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The valuation haircuts applied to  
eligible marketable assets for ECB  
credit operations

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# Abstract

In implementing its monetary policy, the ECB conducts collateralised credit operations with banks. The bulk of the financial risks involved in these collateralised credit operations are mitigated primarily by the valuation haircuts imposed on the mobilised collateral. Since the establishment of the euro in January 1999, valuation haircuts have been formulated mainly on the basis of risk management considerations and have been systematically calibrated with a very low level of risk tolerance. However, their implied risk tolerance may sometimes be used as a monetary policy stance lever, as clearly illustrated when the ECB decided to reduce haircuts to improve funding conditions for the real economy during the outset of the coronavirus (COVID-19) pandemic. In addition, the ECB ensures that financial market developments warranting general methodological changes are incorporated into the calibration of valuation haircuts adequately and in good time. In a particularly challenging economic environment, the ECB has also recently committed to ensuring that climate change risks are considered when calibrating the valuation haircuts applied to corporate bonds. Against this background, the purpose of this paper is to provide an overview and explanation of the main guiding rules, as well as explaining some of the statistical methods currently employed by the ECB when formulating valuation haircuts.

**JEL:** D02, E58, G32, Q54

**Keywords:** monetary policy implementation, risk control framework of credit operations, valuation haircuts

## Non-technical summary

Credit operations are a cornerstone of the ECB's monetary policy implementation framework.<sup>1</sup> The ECB lends money to banks, ranging from very short-term loans (overnight and even intraday) to long-term loans (targeted longer-term refinancing operations of up to four years). It does so to steer the aggregate liquidity situation of banks (for which it also uses outright monetary policy portfolio operations), interest rates and thus the monetary policy stance, with the ultimate objective of maintaining price stability over the medium term in the euro area. The ECB has a statutory obligation to lend money only against adequate collateral. Valuation haircuts – along with eligibility requirements and collateral valuation – are a key tool for ensuring collateral adequacy and mitigating the financial risks involved in the ECB's collateralised credit operations.

In these operations, a haircut is a valuation discount applied to the value of a collateral asset (for instance a fixed income instrument) mobilised by a bank at the request of the ECB to secure repayment of the credit. The formulation of valuation haircuts is determined mainly by risk management considerations.

However, the rules that define valuation haircuts must strike the right balance between risk management requirements and the ECB's responsibility for implementing monetary policy. Haircuts should provide a sufficient level of risk protection for the ECB as lender, while avoiding the need for frequent significant changes to reflect market conditions, which could otherwise lead to a procyclicality bias in the implementation of the monetary policy stance (for example the need to tighten risk measures in times of stress). In addition, and especially in view of the ECB's very broad set of assets eligible as collateral, haircuts should avoid distorting asset prices or overly influencing financial market developments. This could happen if, for instance, unwarranted incentives or penalties were introduced for banks that might influence their decision to hold or mobilise a certain asset.

This paper presents an overview of the underlying methods used to calibrate valuation haircuts for marketable assets.<sup>2</sup> The ECB's credit operations are conducted only with financially sound banks. This represents the first layer of risk protection for the ECB. Counterparty risk is further mitigated by lending only against adequate collateral, which represents the second layer of risk protection. When the ECB demands collateral assets as repayment security in its lending operations, it must consider the risk of the collateral turning out to be worth less at the time of liquidation than the amount originally lent. Hence, the statistical methods employed

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<sup>1</sup> Unless otherwise stated, we will use the term ECB to refer to the Eurosystem, which comprises not only the ECB but also the national central banks (NCBs) of the Member States whose currency is the euro.

<sup>2</sup> The ECB also accepts certain types of non-marketable collateral in its general and temporary collateral framework, mostly loans to non-financial corporates and public sector entities. In contrast to marketable assets, non-marketable collateral is not subject to daily market valuation but instead the outstanding amount is considered. Thus, their haircuts are set such as to also cover for deviations between the outstanding amount and the discounted value. The calibration of haircuts for non-marketable assets is not dealt with in this publication.

by the ECB for calibrating haircuts for marketable assets must in turn take three main elements into consideration, namely (i) the time needed to liquidate an asset, (ii) the risks associated with fluctuations in the market value of the collateral (market risk), and (iii) the credit risk (the risk of default) associated with the financial asset. The latter two elements need to be measured as a function of the first, which explains why haircuts tend to be smaller for more liquid collateral and why market risks are generally more relevant than default risks, given the short time horizons involved. In particular, market risks are modelled from traditional bond risk variables, with a focus on parsimony and robustness. Looking ahead, the ECB is committed to further enhancing its risk management practices. To this end, the ECB ensures that financial market developments warranting general methodological changes are properly integrated into the calibration of valuation haircuts.

This paper also discusses the evolution of the ECB's approach to valuation haircuts since the launch of the euro in 1999. The first valuation haircuts published by the ECB were very parsimonious and simple to implement. They served their purpose at a time when banks' central bank funding requirements were limited. However, over time haircuts have become more granular as the ECB seeks to achieve a higher degree of consistency across asset classes. The haircut schedule has also been adapted in response to developments in financial markets and the need to broaden the collateral framework during episodes of crisis. In this regard, during the global financial crisis of 2008-09 and the subsequent euro area sovereign debt crisis, the ECB implemented four general revisions to its haircut schedule. These revisions were primarily driven by risk management considerations and the aim of maintaining an unchanged risk tolerance level.<sup>3</sup> By contrast, at the outset of the COVID-19 pandemic, the ECB applied a general temporary reduction in haircuts at the same time as introducing a temporary relaxation of the eligibility criteria for collateral.<sup>4</sup> These temporary collateral easing measures were arguably the first instance of the ECB using a risk tolerance parameter related to credit operations as a monetary policy instrument. Previous steps to broaden eligibility criteria were always accompanied by risk mitigation measures with the aim to keep the level of Eurosystem risk tolerance unchanged.

Looking ahead, the ECB is committed to continuously adapting and enhancing its risk management practices as required by changing circumstances. In particular, as communicated in July 2022, the ECB will ensure that climate change risks are also considered when reviewing valuation haircuts.<sup>5</sup>

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<sup>3</sup> We refer to risk tolerance here in the sense of the choice as to what the policy maker considers an adverse but still reasonable scenario for which to cover by means of haircuts. The ECB defines such a scenario as the average loss occurring within the worst percentile of the distribution. In other words, for practical calibration purposes, an adverse scenario is set to correspond to the average loss in the worst 1% of cases, i.e. to the concept of expected shortfall at a 99% (ES99) confidence level. See also ECB (2015).

<sup>4</sup> See the [ECB press release of 7 April 2020](#).

<sup>5</sup> See the [ECB press release of 4 July 2022](#).

# 1 Introduction

**To implement a sound monetary policy, central banks lend money only against adequate collateral.** Apart from entailing high risks, unsecured lending would require extensive knowledge of the counterparty, as well as excessive resources. The Protocol on the Statute of the European System of Central Banks and of the European Central Bank<sup>6</sup> explicitly prohibits uncollateralised lending, always requiring adequate collateral to be used.<sup>7</sup>

**The risk management of collateralised central bank lending to commercial banks has distinct characteristics.** Since the global financial crisis, the bulk of money market activity has taken place via secured transactions in order to mitigate counterparty risks. In such transactions between banks, the quality of the collateral is more important than the haircuts in that no transaction with less than best-quality collateral may take place. By contrast, when the credit risk of the two parties is asymmetric and the collateral provider's credit risk is greater than the cash provider's, as is the case in central bank lending, valuation haircuts are a more important tool for mitigating counterparty credit risk than limits or narrow eligibility criteria.<sup>8</sup> In this context, haircuts are generally only dependent on the characteristics of the collateral asset.<sup>9</sup> Therefore, the haircut schedules in place at central banks (and central clearing counterparties, whose operations with their members are also asymmetric to some extent) are purely asset-dependent and generally presented in tabular format, with a few defining characteristics of the asset determining the haircut.<sup>10</sup>

**Valuation haircuts play an important role in achieving collateral adequacy. The bulk of the risks involved in the ECB's collateralised credit operations are mitigated by the valuation haircuts imposed on the mobilised collateral.** These valuation haircuts are aimed at ensuring "residual risk equivalence" across different types of financial assets which can be potentially mobilised as eligible collateral with the ECB. Residual risk equivalence means that the expected loss in value after haircuts from holding the collateral in an adverse scenario should be the same for the different assets.<sup>11</sup>

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<sup>6</sup> Protocol (No 4) on the Statute of the European System of Central Banks and of the European Central Bank (OJ C 202, 7.6.2016, p. 230).

<sup>7</sup> Article 18 of the Statute of the ESCB states that such lending must only be provided against adequate collateral.

<sup>8</sup> See Ewerhart and Tapking (2008) on this topic of symmetric versus asymmetric counterparties in money market lending transactions.

<sup>9</sup> In other words, they are aimed at capturing exclusively the risks associated with the assets mobilised as collateral. As a matter of policy, they are not in any way intended to capture the individual credit risk of each counterparty pledging such collateral.

<sup>10</sup> For further references to similar methods employed by central clearing counterparties, see the relevant information provided by [LCH SA](#), [Eurex Clearing](#), [Euronext Clearing](#) and [BME Clearing](#).

<sup>11</sup> For example, in an adverse scenario the losses expected from a €1 million loan backed by €1.052 million of ten-year maturity "AAA" sovereign bond collateral should be the same as the expected losses from a loan of the same amount backed by €1.33 million of ten-year maturity BBB rated corporate bonds.

**The ECB's valuation haircuts are also aimed at avoiding undue procyclicality and are therefore calibrated in a conservative manner to the bottom of the cycle.** In particular, they are calibrated in such a way as to provide cover for the potential expected losses in the worst 1% of scenarios, in other words the expected shortfall at the 99% confidence level (ES99), with a long time span used for the calibration. The adoption of such risk metrics means that during periods when financial markets are steady and market volatility is low, the haircuts are relatively conservative, while at times of mounting turmoil in financial markets, the haircuts may be a fairer reflection of potential losses and do not need to be significantly changed. A drawback to this approach is that, because of the stability of haircuts over long time spans, risk equivalence may no longer hold during certain periods, and the ECB haircuts may temporarily penalise some asset classes more than others.

**The aim of this paper is to explain the main guiding rules and some of the statistical methods employed by the ECB for formulating haircuts.** This is of particular interest since the ECB accepts a very broad set of eligible assets, possibly the broadest among central banks. Consequently, in determining haircuts it faces a particularly challenging trade-off between, on the one hand, addressing the most relevant specificities of each eligible asset to equalise residual risks and, on the other hand, maintaining a degree of simplicity and coherence. This has led to a marked evolution in the haircut schedule over time, with the ECB generally striving for a more granular treatment of assets. In other words, the ECB's haircuts have tended to differentiate more and more among the factors that are key to measuring the market risks of collateral in a liquidation scenario. The complex and changing characteristics of the ECB haircut schedule have sometimes been the object of controversy. This may be partly because insufficient information is disclosed about the purpose of haircuts and how they are calibrated. This paper helps to clarify these issues by describing the logic of haircuts and by explaining key guiding rules and methodological technicalities. To keep the paper concise, it is focused solely on haircuts for marketable assets.

**This paper is organised as follows.** Section 2 discusses the role of valuation haircuts within the risk control framework of the ECB's credit operations and the main guiding rules followed when formulating haircuts. Section 3 discusses the main statistical methods used to calibrate the haircuts. Section 4 provides a critical overview of the evolution of the ECB's haircuts since 1999 and further reflects on the main challenges that lie ahead. Section 5 discusses some relevant considerations that need to be assessed to follow up on the recent decision that climate change risks should also be considered when reviewing valuation haircuts. Finally, Section 6 concludes and provides further reflections on the main challenges ahead.

## 2 The role of haircuts within the risk control framework

### 2.1 The main lines of defence of the risk control framework

**The ECB has defined four lines of defence as part of its risk control framework for collateralised credit operations: counterparty eligibility criteria, collateral eligibility criteria, collateral valuation and valuation haircuts.** As a first layer of risk protection for the ECB, its credit operations are conducted only with financially sound banks.<sup>12</sup> The remaining counterparty risk is mitigated by lending only against adequate collateral (second layer), which is valued daily and is subject to valuation haircuts. This daily valuation and the valuation haircuts are the third and fourth layers of risk protection. The more restrictively these last three defence layers are set, the lower the volume of credit a bank can obtain from the ECB for a certain volume of assets, as depicted in **Figure 1**.

**The rules that define what adequate collateral means in practice, also known as eligibility criteria, must strike the right balance between risk management requirements and policy needs.**<sup>13</sup> The ECB conducts credit operations with credit institutions<sup>14</sup> as part of the open market operations that it uses to implement its monetary policy stance. If the ECB only accepted very low credit risk, highly liquid assets, this would in practice curtail the volume of credit operations and the breadth of its counterparties, which in turn could impair monetary transmission in times of financial market tensions. In line with the general features of the ECB as the central bank of a monetary union with not yet fully integrated and harmonised capital markets, the collateral framework should allow as much as possible for the use of a diverse set of assets as collateral and for banks' varied business models (see Bindseil et al., 2017). In turn, this means that adequate valuation and haircuts play an even more important role in mitigating residual risks compared with central banks that have narrower eligibility criteria.

**The amount lent against collateral should depend on the market value of the mobilised collateral.** Frequently updating the value of collateral ensures that, at least prior to the bank's default, the exposure is covered. The ECB has thus developed the tools to value the marketable collateral in an accurate and timely way. For this purpose, the Eurosystem operates the Common Eurosystem Pricing Hub

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<sup>12</sup> For further details on the eligibility criteria for participating in credit operations with the ECB, see Part Three of Guideline (EU) 2015/510 of the European Central Bank of 19 December 2014 on the implementation of the Eurosystem monetary policy framework (General Documentation Guideline) (ECB/2014/60) (recast) (the General Documentation Guideline).

<sup>13</sup> See Part Four of the General Documentation Guideline. See also ECB (2015) for a discussion of other aspects of the risk control framework besides the haircuts.

<sup>14</sup> In this paper, we make no distinction between "banks" and "credit institutions". We use both terms to refer to the counterparties that are eligible to borrow central bank liquidity in credit operations. Note that not all entities with a banking licence are eligible, since certain (prudential and technical) conditions must be fulfilled to become a counterparty. The latter conditions represent the first layer of protection mentioned above as counterparty eligibility.



(CEPH), which provides a daily price for every eligible marketable asset.<sup>15</sup> The CEPH employs market prices – when deemed reliable – to update the valuation of marketable assets used as collateral in credit operations. The CEPH processes asset quotes and metadata from market data vendors and selects reliable and necessary information to value the asset. If the available market quotes are of sufficient quality, a unique market price is derived. In the case of illiquid assets for which no direct and reliable market quotes exist, the CEPH determines a theoretical value derived from liquid benchmark bonds to ascertain the prospective market value of the assets. Daily pricing thus allows for daily mark-to-market or mark-to-model collateral valuation, triggering margin calls when the value of a counterparty's collateral pool falls below a defined threshold of provided liquidity.<sup>16</sup>

**Haircuts are meant to provide cover for the risks that could materialise between the default of the counterparty mobilising the collateral and the liquidation of that mobilised collateral.** Without additional risk mitigants, there is a substantial risk that after the default of a counterparty the collateral value could fall below its outstanding amount of credit. The time required to sell the collateral after the counterparty defaults, which we will refer to as liquidation time, is a key variable when calibrating haircuts. In general, it will tend to be short, at most a few weeks, for marketable assets, but somewhat longer for loans. This implies that the major risk to be covered by the haircut is unlikely to be a default of the issuer or debtor, but rather the risk of a decrease in market value due to changes in the risk-free interest rate, or changes in the risk premia demanded for holding financial assets. This is what we will call market risk, which makes up the lion's share of valuation haircuts, as opposed to pure credit risk, which is understood here as the risk in a jump-to-default scenario.<sup>17</sup> Note that the potential adverse impact of the sale itself on the price is not modelled.<sup>18</sup> Such an impact is assumed to be mitigated by a sufficiently long liquidation horizon, with any residual price impact being covered by the conservative choice of the confidence level for the tail measure used for calibration.

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<sup>15</sup> A value is assigned to each of the roughly 25,000 eligible marketable assets on a daily basis through the CEPH.

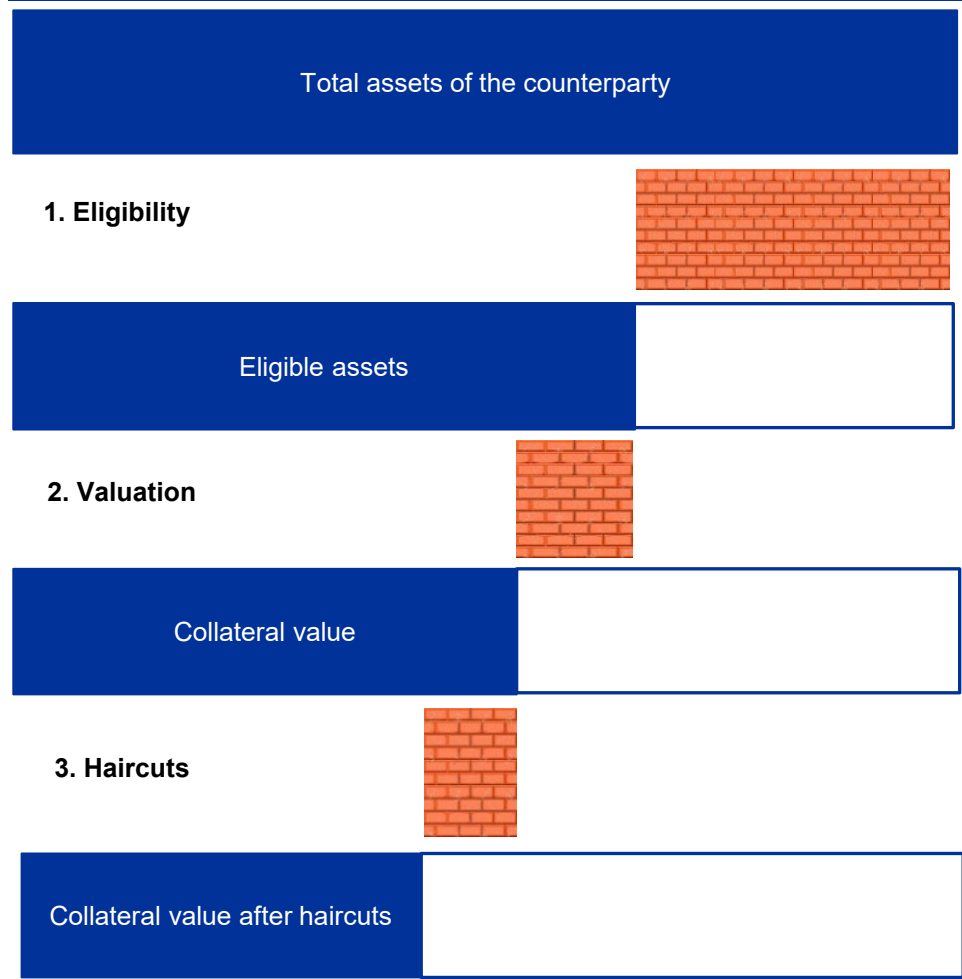
<sup>16</sup> A small amount of leeway, normally set at 0.5% of the liquidity provided, is used to limit the frequency of margin calls.

<sup>17</sup> An increase in the risk premium of an asset – or, in other words, an increase in its spread with respect to a benchmark risk-free interest rate – could in principle be considered as an increase in credit risk. However, such an increase will be covered by what we call market risk in this paper, because it will be embedded in the price fluctuations. The term “credit risk” is only used to mean the direct jump-to-default risk in this paper.

<sup>18</sup> This is because the volume sold would play a large role in ascertaining the sale price impact, but the latter is not known, and defining a different haircut depending on the volume used by a counterparty would greatly reduce the transparency of the risk management framework.

**Figure 1**

Main lines of defence of the risk control framework for collateralised credit operations



Notes: The depicted level of eligible assets is in nominal terms and the collateral value may be higher than the nominal, depending on market prices. Source: ECB.

## 2.2 Guiding rules for formulating valuation haircuts

**Central banks adhere to certain risk management standards and established rules that strengthen their risk management framework.** These rules ensure

adequate, risk-efficient protection and constitute an integral part of the monetary policy decision-making process. To fulfil this goal, risk measures and mitigants should be based on objective methods and metrics that are also transparently communicated, well understood and rooted in well-established best practices. Following firm and stable rules is paramount for achieving more consistent risk policies over time.

**The formulation of valuation haircuts is founded on four key guiding rules.**

Haircuts should (1) be underpinned by objective risk measures, (2) provide adequate protection over the economic cycle, (3) be independent of collateral pool composition

effects and equal across counterparties, and (4) ensure risk-equivalent treatment across asset classes.

**Haircuts are calibrated with reference to the expected shortfall at the 99% confidence level (ES99).** They should be calibrated with the aim of providing cover for the loss in value of collateral that the ECB expects to incur in an adverse scenario. The ECB defines such an adverse scenario as corresponding to the average loss in the worst 1% of cases. This approach ensures that risks are identified and estimated using broadly agreed and transparent assumptions which may be updated when needed. This enables comparability across various financial operations, thus supporting a disciplined approach to the analysis of the central bank's risks, which is necessary for monitoring compliance with the central bank's risk appetite. The quantification of financial risks in the ECB's monetary policy operations relies on the expected shortfall at the ES99, which is comparable to the regulatory recommendations to market participants for setting their margin requirements.<sup>19</sup>

**Haircuts should provide adequate protection over the economic cycle (“through-the-cycle” protection).** As stated above, the ECB defines an adverse scenario as one associated with the average loss in the worst 1% of cases. This should provide a sufficient level of risk protection while avoiding the need for frequent changes to reflect changing market conditions, including the need to tighten risk measures in times of stress, for example.<sup>20</sup> When calibrating haircuts, the ECB uses a broad dataset covering a long time span, which prevents changes to the framework from being unduly procyclical. The dataset includes periods of stress in the euro area so that tail events (such as the global financial crisis, the euro sovereign crisis and the outbreak of the COVID-19 pandemic) are included in the assessment.

**Haircuts should not be set with reference to the collateral pool composition (nor to the characteristics of the counterparty mobilising the collateral).** The ECB defines haircuts on an asset-by-asset basis, rather than basing them on the characteristics of banks' collateral pools. The drawback is that the potentially risk-diversifying features of the collateral pool are ignored. The calibration of haircuts is thus conducted by implicitly assuming that the various assets mobilised as collateral are perfectly correlated.<sup>21</sup> In addition, haircuts are set to be equal for all counterparties. This contrasts with the standard practice of commercial banks, which set haircuts that also take the borrower's creditworthiness into consideration. The

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<sup>19</sup> Article 24 of Commission Delegated Regulation (EU) No 153/2013 of 19 December 2012 supplementing Regulation (EU) No 648/2012 of the European Parliament and of the Council with regard to regulatory technical standards on requirements for central counterparties (OJ L 52, 23.2.2013, p. 41), which provides regulatory technical standards for Regulation (EU) No 648/2012 of the European Parliament and of the Council of 4 July 2012 on OTC derivatives, central counterparties and trade repositories (OJ L 201, 27.7.2012, p. 1), states the minimum confidence intervals that central clearing counterparties (CCPs) must respect. Regulation (EU) No 153/2013 requires a minimum confidence level of 99.5% for derivatives and 99% for other financial instruments.

<sup>20</sup> The confidence level can also be seen as a policy lever that may be used to signal policy changes to the central bank's risk appetite. This was the case, for instance, when the ECB reduced haircuts to ensure collateral availability and to signal its willingness to support the banking system during the outset of the coronavirus (COVID-19) pandemic in April 2020.

<sup>21</sup> It is also plausible that one counterparty might mobilise only one asset as collateral.

aim of the ECB's asset-by-asset approach is to maintain a level playing field among market participants, thus ensuring that monetary policy implementation is orderly and non-discriminatory.

**Residual risks after haircuts are broadly equivalent across different asset classes.** By enforcing risk-equivalent treatment across asset classes, the ECB seeks to avoid distorting asset prices or overly influencing market processes and market participants' behaviour beyond what is required by the specific policy objectives of monetary policy operations. Risk equivalence also leads to risk efficiency, in the sense that the adverse selection of collateral will be mitigated and intrinsic risk differences across assets offset.<sup>22</sup> Enforcing risk-equivalent treatment entails the need to consider the specificities and risk profiles of all eligible assets, identifying the core characteristics driving their risk profile and calibrating haircuts along these dimensions.

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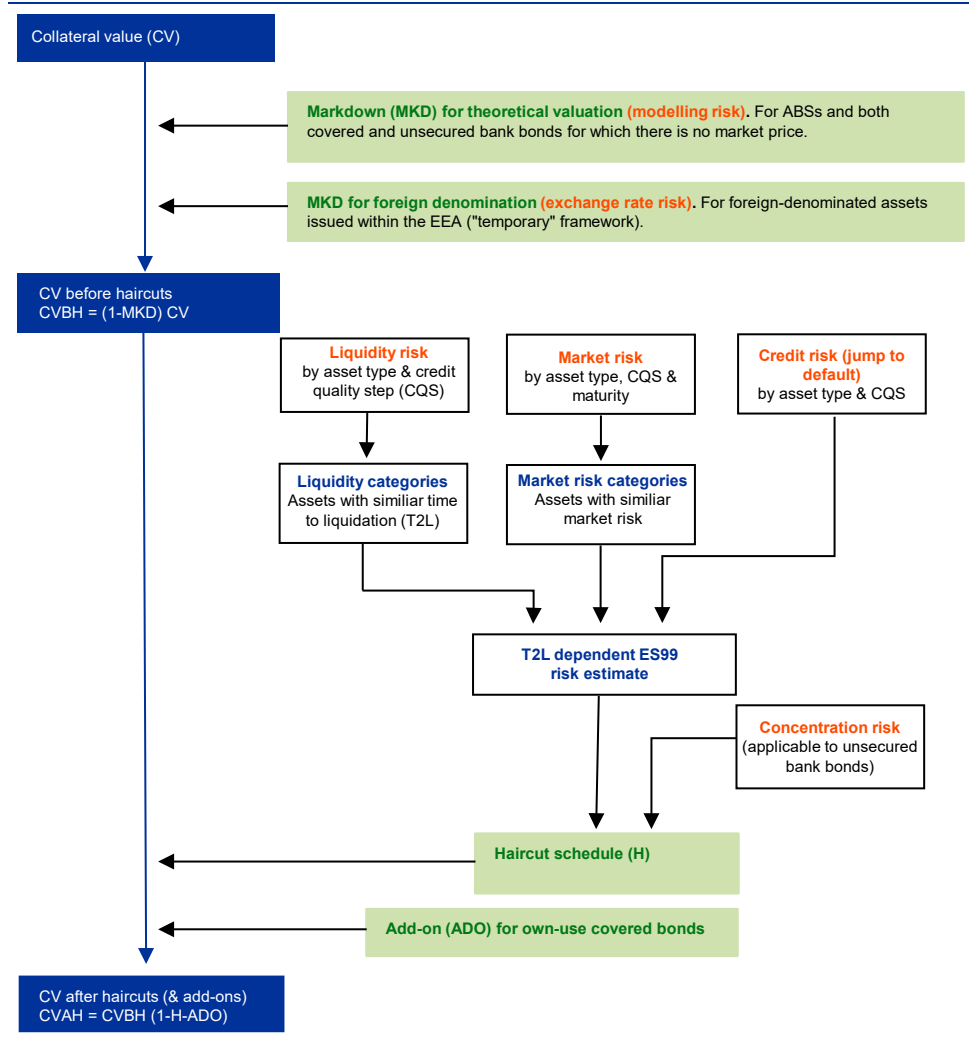
<sup>22</sup> If complete residual risk equivalence is achieved, the ECB should be indifferent to the choice of mobilised collateral, since haircuts offset intrinsic risk differences among eligible assets.

# 3 The calibration of valuation haircuts for marketable assets

## 3.1 Overview

Before a haircut is applied, the value of the collateral is adjusted by means of valuation markdowns, as shown in Figure 2. A valuation markdown can be seen as a separate haircut that is applied to cover certain additional risks not specifically considered in the valuation haircuts. It is also defined as a percentage decrease in the value of an asset.

**Figure 2**  
Risk components contributing to valuation haircuts



Source: ECB.

**The theoretical valuation markdown is used to address the model risk implied when using model estimates to price an asset.** The CEPH uses the market price of liquid bonds to calibrate (discount) yield curves. These (discount) yield curves are then used to determine the 'theoretical' price for other less liquid bonds. Thus, there is no inbuilt liquidity premium adjustment and, consequently, the theoretical valuation markdown serves to address this deficiency.

**A foreign exchange (FX) valuation markdown is applied to financial assets denominated in foreign currency to provide cover for exchange rate risk.**<sup>23</sup> FX valuation markdowns are calibrated on the basis of the ES99 estimated from daily changes in the corresponding currency's exchange rate. The markdown is calibrated conservatively from a risk management perspective. In particular, the estimates are computed with reference to stressed sample periods. Additionally, the markdown provides cover for potential currency depreciations over long periods. These periods are typically much longer than the standard time to liquidation for euro-denominated marketable assets.

**To estimate valuation haircuts, financial assets with similar characteristics are bundled together.** The ECB accepts many thousands of bonds as collateral and does not assess each individual bond's market depth. Instead, bonds are considered as part of institutional market segments with more homogeneous characteristics, namely their typical investor base, transaction volumes and yield volatility.<sup>24</sup> This is the basis for the tabular approach taken for the ECB's haircut schedules and the division of the schedules into haircut categories. This approach incorporates assumptions on the expected time to liquidation of the assets in each category.

**The approach taken for calibrating haircuts for marketable assets consists of three main elements: time to liquidation, market risk and credit risk (jump to default) (Figure 2).** Once an expected time to liquidation has been ascertained, the question is: what variables can be used as proxies for the risk and as dimensions for the haircut table? Market risk is primarily driven by (i) the duration of an instrument's cash flows and (ii) the yield volatility attached to their discounting curve. Regarding (i), the residual maturity can be considered a proxy for the duration in a market largely dominated by non-amortising bonds.<sup>25</sup> The exceptions are asset-backed securities (ABSs), where the weighted average life is used instead. With respect to (ii), as explained in more detail in Section 3.3, there is an empirically observed relationship between risk premium, represented by the spread level, and spread volatility, which makes up the bulk of yield volatility. Therefore, using credit quality as

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<sup>23</sup> The ECB currently accepts foreign denominated marketable assets as collateral under the temporary framework. Marketable debt instruments which are issued and settled in the European Economic Area (EEA) and are denominated in US dollar, pound sterling or Japanese yen have been eligible collateral on a temporary basis since 9 November 2012.

<sup>24</sup> For example, when estimating yield volatility for a given credit quality, all covered bonds (and their spreads) are grouped together for the period since 2002 and a single number is derived, instead of differentiating by issuer. In addition, sovereign, local and regional bonds can be grouped together given their similar underlying characteristics.

<sup>25</sup> Alternatively, basic price sensitivity measures such as modified duration could be used directly for constructing the haircut table. However, this approach has a few drawbacks compared with using residual maturity as a proxy: the basic price sensitivity measures depend on the estimate of the yield curve used, and the latter is generally unobserved. Hence, a haircut based on the ECB's estimate of a bond's duration would be slightly less transparent and predictable.

a proxy for spread volatility makes sense, which is why credit quality steps (CQSs) are used to differentiate haircuts to a much greater extent than jump to default considerations. In other words, the reason for applying a higher haircut to an asset rated “BBB” is not primarily its higher risk of default during the liquidation time, which is fairly small, but its higher yield volatility.

**Time to liquidation assumptions, together with market and credit risk (jump-to-default) estimates are combined into an ES99 estimate.** For each asset class, market risk and credit risk need to be rescaled to reflect the relevant time to liquidation assumption and then aggregated (see Section 3.5). When dealing with unsecured bank bonds, a “sector concentration risk” add-on is applied to the final estimates (**Figure 2**). Sector concentration risk only applies to unsecured bank bonds for which, in the event of a banking sector shock, the mobilising counterparty might default when the mobilised collateral is also particularly exposed to market and credit risk. An additional buffer of 5% is thus added to the total ES99 derived for unsecured bank bonds. The published haircuts primarily reflect the comprehensive ES99 estimate referred to in **Figure 2** as “haircut schedule (H)”, but there is also an element of expert judgement involved.<sup>26</sup>

**The ECB applies additional buffers (add-ons) to deal with the specific “wrong-way” risks associated with own-use covered bonds.** Counterparties must not mobilise their own unsecured bank bonds as collateral, as these bonds obviously lose a huge amount of value when the counterparty defaults and the Eurosystem wants to liquidate the collateral. However, counterparties are entitled to mobilise collateral that is eligible and closely linked to them if the collateral assets are secured by assets whose value does not depend on the counterparty alone (namely own-use covered bonds). In this instance, the usual double layer of protection inherent in covered bonds disappears if a counterparty defaults, as the value of covered bonds issued by the counterparty will depend only on the cover pool of the covered bond in this case. The credit rating of the covered bond does not primarily reflect the pool quality, since it takes into account the joint issuer/pool strength. Hence, the unaccounted risk is dealt with by a haircut add-on applied to the final haircuts. There is a slight technical difference in the way the haircut add-ons are applied with respect to the markdowns. In particular, markdowns are “sequentially applied”, while add-ons are applied to the haircut levels (see the formulae reported in **Figure 2**).<sup>27</sup>

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<sup>26</sup> Such expert judgement might entail policy considerations and consistency checks, for example to preserve the ranking of risk by credit quality and duration (maturity) and to ensure comparability with the previous haircut schedules. In addition, expert judgement entails necessary adjustments to cope with the data scarcity that sometimes occurs. For example, in the longest maturity buckets (over 30 years) there might not be a sufficient number of observations to achieve statistical significance for the estimates. In this case, extrapolation (via regression or some other method) or other qualitative assessments may be needed.

<sup>27</sup> Note, for example, that the theoretical valuation markdown could have been applied after the correction for haircuts, so in effect the adjustment (1-MKD) shown in **Figure 2** could equally have been placed at the bottom of the figure.

## 3.2 Time to liquidation and risk horizon

**Haircuts should depend on the time required to sell an asset in the secondary market after the default of a counterparty. The longer it takes to sell, the higher the exposure to adverse price changes.** The expected time horizon over which an asset mobilised as collateral can be sold in a commercially reasonable manner is called time to liquidation (T2L). Hence, the T2L is a proxy measure of the ECB's exposure to liquidity risk of marketable assets.

**The liquidity profile of marketable assets is examined from both a quantitative and a qualitative perspective.** The qualitative perspective consists of a market intelligence analysis to gather insights into the liquidity conditions on secondary markets and is used to complement the quantitative T2L estimates.

**For the computation of T2L, it is assumed that assets with similar characteristics have similar secondary market liquidity and are thus grouped in the same bucket.** The T2L is calculated following a bucket-time approach. In what follows we use  $B_t$  to define a "bucket" (meaning a set) of assets, at time  $t$ , of similar characteristics. These buckets are formed based on three criteria:

- asset class, where the different classes correspond to various financial market segments and are primarily defined in terms of the type of entity issuing the asset, in other words as central government, European Union, local and regional government, agency, supranational, financial and non-financial bonds;<sup>28</sup>
- credit quality of an asset, which is determined based on the Eurosystem credit assessment framework (ECAAF) and distinguishes between, on the one hand, CQSs 1 and 2 (probability of default up to 0.10%) and, on the other hand, CQS 3 (probability of default between 0.10% and 0.40%);<sup>29</sup>
- coupon type, which distinguishes between zero, fixed and floating coupons.

**The T2L formula reflects (i) the expected ECB exposure to assets mobilised as collateral by a counterparty, and (ii) the indicative market's ability to absorb sales. In population terms, it would be a quotient of expectations.**

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<sup>28</sup> Apart from the type of issuer, asset classes also depend on whether the assets are secured. Hence, covered bonds and ABSs also constitute separate asset classes.

<sup>29</sup> See ECB (2015).



$$T2L_{B_t} = \frac{E[Exposure_{B_t}]}{E[Absorb_{B_t}]}$$

The T2L of a bucket  $B_t$  is expected to be higher (or lower) if the expected mobilised amount of assets in this bucket is higher (or lower). Moreover, the T2L increases as the ability of the market to absorb the exposure deteriorates.

**Exposures are measured by looking at the (average) composition of the mobilised assets.** In order to compute exposures, the mobilised amount of an asset per mobilising counterparty is normalised by its total outstanding amount. This is then averaged by weighting the mobilised amount of the asset with reference to the overall mobilised amount in the bucket. Hence, assets which have a higher rate of mobilisation will contribute more to the expected exposure at bucket level. This is defined more formally using the following formula:

$$Exposure_{B_t} = \frac{\sum_{i \in B_t} \frac{mobilised_{i,t} / \#mfi_{i,t}}{outst_{i,t}} \times mobilised_{i,t}}{\sum_{i \in B_t} mobilised_{i,t}}$$

where  $mobilised_{i,t}$  reflects the nominal amount mobilised as collateral on an asset  $i$  at time  $t$ ;  $\#mfi_{i,t}$  is the number of counterparties that mobilised the asset  $i$  as collateral and  $outst_{i,t}$  is the total outstanding notional amount of asset  $i$ .

**The market's ability to absorb sales is defined with reference to the bid amounts posted by market dealers.** To measure the market's ability to absorb collateral sales, bid amounts are first normalised by the outstanding amounts on an ISIN level. The normalised bid amounts are then averaged over the bucket. Thus, each asset contributes with the same weight to the expected market ability of absorption. More formally:

$$Absorb_{B_t} = \frac{1}{\#B_t} \sum_{i \in B_t} \frac{bidvol_{i,t}}{outst_{i,t}}$$

where  $bidvol_{i,t}$  is the total amount of indicative bid volume observed on the secondary market;  $\#B_t$  is the number of assets in the bucket, and  $outst_{i,t}$  is defined as above.

**Estimates of the expected exposures and market's ability to absorb sales are computed over a defined time period using sample means.** More formally, an estimate of T2L is assembled using the final formula:

$$\widehat{T2L}_{B_t} = \frac{\frac{1}{T} \sum_{t \in T} (Exposure_{B_t})}{\frac{1}{T} \sum_{t \in T} (Absorb_{B_t})}, \quad (1)$$

where  $T$  is the observation period over which T2L is measured. In practice, and in view of data constraints, the composition of the buckets for proxying expected exposures and market's ability to absorb sales (numerator and denominator respectively in the equation above) differs slightly. The denominator usually comprises a larger set of eligible assets, while the numerator is restricted to those eligible assets which are in effect mobilised.

**In a final step, the daily estimate is transformed to a weekly T2L.** The daily estimate derived with equation formula (1) is adjusted for prudential and operational considerations and then linearly extrapolated to a weekly T2L.<sup>30</sup>

### 3.3 Market risk

**Our starting point is the formulation of a simple statistical model of “log” asset returns accounting for market risk.** We define the yield to maturity,  $y_t$ , of a fixed<sup>31</sup> coupon bond of a given maturity as the sum of the base rate,  $r_t$ , and a spread,  $s_t$ , so  $y_t = r_t + s_t$ . We can then approximate the weekly (natural) log-price changes,  $\Delta \log p_t$ , by means of the following first-order Taylor series expansion.

$$\begin{aligned} \Delta \log p_t &\approx \frac{\partial(\log p_t)}{\partial y_t} \frac{\partial y_t}{\partial r_t} \Delta r_t + \frac{\partial(\log p_t)}{\partial y_t} \frac{\partial y_t}{\partial s_t} \Delta s_t \\ &\approx \frac{1}{p_t} \frac{\partial p_t}{\partial y_t} \Delta r_t + \frac{1}{p_t} \frac{\partial p_t}{\partial y_t} \Delta s_t \\ &\approx -d_t \Delta r_t - d_t \Delta s_t \\ &\approx -\mathbf{D}_t \Delta \mathbf{z}_t \end{aligned} \quad (2)$$

With  $\mathbf{D}_t = (d_t \quad d_t)$  and  $\Delta \mathbf{z}_t = (\Delta r_t \quad \Delta s_t)'$ , and where  $d_t$  is the modified duration of the bond,  $\Delta r_t$  is the change in the par base rate for the bond's term and  $\Delta s_t$  the

<sup>30</sup> As explained in Section 3, for the purpose of measuring market risk, asset returns will be computed over a weekly horizon. Volatility over the liquidation horizon will then be extrapolated in line with the estimated T2L.

<sup>31</sup> The same model with a slight tweak could be applied to a floating coupon bond: the approximation remains valid after replacing the vector  $\mathbf{D}_t = (d_t \quad d_t)$  with a vector  $\mathbf{D}_t = (d_t^r \quad d_t^s)$ , containing two distinct durations, one with respect to changes in the risk-free rate (which will be relatively low for floating coupons linked to a standard interest rate benchmark) and another with respect to changes in the spread.

change in the spread for the bond's term, all at time  $t$ .<sup>32</sup> Equation (2) is called the “exponential duration” approximation because it approximates the log-price return. Under suitable distributional assumptions for  $\Delta z_t$ , the exponential duration approximation in equation (2) provides a statistical model for measuring market risk, specifically measuring the impact that changes in the risk-free rate and in the spread have on the bond price.

**The exponential duration approximation provides a conservative estimate of bond returns.** Livingston and Zhou (2005) have proved that this exponential duration approximation is substantially better than the traditional duration approximation to bond returns. In addition, it is almost as accurate as the “duration plus convexity approximation”.<sup>33</sup> Interestingly, Livingston and Zhou show that the duration plus convexity approximation may underestimate the losses in an environment of rising interest rates, while the exponential duration method tends to slightly overestimate the losses.

**Log-price changes have an intrinsic heteroskedasticity that is taken into consideration in the model by including an additional skedastic function in the spread formulation.** The advantage of splitting yield changes into a risk-free rate and a spread is that estimations are then more robust, since it is possible to model directly the heteroskedasticity of changes in spreads, reflecting the empirical evidence that a security trading at a wider spread tends to experience greater absolute spread changes and therefore higher volatility of price returns.<sup>34</sup> Such heteroscedasticity in the spreads is handled with the following alternative formulation:

$$\Delta \log p_t \approx -D_t^* \Delta z_t^* \quad (3)$$

where  $D_t^* = (d_t \quad d_t f(s_{t-1}))$  and  $\Delta z_t^* = (\Delta r_t \quad \Delta s_t / f(s_{t-1}))'$  and the skedastic function  $f(s_{t-1})$  is a positive function.<sup>35</sup>

**We assume  $\Delta z_t^*$  to follow a multivariate normal distribution with zero mean and covariance matrix  $V^*$ .** It then follows that  $\Delta \log p_t \sim N(0, \sigma_t^2)$  where  $\sigma_t^2 = D_t^* V^* D_t^{*'}.$  The expected shortfall can then be computed using an estimate of  $\sigma_t^2$ .

**For the computation of market risk, it is also assumed that assets with similar characteristics have similar risk and are thus grouped into the same bucket.** Market risk is thus also calculated following a bucketing approach (similarly to T2L).

<sup>32</sup> The spread is calculated with reference to a risk-free rate such as the “AAA” euro area yield curve.

<sup>33</sup> The traditional duration approximation is a standard first-order polynomial approximation to bond returns, while the duration plus convexity represents a second-order polynomial approximation. The exponential duration is a first-order approximation to the “log” of bond returns.

<sup>34</sup> The motivation for the methodology is also well explained in Ben Dor et al. (2007).

<sup>35</sup> The skedastic function can be modelled by means of orthonormal cubic B-splines defined by setting a set of knots at certain spread levels. Then, a linear regression can be applied to estimate the best projection of the dependent variable on the set of cubic splines. One advantage of this approach is that the estimation remains within the standard framework of linear regressions. As dependent variable, absolute values or squared changes of  $\Delta s_t$  can be selected, the former being more robust to outliers. Assuming  $\Delta s_t \sim N(0, f(s_{t-1})^2)$  it follows that  $|\Delta s_t|$  has a half-normal (or folded normal) distribution, with mean  $f(s_{t-1}) \cdot \sqrt{2/\pi}$ .

However, the buckets are assembled in a slightly different manner. For the computation of market risk, the buckets are based on the asset class, the credit quality of the asset and the maturity of the asset. Contrary to the buckets for computing T2L, these buckets do not consider the type of coupon. This is primarily on account of the insufficient sample size for zero coupon bonds and floating rate bonds (see more on this below).

**The bucket estimates of log-price change volatility,  $\sigma_{i,CQS,mat}$ , can then be defined as follows:**

$$\hat{\sigma}_{i,CQS,mat} = \sqrt{\bar{D}_{i,CQS,mat}^* \hat{V}_{i,CQS}^* \bar{D}_{i,CQS,mat}^*}$$

where values for  $\bar{D}_{i,CQS,mat}^*$  are the sample mean of the duration of those assets in a bucket of a certain class  $i$ , credit quality and maturity. This sample mean is computed across time and assets.  $\hat{V}_{i,CQS}^*$  is an estimate of the covariance matrix defined above as  $\hat{V}$ , and computed with  $\Delta z_t^*$ . Note that this covariance matrix is defined for buckets that consider only asset class<sup>36</sup> and credit quality, so it ignores maturity. This relies on  $\Delta z_t^*$  being homoscedastic – after the normalisation conducted via the skedastic function – and leads to much greater sample sizes consisting of observations over time for a large number of representative fixed coupon bonds. Such a volatility estimate computed over a large sample spanning a long period of time avoids inducing procyclicality in the haircuts.

**The volatility estimates for the log returns of zero coupon bonds are also derived from the available sample of fixed coupon bonds.** Owing to the relatively small sample of available zero coupon bonds, the volatility estimates for zero coupon bonds can be inferred simply by means of fixing the duration,  $\bar{D}_{i,CQS,mat}^*$ , at the upper boundary of the corresponding maturity bucket.<sup>37</sup>

**The volatility estimates for the log returns of floating coupon bonds are derived by extrapolating the estimate for fixed coupon bonds with expert judgement.** The available sample of floating coupon bond returns is not as rich as that for fixed coupon bonds. This is the case in terms of both its restricted time length and the poor coverage of the sample across asset classes and the various maturities. When extrapolating market risk estimates of fixed coupon bonds for floating coupon bonds, two important factors should be taken into consideration. First, floating coupon bonds are much less subject to risks associated with changes to the risk-free interest rate. However, in relative terms the latter tend to be smaller than spread change risks, for which the sensitivity of the floating coupon bond does not necessarily differ from that of a comparable fixed coupon bond. Second, floating

<sup>36</sup> It should be noted that for the estimation of  $\hat{V}$ , assets with similar characteristics are aggregated together (for instance sovereign, local and regional bonds). This indicates that the estimator measures not only volatility over time but also dispersion across different types of assets in the buckets. In addition, the equal weighting of each bond and day implies that sample periods with different volatility environments are unequally weighted because the panel is unbalanced. Nevertheless, over a very long period of daily data, the results are very stable.

<sup>37</sup> For example, the market risk for the zero coupon bonds in the seven-year to ten-year maturity bucket is calibrated assuming an average duration of ten years.

coupon bonds for certain asset classes tend to be less liquid. Given this combination of factors, the actual risk mitigation afforded by floating rate coupons compared to fixed rate coupons is ultimately not very substantial.

### 3.4 Credit risk (jump to default)

**Credit risk in the context of haircut calibration relates to a sudden jump to default.** In the haircut calibration methodology, credit risk measures the risk of default on a financial asset before liquidation. It should be noted that credit migration risk, in other words the risk of a downgrade in the credit rating, should be already reflected in asset returns (the asset price, or by extension the yield spread). This means that the volatility estimates assembled as proxies for market risk described above should already reflect these migration risks.<sup>38</sup>

**Default risk depends on both the probability of default (PD) and the loss given default (LGD) associated with an asset.** The PD is set to the upper boundary of the relevant ECAF-defined interval for the CQS assigned by the ECB to an asset (Table 1). It is assumed to be 0.10% for assets in CQSs 1 and 2 and 0.40% for assets in CQS 3, and is estimated over a one-year horizon. The LGD assumptions are based on reported data and are calibrated in a conservative manner. LGDs are dependent on the asset class and range from a 40% to a 70% loss on the nominal amount. For a given LGD we compute a corresponding log return. For example, for an LGD of 70% the corresponding loss measured as the log return is approximately  $\ell \simeq -1.20$ . In what follows we will use the symbol  $\ell$  to denote the log return associated with a given LGD. It should be noted that default risk becomes more important (in the context of haircuts) for assets of lower credit quality and for longer liquidation periods. Within the same CQS, a securitised asset<sup>39</sup> will have lower default risk as LGD assumptions are somewhat better for those assets compared with unsecured instruments.

**Table 1**  
Probability of default assumptions by CQS

CQS	1&2	3	4	5	6	7	8
Probability of default – upper boundary	≤ 0.10%	≤ 0.40%	≤ 1%	≤ 1.5%	≤ 3%	≤ 5%	> 5%

Notes: The Eurosystem's credit quality requirement for all eligible assets in the ECAF is defined in terms of a credit assessment of CQSs 1, 2 or 3, with additional credit quality requirements for ABSs and Irish retail mortgage-backed debt instruments. Some NCBs accept (pools of) additional credit claims belonging to CQSs 4 to 8.

<sup>38</sup> This is because the sample itself contains cases of credit drifts. Only sudden defaults are cleansed out of the sample, to ensure that such jump-to-default events are not contained in the market risk estimates.

<sup>39</sup> Assuming it is not an own-use securitised asset.

## 3.5 Formulation of a haircut

**The main parameters characterising the probability distribution of market risk and credit risk need to be rescaled to reflect the relevant time to liquidation assumptions.** The rescaled PD is computed assuming that default events are independent and follow a binomial distribution. The rescaled PD is computed as follows:

$$\tilde{p} = 1 - (1 - PD)^{T2L/52}$$

This means that the reported PD over a one-year horizon is rescaled by the T2L, which is defined in weeks. In the same vein, the weekly estimate of asset return volatility,  $\sigma$ , which serves to measure market risk, needs to be scaled by the T2L:

$$\tilde{\sigma} = \sigma\sqrt{T2L}$$

**The final haircut should provide cover for both market risk and the risk of a sudden jump to default.** A haircut which was narrowly defined from estimates of the market risk associated with fluctuations in the market price would be short-sighted, as it would not cater for the risks associated with default on the bond. It is therefore essential to compute a combined measure for market and credit risk, or in other words the risk that, over the liquidation period, a sudden jump to default might also be observed.

**Asset returns are modelled as a mixture distribution to account for sudden jumps to default.** Asset returns are modelled as a finite mixture distribution between a discrete random variable and a continuous random variable. The discrete random variable defines the sudden jump to default and is associated with a bad return of  $\ell$  (the log return associated with the expected LGD) with corresponding mass probability of  $\tilde{p}$ . The continuous random variable, assigned a probability of  $(1 - \tilde{p})$  in the mixture, is well represented by the parametric model of asset returns described in equation (3), i.e. a normally distributed random variable with zero mean and standard deviation  $\tilde{\sigma}$ . It follows that asset returns are thus well represented by the cumulative distribution function  $F(x)$  which is defined as:

$$F(x) = \tilde{p} 1_{x \geq \ell} + (1 - \tilde{p})\Phi\left(\frac{x}{\tilde{\sigma}}\right) \quad (4)$$

where  $1_{x \geq \ell}$  is an indicator function taking a value of one when the condition on the subscript is true and zero otherwise,  $\tilde{\sigma}$  is the volatility of log asset returns estimated as described in Section 3.3 and  $\Phi()$  is the cumulative distribution of a standard normally distributed variable. **Chart 1** shows the plot of the cumulative distribution of asset returns.

**Closed expressions for the expected shortfall representative of the total risk over the liquidation horizon can be easily derived from the cumulative distribution.** The expected shortfall for the log returns is then defined as:

$$\log ES_{1-\alpha} = \frac{1}{\alpha} \int_{-\infty}^{\text{VaR}(1-\alpha)} x dF(x) \quad (5)$$

where the integral is the Riemann-Stieltjes integral of (the function)  $x$  with respect to the function  $F(x)$ . Closed expressions for that integral can be derived in the following way. The adverse scenario is defined with reference to the worse  $\alpha$  per unit scenarios. For known values of  $\ell, \tilde{\sigma}$  and  $\tilde{p}$  we also know (for a given  $\alpha$ ) the position of such  $\alpha$  in **Chart 1**, as represented there by  $\alpha_1, \alpha_2$  and  $\alpha_3$ .<sup>40</sup> It follows that the closed expressions for the expected shortfall (according to the position of  $\alpha$  in the cumulative distribution) can be computed as follows:

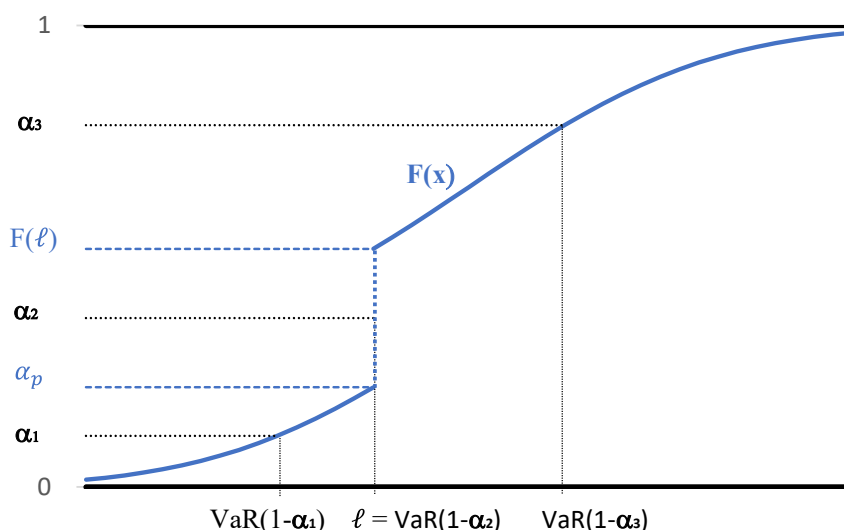
$$\log ES_{1-\alpha} = \begin{cases} -(1-\tilde{p}) \frac{\tilde{\sigma}}{\alpha} \phi \left( \Phi^{-1} \left( \frac{\alpha}{1-\tilde{p}} \right) \right) & \text{if } \alpha \equiv \alpha_1 \\ (\alpha - \alpha_p) \frac{\ell}{\alpha} - (1-\tilde{p}) \frac{\tilde{\sigma}}{\alpha} \phi \left( \frac{\ell}{\tilde{\sigma}} \right) & \text{if } \alpha \equiv \alpha_2 \\ \tilde{p} \frac{\ell}{\alpha} - (1-\tilde{p}) \frac{\tilde{\sigma}}{\alpha} \phi \left( \Phi^{-1} \left( \frac{\alpha - \tilde{p}}{1-\tilde{p}} \right) \right) & \text{if } \alpha \equiv \alpha_3 \end{cases}$$

where  $\alpha_p = (1-\tilde{p})\Phi\left(\frac{\ell}{\tilde{\sigma}}\right)$ , which we also choose to show in **Chart 1**. When implementing these formulas for the purpose of computing haircuts the value of  $\alpha$  is set at 0.01, meaning that it is aligned with an expected shortfall at a 99% confidence level. The derivation of these formulas is set out in Annex I.

<sup>40</sup> The parameters  $\ell, \tilde{\sigma}$  and  $\tilde{p}$  are computed as explained in the previous sections of this paper. In particular, the parameter  $\ell$  is computed from the adopted LGD assumptions as described in section 3.4. For the calibration of the valuation haircut, these parameters are taken at face value. By this it is meant that the parameter uncertainty associated with these estimates is ignored when assembling the estimate of the haircut.

**Chart 1**

Cumulative distribution of log asset returns when accounting for a possible jump to default



Source: ECB.

Finally, the logarithmic ES measure (referring to the expected shortfall in the equation below) is transformed into a haircut expressed in terms of arithmetic returns. The expected shortfall is thus simply computed as  $ES_{1-\alpha} = 1 - \exp(-\log ES_{1-\alpha})$ .<sup>41</sup>

**The model-based estimates of the final haircuts are adjusted by exercising judgement.** Measuring market risk and credit risk is complex, so it would be ill-advised to rely exclusively on a single statistical model. For example, the volatility estimates computed from the model described in Section 3.3 assume that the underlying returns are log-normally distributed. Market risk estimates derived from this model could thus be adjusted by looking at alternative strategies for modelling market risk. One alternative modelling strategy (also employed by ECB staff) is simply looking at the empirical distribution of asset returns and not relying on any distributional assumptions. Looking at the empirical distribution, it allows for potentially fatter tails than a normal distribution, leptokurtic distributions or skewed distributions. However, the reliability of this approach mainly depends on the representativeness of the data sample, as only events that were experienced in the past can be reflected in the market risk estimate. This might potentially lead to an underestimation of future unobserved risk by not including the possibility of outcomes that might be worse than previously experienced. In addition, a large data sample is needed to generate robust estimates. Prudent risk management practice is to consider a multi-model approach. In actual practice, the ECB applies some

<sup>41</sup> In practice, this formal derivation of the total logarithmic expected shortfall is numerically very similar to the straightforward approach of summing up the separately estimated logarithmic expected shortfalls for market and credit risks. Defining the total expected shortfall in logarithmic returns as the sum of market and credit expected shortfalls:  $\log ES_{Total}^{\alpha} \equiv \log ES_{market}^{\alpha} + \log ES_{credit}^{\alpha}$ , we obtain, after converting into arithmetic returns, the simple aggregation formula:  
 $ES_{Total}^{\alpha} = ES_{market}^{\alpha} + ES_{credit}^{\alpha} - ES_{market}^{\alpha} \cdot ES_{credit}^{\alpha}$



discretion and expert judgement, rather than mechanistically relying on the estimates. When doing so, exercising caution and risk prudence is the main aim, also considering the reliability of the estimates and the general consistency of the haircut schedule.

**Other adjustments to the haircuts are also justified because asset market valuations reflect to a certain extent the potential expected losses of risky assets.** This means that a gradual deterioration in credit risk (when spreads widened) may be already captured in our market risk estimates. However, these market risk estimates fail to reflect the jump-to-default risk commonly evaluated by credit risk models. Note that the first summand in our equation (5) in effect provides a “tail” estimate of credit risk, i.e.  $\tilde{p}^{\ell}/\alpha$ . One possible way to adjust this term is to subtract from it the expected losses,  $\tilde{p}^{\ell}$  according to our notation, that are potentially already fully reflected in asset valuations.

## 4 The evolution of the ECB's valuation haircuts

**The ECB regularly reviews its valuation haircuts to ensure that the risk control framework remains sound and risk-efficient across different asset classes.** The ECB manages the collateral framework in such a way as to ensure broad collateral availability, while striving to avoid procyclicality in the valuation haircuts. Both the data available for calibrating the haircuts and the statistical methods employed evolve and improve over time. Developments in financial markets also result in permanent shifts in the risk profiles of certain financial assets. In this context, regularly reviewing the haircut schedule safeguards the ECB's balance sheet and guarantees risk-equivalent treatment across asset classes. This section discusses the evolution of valuation haircuts for marketable assets eligible under the general collateral framework since 1999.<sup>42</sup> A full chronology of the main changes made to the haircut schedule for marketable assets is provided in Annex II, which presents a table with links to the relevant ECB press releases and to the published ECB guidelines documenting the changes.

### 4.1 From Stage Three to the creation of the “Single List”

**At the start of Economic and Monetary Union (EMU), eligible collateral assets were divided into “tier one” and “tier two” assets to accommodate differences in financial structures across euro area countries.** Stage Three of the launch of EMU began on 1 January 1999 with the EMU countries adopting the euro as their single currency. At that time, the ECB adopted a two-tier collateral framework to ensure a smooth transition to the euro. Broadly speaking, tier one assets consisted of liquid marketable debt instruments that fulfilled euro area-wide eligibility criteria, while tier two assets related primarily to non-liquid debt instruments, equity and non-marketable debt. Tier two collateral was of particular importance for many banks in various euro area countries in the early stages of EMU. The ECB applied a more conservative haircut to tier two collateral assets in view of their higher risk and lower liquidity.

**The first collection of valuation haircuts published by the ECB was very parsimonious.** At the start of EMU, haircuts were not very granular. While they took into consideration the maturity of a debt instrument and its coupon type, apart from the assignment of assets to either tier one or tier two no distinction was made among asset classes, for instance government and corporate bonds.<sup>43,44</sup> This parsimonious

<sup>42</sup> Note that the ECB also maintains a temporary collateral framework, although it is less relevant in terms of volumes and is more ad hoc. Haircut amendments in the temporary framework have typically followed those applied in the general framework.

<sup>43</sup> Tier one instruments were accepted by all euro area NCBs with common haircuts, in contrast to tier two instruments belonging to national collateral frameworks. See ECB (1998).

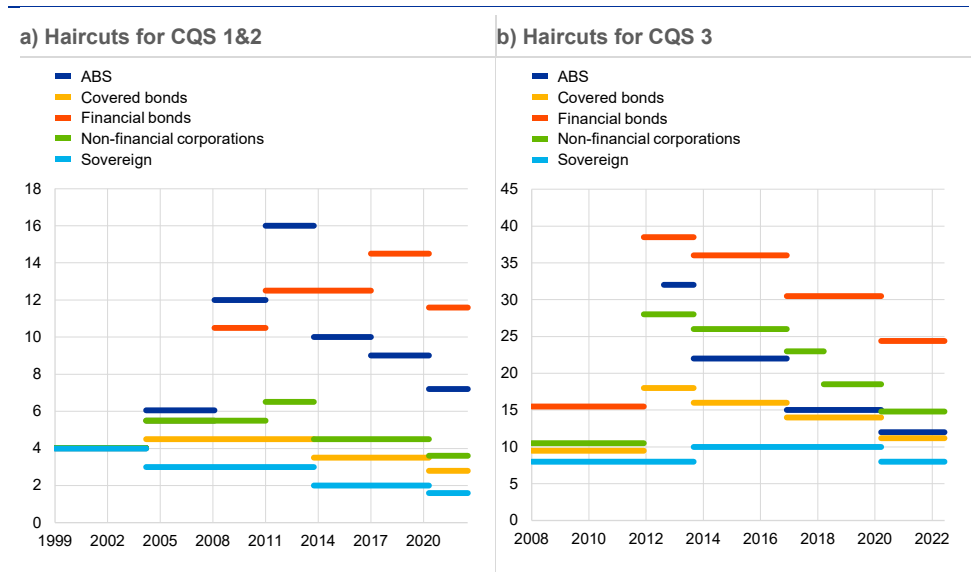
<sup>44</sup> In 2000, the same still applied, except for the introduction of a distinct haircut schedule for instruments with inverse floating coupons. See ECB (2000).

haircut schedule was simple to implement and communicate. It served its purpose at a time when the funding requirements of banks were limited. However, this simplistic haircut schedule was in effect penalising the more liquid marketable assets with relatively high haircuts.

**Since then, haircuts have become more and more granular as the ECB has sought better risk protection and higher residual risk equivalence.** The ECB started to apply a more differentiated haircut approach across asset classes in January 2004. This allowed for more efficient risk protection. Subsequently, the ECB completed the harmonised single collateral framework (referred to as the “Single List”). This single framework replaced the previous two-tier collateral framework (see ECB, 2006). The Single List set the minimum credit standard for eligible marketable assets more conservatively and was broadly aligned with a minimum credit rating of “A”.<sup>45</sup> Certain assets (for example equity) were no longer eligible after the introduction of the framework. However, the Single List included non-marketable assets, previously classified as tier two assets. **Chart 2** shows the evolution of the haircuts applied to fixed coupon assets with a maturity of around six years and belonging to various marketable asset classes since 1999.

### Chart 2

Evolution of ECB valuation haircuts (in percentage) for various marketable debt asset classes with a maturity of around six years since 1999



Source: ECB.

Notes: The haircuts for covered bonds shown in the chart relate to “jumbo” covered bonds. A jumbo covered bond is an EEA legislative covered bond with an issuing volume of at least €1 billion, for which at least three market-makers provide regular bid and ask quotes.

<sup>45</sup> Soon after the establishment of the Single List, the ECB drew a distinction between admissible credit rating grades and one-year probabilities of default across various eligible credit assessment sources, setting, credit quality steps as a function of the one-year probabilities.

## 4.2 From the 2008-09 global financial crisis to the low inflation phase

**Decisions on valuation haircuts were driven by risk management considerations throughout the crisis.** During the years of the global financial crisis, when central bank liquidity needs increased substantially,<sup>46</sup> the ECB implemented four broad reviews to its haircut schedule. These took place in February 2009, January 2011, October 2013 and November 2016 (see Annex II). The revisions were aimed at addressing various shortcomings in the ECB's risk control framework. For the purpose of calibrating these haircuts, the defined risk tolerance adopted by the ECB remained broadly unchanged and at a very low level.<sup>47</sup> During this period, the ECB introduced various measures to alleviate the funding tensions in the banking system. The measures included in particular the easing of collateral eligibility requirements (see Camba-Méndez and Mongelli, 2018 and Bindseil et al., 2017). However, decisions on haircuts were not among the steps taken to alleviate funding conditions.

**The ECB expanded its risk control framework to handle assets of lower credit quality standards.** As part of the collateral easing policies implemented during the global financial crisis, the ECB decided in October 2008 to temporarily set the eligibility requirement with reference to a PD over a one-year horizon of at most 0.40% (credit quality step (CQS) 3, equivalent to a “BBB-” rating class based on a first-best rating rule). However, this decision did not apply to ABSs at the time. Instruments belonging to CQS 3 were initially subject to an additional 5% haircut add-on. In mid-2010, the ECB announced its decision to make the lowering of the minimum credit quality requirement permanent, thus including all marketable assets of CQS 3 (except ABSs) into the general collateral framework.<sup>48</sup>

**During these years, the ECB conducted four broad reviews of its haircut schedule with a view to achieving better risk protection and risk equivalence.** The ECB increased the granularity of the haircut schedule over time to improve risk efficiency. For example, a new haircut schedule with a full set of haircuts defined for each maturity and asset class for CQS 3 was brought into play in January 2011, thus replacing the flat 5% haircut add-on previously used. These new haircuts better reflected the risk differential between, for instance, CQS 3 central government bonds as opposed to senior unsecured bank bonds. In January 2011 risk protection was further strengthened by applying an additional 5% valuation markdown to certain financial assets (initially ABSs but subsequently also covered bonds and unsecured

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<sup>46</sup> In October 2008, in view of the breakdown in money market lending activity due to widespread bank solvency concerns, the ECB switched to a fixed rate tender procedure with full allotment for all its refinancing operations, meaning that it would supply all funds demanded at a fixed interest rate. Banks thus needed larger volumes of central bank collateral.

<sup>47</sup> The main building blocks of the methodology described in Section 3 were set out in 2010 and 2011. Previously, the confidence level used was already 99%, but the benchmark tail measure for the calibration was value-at-risk (VaR), which was slightly less stringent. In addition, instead of employing individual bond returns, bond index returns were used. The latter approach has the drawback of unduly incorporating diversification and tail-smoothing effects.

<sup>48</sup> ABSs of CQS 3 based on the second-best rating became eligible and subject to a specific haircut from September 2012 onwards, although they were, and have remained until today, part of the temporary collateral framework.

debt instruments issued by financial corporations) without a reliable market price that had to be valued with a theoretical model.

The review in October 2013 introduced a haircut add-on for own-use covered bonds following a rapid increase in their mobilisation. This measure required a long lag for implementation, which effectively occurred in early 2016. The haircut add-on was aimed at mitigating the additional risk due to the absence of the first layer of protection in a covered bond when the issuer itself, or a closely linked entity, mobilises the covered bond as collateral.<sup>49</sup>

The review in November 2016 brought about yet more granularity. It did this in two ways. Effective from January 2017, the valuation haircuts applied to ABSs became dependent on their weighted average life, to better reflect their market risks. Effective from April 2018, the ECB introduced a fully-fledged haircut schedule to address the risk associated with floating coupon bonds, whose prices are hedged against increases in interest rate benchmarks but not increases in spreads. This change addressed the risks caused by the lasting significant rise in spread volatility compared with pre-crisis levels, which was especially relevant after the lowering of the credit quality threshold. Floating coupon bonds had hitherto been assigned the haircut corresponding to the lowest maturity bucket. Finally, the substantial reduction in haircuts for category IV assets, mostly made up of unsecured bank bonds, was also partly justified by the more restrictive eligibility criteria made effective in 2019,<sup>50</sup> when non-preferred senior bank bonds lost eligibility following the streamlining of bail-in rules for bank debt brought about by the Bank Recovery and Resolution Directive (BRRD)<sup>51</sup>.

#### **The ECB also decided to report its valuation haircuts in dedicated guidelines.**

The ECB decided to provide information on valuation haircuts for counterparties in standalone legal instruments. Haircuts for marketable assets under the permanent framework are reported in Guideline ECB/2015/35<sup>52</sup>, which has of course been regularly amended following reviews to the haircut schedule. Meanwhile haircuts for marketable assets under the temporary collateral framework are reported in Guideline ECB/2014/31<sup>53</sup> (also with subsequent amendments).

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<sup>49</sup> The calibration of the haircut add-on did not follow a statistical estimation procedure but was primarily based on assumptions about typical covered bond pool characteristics, liquidation scenarios and relative haircut treatment of similar underlying assets. There is a high degree of uncertainty about the value of covered bonds after issuer default owing to the rarity of such an event.

<sup>50</sup> See the [ECB press release of 14 December 2017](#).

<sup>51</sup> Directive 2014/59/EU of the European Parliament and of the Council of 15 May 2014 establishing a framework for the recovery and resolution of credit institutions and investment firms and amending Council Directive 82/891/EEC, and Directives 2001/24/EC, 2002/47/EC, 2004/25/EC, 2005/56/EC, 2007/36/EC, 2011/35/EU, 2012/30/EU and 2013/36/EU, and Regulations (EU) No 1093/2010 and (EU) No 648/2012, of the European Parliament and of the Council (OJ L 173, 12.6.2014, p. 190).

<sup>52</sup> Guideline (EU) 2016/65 of the European Central Bank of 18 November 2015 on the valuation haircuts applied in the implementation of the Eurosystem monetary policy framework (ECB/2015/35) (OJ L 14, 21.1.2016, p. 30).

<sup>53</sup> Guideline of the European Central Bank of 9 July 2014 on additional temporary measures relating to Eurosystem refinancing operations and eligibility of collateral and amending Guideline ECB/2007/9 (ECB/2014/31) (OJ L 240, 13.8.2014, p. 28).

## 4.3 The COVID-19 crisis

**The ECB chose to adjust its risk tolerance level as part of a package of policy measures introduced in March and April 2020 to counter the negative impact of the COVID-19 crisis.** In response to the outbreak of the COVID-19 pandemic, a general 20% reduction in the haircuts was approved in April 2020. This measure was reversed in two steps: (i) a partial reversal in July 2022, together with the partial phasing-out of the COVID-19 collateral easing package, and (ii) a final normalisation, which is planned for mid-2023. It could be argued that this was the first instance of the ECB using haircuts as a monetary policy instrument. That said, if haircuts were to be defined in a broader sense,<sup>54</sup> with ineligible assets simply treated as potentially eligible assets with 100% haircuts, then it would follow that the ECB had in previous occasions implemented a “haircut reduction” by extending eligibility. However, it is worth noting, that in contrast to a specific reduction in haircuts, the extension of collateral eligibility should have no major consequences for the relative risks to the Eurosystem balance sheet after properly calibrated haircuts are applied.

**As well as playing a safeguarding role, haircuts (in the broad sense, that is to say if eligibility is also taken into consideration) could thus also be used as an instrument for both monetary and macroprudential policies.** A haircut reduction provides monetary easing with a direct potential impact on banks’ cost of funding (see Bindseil and Lanari, 2020). Additionally, and as also described by Bindseil and Lanari (2020), the haircut may equally serve as an instrument for macroprudential policy, namely as a tool to provide emergency liquidity to banks, thus avoiding asset fire sales by liquidity-constrained but solvent banks. Independently of whether a central bank chooses to implement a more active policy of haircut changes, it is clear that the choice of the haircut is not a policy-neutral decision. For example, a decision to adopt a more stringent and conservative criterion than the expected shortfall at a confidence level of 99% for the calibration of haircuts has implications for the ability of counterparties to access central bank financing and is thus another parameter that affects the monetary policy stance. From this perspective, the risk appetite embedded in the ECB’s haircuts may vary widely throughout the cycle. At times of great financial volatility, keeping haircuts unchanged (which would be justified by the higher levels of market risk) would be equivalent to allowing for more monetary policy accommodation in turbulent times and would thus be countercyclical.

The temporary haircut easing measures taken in the context of the COVID-19 crisis were unwound with the entry into force of recalibrated haircuts as a result of the review announced in December 2022.<sup>55</sup> In the latter review granularity was further increased via additional maturity buckets and the introduction of maturity-graduated valuation markdowns. Moreover it was decided to reshuffle the composition of haircut categories and to align the treatment of floating-coupon with that of fixed-coupon marketable assets.

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<sup>54</sup> As is the case in Bindseil (2013), for example.

<sup>55</sup> See the [ECB press release of 20 December 2022](#).

## 5 Climate change risk considerations

### **Valuation haircuts should also take climate change risk into consideration.**<sup>56</sup>

Climate change may affect the value and the risk profile of financial assets. The ECB has recently made a commitment to consider climate change risks when reviewing the haircuts it applies to corporate bonds eligible as collateral in credit operations.<sup>57</sup> To the extent that the ECB values assets at market prices, it could be argued that the climate change risks may already be reflected in the market value of an asset. Daily mark-to-market valuation captures climate risk events to the extent that such events lead to a deterioration in the value of the collateral. In this case, there is no financial loss for the ECB. If the value of collateral falls below the amount lent, a margin call is triggered, and the counterparty is asked to replenish the collateral pool. However, climate risks such as price externalities and tail events may not be adequately priced in by market participants if information on the sustainability of financial products remains (i) inconsistent, (ii) largely incomparable, and (iii) unreliable (see Lagarde, 2021). Serious doubts have also been raised over the ability of the market price of CO<sub>2</sub> emissions in the EU's emissions trading system to serve as a proper corrective device (see Schnabel, 2020).

### **The granularity of the ECB's haircut schedule should already reflect climate change risks to a certain extent.**

After a counterparty default, its mobilised marketable collateral is expected to be liquidated within a few weeks depending on the credit quality and liquidity of the assets. Unexpected climate change transition risks are unlikely to materialise over this short time horizon. In addition, to the extent that climate change risks are partly reflected in an issuer's rating, as found in Carbone et al. (2021), then the haircut methods described in Section 3 should also capture those risks.<sup>58</sup> Similarly, if the markets reflected climate change risks in prices and demand<sup>59</sup>, the volatility of the prices and spreads would also be captured in the haircut calibration process. Moreover, if the demand for the bonds with higher climate change risks fell significantly, this would be reflected in the market as liquidity would shrink and time to liquidation would increase. This should naturally increase the estimates for expected shortfall at the 99% confidence level (ES99) and hence the respective haircuts. Therefore, caution is needed to avoid double-counting when considering additional adjustments.

### **As more information becomes available, the clustering of financial assets into haircut categories might need to be redefined to accommodate climate change considerations.**

As indicated in Section 3.1, financial assets with similar

<sup>56</sup> See the [ECB press release of 4 July 2022](#).

<sup>57</sup> See the [ECB climate change action plan in ECB press release of 8 July 2021](#) on the presentation of the climate change action plan following the conclusion of the 2020-21 strategy review; and the [ECB press release of 4 July 2022](#) on further steps taken by the ECB to incorporate climate change into its monetary policy operations.

<sup>58</sup> For example, if the issuer drops from CQSs 1 and 2 to CQS 3 because of increased credit risk induced by its exposure to climate change, its bonds will be considered for the calibration of the haircuts within CQS 3, instead of CQSs 1 and 2 from that point onwards. In addition, the issuer's bonds would immediately have higher haircuts commensurate with the risk estimated for the lower credit quality.

<sup>59</sup> In terms of traded/quoted volume and more generally with respect to the market absorption level.

characteristics are assigned to groups for the calibration of haircuts. At present there are five haircut categories. As more information on the exposures of firms to climate change risks becomes available, the clustering of financial assets into haircut categories may need to be redefined if justified from a risk management perspective. For example, Box 1 looks at the issue of whether tail risk estimates (in terms of ES99) associated with non-financial corporate bonds issued by firms with high levels of greenhouse gas (GHG) emissions are larger than those issued by firms with low levels of GHG emissions.

## Box 1

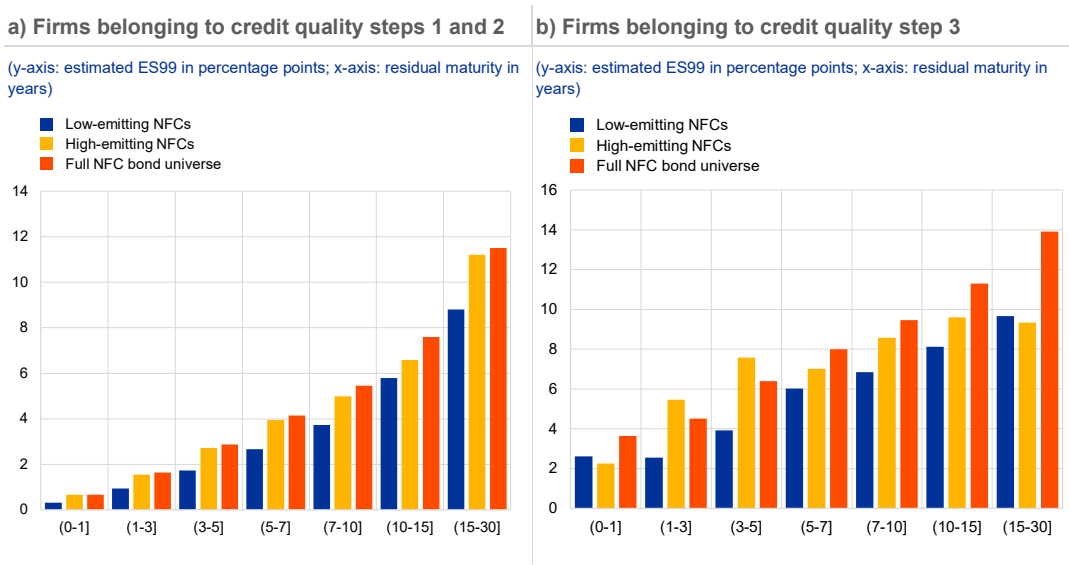
### The risk differential between high and low GHG-emitting issuers

This box presents a statistical analysis of the risk differential between non-financial corporate (NFC) bonds issued by high GHG-emitting issuers and those issued by low GHG-emitting issuers. The tail risk estimates (in terms of ES99) are computed using the methods described in Section 3. The sample used for this analysis is not the full list of the eligible bonds issued by NFCs, but rather those issued by NFCs that choose to disclose data on their carbon emissions.

For our analysis, NFC bond issuers are clustered into two groups based on their relative level of carbon emissions. The relative level of carbon emissions is measured as the ratio between the company's GHG emissions, in tonnes of CO<sub>2</sub> equivalents, and the company's revenues, in USD millions. The company emissions relate to both "direct" emissions generated by the company and "indirect" emissions generated to produce the inputs used by that company for the production process. These are referred to as Scope 1 and Scope 2 GHG emissions respectively under the GHG protocol. After ordering the data according to the level of carbon emissions, we define as high emitters those NFCs in the highest 75th percentile of the overall distribution and as low emitters those in the lowest 25th percentile. The haircuts estimated using both partial samples and the full sample of firms disclosing carbon emissions are shown in Chart A.

## Chart A

### ES99 estimates for NFC bonds according to GHG emissions



Source: ECB staff calculations based on climate metrics provided by Institutional Shareholder Services and Carbon4Finance.



This statistical analysis suggests that the tail risk associated with high emitters is slightly higher than the tail risk associated with low emitters. This difference is more prominent for bonds belonging to CQS 3. Chart A also shows that the ES99 estimates for the whole NFC universe are higher than the estimates for both the low and high-emitting groups, suggesting that the link between emissions and tail risk is not monotonic in our sample. This also indicates that the current haircut schedule is more conservative for both low and high emitters than a more granular haircut schedule that takes into consideration the level of carbon emissions. Hence, the current haircut schedule offers sufficient protection from a financial risk perspective.

The sample size used for our analysis is restricted because we can only focus on the subset of companies voluntarily reporting carbon emissions. The measurement of climate change risk differentials should become more precise in the future as more data become available. On 28 November 2022, the Council of the European Union gave its final approval to the Corporate Sustainability Reporting Directive (CSRD)<sup>60, 61</sup>. The CSRD is aimed at improving companies' disclosures about sustainability issues and the risks arising from them. The current roadmap for the implementation of this legislation envisages a staggered approach in four stages. Companies that already fall under the Non-Financial Reporting Directive (NFRD)<sup>62</sup> will be required to start disclosing such information from 2025 onwards (for the financial year 2024), while other large companies not currently subject to the NFRD and listed small and medium-sized enterprises will be required to start disclosing such information from 2026 and 2027 respectively. Third-country undertakings falling under the CSRD will be required to start disclosures from 2029 onwards. Looking ahead, additional work is also needed to understand how climate risks affect the economy as a whole and how these risks are transmitted to all asset classes beyond the NFC bonds analysed in this box.

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<sup>60</sup> Proposal for a Directive of the European Parliament and of the Council amending Directive 2013/34/EU, Directive 2004/109/EC, Directive 2006/43/EC and Regulation (EU) No 537/2014, as regards corporate sustainability reporting (COM/2021/189 final).

<sup>61</sup> See the [Council of the European Union press release of 28 November 2022](#).

<sup>62</sup> Directive 2014/95/EU of the European Parliament and of the Council of 22 October 2014 amending Directive 2013/34/EU as regards disclosure of non-financial and diversity information by certain large undertakings and groups (OJ L 330, 15.11.2014, p. 1).

## 6 Conclusions and challenges ahead

**The method employed by the ECB to calibrate valuation haircuts of marketable assets follows standard risk management practices.** The ECB's credit operations are conducted only with financially sound counterparties. This represents the first layer of risk protection for the ECB. The remaining counterparty risk is mitigated by lending only against adequate collateral. What constitutes adequate collateral is defined by (i) establishing strict criteria for accepting assets as eligible collateral, including credit quality requirements; (ii) implementing sound methods to value the collateral accurately and in a timely manner; and (iii) applying a discount to the value of the collateral, in other words a valuation haircut. Valuation haircuts are the main tool for mitigating risks incurred by the ECB in collateralised credit operations and are aimed at achieving residual risk equivalence across the ECB's broad range of eligible marketable assets.

**The ECB uses a low level of risk tolerance for the calibration of haircuts, which has remained stable over time, although recent temporary adjustments show that haircuts may also be considered part of the monetary policy toolbox in exceptional circumstances.** Using stringent risk tolerance parameters ensures that very high risk protection is achieved even under adverse market conditions, avoiding the need for frequent changes that would lead to procyclicality. At the same time, a haircut reduction – achieved by increasing the ECB's risk tolerance – can provide monetary easing with a direct potential impact on banks' cost of funding, as decided at the time of the COVID-19 crisis in April 2020.

**Looking ahead, more research work may be warranted to understand the extent to which ECB haircuts affect bond prices.** Some studies have suggested that the haircut level, or the haircut differential attributable to various asset classes, may have a measurable effect on bond prices.<sup>63</sup> Most of these studies focus on measuring the “eligibility premium” (the effect of ECB eligibility on yields) or, alternatively, lowering the implicit 100% haircut on some asset classes. These studies have reported that collateral eligibility has a relatively small impact of on yield spreads (ranging from 7 to 24 basis points). However, the studies are affected by small sample issues due to their construction. The effect of a moderately higher haircut has received less attention in the literature but would naturally be lower than the effect of ineligibility. Historically, point-in-time haircut policy changes, such as the introduction of a haircut add-on for own-use covered bonds in 2017, have not triggered measurable changes in the pricing or the pattern of collateral mobilisation.

**Valuation haircuts should reflect more precisely the risks incurred in credit risk operations backed by “own-use” collateral.** Own-use collateral (consisting of both own-use covered bonds and retained ABSs) represents a very substantial

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<sup>63</sup> See, for example, Ashcraft et al. (2011), Corradin and Rodriguez-Moreno (2016) and Nyborg (2017).

amount of the assets mobilised as collateral with the Eurosystem.<sup>64</sup> However, particular challenges need to be met in order to account properly for the specific “wrong-way” risks associated with structured finance assets that depend on the loan books of counterparties. The ECB currently applies an add-on to the haircut for own-use covered bonds as discussed in Section 3.1. This is a pragmatic way of mitigating such risks. However, this add-on does not sufficiently take into consideration the potential differences between pre-default and post-default cash flows for the covered bondholders, or the risk of subordination to other claims on the bank’s assets in the event of a default. These are very complex matters that depend on factors including the framework established by national laws for post-default management of the covered bond programme, as well as the likelihood of support being provided or of the programme being sold to another bank. These aspects may need to be considered when further refining and calibrating valuation haircuts.

**Further research work on how to employ forward-looking approaches to evaluate climate change risks is also essential.** Currently, there is limited evidence on the impact of climate change risks on the creditworthiness of firms. NGFS (2020) shows that financial institutions surveyed have not established any strong conclusions on a risk differential between green and brown assets. In addition, NGFS (2022) found limited empirical evidence of ex post risk differentials. However, one notable drawback of standard risk assessment models is that they tend to be backward-looking, for instance when analysing whether tail risk estimates are correlated with GHG emissions. There is a growing consensus that forward-looking approaches, which focus on the resilience of financial firms to withstand the impact of future climate events, are crucial when analysing climate change risks. Forward-looking climate change scenarios and stress-testing tools may therefore need to be used (see, for example, NGFS, 2020 and Alogoskoufis et al., 2021). In this context, Carbone et al. (2021) found that disclosing emissions and setting a forward-looking target to cut emissions are both associated with lower credit risk.

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<sup>64</sup> The ECB has defined “retained” mobilised asset-backed securities as those used as collateral in a percentage greater than 75% of the outstanding nominal amount by a counterparty that originated the asset-backed security or by entities closely linked to the originator.

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## Annex I: Formulation of the haircut

As explained in the main text, to formulate the haircut it is necessary to combine the joint market risks and credit risks over the time to liquidation. This is done according to the following three steps.

**Step 1: Finding where the confidence level  $\alpha$  stands in Chart 1.** The cumulative distribution function for asset returns (embedding market and credit risk concerns) is described by equation (4) in the main text. It follows that whenever  $\alpha < (1 - \tilde{p})\Phi\left(\frac{\ell}{\tilde{\sigma}}\right)$  then this is the situation shown in **Chart 1** as  $\alpha_1$ ; if  $\alpha > F(\ell)$  then this is shown in **Chart 1** as  $\alpha_3$ ; and otherwise, we are in the case shown as  $\alpha_2$ .

**Step 2: Computation of  $Var(1 - \alpha)$ .** Note that  $Var(1 - \alpha) = \inf\{x | F(x) > \alpha\}$ , and then it easily follows that:

$$Var(1 - \alpha) = \begin{cases} \tilde{\sigma}\Phi^{-1}\left(\frac{\alpha}{1 - \tilde{p}}\right) & \text{if } \alpha \equiv \alpha_1 \\ \ell & \text{if } \alpha \equiv \alpha_2 \\ \tilde{\sigma}\Phi^{-1}\left(\frac{\alpha - \tilde{p}}{1 - \tilde{p}}\right) & \text{if } \alpha \equiv \alpha_3 \end{cases}$$

**Step 3: Computation of the expected shortfall.** The final step is to compute the integral (5) in the main text. Note that asset returns are represented by a random variable with mass probability  $\tilde{p}$  at  $\ell$  and a standard normal density, weighted by  $(1 - \tilde{p})$  at all other points. The formulation of the expected shortfall for  $\alpha_2$  requires a little more explanation, which we provide further down. However, it easily follows for the cases  $\alpha_1$  and  $\alpha_3$  that:

$$\log ES_{1-\alpha} = \begin{cases} \frac{(1 - \tilde{p})}{\alpha} \int_{-\infty}^{Var(\alpha)} x \frac{1}{\tilde{\sigma}} \phi\left(\frac{x}{\tilde{\sigma}}\right) dx & \text{if } \alpha \equiv \alpha_1 \\ \frac{1}{\alpha} \tilde{p}\ell + \frac{(1 - \tilde{p})}{\alpha} \int_{-\infty}^{Var(\alpha)} x \frac{1}{\tilde{\sigma}} \phi\left(\frac{x}{\tilde{\sigma}}\right) dx & \text{if } \alpha \equiv \alpha_3 \end{cases}$$

By solving those integrals, the expressions of the expected shortfall reported in the main text in equation (5) easily follow. The case of  $\alpha_2$  requires some further explanation. In particular, note that  $F^{-1}(\alpha_2)$  is ill-defined. To address this issue, we pursue the following strategy to obtain a “sensible” estimate of the expected shortfall. First, we redefine the probability mass associated with a default event as  $(\alpha - \alpha_p)$ , where  $\alpha_p = (1 - \tilde{p})\Phi\left(\frac{\ell}{\tilde{\sigma}}\right)$  as defined in **Chart 1**. We can then simply take

$$\log ES_{1-\alpha} = \frac{1}{\alpha}(\alpha - \alpha_p)\ell + \frac{(1 - \tilde{p})}{\alpha} \int_{-\infty}^{Var(1-\alpha)} x \frac{1}{\tilde{\sigma}} \phi\left(\frac{x}{\tilde{\sigma}}\right) dx \quad \text{if } \alpha \equiv \alpha_2$$

as the “sensible” approximation for the expected shortfall.

## Annex II: Haircut chronology

Type of change	Measure	Announcement date	Implementation date	Technical details
<b>Stage Three of EMU</b>	The single monetary policy in Stage Three (haircuts for tier one assets)	18/09/1998	01/01/1999	GD-1998
<b>First ECB guideline released</b>	Minimum haircut requirements for tier two eligible assets	05/12/2000	01/01/2001	ECB/2000/7 (*)
<b>Haircut review</b>	Introduction of more granular maturity breakdown for haircuts Differentiation of haircuts of tier one assets into four haircut categories	06/02/2004	08/03/2004	ECB/2003/16
<b>Single List</b>	Adoption of a single list of collateral (haircut schedule for tier two discontinued)	15/09/2006	01/01/2007	ECB/2006/12
<b>Haircut review</b>	Differentiation of haircuts into five haircut categories (I, II, III, IV and V) Introduction of theoretical valuation markdown of 5% for ABSs	04/09/2008	01/02/2009	ECB/2008/13
<b>Expansion of collateral</b>	Eligibility temporarily set with reference to a PD over a one-year horizon of at most 0.40% (equivalent to a "BBB-" rating class). This decision did not apply to ABSs. Assets rated below "A-" subject to an additional 5% haircut add-on	17/10/2008	22/10/2008	ECB/2008/11 (T)
<b>Expansion of collateral</b>	Marketable debt instruments denominated in US dollar, euro and Japanese yen become temporarily eligible subject to an additional haircut add-on of 8%	12/11/2008	14/11/2008	ECB/2008/11 (T) ECB/2008/18 (T)
<b>Haircut review</b>	Minimum requirement under permanent framework: PD over a one-year horizon of 0.40% as equivalent to credit quality step 3 (credit quality step 3 is broadly equivalent to a "BBB" rating) Introduction of graduated haircuts for assets rated in the "BBB+" to "BBB-" range or equivalent (replacing previous 5% haircut add-on) Non-jumbo covered bonds assigned to haircut category III 5% theoretical valuation markdown extended from ABS to unsecured bank bonds	08/04/2010	01/01/2011	ECB/2010/13
<b>Targeted change</b>	New haircuts for additional ABSs that become eligible under the temporary framework	22/06/2012	29/06/2012	ECB/2012/11 (T)
<b>Targeted change</b>	New haircuts for ABSs rated "BBB" (now eligible under the temporary framework)		14/09/2012	ECB/2012/18 (T)
<b>Targeted change</b>	Greek sovereign debt (below credit quality step 3) subject to specific haircuts	19/12/2012	21/12/2012	ECB/2012/32 (T)
<b>Targeted change</b>	Cypriot sovereign debt (below credit quality step 3) subject to specific haircuts	02/05/2013	09/05/2013	ECB/2013/13 (T)
<b>Haircut review</b>	Introduction of haircut add-on for own-use covered bonds Reduction in haircuts for ABSs	18/07/2013	01/10/2013 to 01/01/2014	ECB/2013/35 ECB/2013/36 (T)
<b>(no change)</b>	Haircuts under the temporary framework reported in a new dedicated guideline			ECB/2014/31 (T)
<b>Targeted change</b>	New haircut schedule for Greek sovereign debt (below credit quality step 3)		15/12/2014	ECB/2014/46 (T)
<b>(no change)</b>	Haircuts under the permanent framework reported in a new dedicated guideline	20/11/2015	20/11/2015	ECB/2015/35
<b>Targeted change</b>	New haircut schedule for Greek sovereign debt (below credit quality step 3) in view of the specific market and credit risk conditions	22/06/2016	29/06/2016	ECB/2016/18 (T)
<b>Haircut review</b>	Switch to weighted average life-graduated haircuts for ABSs Maturity-graduated haircuts for floating rate instruments in Q4 2017	03/11/2016	01/01/2017	ECB/2016/32 ECB/2016/33 (T)

Type of change	Measure	Announcement date	Implementation date	Technical details
<b>Targeted change</b>	Haircut schedule for floating coupon bonds ready for implementation		16/04/2018	<a href="#">ECB/2018/4</a>
<b>COVID-19 measures</b>	General 20% reduction in haircuts as part of collateral easing measures linked to COVID-19	<a href="#">07/04/2020</a>	07/04/2020	<a href="#">ECB/2020/20 (T)</a>
<b>Partial phasing-out of COVID-19 measures</b>	Partial phasing-out of collateral easing measures - halve the temporary reduction in valuation haircuts across all assets from the current 20% adjustment to 10%.	<a href="#">24/03/2022</a>	08/07/2022	<a href="#">ECB/2022/18 (T)</a>
<b>Haircut review</b>	Full phasing-out of collateral easing measures – risk tolerance restored to expected shortfall at the 99% confidence level  Split longest residual maturity bucket into three new categories, alignment of fixed- and floating-coupon haircuts for marketable assets, reclassification of covered bonds and EU bonds	<a href="#">24/03/2022</a> and <a href="#">20/12/2022</a>	29/06/2023	<a href="#">ECB/2022/49</a> <a href="#">ECB/2022/50 (T)</a>

Notes: The changes listed in the table relate to the valuation haircuts of the marketable assets under the general collateral framework. The "Announcement date" and "Technical details" columns provide hyperlinks to the relevant information on the internet. The links in the "Announcement date" column are to press releases. The link in the first row of the "Technical details" column is to general documentation. All other links in the "Technical details" column are to guidelines.

(\*) This had previously been published as an internal ECB publication in 1998, and in the form of an EU guideline in August 2000. In 2000, there were separate haircuts for "inverse" floating coupon bonds; we choose to ignore those assets which are no longer eligible.

(T) indicates a measure affecting the temporary collateral framework; all other measures are part of the permanent collateral framework.



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