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Circular economy, non-financial disclosure and credit risk in Europe

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CIRCULAR ECONOMY, NON-FINANCIAL DISCLOUSURE AND CREDIT RISK IN EUROPE

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Circular Economy, Non-Financial Disclosure and Credit Risk in Europe

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Abstract

The circular economy (CE) is increasingly recognized as a financially material dimension of corporate sustainability, complementing and in some respects surpassing traditional Environmental, Social, and Governance (ESG) metrics. Building on prior evidence of a negative relationship between firms' degree of circularity and their default risk, this paper investigates how non-financial disclosure (NFD) on CE matters interacts with actual circular practices in shaping credit risk. Using a panel of 643 listed firms from 17 resource-intensive industries across the EU-15 and Switzerland over 2018–2023, we combine circularity-related NFD data with multiple market-based and fundamental-based measures of default risk. Employing a two-step methodology, we decompose firms' degree of circularity into a "core" component, capturing substantive engagement in CE, and a disclosure-driven component, to test three hypotheses. First, we find that NFD is positively associated with circularity, consistent with the view that higher-level disclosure reflects greater circular engagement. Second, we show that core circularity, net of disclosure effects, is negatively associated with default risk, confirming its de-risking role. Third, we provide evidence that NFD alone contributes to credit risk assessment, albeit less strongly than core practices. Overall, our findings indicate that while substantive circular transitions are the primary driver of de-risking, disclosure provides a complementary signaling channel valued by creditors. This study contributes to the literature on the financial implications of CE and sustainability practices and offers practical insights for firms, investors, and policymakers concerned with corporate sustainability, credit assessment, and the transition toward a more circular economy.

Keywords: credit risk, non-financial disclosure; de-risking; circular economy; sustainable finance.

JEL code: G32, G21, G10, G39

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1. Introduction

CE is an economic model that decouples growth from resource consumption by closing material loops, reducing waste, and promoting regenerative production cycles (Ellen MacArthur Foundation et al., 2021). Unlike the linear economy, CE prioritizes reuse, recycling, and resource efficiency, ensuring economic resilience and long-term sustainability (European Commission, 2020) and it is increasingly recognized as a new dimension of sustainable development, integrating financial, managerial, and economic strategies to enhance competitiveness (Aivazidou et al., 2025). By embedding circular principles into business models, supply chains, and investment frameworks, CE can lead to cost efficiency, financial stability, and resilience against resource scarcity and market volatility (Silva et al., 2025; World Bank, 2022).

A key debate in financial research concerns whether CE should be classified within the ESG paradigm or as a separate one. For instance, unlike ESG, which is segmented into its three pillars, CE cuts across environmental and social dimensions, albeit some recent novelties in legislation, such as the EU Taxonomy Regulation (No. 2020/852), tend to frame it predominantly in environmental terms. Moreover, Molden et al. (2025) argue that ESG primarily functions as a reporting framework, whereas CE actively transforms economic systems. ESG focuses on measuring impact, while CE creates direct business value through sustainable resource management and circular supply chains (Jakobsen et al., 2025). CE also reduces costs, improves efficiency, minimizes vulnerabilities, and drives green industrialization and economic competitiveness, while ESG is often compliance-driven (Bernal-Ortega et al., 2025; Veloso et al., 2025). Nonetheless, CE-based investments enhance ESG ratings by reducing carbon footprints and improving supply chain efficiency (Shukla et al., 2025), thus supporting the achievement of ESG objectives (UNEP Finance Initiative, 2024). Rather than replacing ESG, CE accelerates its strategic impact goals.

The relevance of CE for financial performance is grounded in its role as a driver of financial materiality within the realm of sustainability. Since the introduction of the Principles for Responsible Investment in 2005, regulatory initiatives at both national and supranational levels have increasingly emphasized the mitigation of and adaptation to climate change – and sustainability in more general terms. As a result, firms have been required to expand their non-financial disclosure (NFD) to demonstrate alignment with more sustainable business models that address environmental protection and social inclusion. While the mainstream of sustainability research and practice has focused on ESG and the SDGs, CE has gained momentum as an additional and distinctive dimension of sustainability.

Adopting circular practices – that is, gradually transitioning toward a circular way of doing business – enables firms to achieve financial benefits by optimizing resources over the long term and

across the entire value chain, with such efficiency being "driven by design" (Ellen MacArthur Foundation, 2012). In particular, transitioning toward a CE helps eliminate waste and pollution, maximize the value of products and materials that are in the economic system, and generate a positive impact on the environment, as it preserves virgin resources by limiting the exploitation of finite stocks of materials and natural capital (Ellen McArthur Foundation et al., 2021). At the company level, CE generates financial benefits by reducing sensitivity to raw material and energy price volatility, mitigating climate-related transition risks, and boosting managerial efficiency by employing inputs for longer cycles. In addition, for the sake of communities at large, CE alleviates negative externalities, leading companies to exhibit a smaller carbon footprint and to more easily withstand exogenous shocks (Zara et al., 2023).

Despite increasing recognition of the financial relevance of CE, its role in credit risk remains underexplored. Prior research on corporate sustainability performance (CSP), typically measured through ESG, has largely focused on corporate financial performance (CFP) outcomes such as market value and cost of capital (Friede et al., 2015; Revelli & Viviani, 2015; Pástor et al., 2022). More recently, evidence has begun to link ESG awareness with credit risk, suggesting that firms with stronger sustainability engagement enjoy better creditworthiness and lower default probabilities (Brogi et al., 2023; Caiazza et al., 2023; Okimoto & Takahoka, 2021). Yet, whether circularity exerts similar financial effects has so far attracted limited empirical attention, and the financial implications of circularity remain relatively underexplored. Early contributions have highlighted the de-risking potential embedded in circular asset classes (Stahel, 2010; Kama, 2015; Lacy et al., 2019; Zara & Ramkumar, 2022), thanks to the fact that abiding by the CE paradigm is usually associated with a more stable profile of cash flows over the long term, particularly in relation to resource procurement and pricing. Evidence also suggests that circularity supports superior risk-adjusted performance (Zara et al., 2022) and that circular firms demonstrated greater resilience during the Covid-19 shock, as a marked reduction in both total risk and its systematic component arose during and in the post-shock phases (Zara et al., 2023). However, empirical studies at the company level remain scarce.

In this context, both policymakers and researchers have acknowledged the financial effects associated with corporate reporting. Over the last years, stakeholders – not merely shareholders and investors – have been using NFD to mold their relationship with companies. This trend is reflected in the ongoing regulatory push, particularly in Europe, where authorities have progressively broadened the scope of disclosure requirements, most recently through the Corporate Sustainability Reporting Directive (CSRD), which aims to enhance data quality and curb greenwashing. Yet, debate remains as to whether NFD merely operates as a transmission channel for underlying practices or

generates financial materiality in its own right. This ambiguity makes it crucial to explicitly consider the role of NFD when assessing how circularity affects firms' financial outcomes.

Building on this gap, the goal of this paper is to examine the relationship between a company's degree of circularity and its credit risk, with NFD acting as a potential channel through which CE practices generate a de-risking effect. To capture firms' circular engagement, we employ the Circularity Score (CS), a firm-level metric developed by Zara & Ramkumar (2022) and further refined in Zara et al., 2023, which is based on Refinitiv ASSET4 data. Because the CS is constructed from non-financial disclosure, we explicitly decompose it to separate the disclosure-driven component from the underlying "core" circularity dimension. This enables us to test whether NFD plays a signaling role in conveying financial materiality to lenders and investors, beyond its function as an input to the score itself.

Our analysis contributes to the literature in three ways. First, we employ a firm-level measure of circularity that explicitly incorporates CE-related indicators disclosed by corporations, thereby providing a more granular perspective on corporate sustainability performance. Second, we investigate the relationship between circularity and credit risk, distinguishing between the effects of substantive business model transformation (i.e., "core" circularity) and firms' disclosure practices. This distinction allows us to deepen our understanding of the communicative and strategic dimensions of sustainability reporting vis-à-vis both shareholders and creditors. Third, we demonstrate that the de-risking effect of circularity persists across alternative specifications and after controlling for firms' ESG performance. This underscores that circularity conveys information incremental to conventional ESG metrics and serves as a complementary source of financial materiality in credit markets.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature and develops the hypotheses to be tested. Section 3 outlines the data collected and defines the key variables. In Section 4, we present the methodology used to construct the variables and implement our empirical strategy. Section 5 provides descriptive statistics, while Section 6 presents the main results and robustness checks. In Section 7, we discuss these findings, and Section 8 concludes with the key takeaways.

2. Literature Review and Hypotheses Development

2.1. ESG and corporate financial performance

A substantial body of research has examined the link between CSP, measured by means of ESG ratings, and CFP. While the impact of a higher CSP on stock performance and bond prices remains debated (e.g., Pástor et al., 2022), stronger empirical evidence emerges when focusing on market value and the cost of capital, the most common proxies of CFP. Meta-analyses and systematic

literature reviews have outlined that, although the share of dissenting studies is not negligible at all (e.g., Whelan et al., 2021), most of the research ends up gauging a positive causal association between CSP and CFP (Friede et al., 2015; Revelli & Viviani, 2015).

Given the focus on a net-zero carbon society, research also indicates that the environmental pillar alone can impact CFP as environmental practices are associated not only with lower debt financing costs and higher credit ratings (Bauer & Hann, 2014), but also with hedging benefits against shocks such as oil price fluctuations (Benlemlih et al, 2024). Still, scholars caution against treating CSP as a monolithic construct. Sassen et al. (2016), for example, emphasize the risks of relying on either single ESG pillars or aggregated indices without considering underlying heterogeneity. Indeed, recent work documents persistent divergence across ESG ratings – termed "aggregate confusion" (Berg et al., 2022) – and relatively low correlations across issuer-level ratings (Balasirishwaron et al., 2022). These findings underscore the importance of standardized measurement practices and of disaggregating the financial effects of sustainability across different aspects of firm activity, such as cash flow generation, idiosyncratic risk, and growth as a result of competitive advantage (Gregory et al., 2014).

Focusing specifically on credit risk as a dimension of CFP, evidence suggests that ESG awareness is positively associated with creditworthiness. Brogi et al. (2023) and Caiazza et al. (2023) find that firms with stronger ESG engagement exhibit lower default risk, even when controlling for endogeneity. The underlying mechanisms are consistent with reduced dependence on external suppliers and markets, leading to more stable revenues and improved cash flow resilience despite higher upfront capital or R&D investments. Other studies highlight market-based measures: in Japan, ESG performance lowers credit spreads, with the effect most pronounced among low-rated firms (Okimoto & Takahoka, 2021). At the sovereign level, Hübel (2022) show that countries with stronger ESG profiles benefit from lower CDS spreads and flatter CDS-implied credit curves. Interestingly, they also find that CDS markets incorporate ESG information differently from rating agencies, assigning an additional spread premium for high ESG risks even after controlling for credit ratings.

2.2. The financial materiality of CE

Replacing the ESG framework with the circular economy offers a way to strengthen the financial materiality of CSP. Unlike ESG, which largely emphasizes the mitigation of negative externalities within a linear model, CE represents a "new economy" that rethinks and redesigns products and processes to achieve sustainable development (Ellen MacArthur Foundation, 2012). Its underlying rationale combines a business logic – higher profitability, reduced systematic and idiosyncratic risks, and enhanced risk-adjusted performance, partly through reputational benefits (Zara et al., 2023)

– with broader societal benefits, as CE is inherently "restorative" and "regenerative by design". Moreover, the circular transition aligns with the United Nations' SDGs and is promoted as a key avenue to foster responsible banking and sustainable finance (UNEP Finance Initiative, 2024).

At the firm level, circularity creates value through multiple channels: the use of more durable or replenishable inputs to address resource scarcity; greater product efficiency through optimized usage; and redesigned end-of-life processes that minimize waste. These mechanisms often lead to the emergence of innovative business models (Lacy & Rutqvist, 2015), with positive spillovers for both firms and financial institutions (UNEP Finance Initiative, 2020).

Empirical research linking CE directly to financial outcomes remains limited but is growing. Zara & Ramkumar (2022) provide the first evidence on the relationship between a firm's degree of circularity, measured through the CS, and its credit risk. Specifically, they show that more circular firms exhibit lower probabilities of default (PD), both in the short run (1 year) and in the medium to long run (5 years). Their dominance analysis further indicates that circularity exerts a relatively significant effect on PDs. Subsequent studies confirm the de-risking potential of circularity: Zara et al. (2022) report that firms more engaged in CE achieve superior risk-adjusted equity performance, while Zara et al. (2023) document that circular firms were more resilient during the Covid-19 shock, experiencing stronger reductions in both total and systematic equity risk. These findings echo broader sustainability research showing that strategic non-linear transitions can buffer firms against exogenous shocks (Godfrey et al., 2009; Das et al., 2018).

2.3. The role of NFD

Shifting from ESG indicators – whether aggregated or disaggregated – to CE metrics in NFD marks an evolution in the way sustainability is communicated. Yet, current practice is shaped by vague guidance on CE disclosure, as reflected in the content observed within corporate sustainability reports. Most reported activities still emphasize end-of-life product management and raw material sourcing, while aspects such as circular product design and business model innovation are addressed less frequently (Stewart & Niero, 2018). Nevertheless, incorporating CE metrics into NFD is essential for advancing our understanding of the link between CSP and CFP, as well as for evaluating how disclosure shapes firms' risk profiles.

The role of information in financial markets has been increasingly recognized in financial research, particularly in the wake of the 2007 financial crisis, which sparked greater interest in the informational role of corporate reporting. With the rise of sustainability, attention has shifted toward NFD, though the evidence on its financial implications remains limited and often inconclusive (Benlemlih et al., 2018). Both agency theory and stakeholder theory suggest that firms with higher CSP

have stronger incentives to engage in NFD: disclosure reduces information asymmetry, enhances investor involvement, and yields positive financial outcomes. Empirical studies indeed document associations between NFD and higher market value (Eng et al., 2021), improved market-to-book ratios (Laskar & Maji, 2018), lower cost of capital (Orens et al., 2010; Dhaliwal et al., 2011), and fewer financing constraints (Cheng et al., 2014; Gjergji et al., 2021). Schiehll & Kolahgar (2021) further show that ESG-related NFD enhances stock price informativeness, with disclosure materiality amplifying this effect.

The relationship between NFD and risk, however, remains contested. Some studies find a negative association with total risk (Alsaifi et al., 2022), while others report that NFD reduces only idiosyncratic risk (Tzouvanas et al., 2020; He et al., 2022). By contrast, James-Overheu & Cotter (2009) find no significant link between corporate governance or sustainability disclosure and default risk. Other contributions suggest that more sustainable firms tend to perform better due to the de-risking role of ESG-related disclosure, highlighting a connection between NFD – and especially its time-varying dynamics – and both systematic risk (cost of capital, market value) and idiosyncratic risk (profitability, tail risk) (Giese et al., 2019; Eliwa et al., 2021). Yoo & Managi (2022) add that while ESG media disclosure appears crucial for short-term profits, substantive sustainable action is essential for long-term financial performance.

Overall, the evidence remains fragmented. Studies vary widely in geographical scope, institutional context, and period of analysis, which complicates cross-country comparisons given persistent divergences in sustainability frameworks and disclosure regulations. This heterogeneity underscores the need for further research on how NFD interacts with firm-level practices – such as circularity – to affect credit risk assessment.

In light of the above, we formulate three hypotheses.

Hp. 1: The intensity of NFD is positively associated with a firm's degree of circularity, measured through the CS.

Hp. 2: A firm's degree of circularity, net of disclosure effects, is negatively associated with default risk in both the short run (2a) and the medium to long run (2b).

Hp. 3: The intensity of NFD alone is negatively associated with default risk in both the short run (3a) and the medium to long run (3b).

Hp. 1 is preliminary and pertains to the first step of our analysis, where the CS is decomposed to separate its disclosure-driven content. This hypothesis tests whether disclosure is systematically related to circularity itself, consistent with the literature on the role of corporate transparency and reporting practices. Hp. 2 and Hp. 3 address financial materiality. Hp. 2 examines whether circularity – once purged of disclosure effects – reduces default risk, thereby extending the CSP–CFP literature by introducing circularity as a new dimension of CSP. Hp. 3 focuses on disclosure alone and assesses whether the intensity of NFD contributes independently to credit risk reduction, consistent with prior research emphasizing the importance of information disclosure in capital markets.

3. Data and variables

3.1. Sample construction

We construct our sample by focusing on firms that are most exposed to the transition toward a circular economy. This focus allows us to capture sharper contrasts between firms that are at the forefront of adopting the new paradigm and those that lag behind. Moreover, we restrict the analysis to the period 2018-2023, when the pace of the circular transition has accelerated markedly. Following the selection criteria of Zara et al. (2023), we identify companies that:

a) operate in the manufacturing, construction, metal mining, oil & gas extraction, and utilities sectors, pursuant to the Standard Industry Classification system (US SIC)[1], based on the relevance that the CE transition holds in these areas;
b) are listed in EU-15 markets[2] or Switzerland, given the pioneering role that these jurisdictions have been playing in the transition to a circular economy, both in the private and the public realm. For instance, the Circular Economy Action Plan (European Commission, 2020) sets forth provisions related to products' design, production processes, and sustainable consumption, intending to enhance waste prevention and resource usage;
c) have non-financial information and data available over the sample period, enabling us to compute their degree of circularity for at least one year.

We end up with a sample made of 643 companies, pertaining to 17 different industries based on the Sustainable Industry Classification System (SICS), developed by the Sustainable Accounting Standards Board (SASB)[3]. Although criterion *(a)* actually identifies 19 industries, two of them –

[1] Within it, companies are assigned a four-digit numerical identifier based on their primary line of business. Thus, each sector has a unique identifier. The SIC system arrays the economy into 11 divisions, that are divided into 83 two-digit major groups, that are further subdivided into 416 3-digit industry groups and finally disaggregated into 1,005 4-digit industries.
[2] "EU-15" denotes those 15 countries that were members of the European Union between 1 January 1995 and 30 April 2004.
[3] For the sake of conciseness, and to avoid confusion with US SIC, which is unrelated to sustainability issues, we shall henceforth refer to those represented in our sample as "SASB industries". Relative to the entities in our sample, a reconciliation between US SIC, on the one hand, and SASB SICS, on the other, is provided in Tellini et al. (2022) and Zara & Bellardini (2023).

namely, *Agricultural Products* and *Building & Furnishing Products* – turn out to be empty after applying *(b)* and *(c)*. A detailed overview of sample composition is provided in Tables 1a-1b, highlighting a good degree of diversification across both countries and industries.

[INSERT TABLES 1a-1b ABOUT HERE]

3.2. Variables

We rely on the methodology developed by Zara & Ramkumar (2022) to measure a company's degree of circularity – that is, its progress toward adopting a circular business model in place of the traditional "take-make-use-dispose" (linear) paradigm. The resulting metric, the *Circularity Score*, incorporates several important updates relative to the original framework. Specifically, the number of ESG indicators relevant to the CE paradigm has been expanded from 140 to 167. In addition, the twelve categories that now compose the five CE-based pillars have been reshaped, which in turn alters the industry-specific adjustment for financial materiality within each category. The decomposition of the CS into pillars and categories is reported in Table 2.

[INSERT TABLE 2 ABOUT HERE]

NFD intensity is expressed by two "factors" – i.e., by construction, two linearly independent variables – resulting from a Principal Component Analysis (PCA), whose details are described in par. 4.1:

- *Information extension*: that is, a measure that mainly depends on NFD quantity and quality, which both legal constraints on NFD and voluntary disclosure can influence.
- *Information protection*: that is, a measure reflecting the strength of investors' protection in a firm's home jurisdiction, beyond the traditional civil versus common law distinction.

Employing a two-step methodology (see par. 4.2 for details), we decompose the CS into its constituents: the two abovementioned PCA factors (i.e., the NFD component), on the one hand, and the first-step regression residuals (i.e., the algebraic difference between the CS observed and fitted values), which we label *Core Circularity Score*. Notice that, unlike the CS, this new variable does not range between 0 and 1.

We proxy credit risk by using four different measures, also for the sake of robustness. All of them are computed by Bloomberg via proprietary algorithms, and they are available in its database:

- *Probability of default, 1-year*; that is, the likelihood of the company becoming insolvent over a 1-year horizon;
- *Probability of default, 5-year*; that is, the likelihood of the company becoming insolvent over a 5-year horizon;
- *Distance to default, 1-year*; that is, a quantitative measure used to assess a firm's credit risk, particularly its likelihood of defaulting on debt obligations.[4] It is defined as the number of standard deviations that a firm's asset value is away from the default point, which is typically the value of its liabilities.
- *Implied CDS spread, 5-year*; that is, in basis points, the risk premium that would be theoretically paid by investors who were willing to hedge themselves against the company's default by purchasing a hypothetical credit default swap (CDS) contract, obtained by interpolating the actually paid premia on existing CDS with the ratings attributed to those companies.

When entering the empirical models as dependent variables (see par. 4.2), all four default risk variables are log-transformed to mitigate the potential biases arising from the presence of outliers and their potential non-linearity (Eichler & Sobański, 2016). Since we need to control for an entity's financial characteristics to isolate the effect played by 'core' circularity and NFD intensity, we also look at a company's size (*Total assets*), leverage (*Debt-to-equity ratio*), liquidity (*Interest coverage ratio*), solvency (*Net debt payback period*) and profitability (*Profit margin*), as well as the possible presence of a capital impairment (*Negative equity, dummy*).

A full description of all the variables that we employ in this study, including those whose construction is detailed in par. 4.1, is provided in Table 3.

[INSERT TABLE 3 ABOUT HERE]

4. Methodology

4.1. Non-financial disclosure factors via PCA

To address the high dimensionality of our NFD dataset, we apply principal component analysis (PCA). This approach allows us to reduce the number of variables while retaining the most informative components, thereby distinguishing between items that materially contribute to our analysis and those that do not. The resulting factors capture interpretable dimensions of disclosure that can be incorporated into our empirical models.

[4] This metric is a central component of Bloomberg's Default Risk (DRSK) model.

In line with prior studies (Laskar & Maji, 2018; Li & Liu, 2018), we measure NFD along two dimensions: the level and the composition of disclosure. While these metrics do not capture disclosure quality in a normative sense, they provide an objective method to distinguish between information that is publicly released and that which is withheld. Specifically, we construct two variables, namely *Disclosure quality* (*DQ*) and *Disclosure level* (DL). For *DQ*, which is pertinent to composition, we assign a score of 2 if an item is quantitatively disclosed, 1 if disclosure is merely qualitative, and 0 if there is no disclosure at all. Among the 167 Refinitiv-based Indicators that are included in CS computation, 73 are quantitative (i.e., expressed as continuous values), whereas 94 are boolean (i.e., expressed in qualitative terms that may be quantified only as discrete values); hence, the maximum possible disclosure score is $2 \cdot 73 + 1 \cdot 94 = 240$. The *DQ* score is computed as the ratio between the sum of the scores assigned to each item and the maximum possible value. Thus, for each company $\tilde{\imath}$, we have:

$$\mathrm{DQ}_{\tilde{\imath}} = \frac{\sum_{d=1}^{n} x_{\tilde{\imath}d}}{240}$$

where d indexes disclosure items and $x_{\tilde{\imath}d} \in \{0; 1; 2\}$ denotes the assigned score.

DL, in turn, measures the extent of disclosure irrespective of composition. It is defined as the ratio of disclosed circular items to the total number of items considered. Thus, for each given company $\tilde{\imath}$, we have:

$$\mathrm{DL}_{\tilde{\imath}} = \frac{\sum_{i=1}^{n} x_{\tilde{\imath}d}}{167}$$

where 167 is the maximum number of circular items.

In addition to *DQ* and *DL*, we include *Legal tradition* as a further variable in the PCA. It is a categorical variable capturing the legal origin of a firm's headquarters country. Following La Porta et al. (2008), it takes values 1 to 4 depending on investor protection strength: 1 if the legal tradition is French, 2 if German, 3 if Scandinavian, and 4 if English. Based on the assumption that tighter investor protection is associated with broader disclosure, the variable increases monotonically with disclosure extension.

Table 4 shows the PCA results.

[INSERT TABLE 4 ABOUT HERE]

Following standard practice, we keep principal components with eigenvalues greater than one. Accordingly, we retain the first and second components, the latter having an eigenvalue approximately equal to one. Together, they explain 99% of the total variance in the input variables and they are linearly independent by design. Principal Component 1 loads heavily on *Disclosure quality* and

Disclosure level, capturing the overall breadth and depth of NFD. We therefore label it as *Information extension*, reflecting the extent to which firms make circular economy-related information available to external stakeholders. On the other hand, Principal Component 2 is strongly associated with *Legal tradition*, thus providing a measure of how NFD is "oriented" toward investors' protection. Coherently, we rename it *Information protection* (see par. 3.2).

4.2. Hypotheses testing

To examine the relationship between a firm's degree of circularity, NFD intensity, and its default risk, we adopt a two-step methodology similar to Fatemi et al. (2018), who studied how disclosure influences the link between ESG activities and firm value. More in general, two-step research designs have become quite common in the accounting-based economic literature (Jackson, 2022), with particularly useful applications in detecting 'discretionary accruals' and, thus, earnings management practices (e.g., Garel et al., 2021) or understanding banks' policies in respect of regulatory capital (e.g., De-Ramon et al., 2022).

The two-step approach allows us to purge the CS of the mechanical influence of disclosure commitment. This adjustment is necessary because disclosure affects the CS in two ways: not only through the *Disclosure & Signalling* Category, but also through the construction of the score itself. Specifically, for each indicator used in the CS, missing data – i.e., non-disclosure – carries informational value and directly reduces the partial score (Zara & Ramkumar, 2022, *Appendix B*). Thus, a firm's CS inherently reflects both its actual circular practices and its willingness (or ability) to disclose them. Our methodology disentangles these effects so that the estimated degree of circularity is not conflated with disclosure intensity.

In the first step of our design, we decompose the CS into its disclosure-driven and disclosure-independent components. Specifically, we run an OLS regression with CS as the dependent variable and the PCA-derived disclosure factors introduced in par. 4.1 as explanatory variables. This procedure isolates the portion of circularity explained by NFD from the residual component, which we interpret as the firm's "core" circularity. The first step thus provides the basis for testing Hp. 1.

(1) $$CS_{i,t} = \alpha + b_1\, Information\ extension_{i,t} + b_2\, Information\ protection_{i,t} + YearFE_t + IndustryFE_i + \varepsilon_{it}$$

where CS is the *Circularity Score*; *Information extension* and *Information protection* are the PCA-derived disclosure factors; $YearFE$ is a set of year dummies; and $IndustryFE$ denotes industry fixed effects. Standard errors are clustered at the company level.

The residuals from Eq. (1) capture the portion of the CS that cannot be attributed to disclosure. We define this measure as the *Core Circularity Score* (CORE_CS):

$$CORE_CS_{i,t} = \varepsilon_{i,t} = CS_{i,t} - \widehat{CS}_{i,t}$$

where $\widehat{CS}$ is the fitted value of CS from Eq. (1).

In the second step, we examine how circularity and disclosure affect default risk. To test Hp. 2 and Hp. 3, we estimate pooled OLS regressions where the dependent variable is a measure of firms' default. We lag the explanatory variables by one year to mitigate endogeneity concerns, particularly reverse causality. The models are specified as:

(2) $$Default\ risk_{i,t} = \alpha + \beta\, CORE_CS_{i,t-1} + \gamma\, Controls_{i,t-1} + YearFE_t + IndustryFE_i + \varepsilon_{it}$$

(3) $$Default\ risk_{i,t} = \alpha + \beta_1\, Information\ extension_{i,t-1} + \beta_2\, Information\ protection_{i,t-1} + \gamma\, Controls_{i,t-1} + YearFE_t + IndustryFE_i + \varepsilon_{it}$$

where *Default risk* is alternatively the logarithmic transformation of either *Probability of default, 1-year*, *Probability of default, 5-year*, *Distance to default, 1-year* or *Implied CDS spread, 5-year*. All regressions are estimated with standard errors clustered at the company level.

5. Descriptive statistics

Table 5 reports summary statistics and Table 6 shows variable correlations. Credit risk is generally low across the sample: the average one-year probability of default is close to zero, while the five-year probability averages about 3%. Distance to default and CDS spreads confirm this pattern, with most firms displaying low risk but a few high-risk outliers. Turning to circularity, the *Circularity Score* averages 0.34, while the *Core Circularity Score* – by construction – centers around zero with limited dispersion. The PCA-derived disclosure factors, as well as *Disclosure quality* and *Disclosure level*, show meaningful variation across firms, reflecting heterogeneity in reporting practices.

[INSERT TABLE 5 ABOUT HERE]

The analysis of the correlation matrix shows a very high degree of independence amongst the variables that are jointly considered in the models introduced in the previous par. 4.2.

[INSERT TABLE 6 ABOUT HERE]

6. Results

6.1. The relationship between NFD intensity and full circularity

The results obtained from Eq. (1) are displayed in Table 7.

[INSERT TABLE 7 ABOUT HERE]

Circularity Score is strongly driven by our NFD measures: both *Information extension* and *Information protection* enter with highly significant coefficients ($p < 0.01$), thus confirming Hp. 1. The coefficient on *Information extension* is larger than that on *Information protection*, suggesting that the breadth of disclosure plays a stronger role in shaping a firm's CS than the level of investors' protection. The model fit is high, with an adjusted R-squared of 0.92.

6.2. The relationship between core circularity and default risk

Table 8 reports the results from Eq. (2).

[INSERT TABLE 8 ABOUT HERE]

Once the effect of NFD intensity is accounted for, a firm's degree of circularity demonstrates a clear de-risking effect. Specifically, the lagged *Core Circularity Score* shows a negative and statistically significant association at the 1% confidence level with all four measures of default risk. These results support Hp. 2, confirming the inverse relationship between circularity and default risk (Hp. 2a), which holds across alternative risk metrics and horizons (Hp. 2b).

The control variables, reflecting firms' financial structure and performance, display strong and consistent associations with default risk. In particular, *Debt-to-equity ratio* and *Interest coverage ratio* both emerge as statistically significant, as companies with more (less) debt and a smaller (greater) ability to meet their interest expense are more (less) likely to default, regardless of the risk measure and the horizon we consider. Similarly, longer net debt payback periods are associated with higher default risk, in line with a slower ability to repay outstanding obligations. As expected, *Profit margin* shows negative and significant coefficients, indicating that more profitable firms tend to experience reduced default risk. Size, proxied by the natural logarithm of *Total assets*, is generally

negatively linked to default risk. The adjusted R-squared ranges between 0.41 and 0.45, indicating a good model fit.

6.3. The relationship between NFD intensity and default risk

The results obtained from Eq. (3) are displayed in Table 9.

[INSERT TABLE 9 ABOUT HERE]

The *Information extension* variable is negatively and significantly associated with all default risk measures besides *Distance to default*. This exception may reflect the nature of this variable, which is based on Bloomberg's proprietary model and transformation of financial data. By contrast, *Information protection* exhibits a significant negative effect only for the one-year probability of default, suggesting that its influence on credit risk is not generalized across measures. Taken together, these findings indicate that, in the context of NFD, the scope and quality of disclosure on circular-economy practices play the most consistent role, thus offering partial support for Hp. 3.

Turning to the control variables, they behave as expected and remain true to prior outcomes. Likewise, the adjusted R-squared remains high and shows no notable changes across specifications.

6.4. Robustness checks

To test the robustness of our results, we run a battery of alternative regression models.

6.4.1. Inclusion of country fixed effects

First, we re-estimate Eq. (2) with the inclusion of country fixed effects. This specification accounts for institutional, regulatory, and macroeconomic heterogeneity across jurisdictions and allows us to assess whether the de-risking role of firms' core circularity is driven by cross-country differences. The results, reported in Table 10, closely mirror our baseline estimates, confirming that the negative association between core circularity and default risk is robust to the inclusion of country-specific factors.

[INSERT TABLE 10 ABOUT HERE]

6.4.2 Subsample analysis

As previously discussed, our sample consists of European firms operating in industries that are particularly exposed to the CE transition, irrespective of whether they are frontrunners or laggards in adopting CE practices. To further investigate the dynamics behind the de-risking effect, we partition the sample into quartiles based on the distribution of firms' CS within each year and industry, and re-estimate Eq. 2 for the top and bottom quartiles. This approach serves both as a robustness test and as a means of exploring potential heterogeneity in the circularity–risk relationship, allowing us to assess whether the observed effects are concentrated among firms at the forefront of the CE transition or also present among those in the early stages of adoption or not engaged at all.

[INSERT TABLE 11 ABOUT HERE]

Panel A of Table 11 reports results for the bottom quartile, while Panel B presents estimates for the top quartile, corresponding to the subsample of firms most advanced in circularity. The outcomes indicate that the negative and statistically significant association between the *Core Circularity Score* and credit risk is confirmed for firms in the highest quartile of circularity. This suggests that although circular practices are generally linked to lower default risk, the de-risking effect is most pronounced for firms that have progressed further in the transition. By contrast, for firms in the lowest quartile, the relationship loses significance – except for *Distance to default* – suggesting that limited or absent implementation of circular practices does not meaningfully reduce credit risk exposure.

6.4.3 Replacement of PCA-derived disclosure factors with original NFD variables

Since the two disclosure factors in Eq. (3) are derived from a PCA, we re-estimate the specification using the original NFD variables that underpin the components. Specifically, *Disclosure quality* and *Disclosure level* – which together form the basis of the first PCA factor (*Information extension*) – are included separately in the regressions (Table 12, Panels A and B), while *Legal tradition* – closely aligned with the second PCA factor (*Information protection*) – is also retained as an explanatory variable.

[INSERT TABLE 12 ABOUT HERE]

The results remain consistent with the main analysis in Table 9. Both *Disclosure quality* and *Disclosure level* are negatively and significantly associated with the one- and five-year probabilities of default, confirming the de-risking role of disclosure. In addition, the *Legal tradition* variable shows a significant positive relation with CDS spreads, suggesting that firms headquartered in jurisdictions

with stronger outside investor protection, typically common law systems, are priced with higher credit risk premia than their civil-law counterparts.

6.5. Additional analyses

6.5.1. Using Circularity Score as dependent variable

As an additional analysis, we benchmark our specification against the approach used in Zara & Ramkumar (2022). Replicating their model on our dataset allows us to assess whether our findings are consistent with prior evidence and to verify that the documented de-risking effect is not an artifact of our two-step design. Moreover, our dataset is both larger and spans a longer time period, thereby providing a stronger empirical setting for this test. Specifically, we replace the *Core Circularity Score* with the full *Circularity Score* and re-estimate Eq. (2). The results, reported in Table 13, remain negative and statistically significant, confirming that the de-risking effect holds even without decomposing circularity into its disclosure and non-disclosure components. Overall, this suggests that the link between circularity and credit risk reflects a stable and substantive relationship rather than a feature of model design.

[INSERT TABLE 13 ABOUT HERE]

6.5.2. Core Circularity Score and disclosure factors

Up to this point, our results have consistently pointed to the primary role of a firm's actual degree of circularity in mitigating credit risk, while also indicating that the transparency, scope, and quality of NFD play an important complementary role in shaping default probability. Building on this evidence, a natural next step is to ask whether the observed correlation between disclosure factors and default measures retains significance once the firm's degree of circularity is explicitly accounted for. To investigate this, we augment Eq. (3) by including the *Core Circularity Score* as an additional regressor and re-estimate the model.

The results, presented in Table 14, are broadly consistent with those of the baseline specification. *Core Circularity Score* continues to display a negative and statistically significant association with default risk, as expected. Importantly, however, the first PCA-derived disclosure component (*Information extension*) also remains negative and significant across specifications. This finding implies that, even after controlling for a firm's substantive commitment to circularity practices, the information it communicates publicly and the degree of transparency it achieves remain useful for credit

risk assessment. In this sense, NFD serves as a valuable channel for gauging the extent of firms' actual engagement in the circular economy. In addition, the positive and significant linkage between *Information protection* and CDS spreads persists, suggesting that in countries with stronger outside investor protection, markets more actively reprice firm-specific risks.

[INSERT TABLE 14 ABOUT HERE]

6.5.3. Inclusion of firms' ESG rating

As emphasized in the literature review, the circular economy constitutes an economic model that goes beyond conventional ESG practices. Nevertheless, one potential concern is that the observed de-risking effect of circularity might simply be capturing a firm's broader sustainability profile, regardless of its specific engagement in circular practices. To address this issue, we augment Eq. (2) by including firms' ESG performance as an additional regressor, thereby testing whether the financial benefits associated with circularity reflect more than just an enhanced awareness of sustainability in general. This step allows us to disentangle the role of circularity from the firm's overall ESG standing and to verify whether the de-risking channel we document is independent of standard ESG measures.

To operationalize ESG performance, we rely on the MSCI ESG rating, a widely adopted benchmark in both academic research and investment practice. The rating is based on a seven-point scale ranging from AAA to CCC and reflects how effectively a firm manages financially material ESG risks and opportunities (MSCI ESG Research, 2024). Table 15 reports the results of including the variable *MSCI ESG rating* in Eq. (2). The coefficients on the *Core Circularity Score* remain consistently negative and statistically significant across all four measures of credit risk, indicating that the de-risking effect of circularity is not subsumed by ESG performance. On the contrary, circularity demonstrates a distinct and independent financial materiality that extends beyond a firm's general ESG standing.

[INSERT TABLE 15 ABOUT HERE]

7. Discussion of results

Having presented the empirical findings, we now turn to a critical discussion of their significance and alignment with prior research. First, our results provide strong support for Hp. 1, as both NFD factors are positive and highly significant in relation to the full *Circularity Score*. These findings suggest that companies engaging more actively in non-financial disclosure also tend to exhibit higher

levels of circularity. This evidence aligns with prior studies, such as Papoutsi & Sodhi (2020) and Eng et al. (2021), which argue that firms with strong CSP are more inclined to disclose such information, recognizing its strategic value.

The results obtained from estimating Eq. (2) are fully consistent with those reported by Zara & Ramkumar (2022), reinforcing the evidence that circularity exerts a distinct de-risking effect – even when the disaggregated NFD components are excluded from the analysis. Furthermore, we observe no substantial differences between short-term and long-term measures of default risk, providing robust support for both Hp. 2a and 2b. These findings indirectly echo prior research suggesting that firms with stronger sustainability profiles tend to feature lower credit risk and improved creditworthiness (e.g., Okimoto et al., 2021, Brogi et al., 2023; Caiazza et al., 2023).

Moreover, consistent with extant literature suggesting that NFD serves as a credible proxy for CSP and can be material for CFP (e.g., Schiehll & Kolahgar, 2021; Alsaifi et al., 2022), we find a significant negative relationship between the extent of NFD and firms' credit risk.

Taken together, our results indicate that deeper engagement in the circular transition enhances creditworthiness and that the de-risking effect is attributable to substantive changes in business models ("core" circularity). At the same time, the quality and scope of NFD serve as an observable signal of circular economy engagement, with more transparent and targeted disclosure translating into financial materiality through improved credit risk assessment by lenders.

Results from our robustness checks generally confirm our main findings and highlight some interesting side effects that contribute to a better understanding of the relationship between CS, NFD, and credit risk metrics. First, the de-risking effect persists even after controlling for macroeconomic and country-level factors that may jointly influence firms' commitment to circularity and their default probability. Second, the quartile analysis highlights that the financial materiality of circularity becomes most evident once firms reach higher levels of adoption. When firms are at the early stages of circular economy adoption – or have not engaged at all – the relationship becomes weaker and less persistent, limiting the observable de-risking effect. Third, when the original NFD variables are used in place of the PCA-derived factors, the results mirror our baseline specification, confirming that both the level and quality of disclosure are negatively linked to credit risk. However, when CDS spreads are used as the dependent variable, we detect a positive relationship with the legal tradition of a company's headquarters country. This pattern suggests that in countries with stronger investor protection and stricter disclosure requirements, creditors gain greater visibility into firm-specific risks. As a result, the likelihood of triggering credit protection increases, which in turn leads to higher risk premia reflected in CDS prices.

Our additional analyses further reinforce these insights. The de-risking effect remains when the "full" CS is used in place of the "core" measure, reaffirming the financial materiality of circularity even without disaggregation and confirming that our results are not driven by model design. Furthermore, when all components of circularity are considered, NFD continues to play a role in affecting credit risk reduction. This suggests that lenders and investors value the substance of circular practices and refer to the extent of disclosure as a credible signal of commitment, underscoring the dual channels through which circularity influences financial outcomes.

Finally, we demonstrate that the role of circularity extends beyond conventional ESG metrics. The persistence of the de-risking effect after controlling for MSCI ESG ratings suggests that creditors differentiate between general sustainability profiles and structural shifts toward circular practices. Collectively, these results reinforce our central claim: circularity constitutes a distinct channel through which firms can enhance their creditworthiness, and incremental information on CE should be regarded as a useful element in credit risk assessment.

8. Conclusions

Our results show that concrete engagement in CE-related business model transformations triggers a de-risking effect, thus confirming the relationship between CSP and CFP in the context of CE. Moreover, we find that an extensive NFD can signal the existence of this relation. For this reason, we can state that the extent of CSP disclosed can affect the possibility of obtaining a positive CFP in the case of CE and the risk of default. The practical implications of these findings are plentiful and relevant for multiple stakeholders.

For non-financial undertakers, the evidence suggests that engaging in CE practices and communicating them extensively can enhance their creditworthiness. While disclosure is valuable, lenders reward genuine business model transformation more strongly, as it translates into lower values for default risk metrics both in loan markets and CDS ones. Companies therefore stand to benefit not only from reputational gains but also from tangible financial advantages when they undertake active circular practices.

For lenders, the findings demonstrate that promoting portfolios of circular loans can deliver a double materiality benefit: achieving credit risk reduction (i.e., financial materiality) while supporting the broader transition toward a sustainable economy (i.e., stakeholders' materiality). Furthermore, the extent of NFD may serve as a useful signal of circular engagement. In the absence of fully developed metrics to capture CE activities, the extent of NFD can be employed as a practical proxy within credit assessments to gauge the depth of borrowers' commitment to the circular transition.

For investors, creditors, and policymakers, the study highlights that circularity as a content of CSP provides original information useful for credit risk evaluation, which conventional ESG indicators cannot either substitute or fully replace. In particular, this distinction carries clear implications for regulatory design. Policymakers and regulators should establish incentives that encourage undertakers to carry on in the circular transition, while simultaneously maintaining disclosure requirements that allow markets to assess its extent. In this way, regulation can support the sustainability transition as well as financial stability. In light of our findings and focusing on the European context, an instructive contrast emerges between the forthcoming Circular Economy Act, scheduled for adoption in 2026, and the Omnibus package proposed by the European Commission in February 2025. The former reflects regulators' growing recognition of the role that can be played by circular economy to strengthen the EU's economic competitiveness and resilience, along with decarbonization objectives (European Commission, 2025). In contrast, by narrowing both the scope and the timeline of the CSRD, the latter risks undermining the role of NFD as a signal of financial materiality, thereby complicating the assessment of its link with de-risking.

These findings are subject to certain limitations. Our sample period is limited to a five-year time frame, our analysis is restricted to European undertakers in selected industries, and the NFD variables employed remain few and merit further development. Future research could extend the analysis to other geographies, more industries, longer horizons, and extend the breadth of representation of NFD with the aim of increasing the inference of our results.

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Table 1a
Sample composition by country.

Country	Number of companies	Percentage
United Kingdom	158	24.57%
Germany	81	12.60%
Switzerland	65	10.11%
France	63	9.80%
Sweden	53	8.24%
Italy	37	5.75%
Netherlands	35	5.44%
Spain	30	4.67%
Belgium	23	3.58%
Ireland	23	3.58%
Finland	22	3.42%
Denmark	21	3.27%
Austria	14	2.18%
Greece	7	1.09%
Portugal	6	0.93%
Luxembourg	5	0.78%
Overall	**643**	**100.00%**

Table 1b
Sample composition by industry.

Industry	Number of companies	Percentage
Chemicals	137	21.31%
Industrial Machinery & Goods	78	12.13%
Electrical & Electronic Equipment	67	10.42%
Construction Materials	62	9.64%
Medical Equipment & Supplies	47	7.31%
Oil & Gas	37	5.75%
Automobiles	29	4.51%
Processed Foods	28	4.35%
Utilities & Power Generators	28	4.35%
Containers & Packaging	24	3.73%
Apparel, Accessories & Footwear	23	3.58%
Iron & Steel	23	3.58%
Metals & Mining	18	2.80%
Beverage	15	2.33%
Aerospace & Defence	15	2.33%
Meat, Poultry & Dairy	8	1.24%
Toys & Sporting Goods	4	0.62%
Overall	**643**	**100.00%**

Table 2
Classification of CE indicators.

Pillar	CE Category	N. of indicators
Circular design & inputs	Innovation	24
	Materials	8
	Product Responsibility	9
	Total Circular design & inputs Pillar	**41**
Circular production & resources	Utilities	23
	Emissions	41
	Supply chain	7
	Total Circular production & resources Pillar	**71**
Circular use	Rehabilitation of degraded land	10
	Total Circular use Pillar	**10**
Circular value recovery	Production waste and wastewater	17
	Consumption waste	3
	Total Circular value recovery Pillar	**20**
Circular enablers	Disclosure & Signalling	10
	Agenda 2030	8
	Community	7
	Total Circular enablers Pillar	**25**
	Total Indicators	**167**

Table 3
Variable description.

Variable	Description	Source of input data
Dependent variables ***(log-transformed when featured in panel regressions)***		
Probability of default, 1-year	A company's probability of defaulting on debt over a 1-year horizon, estimated through a Bloomberg proprietary algorithm.	Bloomberg
Probability of default, 5-year	A company's probability of defaulting on debt over a 5-year horizon, estimated through a Bloomberg proprietary algorithm.	Bloomberg
Distance to default, 1-year	A quantitative measure used to assess a firm's credit risk, particularly its likelihood of defaulting on debt obligations. The orientation of the scale is such that lower the distance and higher is the credit risk.	Bloomberg
CDS spread, implied, 5-year	The risk premium (in basis points) charged on credit default swaps contracts, issued to hedge against the event of a company's default over a 5-year horizon.	Bloomberg
Main explanatory variables		
Circularity Score	A company's degree of circularity, computed on a revised version of the methodology by Zara and Ramkumar (2022).	Authors' elaboration based on data retrieved from Refinitiv Eikon
Core Circularity Score	A company's degree of circularity, net of the effects played by non-financial information disclosure, computed as the residuals from regressing *Circularity Score* on *Information content* and *Information integration* (see below).	Authors' own elaboration
Disclosure quality	The intensity of a company's non-financial information disclosure, computed by distinguishing between quantitative and qualitative disclosure.	Authors' elaboration based on data retrieved from Refinitiv Eikon
Disclosure level	The intensity of a company's non-financial information disclosure, computed without distinguishing between quantitative and qualitative disclosure.	Authors' elaboration based on data retrieved from Refinitiv Eikon
Legal tradition	Categorical variable ranging from 1 to 4 according to the legal tradition of the country in which the company is headquartered.	Authors' elaboration based on La Porta et al. (2008)
Information extension	The first factor resulting from a principal component analysis run on *Disclosure quality*, *Disclosure level*, and *Legal tradition*.	Authors' own elaboration
Information protection	The second factor resulting from a principal component analysis run on *Disclosure quality*, *Disclosure level*, and *Legal tradition*.	Authors' own elaboration
Control explanatory variables		
Total assets	Natural logarithm of a company's total assets, averaged between BoY and EoY figures.	Bloomberg

Debt-to-equity ratio	Natural logarithm of the ratio between a company's total debt (numerator) and total equity (denominator), both averaged between BoY and EoY figures.	Bloomberg
Interest coverage ratio	Ratio between a company's EBITDA (numerator) and interest expense (denominator).	Bloomberg
Net debt payback period	Ratio between a company's financial debt, net of cash-on-hand (numerator), and EBITDA (denominator).	Bloomberg
Profit-on-sales ratio	Ratio between a company's net income (numerator) and revenues (denominator).	Bloomberg
Negative equity, dummy	Dummy variable that takes value 1 if the company's total equity is negative, and 0 otherwise.	Bloomberg

Table 4
Principal components analysis.

Panel A (rotation: unrotated = principal)

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	2.014	1.048	0.671	0.671
Comp2	0.966	0.945	0.322	0.993
Comp3	0.021		0.007	1.000

Panel B: Principal components (eigenvectors)

Variable	Comp1	Comp2	Comp3	Unexplained
Disclosure quality	0.697	0.114	0.708	0
Disclosure level	0.694	0.143	-0.706	0
Legal tradition	-0.182	0.983	0.021	0

Table 5
Descriptive statistics.

	N	Mean	SD	Min	Max	Skew-ness	Kurto-sis
Probability of default, 1-year	3121	0.004	0.013	0	0.087	4.877	28.224
Probability of default, 5-year	3175	0.031	0.045	0	0.257	3.116	13.746
Distance to default, 1-year	3156	0.176	0.130	0.036	0.822	2.585	11.587
Implied CDS spread, 5-year	3175	85.958	61.232	8.100	343.5	1.835	7.149
Circularity Score	3215	0.344	0.112	0	0.563	-1.498	5.597
Core Circularity Score	3215	0	0.032	-0.098	0.114	0.003	2.904
Information extension	3215	0	1.419	-4.906	2.319	-1.855	7.058
Information protection	3215	0	0.983	-2.008	1.679	0.130	1.738
Disclosure quality	3215	0.525	0.168	0	0.817	-1.526	5.773
Disclosure level	3215	0.617	0.172	0	0.850	-2.438	9.363
Legal tradition	3215	2.392	1.201	1	4	0.188	1.496
Total assets	3179	18035.461	41677.805	119.553	273945.75	4.112	22.062
Debt-to-equity ratio	3173	80.821	95.798	0	586.749	3.040	14.289
Interest coverage ratio	3141	44.244	112.414	-204.926	752.341	3.974	22.790
Net debt payback period	3179	1.325	3.946	-15.367	19.737	0.619	12.018
Profit margin	3154	-0.013	0.574	-4.294	0.829	-6.053	43.167
Negative equity, dummy	3215	0.014	0.119	0	1	8.180	67.906

Table 6

Correlation matrix.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1) Probability of default, 1-year	1.000																
(2) Probability of default, 5-year	0.882***	1.000															
(3) Distance to default, 1-year	0.840***	0.862***	1.000														
(4) Implied CDS, 5-year	0.574***	0.648***	0.681***	1.000													
(5) Circularity Score	-0.167***	-0.180***	-0.094***	-0.144***	1.000												
(6) Core Circularity Score	-0.094***	-0.141***	-0.141***	-0.131***	0.419***	1.000											
(7) Information extension	-0.155***	-0.149***	-0.054***	-0.113***	0.952***	0.140***	1.000										
(8) Information protection	0.021	-0.020	-0.024	0.003	0.115***	0.040**	0.000	1.000									
(9) Disclosure quality	-0.147***	-0.151***	-0.055***	-0.098***	0.960***	0.166***	0.989***	0.112***	1.000								
(10) Disclosure level	-0.153***	-0.148***	-0.057***	-0.125***	0.947***	0.121***	0.985***	0.141***	0.979***	1.000							
(11) Legal tradition	0.059***	0.018	-0.010	0.032*	-0.135***	0.003	-0.258***	0.966***	-0.147***	-0.118***	1.000						
(12) Total assets	-0.062***	-0.072***	-0.028	-0.072***	0.232***	0.097***	0.224***	0.002	0.249***	0.194***	-0.053***	1.000					
(13) Debt-to-equity ratio	0.355***	0.375***	0.422***	0.358***	0.066***	0.000	0.079***	-0.052***	0.088***	0.055***	-0.070***	0.061***	1.000				
(14) Interest coverage ratio	-0.141***	-0.232***	-0.231***	-0.218***	0.000	0.029*	-0.007	-0.017	-0.015	-0.003	-0.014	-0.053***	-0.211***	1.000			
(15) Net debt payback period	0.011	0.049***	0.076***	0.117***	-0.026	-0.016	-0.023	-0.003	-0.018	-0.029*	0.004	-0.011	0.170***	-0.175***	1.000		
(16) Profit margin	-0.296***	-0.364***	-0.227***	-0.134***	0.189***	0.171***	0.153***	-0.002	0.164***	0.137***	-0.040**	0.061***	-0.048***	0.226***	0.024	1.000	
(17) Negative equity, dummy	0.348***	0.273***	0.248***	0.217***	-0.076***	-0.046***	-0.069***	0.002	-0.067***	-0.069***	0.020	-0.032*	0.335***	-0.058***	0.069***	-0.153***	1.000

*** *p<0.01,* ** *p<0.05,* * *p<0.1*

Table 7
Circularity vs. non-financial disclosure.

	(1) *Circularity Score*
Information extension	0.075*** (0.001)
Information protection	0.013*** (0.001)
Year FE	Yes
Industry FE	Yes
Adjusted R^2	0.924
Observations	3215.000

Standard errors are clustered at the firm level and reported in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Table 8
Default risk vs. "core" circularity.

	(1) *Probability of default, 1-year*	(2) *Probability of default, 5-year*	(3) *Distance to default, 1-year*	(4) *Implied CDS spread, 5-year*
Core Circularity Score$_{t-1}$	-11.066***	-3.699***	-1.790***	-2.438***
	(2.461)	(0.868)	(0.402)	(0.526)
Total assets$_{t-1}$	-0.411***	-0.158***	-0.063***	-0.080***
	(0.053)	(0.017)	(0.008)	(0.010)
Debt-to-equity ratio$_{t-1}$	1.092***	0.376***	0.202***	0.233***
	(0.095)	(0.034)	(0.013)	(0.019)
Interest coverage ratio$_{t-1}$	-0.005***	-0.002***	-0.001***	-0.001***
	(0.001)	(0.000)	(0.000)	(0.000)
Profit margin$_{t-1}$	-0.788***	-0.388***	-0.131***	-0.102***
	(0.154)	(0.052)	(0.029)	(0.030)
Net debt payback period$_{t-1}$	0.052***	0.017**	0.005	0.008**
	(0.020)	(0.007)	(0.003)	(0.004)
Negative equity, dummy$_{t-1}$	1.593**	0.649*	0.404**	0.448***
	(0.791)	(0.349)	(0.170)	(0.130)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Adjusted R^2	0.414	0.451	0.450	0.418
Observations	2867.000	2920.000	2906.000	2920.000

Standard errors are clustered at the firm level and reported in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Table 9
Default risk vs. PCA-derived components on NFD.

	(1) *Probability of default, 1-year*	(2) *Probability of default, 5-year*	(3) *Distance to default, 1-year*	(4) *Implied CDS spread, 5-year*
Information extension$_{t-1}$	-0.198***	-0.063***	-0.011	-0.024*
	(0.062)	(0.023)	(0.012)	(0.014)
Information protection$_{t-1}$	-0.142*	-0.033	-0.009	0.027
	(0.084)	(0.030)	(0.014)	(0.017)
Total assets$_{t-1}$	-0.390***	-0.151***	-0.065***	-0.080***
	(0.058)	(0.019)	(0.009)	(0.011)
Debt-to-equity ratio$_{t-1}$	1.097***	0.379***	0.202***	0.239***
	(0.097)	(0.035)	(0.014)	(0.019)
Interest coverage ratio$_{t-1}$	-0.005***	-0.002***	-0.001***	-0.001***
	(0.001)	(0.000)	(0.000)	(0.000)
Profit margin$_{t-1}$	-0.829***	-0.403***	-0.144***	-0.116***
	(0.153)	(0.052)	(0.029)	(0.029)
Net debt payback period$_{t-1}$	0.051**	0.016**	0.005	0.008**
	(0.020)	(0.007)	(0.003)	(0.004)
Negative equity, dummy$_{t-1}$	1.648**	0.662*	0.416**	0.444***
	(0.823)	(0.363)	(0.177)	(0.141)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Adjusted R^2	0.410	0.447	0.442	0.410
Observations	2867.000	2920.000	2906.000	2920.000

Standard errors are clustered at the firm level and reported in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Table 10
Robustness test: inclusion of country fixed-effects.

	(1) *Probability of default, 1-year*	(2) *Probability of default, 5-year*	(3) *Distance to default, 1-year*	(4) *Implied CDS spread, 5-year*
Core Circularity Score$_{t-1}$	-10.125***	-3.431***	-1.656***	-2.425***
	(2.355)	(0.844)	(0.390)	(0.485)
Total assets$_{t-1}$	-0.410***	-0.163***	-0.062***	-0.058***
	(0.056)	(0.018)	(0.008)	(0.011)
Debt-to-equity ratio$_{t-1}$	1.046***	0.366***	0.196***	0.210***
	(0.099)	(0.036)	(0.014)	(0.019)
Interest coverage ratio$_{t-1}$	-0.005***	-0.002***	-0.001***	-0.001***
	(0.001)	(0.000)	(0.000)	(0.000)
Profit margin$_{t-1}$	-0.811***	-0.388***	-0.135***	-0.114***
	(0.154)	(0.053)	(0.028)	(0.028)
Net debt payback period$_{t-1}$	0.057***	0.018**	0.005	0.007*
	(0.020)	(0.007)	(0.003)	(0.004)
Negative equity, dummy$_{t-1}$	1.814**	0.701*	0.436**	0.480***
	(0.886)	(0.387)	(0.172)	(0.142)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Adjusted R^2	0.432	0.464	0.466	0.470
Observations	2867.000	2920.000	2906.000	2920.000

Standard errors are clustered at the firm level and reported in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Table 11
Robustness test: subsample analysis.

Panel A: Low-CS firms

	(1) *Probability of default, 1-year*	(2) *Probability of default, 5-year*	(3) *Distance to default, 1-year*	(4) *Implied CDS spread, 5-year*
Core Circularity Score$_{t-1}$	2.319	-1.909	-1.965**	0.104
	(5.221)	(1.766)	(0.951)	(1.090)
Total assets$_{t-1}$	-0.250**	-0.109**	-0.039*	-0.052**
	(0.122)	(0.042)	(0.021)	(0.025)
Debt-to-equity ratio$_{t-1}$	0.849***	0.295***	0.190***	0.182***
	(0.145)	(0.050)	(0.021)	(0.026)
Interest coverage ratio$_{t-1}$	-0.007***	-0.003***	-0.001***	-0.001***
	(0.001)	(0.001)	(0.000)	(0.000)
Profit margin$_{t-1}$	-0.651***	-0.309***	-0.112***	-0.092***
	(0.152)	(0.052)	(0.028)	(0.033)
Net debt payback period$_{t-1}$	0.053	0.015	0.001	0.007
	(0.033)	(0.012)	(0.006)	(0.006)
Negative equity, dummy$_{t-1}$	2.329**	0.900**	0.397*	0.513***
	(1.100)	(0.455)	(0.218)	(0.156)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Adjusted R^2	0.372	0.426	0.410	0.375
Observations	679.000	690.000	679.000	690.000

Panel B: High-CS firms

	(1) *Probability of default, 1-year*	(2) *Probability of default, 5-year*	(3) *Distance to default, 1-year*	(4) *Implied CDS spread, 5-year*
Core Circularity Score$_{t-1}$	-18.245***	-5.513***	-2.255***	-3.580***
	(5.350)	(1.719)	(0.769)	(0.868)
Total assets$_{t-1}$	-0.589***	-0.194***	-0.085***	-0.108***
	(0.108)	(0.037)	(0.017)	(0.021)
Debt-to-equity ratio$_{t-1}$	1.158***	0.395***	0.184***	0.270***
	(0.188)	(0.067)	(0.028)	(0.040)
Interest coverage ratio$_{t-1}$	-0.008**	-0.003***	-0.001**	-0.001*
	(0.003)	(0.001)	(0.000)	(0.001)
Profit margin$_{t-1}$	-1.028	-0.426	-0.154	-0.168
	(0.997)	(0.359)	(0.158)	(0.142)

Net debt payback period$_{t-1}$	0.052	0.020*	0.007	0.011*
	(0.032)	(0.012)	(0.006)	(0.006)
Negative equity, dummy$_{t-1}$	-0.992	-0.202	0.120	-0.458
	(1.685)	(0.716)	(0.475)	(0.439)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Adjusted R^2	0.491	0.496	0.498	0.511
Observations	730.000	744.000	744.000	744.000

Standard errors are clustered at the firm level and reported in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Table 12
Robustness test: using original NFD variables.

Panel A: Disclosure quality and Legal tradition

	(1) *Probability of default, 1-year*	(2) *Probability of default, 5-year*	(3) *Distance to default, 1-year*	(4) *Implied CDS spread, 5-year*
Disclosure quality$_{t-1}$	-1.870***	-0.593***	-0.122	-0.135
	(0.536)	(0.195)	(0.100)	(0.117)
Legal tradition	-0.090	-0.019	-0.006	0.026*
	(0.070)	(0.025)	(0.012)	(0.015)
Total assets$_{t-1}$	-0.383***	-0.149***	-0.064***	-0.081***
	(0.059)	(0.019)	(0.009)	(0.012)
Debt-to-equity ratio$_{t-1}$	1.099***	0.380***	0.202***	0.239***
	(0.097)	(0.035)	(0.014)	(0.019)
Interest coverage ratio$_{t-1}$	-0.005***	-0.002***	-0.001***	-0.001***
	(0.001)	(0.000)	(0.000)	(0.000)
Profit margin$_{t-1}$	-0.825***	-0.401***	-0.143***	-0.116***
	(0.154)	(0.052)	(0.029)	(0.029)
Net debt payback period$_{t-1}$	0.051**	0.016**	0.005	0.008**
	(0.020)	(0.007)	(0.003)	(0.004)
Negative equity, dummy$_{t-1}$	1.648**	0.661*	0.416**	0.444***
	(0.818)	(0.361)	(0.176)	(0.141)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Adjusted R^2	0.410	0.447	0.443	0.410
Observations	2867.000	2920.000	2906.000	2920.000

Panel B: Disclosure level and Legal tradition

	(1) *Probability of default, 1-year*	(2) *Probability of default, 5-year*	(3) *Distance to default, 1-year*	(4) *Implied CDS spread, 5-year*
Disclosure level$_{t-1}$	-1.763***	-0.532***	-0.079	-0.167
	(0.491)	(0.178)	(0.092)	(0.107)
Legal tradition	-0.083	-0.016	-0.005	0.026*
	(0.070)	(0.025)	(0.012)	(0.015)
Total assets$_{t-1}$	-0.398***	-0.154***	-0.066***	-0.081***
	(0.057)	(0.019)	(0.009)	(0.011)
Debt-to-equity ratio$_{t-1}$	1.095***	0.378***	0.202***	0.239***
	(0.097)	(0.035)	(0.014)	(0.019)
Interest coverage ratio$_{t-1}$	-0.005***	-0.002***	-0.001***	-0.001***

	(0.001)	(0.000)	(0.000)	(0.000)
Profit $margin_{t-1}$	-0.834***	-0.405***	-0.145***	-0.116***
	(0.153)	(0.052)	(0.029)	(0.029)
Net debt payback $period_{t-1}$	0.051**	0.016**	0.005	0.008**
	(0.020)	(0.007)	(0.003)	(0.004)
Negative equity, $dummy_{t-1}$	1.650**	0.662*	0.416**	0.443***
	(0.829)	(0.364)	(0.177)	(0.141)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Adjusted R^2	0.410	0.447	0.442	0.410
Observations	2867.000	2920.000	2906.000	2920.000

Standard errors are clustered at the firm level and reported in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Table 13
Additional analysis: using Circularity Score as the dependent variable.

	(1) *Probability of default, 1-year*	(2) *Probability of default, 5-year*	(3) *Distance to default, 1-year*	(4) *Implied CDS spread, 5-year*
Circularity Score$_{t-1}$	-3.779***	-1.213***	-0.343**	-0.532***
	(0.795)	(0.287)	(0.148)	(0.174)
Total assets$_{t-1}$	-0.356***	-0.140***	-0.060***	-0.074***
	(0.058)	(0.019)	(0.009)	(0.011)
Debt-to-equity ratio$_{t-1}$	1.116***	0.383***	0.204***	0.236***
	(0.095)	(0.034)	(0.014)	(0.019)
Interest coverage ratio$_{t-1}$	-0.005***	-0.002***	-0.001***	-0.001***
	(0.001)	(0.000)	(0.000)	(0.000)
Profit margin$_{t-1}$	-0.789***	-0.389***	-0.140***	-0.108***
	(0.153)	(0.052)	(0.029)	(0.029)
Net debt payback period$_{t-1}$	0.048**	0.015**	0.004	0.008**
	(0.020)	(0.007)	(0.003)	(0.004)
Negative equity, dummy$_{t-1}$	1.554*	0.637*	0.406**	0.448***
	(0.807)	(0.355)	(0.174)	(0.134)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Adjusted R^2	0.414	0.451	0.445	0.412
Observations	2867.000	2920.000	2906.000	2920.000

Standard errors are clustered at the firm level and reported in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Table 14
Additional analysis: Core Circularity Score and PCA-derived variables on NFD.

	(1) *Probability of default, 1-year*	(2) *Probability of default, 5-year*	(3) *Distance to default, 1-year*	(4) *Implied CDS spread, 5-year*
Core Circularity Score$_{t-1}$	-11.346***	-3.795***	-1.803***	-2.505***
	(2.484)	(0.876)	(0.405)	(0.532)
Information extension$_{t-1}$	-0.212***	-0.068***	-0.013	-0.027*
	(0.063)	(0.023)	(0.012)	(0.014)
Information protection$_{t-1}$	-0.135	-0.030	-0.008	0.029*
	(0.083)	(0.030)	(0.014)	(0.017)
Total assets$_{t-1}$	-0.353***	-0.139***	-0.060***	-0.072***
	(0.057)	(0.019)	(0.009)	(0.011)
Debt-to-equity ratio$_{t-1}$	1.096***	0.379***	0.202***	0.239***
	(0.095)	(0.034)	(0.014)	(0.019)
Interest coverage ratio$_{t-1}$	-0.005***	-0.002***	-0.001***	-0.001***
	(0.001)	(0.000)	(0.000)	(0.000)
Profit margin$_{t-1}$	-0.743***	-0.374***	-0.129***	-0.097***
	(0.153)	(0.052)	(0.029)	(0.029)
Net debt payback period$_{t-1}$	0.048**	0.015**	0.004	0.007*
	(0.020)	(0.007)	(0.003)	(0.004)
Negative equity, dummy$_{t-1}$	1.567**	0.635*	0.405**	0.426***
	(0.754)	(0.339)	(0.169)	(0.130)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Adjusted R^2	0.419	0.454	0.450	0.420
Observations	2867.000	2920.000	2906.000	2920.000

Standard errors are clustered at the firm level and reported in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

Table 15
Additional analysis: inclusion of MSCI ESG Rating.

	(1) *Probability of default, 1-year*	(2) *Probability of default, 5-year*	(3) *Distance to default, 1-year*	(4) *Implied CDS spread, 5-year*
Core Circularity Score$_{t-1}$	-0.311***	-0.099***	-0.040***	-0.062***
	(0.086)	(0.030)	(0.014)	(0.018)
MSCI ESG Rating$_{t-1}$	-0.232**	-0.069**	-0.051***	-0.052**
	(0.096)	(0.034)	(0.016)	(0.021)
Total assets$_{t-1}$	-0.330***	-0.129***	-0.049***	-0.065***
	(0.059)	(0.019)	(0.009)	(0.012)
Debt-to-equity ratio$_{t-1}$	1.123***	0.377***	0.194***	0.233***
	(0.093)	(0.033)	(0.014)	(0.020)
Interest coverage ratio$_{t-1}$	-0.004***	-0.002***	-0.001***	-0.001***
	(0.001)	(0.000)	(0.000)	(0.000)
Profit margin$_{t-1}$	-0.910***	-0.446***	-0.148***	-0.107***
	(0.187)	(0.061)	(0.035)	(0.036)
Net debt payback period$_{t-1}$	0.029	0.009	0.002	0.005
	(0.018)	(0.007)	(0.004)	(0.004)
Negative equity, dummy$_{t-1}$	1.597	0.696	0.383**	0.320*
	(0.999)	(0.433)	(0.192)	(0.171)
Year FE	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes
Adjusted R^2	0.409	0.443	0.441	0.409
Observations	2494.000	2538.000	2533.000	2538.000

Standard errors are clustered at the firm level and reported in parentheses.
* p<0.10, ** p<0.05, *** p<0.01

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