frequency, etc.), such that problematic reporting effects are minimized.

The market value of each IRS is assessed using a full-valuation method, calculating the net present value of its cash flows on a standard discounting approach. Unlike delta-gamma approximations, the full-valuation method accounts for additional costs caused by the decrease in time to maturities of each swap contract. Discounting factors are derived from a zero coupon rate curve, constructed from carefully selected financial instruments by LCH Ltd. Curves are available from January 2005 to January 2015, and displayed in Annex III. Floating rates are determined from zero coupon curves, consistent with the type of the floating rate index (e.g. Libor 6M, SONIA, etc.). Distinct day-count conventions (e.g. ACT/360, ACT/ACT, 30E/360, etc.) and payment frequencies (e.g. 3M, 6M, 1Y, 1T, etc.) for each one of the legs of the swap are also considered in the valuation process. These features provide a comprehensive framework for assessing the MtM of currently outstanding IRS contracts. Similarly, the DV01 is based on a full-valuation process, considering a shock on the discount and forward curves.

The evaluation of the hedging strategy impact on risks and transactions costs is performed in two exercises. First, in a descriptive manner, the analysis focuses statically on the dates between 15/01/2015 and 22/01/2015, after the Swiss National Bank unexpectedly changed its exchange rate policy in respect of the EURCHF rate (sub-section Static Hedging Effects). A particular clearing member is assumed to default at end of January 15 (the reference date), and closeout procedures are implemented from 16/01/2015 ($T+1$) to 22/01/2015 ($T+5$).[37] Trades cleared by the 5 largest CMs on the period, spread over 20 distinct maturity silos, are used as reference to design the hedging strategies. Different metrics for the defaulter's portfolio, hedged and unhedged, are assessed over this period (e.g. PnL, DV01, transient loss, and transaction costs), comparably measuring the marginal effects of the closeout strategies over them.

The second implementation is a forecasting exercise (sub-section Risk Metrics and Hedging Effects). The analysis is repeated using the changes on the interest rate curves observed during the period between 10/01/2005 and 15/01/2015 to simulated different market conditions for the closeout process. Similarly, transaction costs are derived from trades cleared by the 5 largest CMs on the period preceding the theoretical default (i.e., from 15/12/2014 to 15/01/2015), labelled as the hedging set of trades, and adjusted when assessed over the 10 years lookback period.[38] This

[35] All EU derivative market participants are subject to reporting obligations under EMIR, whether they enter into the derivatives with other EU or third-country counterparties. Data is submitted to a TR in the form of a state report, and participants should inform the entry, modification and the termination of all derivatives contracts (OTC and ETD).

[36] See available attributes and field descriptions in www.dtcc.com/~/media/Files/Downloads/Data-and-Repository-Services/GTR/GTR-Europe/Summary_ESMA_Technical_Standards.pdf

[37] The defaulter's portfolio is modified and scaled to avoid identification of the clearing member.

[38] Ideally the two time windows would be aligned, but current data availability limits the implementation. Therefore, transaction costs were estimated using the more recent data, and adjusted to account for different levels of the interest rates when considered over the longer lookback period.

historical simulation approach allows the point-dependent outcomes from the first exercise to be extrapolated, enabling results to be directly mapped into risk metrics (e.g. Historical *VaR*), or used to specifically test adequacy of risk figures derived from other methods of margin calculation. In addition, efficient configurations for hedging strategies are tested, and their marginal impact on risk metrics assessed.[39]

Market Environment

The market structure in which the hedging trades take place influences the sensitivities of the risk exposures to the closeout strategies. For cleared IRS GBP, evidence suggests a certain degree of concentration, which theoretically could render the default management more challenging. Using a snapshot of all outstanding positions for 15 January 2015, out of around 20 members with exposure, the first 5 largest CMs are responsible for approximately 70% of the contracts cleared through the leading CCP in the IRS GBP market. Contracts tend also to be more frequent in a few maturity silos, the most representative ones being 1Y, 2Y, 5Y and 10Y. Across these silos, the concentration pattern appears to be reasonably stable, but the relative relevance of a specific CM may change. Figure A.ii in the annex presents the outstanding inventory of contracts for clearing members and maturity silos.

The severity of transaction costs in the IRS market depends on the behaviour of fixed rate spreads around the future expected interest rates. Considering the cleared trades of the largest 5 CMs on the period between 15/12/2014 and 22/01/2015, evidence suggests that fixed rate spreads may be present in the market. Spreads seem to vary with the time to maturity of contracts, as well as with the member clearing the trade, as displayed in Figure A.iii in the annex. A closer analysis of the trades for the most liquid maturity silos (i.e., 1Y, 2Y, 5Y and 10Y) suggests that spreads tend to widen as time to maturity increases. Likewise, for particular maturity silos, the range of the fixed rate distribution also differs substantially for distinct clearing members. The relevance of the notional size of the trades on the fixed rates is presented on Figure A.iv. Although not possible to derive extensive conclusions, for particular CMs and silos it seems that spreads tend to increase with the size of the trade. Notably, for longer time to maturity silos, trades concentrate in smaller notional sizes, but dispersion across fixed rates appears to increase slightly.

Even though a good proxy for transaction costs, fixed rate spreads can vary according to different contract specifications (e.g. floating rate index, payment frequency, etc.). As proposed, assessing the MtM of the trade on the day it was registered, correcting for any up-front payment, may reveal some information on the severity of spreads incurred. In particular, Figure A.v. in the annex presents the distribution of the PUF-corrected MtM for one unit of traded notional, adjusting for the duration of each contract. Similar conclusions to the above assessment on fixed rate spreads emerge from the analysis of the adjusted MtM. The adjusted MtM tends to concentrate around zero, but dispersion appears to increase for some clearing members and specific maturity silos. Therefore, not only adjusted MtM may assist in controlling the effects of different contract specifications in the fixed rate spread, but also it could be a straightforward way to detect the existence of relevant transaction costs.

[39] Each hedging strategy $\mathbf{Q}$ is calculated using 15/01/2015 as a fixed reference date. The strategy is assessed over the 10 year lookback period, with overlapping 5 days horizon. This simulation approach can easily be extended for other types of scenarios, theoretically or hypothetically driven, but these are not accomplished on the present study.

Static Hedging Effects

The total EOD market value of the defaulter's portfolio on 15/01/2015 ($T+0$), the last marked-to-market date before the theoretical default, approximates £6.31 billion.[40] The majority of contracts and outstanding notional are concentrated on 5Y, 10Y, and 30Y maturity silo, in a largely "receive fixed rate" strategy (i.e. losing money if rates increase), as displayed in Figure A.vi on the annex. Without any hedging trades, by the end of $T+5$, the total market value of the defaulter's portfolio increases to £6.36 billion, with gains originating from interest rate fluctuations. Nonetheless, on $T+1$ the portfolio value falls to £6.29 billion, implying a transient loss of £21 million to be exchanged in the form of variation margin payments. Figure I and Figure II present further details on the portfolio's market value and cumulative PnL over the close-out period considered.

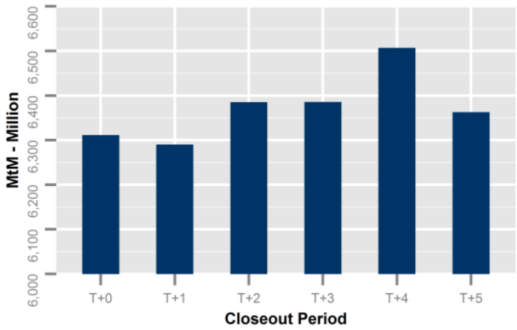

Figure I – Market Value of the outstanding portfolio for different periods of the closeout period; values expressed in GBP; portfolio reference date 15/01/2015 (T+0).

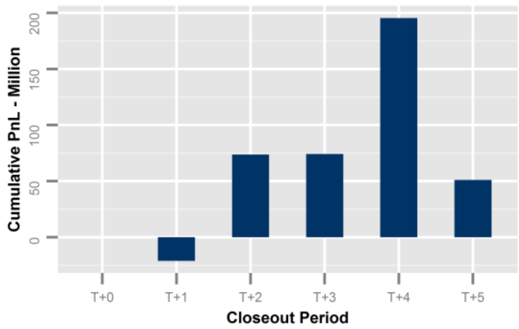

Figure II – Cumulative PnL for different periods of the closeout period; values expressed in GBP; portfolio reference date 15/01/2015 (T+0).

In order to assess the effects of the hedging process over the portfolio's level of risk exposure and transaction costs, the above described counterfactual approach is implemented. Specifically, trades cleared by the 5 largest CMs over the closeout horizon (i.e. $T+1$, …, $T+5$) are used as reference in terms of contractual clauses (e.g. expiry date, coupon frequencies, etc.) and market attributes (e.g. notional amount, bid-ask spread, etc.). For each day of the closeout horizon a different set of trades is sourced, without any overlapping and cumulative mechanism (i.e. clearing conditions are treated separately for each day, and unused volumes in a specific day do not accumulate to the next ones). In the event of a default on $T+0$, these trades should characterize the market environment to be faced during the implementation of the default management procedures and the hedging process (in the counterfactual absence of potential disturbing effects caused by the clearing member default, which could propagate to the rest of the market).

In particular for market risk, the impact of the hedging process is assessed considering its effect on the DV01 of the defaulter's portfolio. At $T+0$, the unhedged portfolio DV01 is close to -£40 million. As the number of maturity silos (N_s) considered in the hedging process increases, the DV01 reduces progressively. Not all DV01 can be neutralised, given the imposed restriction that total hedging amounts should not exceed cleared volumes from the largest 5 CMs on each day of the closeout horizon.[41] The marginal efficiency of incorporating more silos into the hedging process also

[40] As stated in footnote 37, results presented in this and the following sub-section should be interpreted illustratively, as the original portfolio was altered to avoid identification of the clearing member.

[41] As previously discussed, different conditions could be assumed for the market liquidity, rendering the exercise more or less stringent. Nonetheless, the implicit assumption considered here is that similar trading conditions of those observed for

decreases with the number of silos, starting with larger magnitudes (i.e. from no hedge to one maturity silo) but reducing to almost no change when less liquid silos are introduced. The initial DV01 for the unhedged portfolio does not change substantially when evaluated at different days of the closeout period (i.e. $T+1$, …, $T+5$), with the hedging process being able to neutralise only a fraction the market risk no matter the starting date (T_1). Nonetheless, as displayed in Figure III, the later the hedging process starts the less efficient it is, as fewer opportunities to hedge become available.[42] For instance, when $T_1 = T+1$, a broader range of hedging trades are available, and any unhedged fraction of the portfolio after this day can be neutralised in the remaining part of the closeout horizon.[43]

The execution of the hedging strategies does not come at zero cost. Specifically, the larger the number of maturity silos considered in the hedging process, the more precise the DV01 mitigation, but also the more expensive the strategy, as Figure IV suggests.[44] Importantly, the surge in costs arise not only from the fact that more trades are executed, but also from trading at less liquid instruments with a relatively wider bid-ask spreads. The pattern seems to be relatively stable regarding the starting date of the hedging process, as the largest fraction of transaction costs arise from the fixed charges. Nonetheless, total costs are lower for late starting hedging processes, due to the more limited number of hedging trades that can be executed.

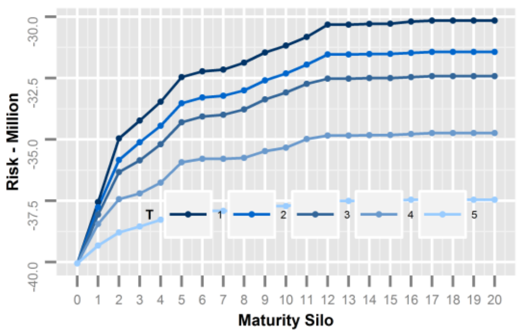

Figure III – DV01 for different configurations of the total number of maturity silos (0 to 20) and first date to start the hedging process (T+1 to T+5); values expressed in GBP; reference dates 15/01/2015 to 22/01/2015.

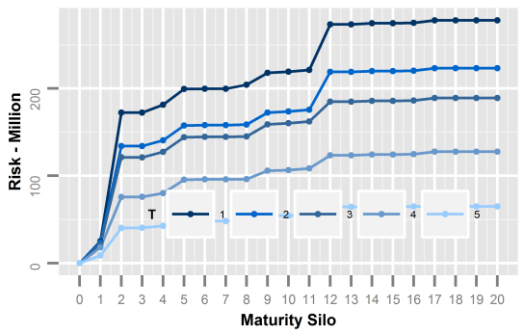

Figure IV – Transaction Costs for different configurations of the total number of maturity silos (0 to 20) and first date to start the hedging process (T+1 to T+5); values expressed in GBP; reference dates 15/01/2015 to 22/01/2015.

Risk Metrics and Hedging Effects

The descriptive evaluation of the marginal effects of hedging strategies for a single reference date as analysed in the previous subsection, although informative, exhibits limitations as a risk management tool. In order to expand the analysis, a historical simulation approach is used to assess how different

the largest 5 CMs could be obtained during the hedging process, as long as total amounts for the later are smaller or equal to the cleared ones.

[42] For a technical approach to assess hedging performance see Alexander *et al*. (2013), and references therein.

[43] The risk profile of the portfolio and actual changes on the interest rates from $T+1$ to $T+5$ imply that transient losses are sensitive to the time when the hedging process starts. As liquidity pressure builds only in $T+1$, following an upward dislocation on the interest rate curve on 16/01/2015 (i.e. level and curvature), any attempt to hedge after $T+2$ does not alleviate the need for cash. As previously described, liquidity needs are measured only as a function of variation margin and do not include transaction costs (e.g. bid-ask spreads) or operation charges (e.g. fees, taxes, etc.). Nonetheless, in reality these costs may further amplify the need for cash during the closeout process.

[44] See section III and footnote 26 for the precise characterization of transaction costs.

configurations of the closeout strategy may impact directly the relevant risk metrics. In particular, for each fixed combination of the number of maturity silos (N_s) and starting date to hedge (T_1), the market risk, the funding needs, and the total risk of the portfolio over the period analysed is determined. Performing the calculation for all possible combinations of hedging strategies creates a level-curve for N_s and T_1, in which the trade-offs and sensitivities over the risk metrics can be assessed. Most importantly, the exercise allows the determination of an efficient hedging strategy for the defaulter's portfolio, establishing a direct connection between the risk modelling framework and default management procedures. The relationship is explored in a multidimensional basis, such that a full spectrum of different DMP outcomes can be mapped into the analysed risk metrics. Therefore, the approach expands the view of a pure historical simulation, introducing a model-endogenous decomposition of the risk metric.

For a standard historical simulation approach with no hedging, the total risk of the defaulter's portfolio, accumulated from the moment it was last marked-to-market to the 5^{th} day of the closeout period, amounts to £1.5 billion. Theoretically, these potential losses would arise if the market movements after the 17/06/2013 were to be repeated following 15/01/2015. In particular, as a long fixed rate portfolio, the risk emerges mostly from the sequence of observed increases in the major currency interest rates following the unexpected surge in the Chinese interbank overnight lending rates after 19/06/2013, triggered by a change in the PBOC banking policy. The totality of the losses is derived from market risk, and no extra funding need characterizes the risk of the portfolio due to the pattern of the interest rate changes. Figure A.vii to Figure A.ix in the annex display the distribution of the profits and losses, the market risk and the funding needs (equation 4) over the period analysed for the unhedged portfolio, evidencing that a few historical events drive most of the risk on the simulation.

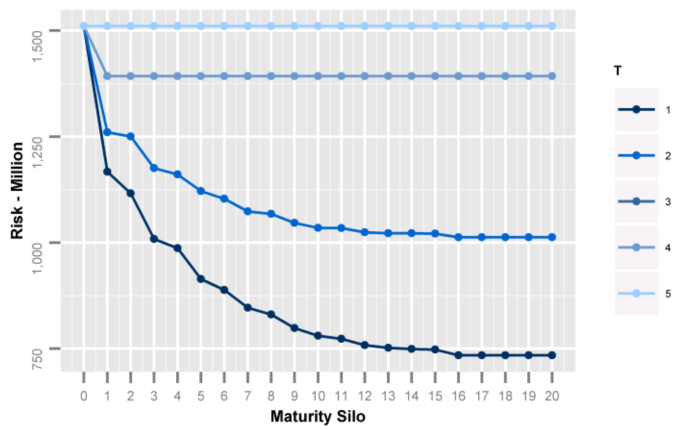

Figure V – Total Risk (Market Risk plus Funding Needs) for different configurations of the total number of maturity silos (0 to 20) and first date to start the hedging process (T+1 to T+5); values expressed in GBP.

The total risk of the defaulter's portfolio can be alleviated with the introduction of hedging trades, reducing the impact of the interest rate movements. In particular, the minimum total risk is reached when 16 maturity silos are used on the hedging strategy, and hedging starts at the first day of the closeout horizon (i.e. $N_s = 16$ and $T_1 = T + 1$). As a consequence of this hedging strategy, total risk is reduced from £1.5 billion to £734 million, as shown on Figure V. Any modification on the number of maturity silos, N_s, and closeout starting period, T_1, increases the amount of losses, with the above configuration displaying the most efficient hedging strategy for the simulation exercise. Specifically, the delay in starting the hedging process can have a relevant impact on the capability to mitigate losses, as highlighted on Figure V, given that funding needs incurred on the first days of the closeout period become the main source of risk. The relevance of hedging strategies can also be visualised assessing their impact on whole distribution of potential profits and losses of the portfolio for the period analysed. As presented on Figure A.x in the annex, the more tailored the hedging process the less dispersed the distribution is.

Ceteris paribus, the increase in the number of maturity silos used in the neutralisation process augments the efficiency of the hedging, but also elevates the amount paid in transaction costs.[45] In this sense, the risk reducing benefits of the efficient hedging strategy don't come at zero cost, and total transaction charges sum to £756 million at the efficient hedging strategy, $N_s = 16$ and $T_1 = T + 1$. Attempting to reduce the amount of these costs results in a deterioration of the hedging process, with losses increasing almost monotonically. Nonetheless, from a collateralization perspective, the relevant risk figure for the CCP combines potential losses arising from the total risk of the defaulter's portfolio and transaction costs incurred with the hedging strategy. Under the delineated simulation conditions, the CCP would be slightly better off when pursuing the efficient hedging strategy, reducing its potential loss from the original unhedged amount of £1.5 billion to £1.49 billion after hedging is introduced (£1.49 billion composed of £734 million from total risk and £756 million from transaction costs).[46]

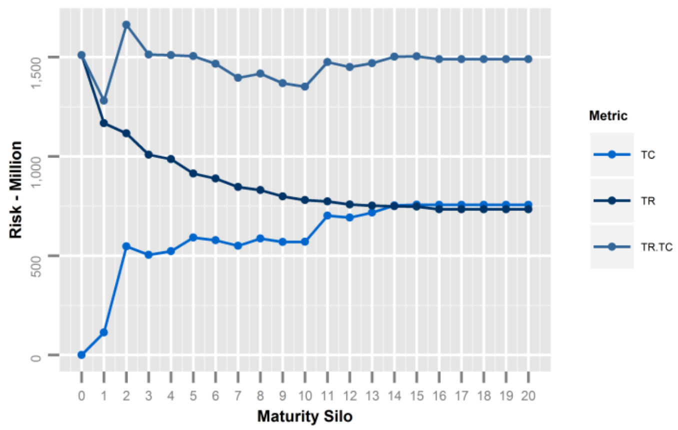

Figure VI – Total Risk (TR defined as the Market Risk plus Funding Needs), Transaction Costs (TC), and Total Risk plus Transaction Costs (TR.TC) for different configurations of the total number of maturity silos (0 to 20) and first date to start the hedging process equal to T+1; values expressed in GBP.

The consideration of transaction costs inserts an extra trade-off assessment for the design of closeout procedures. As display in Figure VI, the efficient hedging strategy changes when total risk and transaction costs are considered together, now defined by $N_s = 1$ and $T_1 = T + 1$. The final risk figure under the enhanced approach is £1.28 billion, and no other configuration for the hedging strategy would be able to render a lower value. Specifically, introducing the first maturity silo in the

[45] See section III and footnote 26 for the precise characterization of transaction costs.

[46] Transaction costs obtained according to the paper's proposed approach were compared with those estimated via market quoting under stress situations, and results were comparable.

hedging process costs the CCP £113 million in transaction charges, while the reduction in total risk, market risk and funding needs, approximates £343 million.[47] Up to this stage, the marginal cost of the hedging is offset by the reduction in the total risk figure, a feature that does not hold for other configurations of the strategy.

In a simplistic out-of-sample assessment, the above forecasting results could be used comparatively against the outcomes derived from the hedging process implementation for the period between 16/01/2015 and 22/01/2015. Under the strategy $N_s = 1$ and $T_1 = T + 1$, total losses (the sum of permanent loss, transient loss, and transaction costs) for the 5 days period amount to £46 million, while for the historical simulation the final risk figure is £1.28 billion. In addition, to evaluate the robustness of the approach, the historical simulation exercise is repeated for different portions of the 10y lookback period.[48] Overall, the pattern of results remain unchanged, supporting the proposition that the approach could assist CCPs in the calibration of their risk models, as well as to supplement fire-drills exercises in assessing existing default management procedures. Nonetheless, it is important to observe that the above conclusions may yet be sample-dependent (only tested for one type of derivative and a particular portfolio), and linked to a specific definition of transaction costs that could not be suitable for all derivatives.

FINAL REMARKS

Default management procedures allow CCPs to respond to events that challenge the continuity of their operations, most frequently triggered by the default of one or more clearing members. The procedures ensure the regularity of the settlement process through the prudent and orderly closeout of the defaulter's portfolio. Traditional approaches to CCPs' margin requirements typically assume a static closeout profile, and do not consider the "*real-life*" constraints embedded on the closeout process. Regulation contemplates the relevance of closeout procedures to prudential requirements, but also recognises that CCPs are diverse and may account for their interaction differently. In particular, no prescriptive regulatory standard defines how CCPs should map default procedures into risk metrics, and a principle-approach establishes that models, parameters, and assumptions should capture the risk characteristics of products cleared, not limited to market risk.

The paper proposes a simple approach of evaluating how distinct hedging strategies may expose a CCP to different sets of risk and costs, and consequently could impact the sufficiency of financial resources to cover its risk exposure to a default. The counterfactual simulation approach evaluates a full spectrum of possible outcomes arising from the hedging design in an exploratory and *model-free* manner, suitable for different representations of futures states of the world (i.e. historical data, Monte Carlo simulation, parametric distributions, etc.). Specifically, derived metrics are *endogenous* and dependent on specific *market architectures*, allowing CCPs to prudently consider market frictions that affect the outcome of the hedging process of the defaulter's portfolio. These characteristics suggest that the proposal:

- adheres to the current principle-based regulatory guidance, recognizing the diversification of CCPs, and that there are different ways to achieve the same outcome, in which some discretion/variation across firms is expected and desirable;

[47] See Figures A.xi to A.xiii for individual marginal effects of each hedging strategy component.
[48] See Figures A.xiv and Figure A.xv for the trade-off between risk and transaction costs for different compositions of a 5y lookback period.

- could assist CCPs to better design closeout procedures, evaluating a full spectrum of possible outcomes arising from the implementation of default management procedures;
- could function as a complementary tool to test the sufficiency of resources to manage a default, introducing more realistic assumptions when calculating potential losses from closeout procedures, and;
- could support CCPs in the enhancement of their risk management frameworks with the segregation of market risk from funding needs derived from the close out of the defaulter's portfolio.

However, the proposed framework should not be interpreted as an isolated risk methodology, but an approach to supplement existing margin models in CCPs. Especially important, the simulation approach focuses only on hedging strategies, and does not explore how other closeout elements (i.e. splitting and liquidation) could distort the results. In particular, to fully understand the benefits of the hedging process, the effects over the auction bids of the hedged portfolio should also be considered. Therefore, further work to expand the scope of the simulation process would enhance the applicability of the results. Likewise, the inclusion of other markets in a portfolio-based framework should make the exercise a better approximation of reality faced by CCPs when managing the default of a clearing member with a large and diversified portfolio.

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ANNEX I – DEFAULT MANAGEMENT PROCEDURES: GENERAL STAGES

Default Identification

A default normally constitutes a financial indebtedness of the clearing member not being paid to the clearing house when due, although distinctions are observed across CCPs. Nonetheless, CCPs must differentiate a defaulting behaviour from delayed payments originated from operational failures.[49] Further complexity is added when a missing payment does not originate from CM's house account. Consequently, the time elapsed between the identification and the last margin collection can be prolonged.[50] The identification of the default is commonly accompanied by a declaration statement made to CCPs' participants and regulatory authorities. Relevant stakeholders are engaged in the process (e.g. traders, dealers, liquidity providers, etc.). In addition, services provided to the defaulting clearing member are altered. Commonly new orders are blocked, while trading and registration are suspended. Settlement outflows are obstructed, and collateral management becomes restricted, with no withdrawals.

Portfolio Porting

The identification process allows CCPs to precisely determine the origins of clearing member failure, enabling them to segregate non-defaulting from defaulting accounts. For non-defaulting accounts, porting is a desirable outcome. The fundamental idea is to preserve the normality of the clearing process, reducing the total amount of interventions as far as possible. Differences exist across CCPs on the implementation of the porting process (i.e., chain of responsibility, type of clearing member affiliation to the CCP, type of account under consideration, etc.). Nonetheless, the procedures broadly encompass clients' approval, substitute clearing member acceptance, transference of positions, transference of settling obligations and collateral. Upon the conclusion of the process, operational activities from ported accounts migrate to the parenting clearing member and have to be fulfilled accordingly.

Closeout Procedures

Defaulting accounts need to be closed out by CCPs, including positions and collateral (if an account could not be ported, it will usually be closed out). The process commonly involves the conjoint phases of portfolio splitting, hedging and liquidation. The balance between these elements is a complex task that CCPs need to manage, and no prescribed order exists. The challenges increase considering the short period of time that risk managers have to design the closeout strategies. In particular, splitting is the process through which the original portfolio is segregated into smaller sets. The number of sub-portfolios can be defined exogenously or endogenously to the closeout process, in accordance with the DMP. Each contract attribute is a potential category for segregation, but most frequently settlement currency and underlying risk factor are used.

Hedging and liquidation are two more intricate concepts, and differentiating them may be misleading in some circumstances. Nonetheless, for the purposes of the analysis hedging is considered as the sequence of market operations to reduce *net* financial exposure (gross exposure

[49] The CCP is entitled full responsibility over the defaulting portfolio, and must cover all financial obligations arising from it (e.g. variation margin, coupon payments, corporate actions, and so on). Therefore, the swifter the CCP proceeds to characterize the default, the higher the chances to minimise potential losses.

[50] The relevant information is the point in time that resources last collected refer to, i.e. the reference date when the risk was last assessed regarding portfolio composition and market prices.

may rise). Commonly, these operations are executed through existing trading facilities. As a result of the hedging strategy, new positions may be added to the original portfolio.[51] Conversely, liquidation is the sequence of market operations to reduce *gross* financial exposure. Usually, these operations occur through special trading architectures not commonly available on BAU basis. No additional position is introduced into the portfolio, and at the end of the liquidation process, no positions are left at the defaulter's portfolio, as the ownership of contracts is transferred to new participants or extinguished. Typically liquidation assumes the form of an auction, but may be operationalized in more or less sophisticated arrangements.

Recovery Measures

Prudential requirements collected from the CCP's participants and from the CCP itself form the set of available resources to offset losses arising from the defaulter's portfolio financial obligations, as well as the closeout procedures. Nevertheless, if these funds are insufficient, the CCP may introduce additional measures to ensure the continuity of clearing services as expected. Such measures are generally labelled recovery procedures, and may involve extra funds called from non-defaulting clearing members (e.g. limited replenishment to default fund), resorting to the CCP's own capital, loss attribution (e.g. variation margin haircut) or portfolio allocation (e.g. contracts tear-up).[52]

[51] In an ETD market, where contracts are fungible, new trades will actually reduce the total outstanding open-interest positions.
[52] For details see CPMI/IOSCO (2014), FSB (2014) and ISDA (2015).

ANNEX II – NEUTRALISATION ALGORITHM

The neutralisation algorithm is defined as the process to determine the hedging trades for the defaulter's portfolio based on synthetically replicated market conditions existing at a particular point in time. In particular, given the hedging strategy arguments N_s (number of maturity silos) and T_1(starting date of the hedging), the neutralization process defines $\mathbf{Q}$ (instruments and volumes) using as contractual references (e.g., fixed rate, coupon frequency, etc.) the positions cleared during the assessment period by non-defaulting members. The algorithm is designed to reduce the DV01 of the defaulter's original portfolio, taking into account the transaction cost of each hedging trade.[53] The framework is modelled as a simple linear constrained optimization problem, for which standard algorithms can be implemented to derive solutions. Specifically,

$$\min_{\mathbf{q},q_{N+1},q_{N+2}} \mathbf{q}\cdot\mathbf{d} + q_{N+1}\phi_1 + q_{N+2}\phi_2$$

s.t.

$$\mathbf{q}\cdot\mathbf{d} + q_{N+1}\phi_1 + d_0 > 0,$$

$$\mathbf{q}\cdot\mathbf{d} + d_0 < 0,$$

$$0 \leq q_{n,h} \leq 1, \;\; q_{n,h} \in \mathbf{q},$$

$$\mathbf{q}\cdot\mathbf{m} + q_{N+2}\phi_2 > 0,$$

in which $\mathbf{q} = \left[q_{1,1} \;\; q_{1,2} \;\; \ldots \;\; q_{N,H-1} \;\;\; q_{N,H}\right]$, and $q_{n,h} = Q_{n,h}/Q_{n,h}^{\mathrm{mkt}}$ represents the relative quantity of the hedging trade $Q_{n,h}$, performed with the n-th instrument at the h-th period, when compared with the original quantity observed on the market, $Q_{n,h}^{\mathrm{mkt}}$; $\mathbf{d}$ represents the DV01 vector for the contracts on the hedging portfolio; q_{N+1} and q_{N+2} represent auxiliary variables with weights ϕ_1 and ϕ_2; d_0 represents the DV01 of the defaulter's original portfolio to be hedged; and $\mathbf{m}$ represents the vector of transaction costs for the contracts on the hedging portfolio. Other operational constraints are omitted as they are less relevant to the characterisation of the problem.

[53] For the characterisation of transaction costs and DV01 see section III and IV respectively.

ANNEX III – DATA ANALYSIS

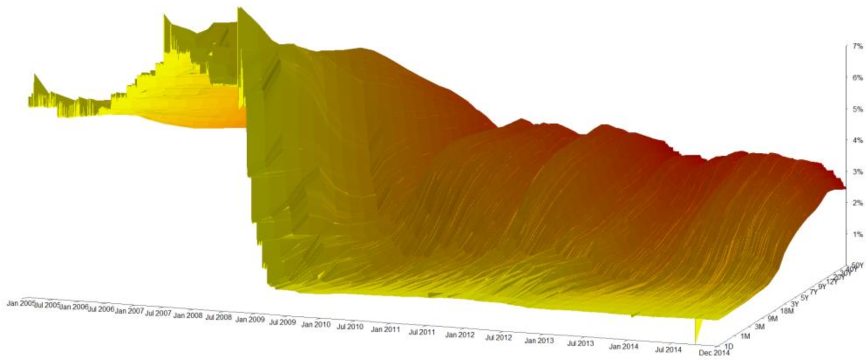

Figure A.i – Discounting Interest Rate Curves from 10/01/2005 to 22/01/2015. Axes X (horizontal) represents the date of the curve, axes Y (horizontal) represents the time to maturity, and axes Z (vertical) represents the value of the interest rate measured in annual terms.

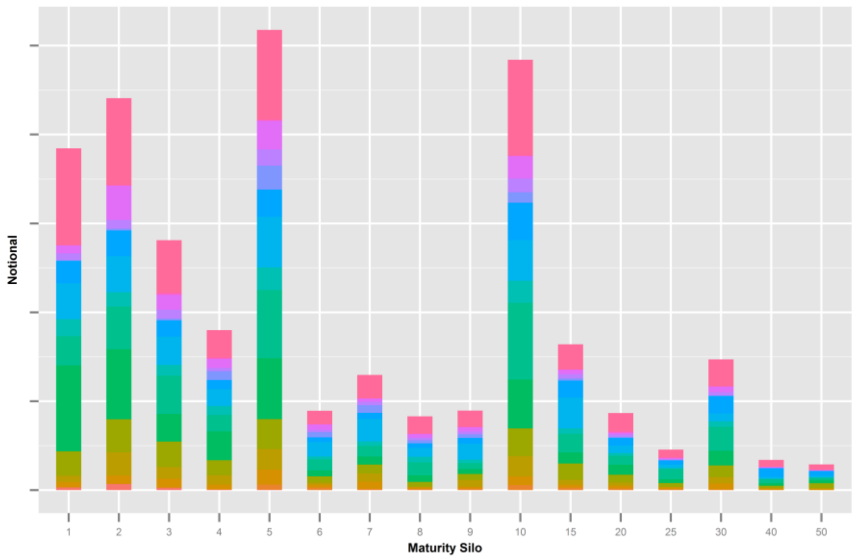

Figure A.ii – Total Notional Amount for GBP IRS across clearing members (colours) and time to maturity silos; distribution for contracts that receive Fixed Rate; vertical axis scale intentionally omitted; reference date 15/01/2015.

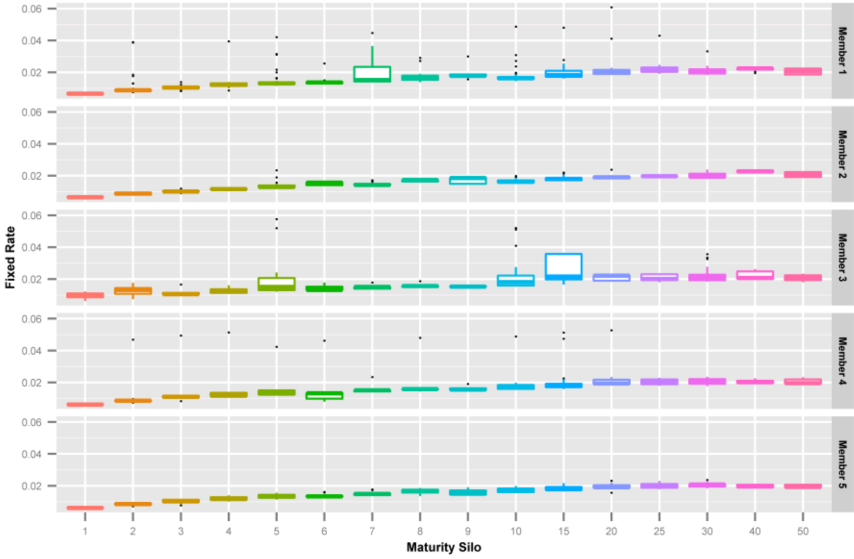

Figure A.iii – Boxplot for Fixed Rate across clearing members and time to maturity silos; trades sampled from the 5 largest clearing members and registered between 15/12/2014 and 22/01/2015.

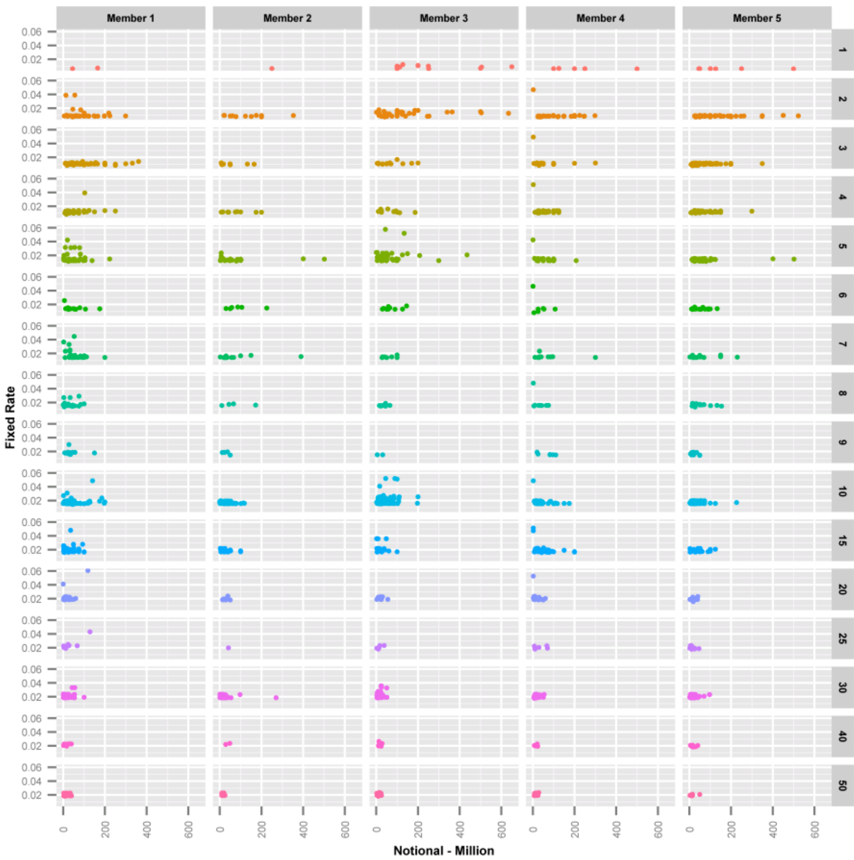

Figure A.iv – Dotplot for Fixed Rate and Notional Amount across clearing members and time to maturity silos; trades sampled from the 5 largest clearing members and registered between 15/12/2014 and 22/01/2015.

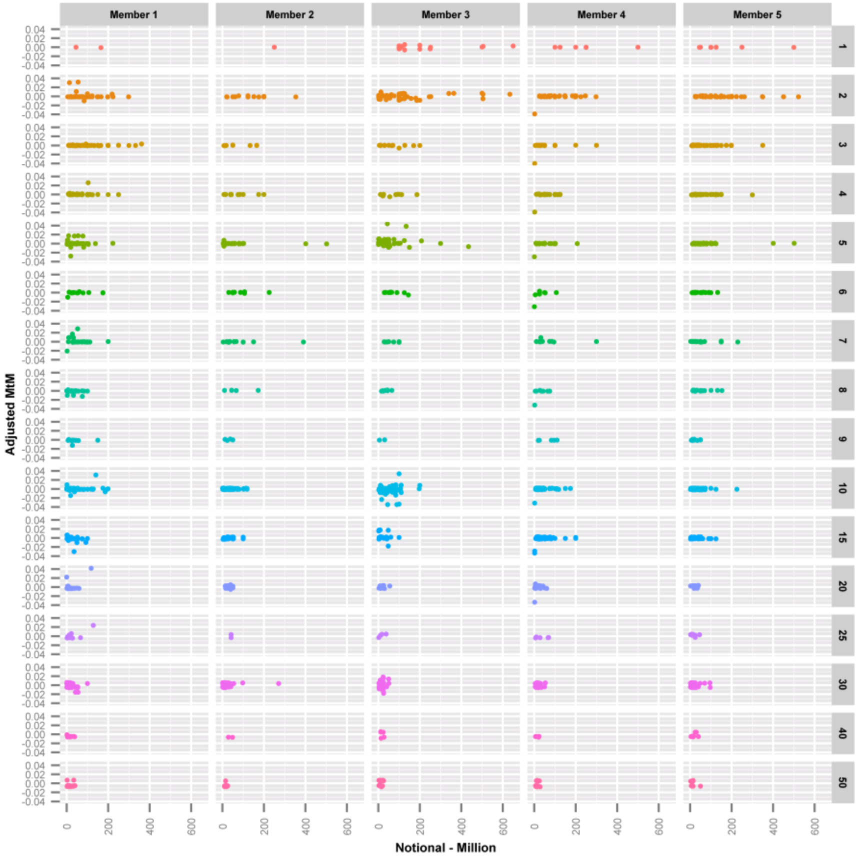

Figure A.v – Dotplot for Adjusted MtM across clearing members and time to maturity silos; trades sampled from the 5 largest clearing members and registered between 15/12/2014 and 22/01/2015; Adjusted MtM is defined as the MtM of the trade on the date it was registered divided by its notional and its time to maturity.

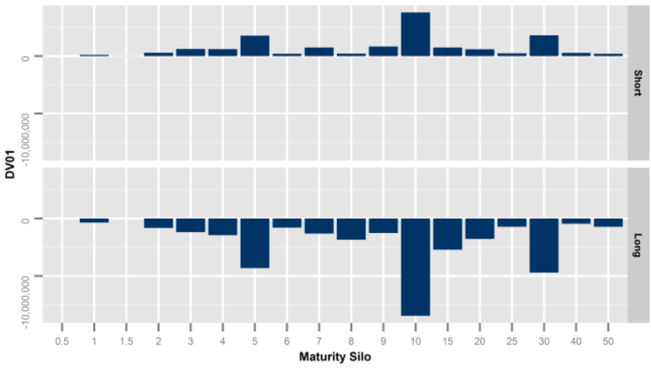

Figure A.vi – DV01 of the outstanding portfolio for different time to maturity silos; Long represents a contract that receives Fixed Rate and Short one that pays; values expressed in GBP; reference date 15/01/2015.

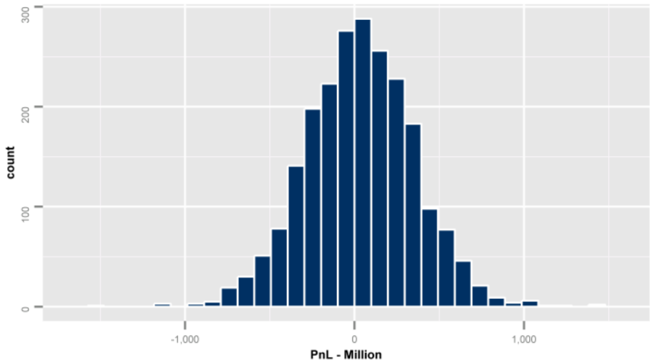

Figure A.vii – Profits and Losses (PnL) Histogram for the unhedged outstanding portfolio over the period 23/01/2006 and 22/01/2015; values expressed in GBP.

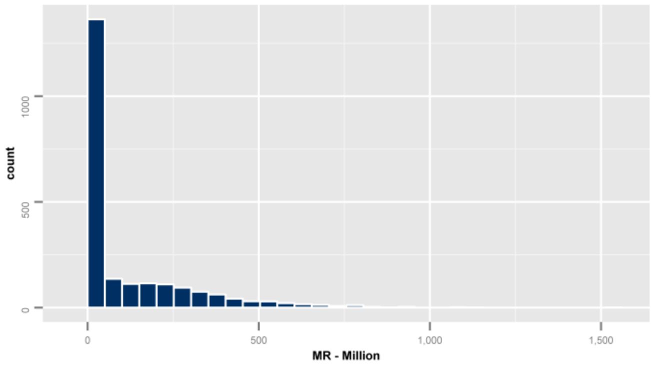

Figure A.viii – Market Risk (MR) Histogram for the unhedged outstanding portfolio over the period 23/01/2006 and 22/01/2015; values expressed in GBP.

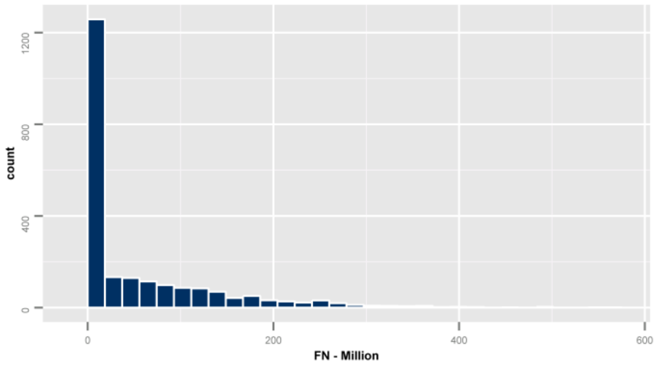

Figure A.ix – Funding Needs (FN) Histogram for the unhedged outstanding portfolio over the period 23/01/2006 and 22/01/2015; values expressed in GBP.

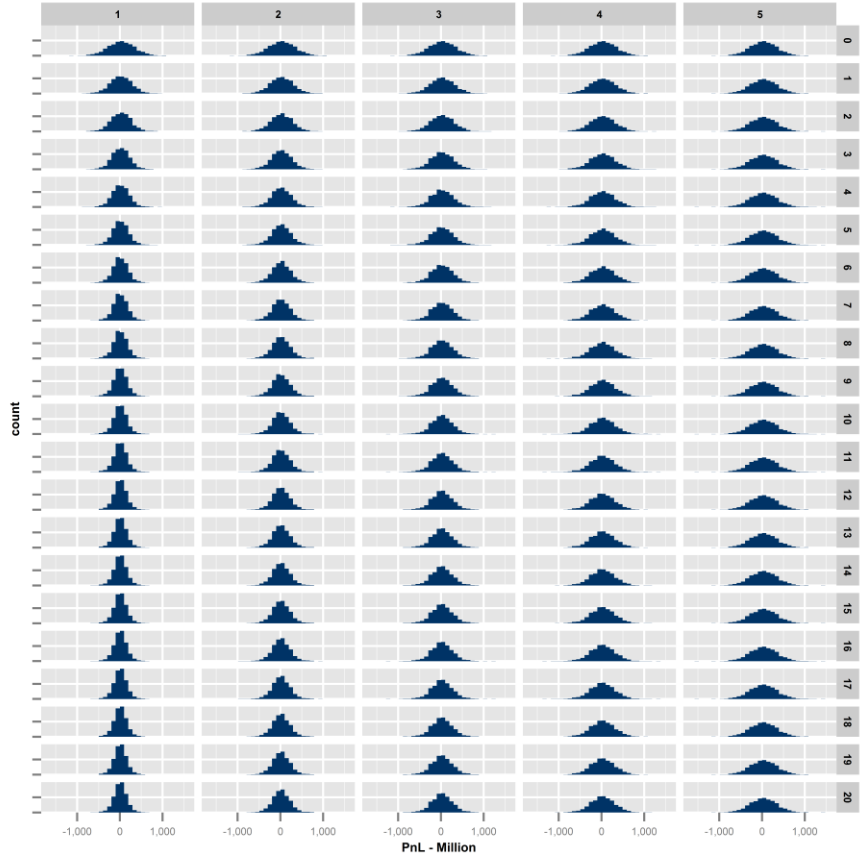

Figure A.x – Profits and Losses (PnL) Histogram for different configurations of the total number of maturity silos (0 to 20) and first date to start the hedging process (T+1 to T+5) over the period 23/01/2006 and 22/01/2015; values expressed in GBP.

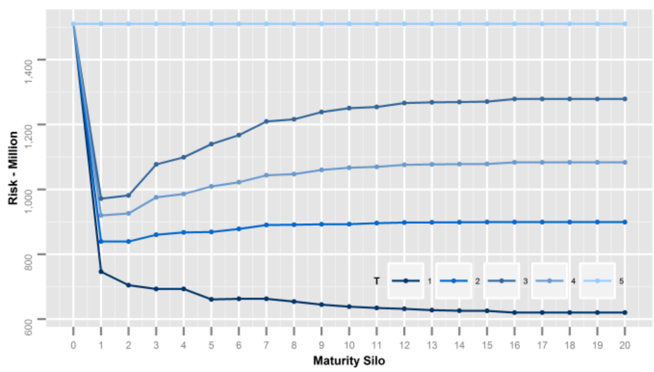

Figure A.xi – Market Risk (MR) for different configurations of the total number of maturity silos (0 to 20) and first date to start the hedging process (T+1 to T+5) over the period 23/01/2006 and 22/01/2015; values expressed in GBP.

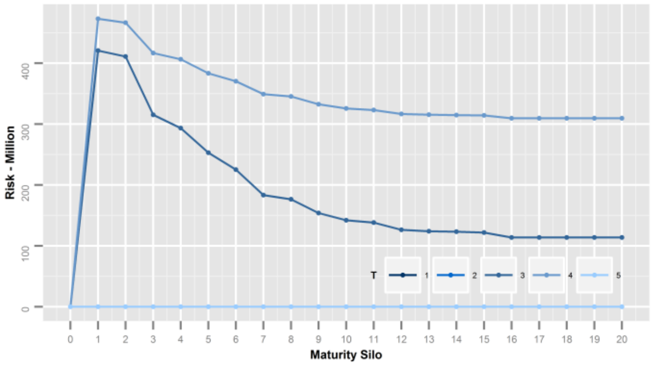

Figure A.xii – Funding Needs (FN) for different configurations of the total number of maturity silos (0 to 20) and first date to start the hedging process (T+1 to T+5) over the period 23/01/2006 and 22/01/2015; values expressed in GBP.

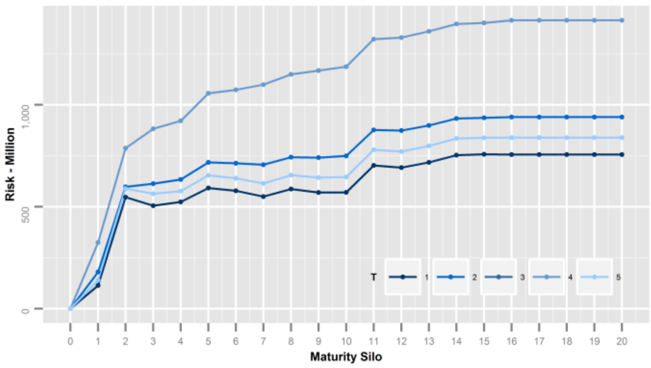

Figure A.xiii – Transaction Costs (TC) for different configurations of the total number of maturity silos (0 to 20) and first date to start the hedging process (T+1 to T+5) over the period 23/01/2006 and 22/01/2015; values expressed in GBP.

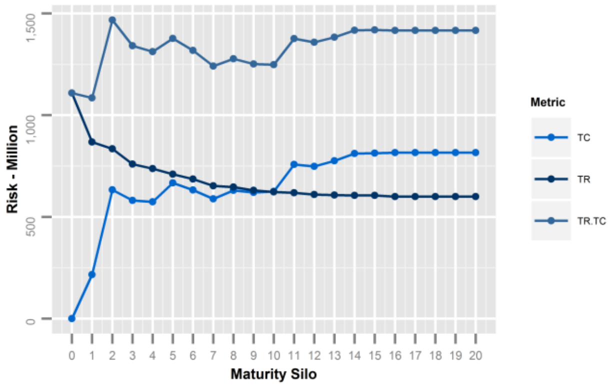

Figure A.xiv – Total Risk (TR defined as the Market Risk plus Funding Needs), Transaction Costs (TC), and Total Risk plus Transaction Costs (TR.TC) for different configurations of the total number of maturity silos (0 to 20) and first date to start the hedging process equal to T+1; values expressed in GBP; reference period 10/01/2005 and 15/01/2010.

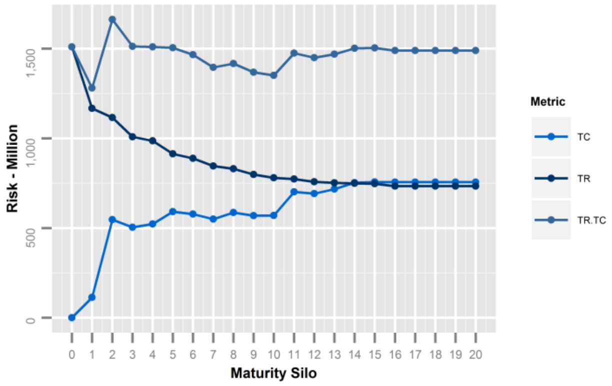

Figure A.xv – Total Risk (TR defined as the Market Risk plus Funding Needs), Transaction Costs (TC), and Total Risk plus Transaction Costs (TR.TC) for different configurations of the total number of maturity silos (0 to 20) and first date to start the hedging process equal to T+1; values expressed in GBP; reference period 18/01/2010 and 15/01/2015.