A Biodiversity Stress Test of the Financial System

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Abstract

This paper provides the first rigorous assessment of the financial sectors' resilience to biodiversity transition risk. We provide "bottom-up" stress tests using comprehensive euro-area credit registry data and a market-based "top-down" stress test based on banks' stock return sensitivities to biodiversity risk. Industries exposed to biodiversity transition risk account for approximately 15% of total bank credit to non-financial firms, compared to about 25% for climate-exposed industries. Stress test scenarios indicate that even under severe conditions, additional losses in biodiversity-exposed industries would constitute only 0.3 to 0.5% of the financial system's corporate loan portfolio. A top-down market-based approach yields similar results with capital shortfalls following a biodiversity shock peaking at 0.1% of banks' assets. Our evidence indicates that financial stability concerns related to biodiversity transition risk are moderate. Therefore, they should not hinder good biodiversity policy.

JEL classifications: Q54, Q57, C53, G20

Keywords: Biodiversity risk, Climate risk, Financial stability, Systemic risk

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"The economy needs nature to survive. Financial stability needs nature to survive." Frank Elderson, Vice-Chair of the Supervisory Board, European Central Bank, 2024

"Biodiversity loss could have significant macroeconomic implications. Failure to account for, mitigate, and adapt to these implications is a source of risks relevant for financial stability." Network for Greening the Financial System, 2022[1]

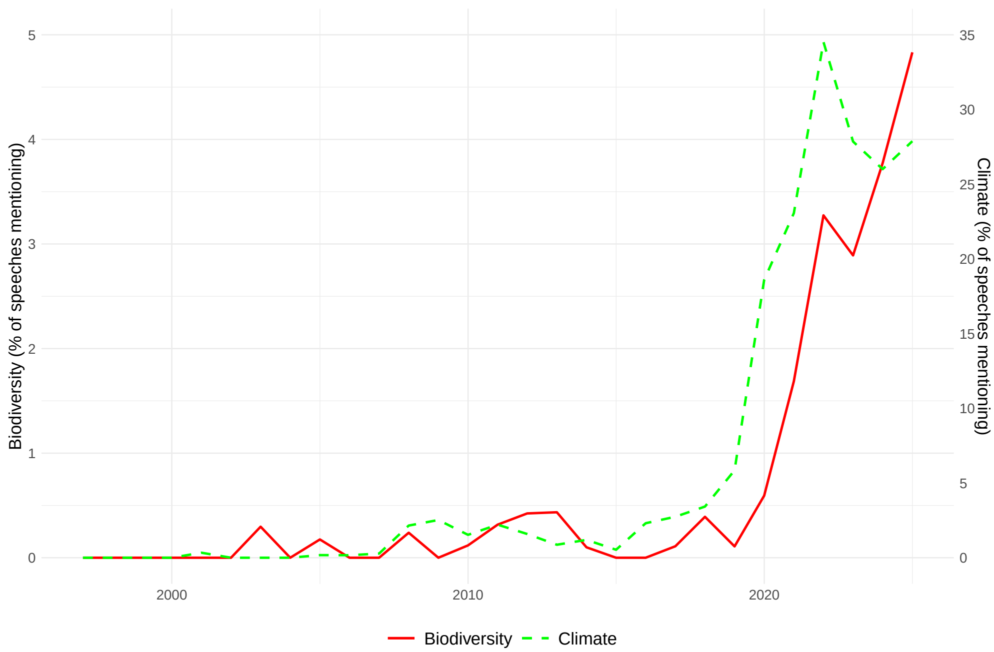
1 Introduction

A wide range of indicators point to rapid realized and projected biodiversity loss (IPBES, 2019). Biodiversity richness provides economic value through ecosystem services such as pollination. Biodiversity loss is, therefore, costly. The World Bank (2021) projects real GDP losses of expected biodiversity loss to equal $225 billion globally by 2030. Under stress scenarios assuming the collapse of ecosystem services, projected losses rise to $2.7 trillion.

Financial regulators are concerned that these losses are large enough to cause financial instability. Their concerns are salient in their communication, as indicated by the quotes above, and reflected in a range of publications about biodiversity-related risk (among others, NGFS, 2022; ECB, 2023b; Hadji-Lazaro et al., 2024; DNB, 2020). Strikingly, as we document in Figure 1, attention by central banks to biodiversity issues has increased significantly in recent years. While climate change is mentioned more often in central bank speeches, the attention given to biodiversity is following a similarly steep upward trajectory. In this paper, we conduct a biodiversity stress test to assess the resilience of the European financial system to biodiversity-related transition risk.

[1]European Central Bank (ECB) quote: Biodiversity COP16, 2024, accessible via https://www.bankingsupervision.europa.eu/press/speeches/date/2024/html/ssm.sp241028~b3c4437ba0.en.html; Network for Greening the Financial System (NGFS) quote: from the Foreword (page iv) of NGFS (2022), accessible via https://www.ngfs.net/system/files/import/ngfs/medias/documents/central_banking_and_supervision_in_the_biosphere.pdf.

Figure 1: Central bank speeches related to biodiversity and climate change



This figure shows the fraction of central bank speeches mentioning biodiversity-related (left-axis) and climate-related (right-axis) words by central banks worldwide between 1996-2024.[2]

We focus on transition risk because it is the most immediate biodiversity-related financial stability concern. In our setting, transition risk refers to financial stability risk originating from biodiversity regulation or societal changes. Physical damages of climate change and biodiversity loss are projected to be long-term while regulation to avoid these future damages becomes effective earlier, as illustrated by the survey evidence about climate risk by Stroebel and Wurgler (2021). Therefore, transition risk poses a more immediate financial stability concern that warrants a timely analysis.[3] We study Europe because it provides a great laboratory to study biodiversity transition risk. The European Union (EU) has recently

[2]Central bank speeches were collected from the BIS database accessible via `https://www.bis.org/cbspeeches/index.htm`. Biodiversity-related words used are: 'biodiversity', 'nature risk', 'nature degradation', 'nature loss', 'degradation of nature', 'nature-related risk', 'ecosystem service'. Climate-related words are 'climate change', 'global warming', 'climate risk'.

[3]Our focus on transition risk mirrors the climate stress testing literature. For example, FSB-NGFS (2022) document that 90% of the climate scenario analyses by financial authorities study transition risk, while only two-thirds study physical risk.

initiated multiple laws to protect nature. For example, the EU Nature Restoration Law became active in August 2024 and sets binding targets for ecosystem restoration. In addition, European central banks are vocal about biodiversity risk, indicating that banking supervision may incorporate nature-related risk earlier than elsewhere.

Biodiversity and climate transition risk differ. However, stress-testing methodology developed for climate transition risk is well-suited to apply to biodiversity transition risk, because biodiversity and climate regulation are similar in nature. For both, regulation is expected to increase the production costs of polluting firms, with large uncertainty around the exact impact.[4] Therefore, our approach is to apply common climate stress testing methodology to biodiversity. A benefit of this approach is that it allows us to compare the financial stability impact of biodiversity and climate transition risk clearly, giving us a useful benchmark for our results. Our contribution is to provide a complete picture of the financial stability impact of biodiversity transition risk. We do so by (i.) thoroughly documenting exposures of the financial system to industries exposed to biodiversity transition risk (short: "biodiversity industries"), (ii.) conducting two complementary stress tests: a bottom-up stress test based on granular credit registry data and a top-down, market-based, stress test, and (iii.) benchmarking our results to the financial stability impact of climate transition risk, using the same methods and samples.

Our key findings are as follows: First, biodiversity industries account for about 15% of the total outstanding bank credit to non-financial firms. This is significantly lower than the exposure to climate transition risk-related industries (short: "climate industries"), whose portfolio share is about 25%. Second, even a tripling of the default probability (PD) of borrowers in biodiversity industries *and* a reduction of collateral value to 30%, only leads

[4]Climate regulation is often focused on pricing greenhouse gas (GHG) emissions. Biodiversity regulation spans a range of pollutants and broader topics such as deforestation. Both sets of regulations imply increasing production costs of affected firms when policy tightens, either because of direct effects (paying more for permits to emit GHG) or because of indirect effects (decreasing crop yields with stricter pesticide regulation, declining fish harvests with stricter permits).

to *additional* losses (relative to a "no stress scenario") in the range of 0.3 to 0.5 percentage points of the financial system's total corporate loan portfolio. This is small in absolute terms and about two-thirds of the additional losses in a comparable climate stress scenario. Third, a market-based top-down stress testing approach confirms that biodiversity exposure is small, with a peak exposure of about 0.1% of the banks' total assets in 2022. Our estimates suggest that the direct exposure of the European financial system to biodiversity transition risks is moderate, at best.

Our analyses use rich credit registry data from the European AnaCredit, which includes **all** loans above €25,000 by lenders subject to full reporting to the European Central Bank (ECB). That is, the credit registry provides an (almost) complete picture of the actual exposures of European banks. Using this database and a definition of which firms are exposed to biodiversity or climate transition risk we can estimate simple stress scenarios, i.e., the expected capital shortfall for the European banking sector (or individual institutions) conditional on a shock to the credit risk of borrowers exposed to biodiversity (or climate) transition risk.

We use a simple and transparent approach to identify borrowers exposed to biodiversity or climate transition risk. We define exposure on the industry level because regulation often targets industries.[5] We base these industries on the firms targeted by Nature Action 100, a global investor-led engagement initiative focused on supporting greater corporate ambition and action to reverse nature and biodiversity loss. Nature Action 100 identifies key sectors deemed to be systemically important in reversing nature loss.[6] We follow the same approach

[5]For example, the European emissions trading system (EU ETS) covers emissions of firms within energy-intensive industries. Apart from a few exceptions such as for intercontinental aviation and shipping, entire industries are covered by the EU ETS. Within industries, there is firm-level heterogeneity in regulatory stringency depending on the relative greenness of the firm. We abstract from this by assuming that every firm within an industry is equally exposed. Essentially, we overestimate the impact of transition risk on the least affected firms in an industry by applying equally severe regulatory stress scenarios to those firms.

[6]Garel et al. (forthcoming) document that the Nature Action 100 list correlates highly with the Iceberg Corporate Biodiversity Footprint measure.

for industries exposed to climate-related transition risk by focusing on the Climate Action 100+ initiative. Sectors that are more exposed to biodiversity transition risk are industries with significant land use (such as Agriculture, Paper, and Merchandise), while sectors more exposed to climate transition risk are industries with carbon-intensive firms (such as Oil, Coal, and Gas Extraction and Processing).

We start with simple descriptive analyses of the system-wide exposure to biodiversity and climate transition risk. We focus on term loans and drawn credit lines to non-financial firms and estimate exposures relative to the total outstanding credit in the financial system. Climate industries account for about 25% of total outstanding bank credit compared to about 15% for biodiversity industries. Both measures show little time-series variation.

We then turn to our bottom-up stress test. In the most extreme biodiversity risk scenario additional losses amount to 0.3 to 0.5 percent of the total non-financial corporate loan portfolio of the financial system, peaking around €6 billion in absolute numbers. The baseline portfolio includes industries that are also defined as being exposed to climate transition risks. Focusing on only the "biodiversity-only industries" (or "residual biodiversity portfolio"), additional losses range from 0.2 to 0.3 percent of total lending, peaking at €4 billion. Additional losses due to climate exposures are somewhat larger (but still limited) and range from 0.5 to 0.8 percent of total lending, peaking at €8 billion. In comparison, the average gross profits of the ten largest listed banks in Europe equals €11.3 billion in 2023, the same year of the peak losses in the stress test. Thus, a single large bank would have recovered unexpected losses from this stress test within the year.

A concern with our bottom-up stress testing approach is that we assume that stress situations arise in isolation, i.e., that biodiversity sectors are affected without spillovers to other parts of the economy. To more rigorously examine how exposed the financial sector is to biodiversity transition risk, we implement a market-based, top-down stress test in the spirit of Brownlees and Engle (2017) and Jung et al. (2023). This approach is based on estimating biodiversity and climate betas for each financial institution to obtain a time-varying institution-specific measure of exposure to biodiversity and climate transition risk. Using these sensitivities the expected capital shortfall conditional on a "biodiversity shock" (or "climate shock") is estimated for each financial institution. That is, we introduce a BRISK measure similar to Jung et al. (2023)'s CRISK measure and compare biodiversity and climate transition risk exposures.

On average, both climate and biodiversity betas are small, ranging between -0.35 and 0.15. That is, the biodiversity portfolio and climate portfolio do not explain much of the variation in bank stock returns after market risk is accounted for. It is important to note that we orthogonalize bank stock returns with respect to the market portfolio to isolate incremental climate and biodiversity exposure. This approach underestimates exposures to the extent that the market factor itself captures part of the climate and/or biodiversity transition risk. Conceptually, what we assume is that any market risk is accounted for in baseline stress test scenarios—as is standard in stress tests by central banks around the world. Hence, we are interested in the *incremental* risk due to exposure to climate or biodiversity risk.

At its peak in 2022, the Euro Area aggregate BRISK (CRISK) above the baseline scenario without biodiversity (climate) stress reaches about €23 (€70) billion. Intuitively, this is the additional undercapitalization of the financial system that would be observed in 2022 if a biodiversity (climate) shock occurred. This amounts to 0.1% and 0.3%, respectively, of the total assets of stressed banks. To put these numbers into perspective, the joint gross profits of the ten largest banks in the sample in 2022 are €87 billion, which implies that these ten banks would have recovered the aggregate BRISK in roughly a quarter, and CRISK within a year. These losses are likely manageable.

Towards the end of our sample in December 2023, aggregate BRISK (CRISK) equals €8 billion (€33 billion) or 0.03% (0.12%) of total assets of stressed banks. In the same year, the ten largest banks in the sample have joint gross profits of €113 billion, indicating that they would have earned back the end-of-sample stressed losses in roughly a month and a quarter for BRISK and CRISK, respectively.

Overall, we find only limited evidence that biodiversity or climate transition risk significantly affects banks in the Euro Area. In addition, biodiversity transition risk is always less of a financial stability concern than climate transition risk. Importantly, we (i) focus on transition risk, i.e., ignore climate or nature-related physical risks (floods, droughts, ...) and (ii) our methodology captures only biodiversity and climate risk that is not contained in the market portfolio, by design. That is, our evidence should not be viewed as indications that climate and biodiversity risks are not relevant to the financial system. Both risks, however, seem to be captured well in the overall market exposure, a risk factor that is commonly captured in standard stress testing approaches.

Prof. Claudia Buch, the current Chair of the Supervisory Board at the ECB, recently stated: "[C]limate policy transition risks (...) are manageable for most financial institutions (...) Concerns about losses in the financial sector should therefore not stand in the way of a good climate policy."[7] Our policy implication is similar for biodiversity: losses caused by biodiversity transition risk are likely not a financial stability concern in Europe. Therefore, financial stability concerns should not hinder good biodiversity policy.

This paper contributes to several strands of the literature. First, it contributes to the nascent literature on biodiversity finance (Garel et al., forthcoming; Giglio et al., 2023, 2024; Flammer et al., 2023; Coqueret et al., 2024; Chen et al., 2024). To the best of our knowledge, we are the first to look at the financial stability implications arising from biodiversity-related transition risk. Second, our paper relates to the literature on stress testing in general (see Hirtle and Lehnert, 2015, for an overview), and climate stress testing in particular (see

[7] This is from the presentation of the Deutsche Bundesbank's 2023 Financial Stability Review, when Prof. Claudia Buch was Vice-President of the Deutsche Bundesbank. The full text is available here: https://www.bundesbank.de/en/press/speeches/statement-at-the-presentation-of-the-deutsche-bundesbank-s-2023-financial-stability\protect\penalty\z@-review-918864.

Acharya et al., 2023, for an overview). We rely on the method developed in Brownlees and Engle (2017) (systemic risk) and Jung et al. (2023) (climate risk) for our top-down stress test, and we are the first to apply this stress testing procedure to test the resilience of financial institutions to biodiversity-related risks. In addition, we provide a bottom-up stress test using credit registry data that allows us to get a complete picture of the loan portfolio of European financial institutions.

2 Data

Our study focuses on European firms and financial institutions (EU28 countries, i.e., EU member states and the United Kingdom). Europe is at the forefront of biodiversity-related regulation, making it an ideal laboratory to assess biodiversity-related transition risks. We access a range of datasets including credit registries, firm-level balance sheet information, and stock price data. For all our computations, we use amounts and prices in euros.

Market and Bank Balance Sheet Data. For our top-down stress test, we require stock returns and fundamentals, which we obtain from Compustat Global (securities daily and fundamentals quarterly datasets). The data is cleaned based on the filters in Chaieb et al. (2021), Bessembinder et al. (2019), and Alves et al. (2023), with minor adjustments, as discussed in detail in Appendix A.3. Our sample period is January 2010 until December 2023 (data used to estimate bank-level betas already starts in 2008 to have a sufficient pre-event estimation period).

AnaCredit. The primary data source for the bottom-up stress test is credit registry data from AnaCredit. AnaCredit encompasses all loans exceeding €25,000 by lenders subject to reporting to the European Central Bank. Consequently, the credit registry offers an almost complete depiction of the actual loan exposures of European banks. We begin our AnaCredit sample from June 2019 onwards.

AnaCredit Europe not only provides extensive data on loan exposures but also includes detailed information on borrowers' creditworthiness and the collateral assigned to each loan, based on its most recent valuation by the lender. These metrics can be utilized to assess the probability of default (PD) and the loss given default (LGD) of borrowers. Although AnaCredit directly reports the PD assigned to a borrower by each bank, it does not directly report LGDs. However, LGDs is approximated by the outstanding credit amount minus the collateral value. Therefore, AnaCredit can be used not only to gauge the extent of exposure to biodiversity and climate-related transition risks but also to evaluate the riskiness—and thus the vulnerability—of each exposure to potential shocks.

Other Data on Climate and Biodiversity Exposures. We compare the climate and biodiversity exposure defined using AnaCredit with measures based on commercially available datasets. We use DealScan to assess the exposure of a broader set of financial institutions to origination of syndicated loans (see Martini et al. (2023) for a similar approach to assess climate risk for banks). We complement this analyses using firm-level balance sheet data from S&P's Capital IQ and BvD's Orbis to compute debt exposures of European firms in climate and biodiversity industries. All datasets and methods to compute system wide exposures to biodiversity and climate transition risk are discussed in detail in Appendices A.1.1 to A.1.4. In contrast to AnaCredit these datasets are available over a longer sample period, i.e., we can estimate exposures starting in 2010.

Climate Transition Risk Events. We use the list of climate-related transition risk events originally collected by Barnett (2019) and extended to 2021 by Jung et al. (2023) to validate our climate and biodiversity transition risk factors, described in detail in the next section. These events include a wide range of shocks to expected climate policy, such as the elections of new presidents in the United States (US), publications of reports by the Intergovernmental

Panel on Climate Change, and disasters such as the damage to the Fukushima powerplants in Japan. We use all 63 events after the start of our sample in 2010, including the directional assessments about whether these events increase or decrease climate transition risk.

3 Methodology

We implement a bottom-up and a top-down stress test. For both, we need cross-sectional borrower-level exposures to biodiversity and climate transition risk, discussed in Section 3.1. We then discuss our stress testing methodologies and how we define the exposure of the financial system to biodiversity and climate-related transition risk in Section 3.2.

3.1 Exposure to biodiversity and climate transition risk

To assess cross-sectional firm-level exposure to biodiversity transition risk, prior papers have used either firm disclosure data from annual reports (Giglio et al., 2023), earnings calls (Garel et al., forthcoming), or external assessments from specialized data providers (such as Iceberg Data Lab's Corporate Biodiversity Footprint (CBF), see Garel et al. (forthcoming)). These measures are typically available only for listed firms and are thus not well suited to form financial institutions' exposures, which are to both listed and unlisted firms.

Therefore, we follow a simple and transparent approach: we define exposure on the industry level and use those industries targeted by Nature Action 100, a global investor-led engagement initiative focused on supporting greater corporate ambition and action to reverse nature and biodiversity loss. Nature Action 100 follows a two-step approach: in the first step, Nature 100 has identified key sectors deemed to be systemically important in reversing nature loss. In the second step, selected firms from each sector are targeted for specific investor engagement. We define the sectors targeted by Nature 100 as the key sectors subject to biodiversity-related transition risk. Reassuringly, Garel et al. (forthcoming) document that the Nature Action 100 list correlates highly with the Iceberg Corporate Biodiversity Footprint measure. We follow the same approach for industries exposed to climate-related transition risk by focusing on the Climate Action 100+ initiative. The methodology is straightforward and the exact industries selected are discussed in Appendix A.1. Sectors that are more exposed to biodiversity transition risk are industries with significant land use (such as Agriculture, Paper, and Merchandise), while sectors more exposed to climate transition risk are industries with carbon intensive firms (such as Oil, Coal, and Gas Extraction and Processing). In the following, we often refer to firms/sectors exposed to biodiversity-related (climate-related) transition risk as "biodiversity firms/sectors" ("climate firms/sectors") for simplicity.

3.2 Stress tests

3.2.1 Bottom-up approach

We use a bottom-up approach to assess the impacts of biodiversity and climate stress. This methodology allows us to estimate the potential under-capitalization of the Euro area financial system following a significant regulatory shock to the climate, biodiversity, and residual biodiversity sectors. The primary data source for our bottom-up stress test is the European AnaCredit credit registry which offers a comprehensive overview of lending in the Euro Area. We restrict our sample to banks reporting PDs.[8] We exclude all French lenders due to reporting irregularities in their PDs. Our sample includes 37% of total non-financial credit exposure in AnaCredit.

Our bottom-up stress test focuses on credit risk assuming that banks do not change their balance sheet in response to the stress scenario (a static balance sheet). We refer to the baseline scenario losses as the expected losses without additional stress computed as the

[8] Only banks that use an internal ratings based (IRB) risk management approach are required to report estimated PDs.

PDs times the LGDs times the exposures, all from AnaCredit data. We then shock the PDs and LGDs of the climate, biodiversity, and residual biodiversity sectors of the non-financial corporate term loans, drawn credit lines, and revolving credit. We shock PDs by multiplying them with a factor of two or three for the medium and extreme stress scenarios but cap them at 100%. We stress LGDs by multiplying collateral with a factor of 0.3. In cases where the collateral exceeds to outstanding amount of the credit, we assume a zero loss. Since we define LGDs as uncollateralized loan exposure, this shock to collateral strongly increases LGDs. Stressed losses are defined as the difference in the expected losses in the stress scenario above the baseline scenario for each point in time. We report these incremental losses relative to the total outstanding non-financial corporate debt of the stressed banks.

Our approach differs from conventional stress tests that model an adverse scenario for the entire economy which translates into firm-level changes to PD and LGD. By directly shocking PDs and LGDs through collateral, our approach is more tractable. We ensure that we do not underestimate stress impact by applying PD and LGD shocks that are more severe than those used in other stress tests. For instance, in the recent ECB (2023c) climate stress test, PDs increase 1.8 times in the most adverse scenario from 2022 to 2030. Similar increases are reported in market stress tests such as the Supervisory Review and Evaluation Process (SREP). For example, ECB (2023a) reports that the median PDs for corporate credit double after the stress scenario is implemented in the most recent SREP.[9] Thus, our two-fold increase in PDs is comparable to the impact of these stress tests, and our three-fold increase in PDs is more extreme. Regarding LGDs, while the ECB (2023c) climate stress test assumes full collateral recovery in stress scenarios, our worst-case scenario assumes that only thirty percent of the collateral is recovered. Overall, our stress scenarios should be

[9]The SREP stress test reports point-in-time PDs from 2022 to 2025. Since PDs are shocked from 2023 onwards, we interpret the difference between reported PDs in 2022 and 2023 as the shock impact. We do not observe the counterfactual 2023 PDs without stress impact. Therefore, our inference assumes no underlying PD trend from 2022 to 2023.

interpreted as at least similarly severe as commonly used central bank stress tests.

3.2.2 Top-down approach

Jung et al. (2023) introduce CRISK as the expected capital shortfall of a bank in a climate stress scenario. We analyze BRISK in the same fashion, based on a biodiversity stress scenario. We compare BRISK with CRISK computed using the same methodology, the same sample, and the same period. In addition to this, we quantify residual BRISK that captures biodiversity risk after climate risk is accounted for.

In contrast to the bottom-up approach, this methodology is market-based. This allows us to capture more complex effects of biodiversity and climate risk on bank balance sheets to the extent that these are priced correctly in the market. For example, in the bottom-up stress test, we assume that a shock to biodiversity firms happens *in isolation*, e.g., credit risk for agricultural firms increases but this has no effect on other sectors. While this gives a good first benchmark for direct effects on banks' balance sheets, it likely underestimates the risks for the financial sector. In the top-down stress test, indirect effects are included.

We first estimate daily betas that capture the sensitivity of the banks' stock returns to biodiversity, climate, and residual biodiversity risk. We do this for each bank (SIC starting with 60 or 61) in our sample. This gives us a time-varying bank-specific measure of exposure to biodiversity, climate, and residual biodiversity transition risk.

To estimate these betas, we first define a biodiversity portfolio (BP) and a climate portfolio (CP), which are long-only value-weighted portfolios including all stocks of industries heavily exposed to biodiversity and climate transition risk, respectively. The industry selection is discussed in Section 3.1. We also construct the market portfolio return (MKT) as the value-weighted return of non-financial (excluding SIC 6) stocks in our sample. Portfolio weights are determined based on lagged market capitalizations, and returns are available for each trading day.

Because BP and CP are correlated with MKT, we use a two-step procedure to estimate betas. For the biodiversity and climate betas, we first estimate the exposure of returns to the market portfolio and then compute betas from the residuals of this first regression in the second step. For the residual biodiversity betas, we add the climate portfolio next to the market portfolio in the first step and compute betas based on the residuals after orthogonalizing on both portfolios.[10] Intuitively, the biodiversity and climate betas capture the sensitivity of banks' stock returns to biodiversity and climate transition risk that is not captured in the returns of the market portfolio. Therefore, our analysis is focused on the additional equity risk due to biodiversity and climate transition risk for a bank that manages market risk well.[11] Similarly, the residual biodiversity beta captures the sensitivity of the banks' stock return to biodiversity transition risk that is not captured by market and climate transition risk.

The equations to compute the betas are

$$\begin{aligned} Ret_{i,t} &= \beta_{m,i} MKT_t + \mathbb{I}_{residual} \left[\beta_{cres,i} CP_t \right] + \epsilon_{i,t}, \\ \hat{\epsilon_{i,t}} &= \beta_{X,i} XP_t + \tilde{\epsilon}_{i,t}, \end{aligned} \tag{1}$$

where $Ret_{i,t}$ is the return of financial institution i at time t and MKT and XP are the value-weighted portfolio returns of the market portfolio and either the BP or the CP, respectively. $\mathbb{I}_{residual}$ is an indicator function implying that the first step includes an orthogonalization on the returns of CP for the estimation of the residual biodiversity beta. We are interested in $\beta_{X,i}$ from the second step, which is the biodiversity, climate, or residual biodiversity beta,

[10] This is a slight deviation from the methodology in Jung et al. (2023), who jointly estimate the market and climate betas in a single regression. In their setting, the correlation between these portfolios is smaller because they include a short position to MKT in their climate factor. In our setting, we orthogonalize more formally.

[11] If the returns of the market portfolio are systematically driven by biodiversity and climate transition risk, our results do not capture this. This suggests that we may underestimate the real biodiversity and climate transition risk in the banking system. However, we think it is reasonable to focus on biodiversity and climate transition risk in excess of market risk under the assumption that market risk is already well supervised through other channels than biodiversity and climate stress tests.

respectively, for X equal to B, C, or B_{res}.

We apply a rolling window regression using the last 252 daily observations (based on the number of trading days per year) with a minimum of 200 available observations to compute betas for each bank.[12] We then smooth the daily betas with a one-month (21 trading days) moving average to decrease noisiness in the bank-level betas before using them to compute risk exposures.

We compute BRISK, CRISK and residual BRISK for each bank as the expected capital shortfall conditional on a shock to BP, CP, and BP, respectively. We refer to these as XRISK where X can equal B, C or 'Residual B'. Formally, XRISK for institution i equals

$$XRISK_{i,t} = kD_{i,t} - (1-k)W_{i,t}\exp(max(\beta_{X,i,t}, 0)\log(1-\theta)), \tag{2}$$

where D is the total debt of financial institution i at time t, W is its market cap, k is the prudential capital fraction, and θ is the price shock used as stress scenario. We follow Jung et al. (2023) and set $k = 5.5\%$ and $\theta = 50\%$. To decrease noisiness, we use a one-month (21 trading days) moving average of beta to compute XRISK. We truncate betas at zero to ensure that we are only counting negative shocks.

We compute aggregate XRISK as the systematic exposure to biodiversity or climate transition risk in the EU28 by summing all non-negative bank-specific XRISK values. This measure captures the total non-negative expected capital shortfall by banks in the EU28 following a stress scenario, which is intuitively driven by two parts: (i.) the impact of the stress scenario, and (ii.) the ex-ante capitalization of the financial sector unrelated to the scenario. We aim to analyze the impact of biodiversity and climate risk irrespective of current capitalization levels. Therefore, we compute the baseline aggregate undercapitalization as XRISK without stress (i.e., when $\theta = 0$) and report the aggregate XRISK above the aggregate

[12] Jung et al. (2023) apply a DCC-GARCH approach to estimate time-varying daily betas and confirm in their appendix that rolling window regressions give similar output.

risk in the baseline scenario as our measure of interest. We refer to this measure as 'XRISK above the baseline scenario'. Intuitively, this captures the part of the losses following shocks to the BP and CP that end up making banks undercapitalized, and it ignores losses that do not result in undercapitalization of the bank. To get a complete picture, we also document aggregate losses, defined as marginal XRISK by Jung et al. (2023).

Descriptive statistics of the portfolio returns are presented in Table 2. Our market portfolio has an average market capitalization of €7.2 trillion from 2010 until 2023. In comparison, the December 2023 market capitalization of the Euro Area is €9.7 trillion according to the ECB.[13] The biodiversity portfolio has half of the market capitalization of the climate portfolio, but its performance is quite similar. Descriptives of the bank characteristics are presented in Table 3. Most of the banks we analyze are deposit banks. These are larger but similarly levered as other listed banks on average. Total assets, debt, and market capitalization all have minimum values of zero. These are explained by the bank-day observations of the few banks in our sample that went bankrupt some days after. These are generally not zero, but very small numbers rounded to zero in this table.[14]

4 A biodiversity stress test of the financial system

4.1 Financial system exposure

We start with simple descriptive analyses of the system-wide exposure to biodiversity and climate transition risk. Figure 2 shows the total biodiversity and climate transition risk exposure of the financial sector.

To provide a comprehensive overview, the figure shows results for four different datasets.

[13]Source: https://data.ecb.europa.eu/main-figures/securities/listed-shares?tab=Total&indicator=Stocks

[14]The exception is the zero market capitalization for two bank-day observations. These two banks went bankrupt on that date, but we leave these observations in because we do not want to filter out the delisting return.

The first figure (top-left) uses data from AnaCredit, i.e., full credit registry data available since 2019 (including lending to small and large firms). We focus on term loans and drawn credit lines to non-financial firms. We plot total outstanding credit to firms in biodiversity and climate industries as a fraction of total outstanding credit. The figure shows that climate industries account for about 25% of total outstanding bank credit compared to about 15% for biodiversity industries. We further plot the "residual biodiversity" exposure, which is the biodiversity exposure excluding industries that are exposed to both climate and biodiversity transition risk. This exclusion reduces the biodiversity exposure to about 10% of the total bank credit volume in Europe.

These measures show little time-series variation but there is cross-sectional heterogeneity in exposure between banks. Table 1 presents the distribution of the corresponding bank-specific exposures for each risk type. The cross-sectional standard deviations of the exposures are sizable, as is the difference between the first and third bank quantile observations. We note that we do not report the entire distribution including minimum and maximum values due to data confidentiality reasons.

The second panel of Figure 2 (top-right) defines bank exposures based on newly originated syndicated loans using DealScan data over the 2010 to 2023 period. The sample includes both term loans as well as drawn and undrawn credit line exposures (drawdown ratios are not included in the origination data). The biodiversity risk exposure in the syndicated loan market is almost identical to that using credit registry information (the residual biodiversity exposure is somewhat smaller). The exposure to climate industries, in contrast, is significantly larger (about 40% of total credit). This might indicate that climate industries have a disproportional share in credit outstanding to large public firms (active in the syndicated loan market).

We now move from the lender to the firm perspective by analyzing the debt of European firms. The third figure (bottom-left) uses Capital IQ debt structure data, available only for public firms. Capital IQ provides information on outstanding credit at the firm level on an annual basis. We again focus on term loans and drawn credit lines and split the sample into biodiversity and climate firms. Results mirror the results using DealScan data (which contains a similar set of firms).

Finally, the fourth figure (bottom-right) uses ORBIS data, which includes private and public firms. In this dataset we cannot distinguish between bank and non-bank (bond) debt, i.e., total debt by biodiversity and climate firms is used. Overall patterns are similar, with the climate exposure being somewhat more muted compared to the previous two figures. This again highlights that climate exposures are higher in datasets that exclusively focus on public firms. The (residual) biodiversity risk exposure is consistently around 10-15% (7-10%) irrespective of the dataset that is used. Overall, the figure shows that the credit risk exposure to climate industries is larger than to biodiversity industries. Biodiversity transition risk exposure is moderate.

The exposure analyses so far focus on the total €-exposure of the financial system to a sector. However, an assessment of credit risk is also relevant since a large exposure might pose little risk if default probabilities are very low. Figure 3 shows the loan-volume-weighted average probabilities of default (PDs) and loss given default (LGD) for the biodiversity and climate industries, as derived from the AnaCredit dataset. Similar to the exposure calculation, PDs are determined for all borrowers possessing either a term loan or a drawn credit line. The PD, reported by the lender, is defined as the likelihood that a borrower will default on their obligations over a one-year horizon.

Interestingly, PDs associated with biodiversity industries risks are significantly ($\sim$40%) higher than those linked to climate industries. This in particular holds for the residual (non-overlapping) biodiversity exposure. PDs increased considerably in 2022 around the start of the Ukraine conflict. This is expected given the resulting energy crisis and the large fraction of firms in the energy and related sectors contained in particular in the climate exposure.

The residual biodiversity sectors do not exhibit an increase in PDs.

While PDs for biodiversity firms are larger, LGDs are significantly smaller. This indicates that collateralization rates are higher in these sectors. Overall, the results do not support the conjecture that recovery rates for biodiversity borrowers are lower compared to climate borrowers. If anything, the opposite seems to be the case.

4.2 Bottom-up stress test

In this section, we report the results of the bottom-up stress tests. As discussed in Section 3, we define four scenarios: (i.) 2x PD, (ii.) 3x PD, (iii.) collateral value reduced to 30%, and (iv.) 3x PD *and* collateral value reduced to 30%. For each scenario, we calculate the implied *incremental* losses for the entire financial system (as captured by our AnaCredit dataset, described in more detail in Section 2) in percent of total credit to non-financial firms. Incremental losses are defined relative to the baseline scenario (baseline PDs and full collateral values).

Figure 4 shows the results. Focusing on the most extreme scenario (bottom right) we find additional losses of around 0.5 to 0.8 percentage points of total credit following a shock to the biodiversity and climate industries, respectively (the magnitude increases following the Russia-Ukraine conflict and the resulting effects on energy markets). That is, even in an extreme case the effect is small. For the residual biodiversity industries (i.e., firms not also included in the climate industries), the effect ranges from 0.2 to 0.3 percent of total credit that is at risk following a shock to biodiversity sectors.

In Table 4 we report the numbers for the month with the the highest absolute losses (June 2023). The total incremental climate-related losses would amount to €8.05 billion. This amounts to only 0.042 p.p. of total assets of the financial system. Effects for biodiversity-related losses are of even smaller magnitude. In addition to "peak loss day effects," we report estimates for the last month in our sample period (December 2023) with similar conclusions.

These numbers are also small in absolute terms. For example, the peak climate-related losses of €8.05 billion in 2023 are smaller than the average gross profit of the ten largest listed European banks in the same year, at €11.3 billion. Thus, a single large bank earns back the most extreme aggregate Euro Area stressed losses within a year.

The aggregate numbers might mask heterogeneity across institutions. Table 5 reports the distribution of incremental losses scaled by corporate lending in the cross-section of banks for the peak loss month. While there is some heterogeneity, total losses amount to only 0.5 to 0.8 percent of the total non-financial corporate loan portfolio even at the 75th percentile of the distribution. The mean loss for the five banks with the highest losses (averages across 5 banks for confidentiality reasons) is 2.72% for residual biodiversity, 3.98% for total biodiversity, and 5.84% for climate.

Overall, the results from the bottom-up stress tests indicate a limited effect of biodiversity and climate transition risk on European banks. This might be because: (i.) overall portfolio exposure, in particular to biodiversity sectors is moderate (10-15% of banks' loan portfolio), (ii.) we estimate effects only for banks' non-financial corporate loan portfolio (and assume that other positions are unaffected), and (iii.) we abstract from any spillover effects (i.e., assume that any effect to climate or biodiversity sectors is contained within the respective sector). In particular assumption (iii.) might lead to a significant underestimation of climate and biodiversity risks to financial stability. To better capture such effects we next turn our attention to the top-down market-based stress testing approach, which does not have assumptions (ii.) and (iii.).

4.3 Top-down stress test

In this section, we present the results of the top-down stress test. Before we turn to the stress test results, we examine in Section 4.3.1 if the climate and biodiversity risk factors (defined on the sectorial level) indeed capture climate and biodiversity transition risk. We then turn to the main stress test results in Section 4.3.2.

4.3.1 Biodiversity and climate responses to climate transition risk events

To test whether the constructed climate and biodiversity risk factors used in the top-down approach indeed capture the respective transition risk, we conduct an event study analysis. While there is only a limited number of biodiversity transition risk events so far, we can examine the sectorial responses to climate transition risk events. We consider all climate transition risk events defined by Barnett (2019) and Jung et al. (2023) since 2010, the start of our sample. This gives us a total of 63 events that we use for our event study.

We analyze whether stocks that are included in the climate or biodiversity portfolios respond differently to climate transition risk events than other stocks. In addition to portfolio-level analyses, we test industry-level stock return responses to climate transition risk events, relative to all other industries. Specifically, we estimate

$$Ret_{i,t} = \beta_0 + \beta_1 Treat_i Post_t + \delta_i + \gamma_t + \epsilon_{i,t}, \tag{3}$$

where $Ret_{i,t}$ is the daily return of stock i and stocks are treated when they are within the industries of interest. Post equals one or minus one from the day of the event, mimicking the directional assessments (by Barnett (2019) and Jung et al. (2023)) about whether these events increase or decrease climate transition risk. We include fixed effects for stock and date. For each event, we include firms for which we observe stock returns in the entire 6-day event window from three trading days before until two trading days after the event date.[15] To improve the precision of our estimates, we estimate these regressions at once for all 63 events by stacking the samples of six-day stock returns for all events. We run this event

[15]This specification is almost the same as Garel et al. (forthcoming), but our treatment dummy is a simple industry indicator since we determine whether a stock is included in the biodiversity and climate portfolios based on its industry. In the original paper, the 'treat' is replaced by a dummy that indicates that the firm has high biodiversity exposure.

study for each industry,[16] the climate portfolio, and the residual biodiversity portfolio that includes the biodiversity sectors except those that are also part of the climate portfolio.

Figure 5 shows the industry-level stock market reaction around the climate transition risk events. The industries with large carbon emissions that are contained in our baseline climate portfolio show significant negative relative returns. Coal Mining, Oil and Gas Extraction, and Petroleum Refining, all contained in the climate portfolio, are the three most negatively exposed industries overall. The climate-exposed industries Metal Mining and Chemicals also show a negative stock market performance. The overall climate portfolio has a statistically significant negative estimate, confirming that our baseline industry classification is reasonable.

However, also the industries Water Transportation and Engineering that are not contained in the baseline climate portfolio have significantly lower returns around the climate transition risk events. This is plausible, e.g., Water Transportation contains cruise lines and sea freight operators, both highly pollutive industries. Engineering contains sub-sectors such as boat design and petroleum engineering, i.e., a negative exposure is plausible.

Transportation Equipment, on the other hand, is one of the least negatively affected sectors despite being flagged as a climate sector (note that all effects are relative, i.e., a positive estimate does not imply that an industry "benefits" from climate transition risk events but just that the industry reacts more positively to the event compared to other industries). While surprising at first glance, this is a diverse sector and can contain producers of combustion vehicles and airlines but also producers of electronic vehicles and railway operators, i.e., firms that are less exposed to climate transition risk.

Sectors contained in our baseline biodiversity portfolio do not show a significant reaction to climate transition risk events. This highlights that both risks are distinct from each other,

[16] We define industries based on two-digit SIC and aggregate those with insufficient observations. In particular, we combine agriculture, forestry and fishing (all SICs starting with '0'); railroads and local transit (40 and 41); and the smaller service industries (72, 75, 76, 81, 83, 84, 89).

i.e., biodiversity transition risk warrants a separate assessment and is not already contained in climate transition risk. The only sectors contained in the biodiversity portfolio that have negative reactions are the two sectors that are also defined as being exposed to climate transition risk (Metal Mining, Chemicals). The negative reaction of these industries is thus unsurprising. The residual biodiversity portfolio that excludes the sectors also contained in the climate portfolio exhibits a positive performance (relative to all other industries, including climate sectors).

4.3.2 Stress test results

We start by estimating climate and (residual) biodiversity betas for each financial institution. It is important to again note that we orthogonalize bank stock returns with respect to the market portfolio to isolate incremental climate and biodiversity exposure. This approach underestimates exposures to the extent that the market factor itself captures part of the climate and/or biodiversity transition risk. Conceptually, what we assume is that any market risk is accounted for in baseline stress test scenarios—as is standard in stress tests by central banks around the world. Hence, we are interested in the *incremental* risk due to exposure to climate or biodiversity risk.

Figure 6 plots the distribution of betas over time. These betas determine the impact of the stress scenarios on bank equity. Absolute betas are small, ranging between -0.35 and 0.1 for biodiversity and between -0.1 and 0.15 for climate. That is, the biodiversity portfolio and climate portfolio do not explain much of the variation in bank stock returns after market risk is accounted for. There are several striking differences between the biodiversity and climate betas. First, the median bank has more climate exposure than biodiversity exposure. In addition, both the median and average climate betas increase over our sample while there is no clear trend for biodiversity. Second, positive climate betas are larger than biodiversity betas. The cross-sectional beta distribution is negatively skewed for biodiversity and positively skewed for climate, as visible from the 10-90% distribution. Third, climate exposures are concentrated with large banks, while biodiversity exposures are concentrated with small banks. The value-weighted average climate beta is much higher than the (equally-weighted) median climate beta, while the opposite holds for biodiversity. Fourth, biodiversity and climate betas both peak in 2022, towards the end of our sample, but the average and median biodiversity betas are still zero then. Finally, residual biodiversity betas, where climate risk has been taken out of bank stock returns, are quite similar but at times somewhat below the normal biodiversity betas. These differences imply that climate stress scenarios will have significantly more impact on the undercapitalization of the banking system than biodiversity stress scenarios: shocks (betas) will generally be larger in relative terms and larger shocks will be concentrated among larger banks.

Figure 7 shows the main results of the top-down stress test: aggregate losses and implied undercapitalization for the listed banks in the EU28 countries over time, smoothed with a one-year (252 trading days) moving average to remove noise in the daily estimates. In Panels A and B, we show the aggregate marginal BRISK, CRISK, and residual BRISK in absolute numbers and relative to total bank assets, respectively. These are the aggregate losses caused by a shock to the biodiversity or climate portfolios. Biodiversity-related losses are generally small throughout the sample and peak at around €15 billion or 0.06% of total assets in 2022. This is a direct reflection of the distribution of biodiversity betas: the peak in biodiversity losses coincides with the highest distribution of biodiversity betas. Climate stress scenarios cause more severe loss episodes, increasing over the sample. Climate-related losses also peak in 2022, at around €52 billion or 0.2% of total assets. Climate-related losses are increasing over our sample, indicating that climate transition risk is getting more impactful for the European banking sector.

Panels C and D of Figure 7 present how these losses translate into undercapitalization of the banking industry by presenting aggregate BRISK, CRISK, and residual BRISK, again in absolute numbers and relative to total assets, respectively. As discussed in Section 3.2.2, all exposures are defined relative to a baseline non-stress scenario. Hence, our estimates capture losses following shocks to the biodiversity or climate risk factor that end up making banks undercapitalized above and beyond ex-ante undercapitalization. At its peak, the aggregate BRISK (CRISK) above the baseline scenario reaches about €13 (€44) billion, which translates to 0.05% (0.16%) of assets for the banks in our sample. Because biodiversity and climate risks overlap, accounting for climate risk decreases biodiversity-related losses. Therefore, Residual BRISK is always close to zero and smaller than BRISK.

Table 6 reports peak day estimates. The days with the highest biodiversity and climate exposures are in 2022 with aggregate BRISK (CRISK) above the baseline scenario of €23 (€70) billion. We note that these numbers exceed the values reported in Figure 7 because the figure reports rolling averages. Relative to the total assets of the banks in the sample, these peak exposures are 0.1% to 0.3% for BRISK and CRISK, respectively.

Even at the peak, these losses are likely manageable. For example, in 2022, the ten largest banks in our sample jointly made €87 billion in gross profits. This indicates that just ten banks would have recovered the aggregate undercapitalization caused by the biodiversity and climate stress scenarios in roughly a quarter and year, respectively. In addition, the most recent exposures are smaller. In December 2023, the €8 (€33) billion aggregate BRISK (CRISK) above the baseline scenario is only a small part of the €113 billion 2023 gross profit of the ten largest banks in our sample. The end-of-sample aggregate BRISK and CRISK are 0.03% and 0.12% of the total assets of stressed banks, respectively.

Overall, we find only limited evidence that biodiversity or climate transition risk poses a financial stability concern in the Euro Area. Importantly, our methodology captures only biodiversity and climate risk that is not contained in the market portfolio, by design. That is, this evidence should not be viewed as indications that climate and biodiversity risks are not relevant for the financial system. Both risks, however, seem to be captured well in the overall market exposure, a risk factor that is commonly captured in standard stress testing approaches.

5 Conclusion

Our study provides a comprehensive assessment of the European financial system's exposure to biodiversity-related transition risk, alongside a comparative analysis with climate-related transition risk. Using both a bottom-up and top-down stress testing approach, we find that while a non-negligible share of bank credit is linked to industries exposed to biodiversity transition risk (approximately 15% of total credit to non-financial firms), the overall financial system impact appears moderate. The bottom-up stress test indicates that even under severe stress scenarios, the additional losses from biodiversity risks are estimated at only 0.3 to 0.5% of the total non-financial corporate loan portfolio. The top-down market-based approach confirms these findings and documents that the capital shortfall associated with a severe shock to the biodiversity risk factor would only amount to about 0.1% of banks' assets.

These results suggest that biodiversity transition risk, while relevant, does not currently pose a substantial threat to the stability of the Euro Area's financial system. Therefore, financial stability concerns should not hinder good biodiversity policy.

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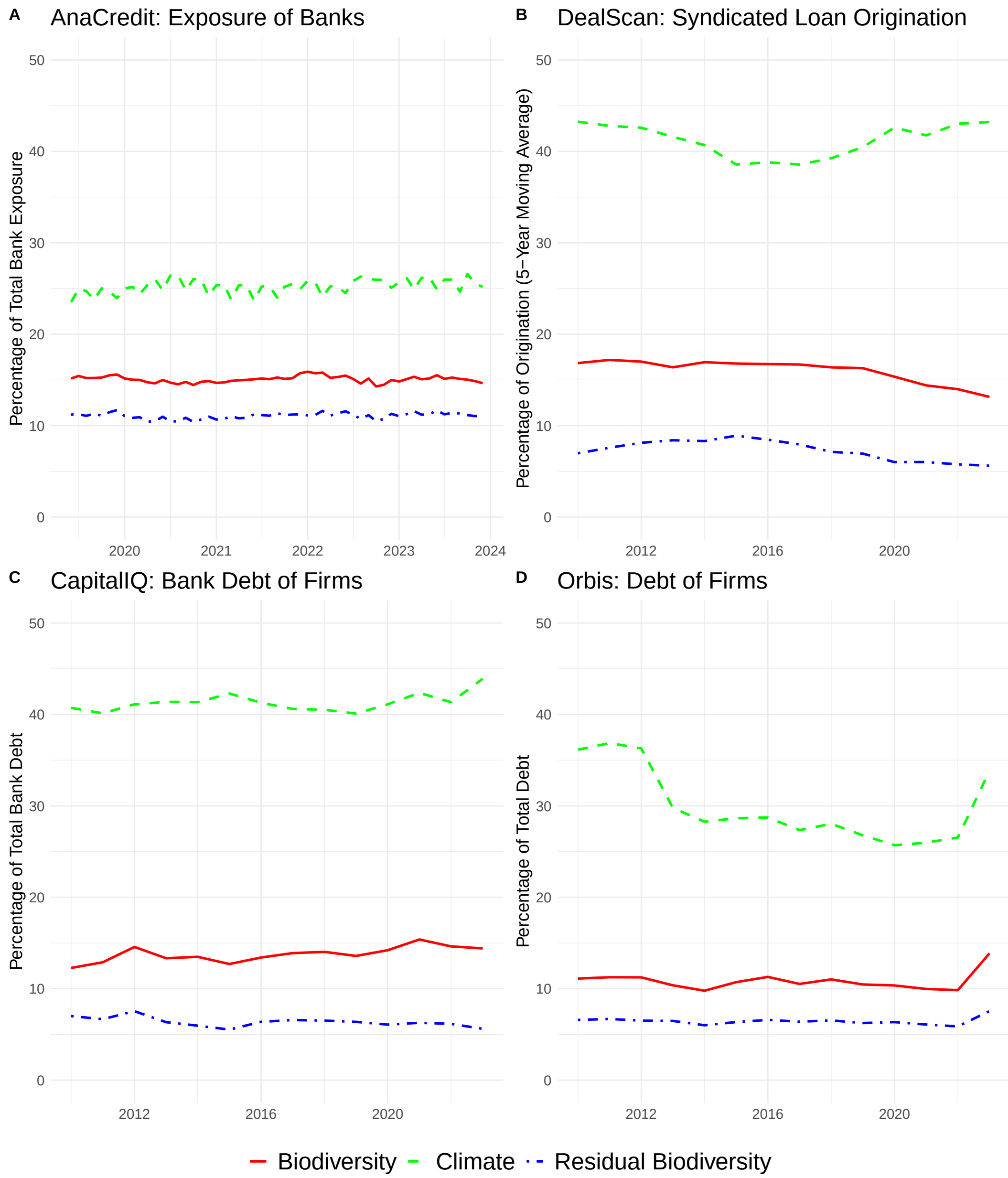
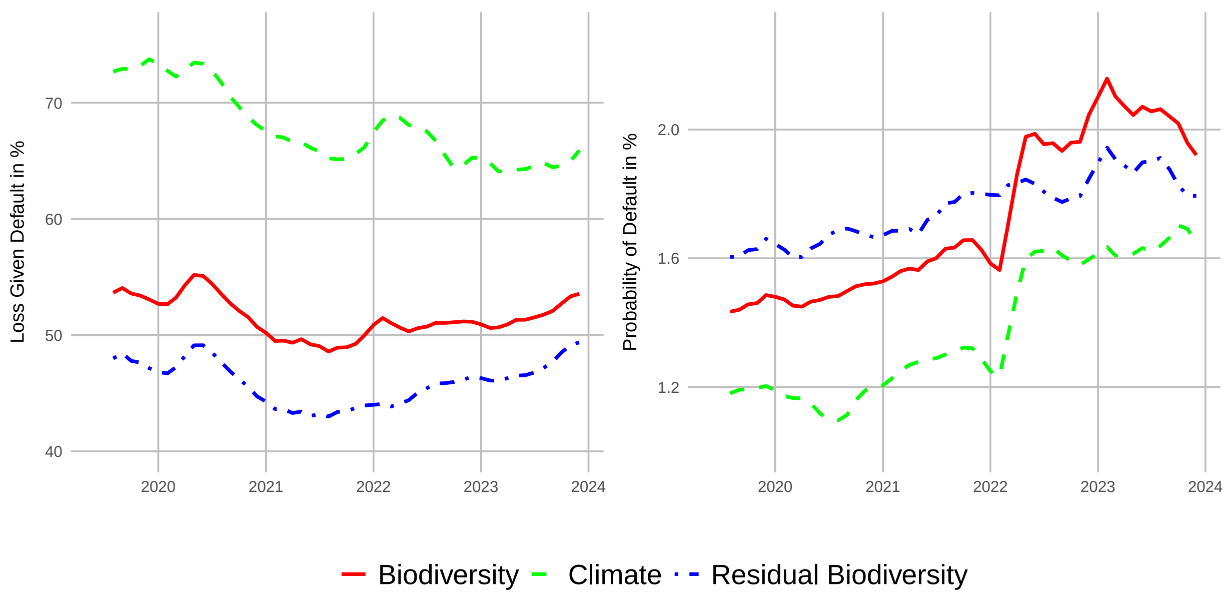
Figure 2: European financial system exposure to transition risk



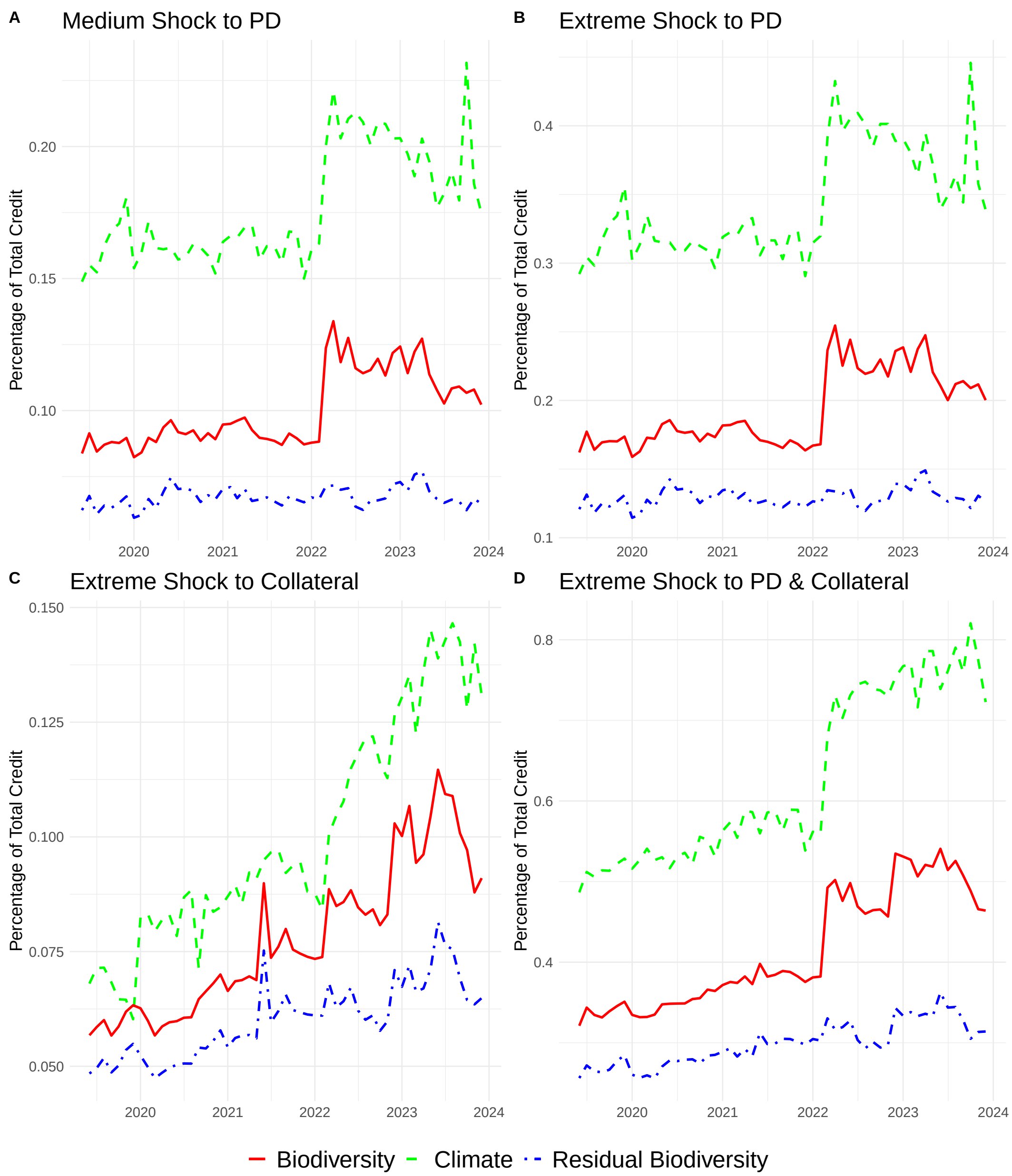
This figure documents the exposure of the European financial system to biodiversity and climate transition risk. In each subplot, we compute the loan exposure towards industries with high biodiversity or climate transition risk and divide this by the total loan exposure to non-financial corporate loans excluding real estate and public borrowers. The residual biodiversity exposure is the part of the biodiversity exposure that is not also included in the climate exposure. Panel A shows the exposure of all European banks reporting within AnaCredit Europe. Panel B shows the exposures based on syndicated loan origination activity by lenders in the EU27 as well as the United Kingdom (EU28). In this panel, new origination is smoothed through a five-year moving average to approximate exposures instead of new sales. In contrast to these exposures by European lenders, Panel C and D show the exposures based on firms in the EU28 using data from CapitalIQ and Orbis, respectively.

Figure 3: Euro Area loss given default and probability of default



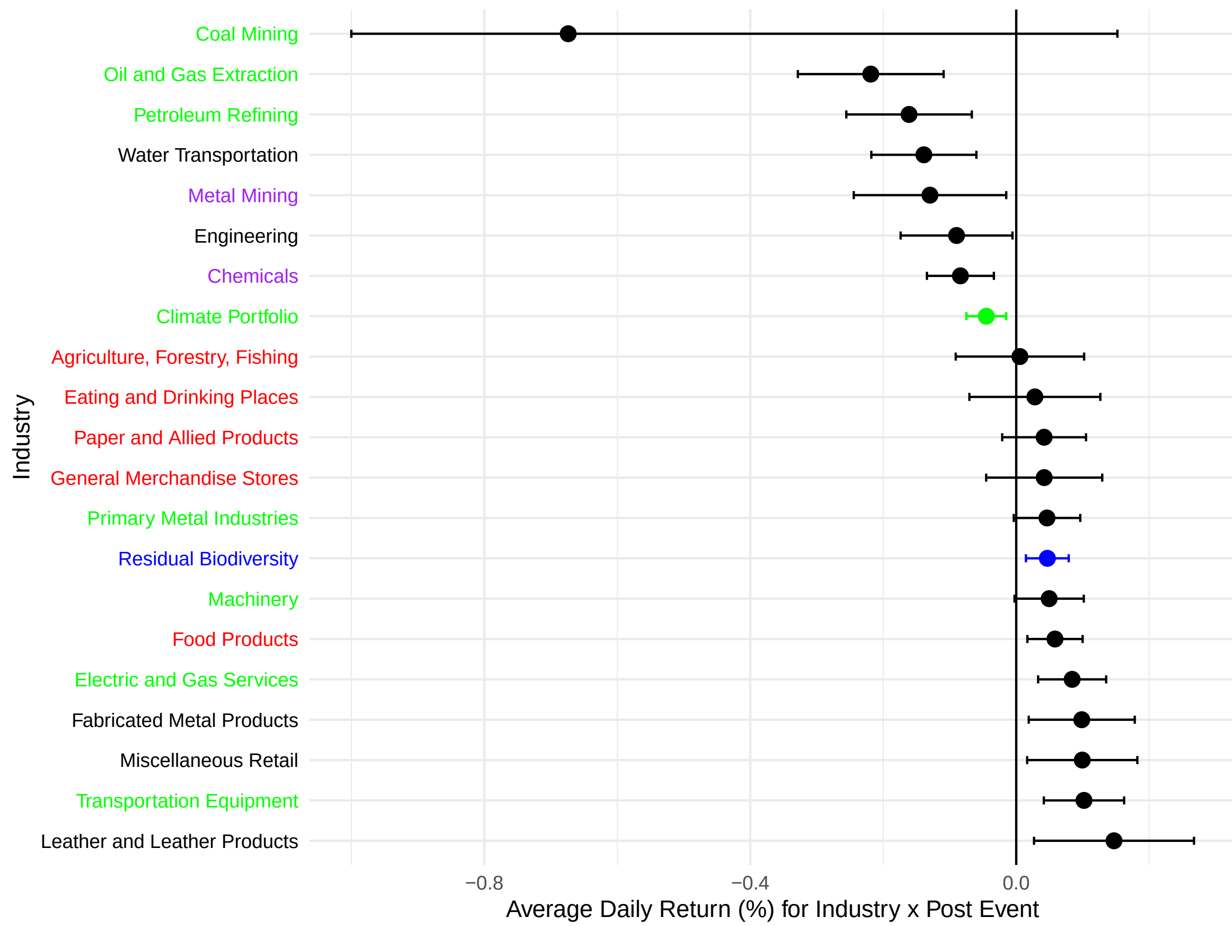
This figure presents the loan volume weighted average of the loss given default (LGD) and the probability of default (PD) for Euro Area firms. We apply a three-month moving average in order to smooth the representation. The LDG is defined as the nonnegative outstanding non-financial credit at after deducting the collateral value. The PD is defined as the likelihood that a borrower will default on their obligations over a one-year horizon.

Figure 4: Bottom-up stress test: incremental losses



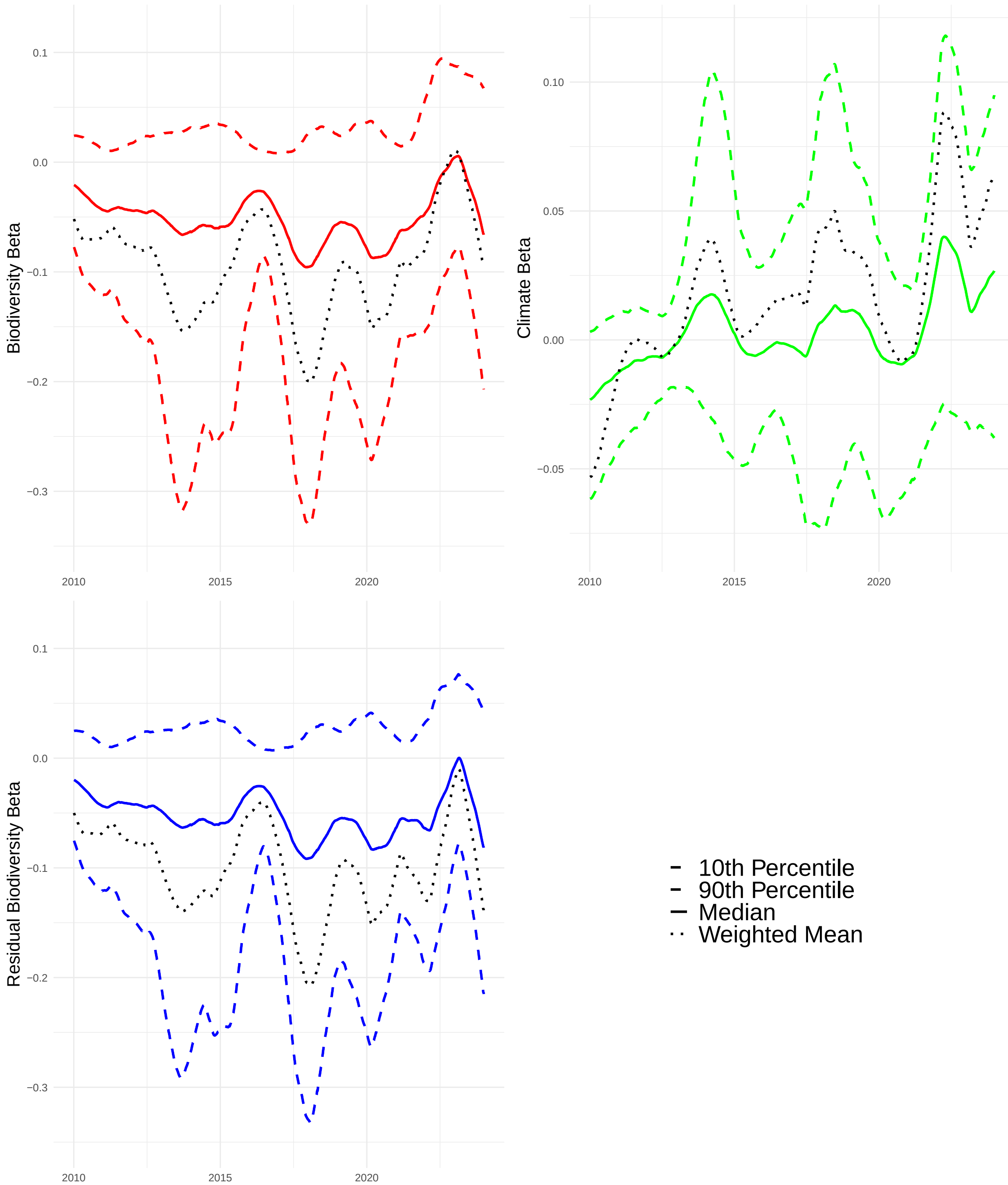
This figure illustrates the losses incurred from different shock scenarios over time scaled by non-financial credit exposure. The losses are determined through a two-step process. First, we calculate a baseline scenario without any stress based on probabilities of default (PDs) and loss given defaults (LGDs) reported in AnaCredit. Secondly, we shock the PDs and LGDs in stress scenarios. Incremental losses are the difference in expected loss (PD times LGD times Exposure) between the stress scenarios and the baseline scenario. These incremental losses are expressed as a proportion of the total non-financial lending. In (A), we apply a doubling of PDs. In (B), we triple the PDs. In (C), we multiply the collateral by 0.3, which increases LGDs. In (D), both the collateral value and the PD are shocked by multiplying the PD by 3 and the collateral by 0.3.

Figure 5: Industry responses to climate transition risk events



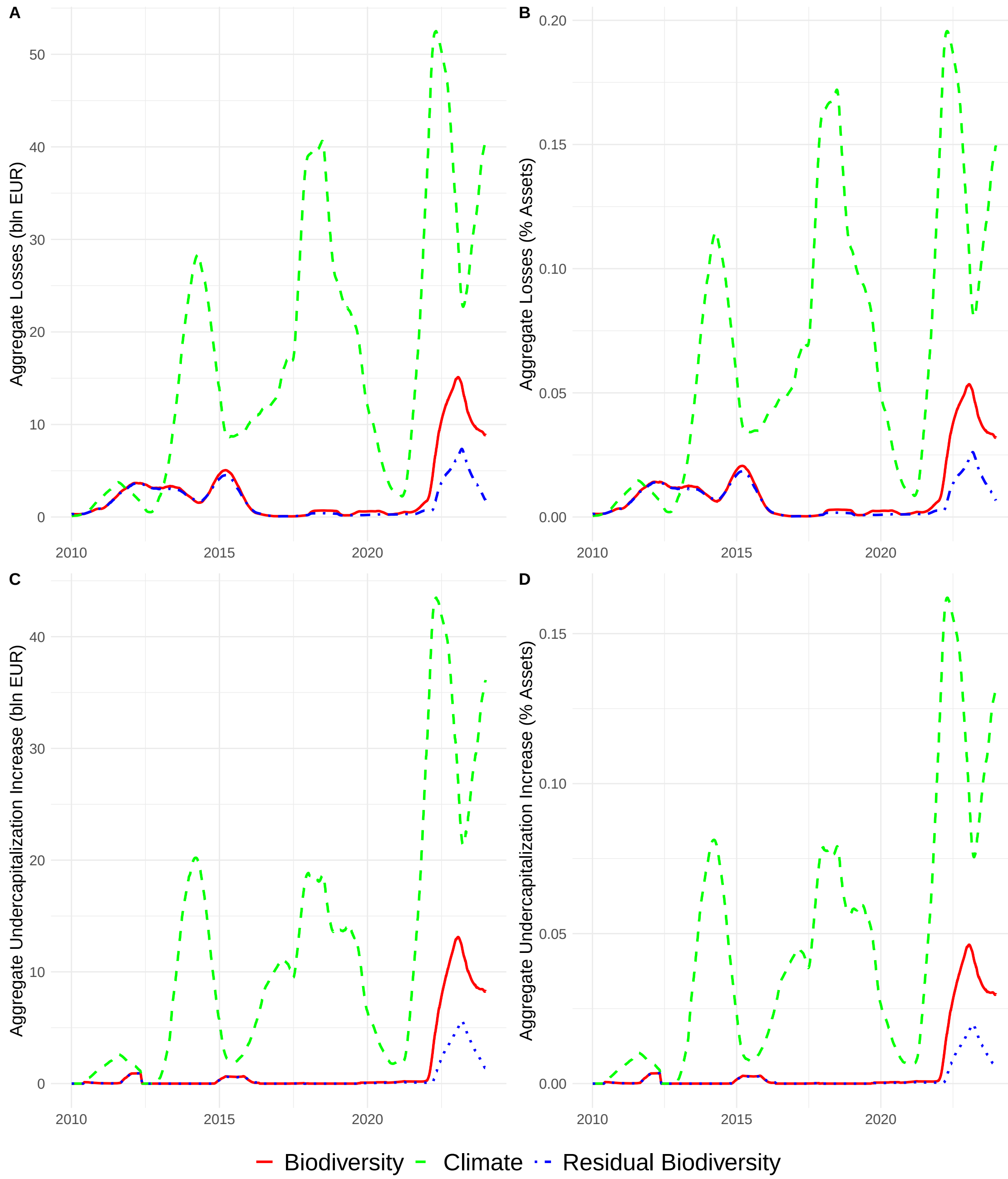
This figure shows the industry-level average relative return impact around 63 climate transition risk events between 2010 and 2021, as collected by Barnett (2019) and Jung et al. (2023). See Section 4.3.1 for details on the estimation. Industries contained in the baseline climate and biodiversity portfolio are highlighted in green and red, respectively. Industries in both the climate and biodiversity portfolio are highlighted in purple. The climate and residual biodiversity portfolio estimates are highlighted in green and blue, respectively. The figure shows all statistically significant estimates as well as all industries contained in the climate or biodiversity portfolio. In addition to industry-level estimates, the figure shows the relative performance of our baseline climate portfolio (CP) around the events as well as the performance of the baseline biodiversity portfolio (BP), excluding industries that are in CP (the residual biodiversity portfolio). The bars around the coefficient estimates reflect the 95% confidence interval based on standard errors clustered at the firm level. We note that the confidence interval for "Coal Mining" is truncated at -1% to enhance the readability of the figure.

Figure 6: Biodiversity, climate and residual biodiversity betas over time



This figure shows the cross-sectional distribution of the biodiversity, climate and residual biodiversity betas in the top left, top right, and bottom left panels, respectively. In each panel, we show the 10th percentile, median, and the 90th percentile as well as the value weighted (by lagged market capitalization) average of the betas over time. These values are smoothed with a one-year (252 trading days) moving average.

Figure 7: Top-down stress levels over time



This figure shows the 1-year (252 trading days) moving average of the aggregate losses and undercapitalization caused by biodiversity and climate stress scenarios in the top-down stress test. Panels A and B show the aggregate losses (marginal BRISK, CRISK, and Residual BRISK) caused by biodiversity and climate stress in absolute numbers and relative to the total assets of the banks in the sample. Panels C and D show how these losses translate to undercapitalization by presenting the aggregate BRISK, CRISK and Residual BRISK above the baseline scenario without equity price shocks, again in absolute and relative values. All numbers are in billions of euros.

Table 1: Exposure distribution of banks to transition risks

This table presents the distribution of exposures in the cross-section of banks to climate and biodiversity transition risk. For each bank, we compute the loan exposure towards biodiversity and climate industries and divide this by the total loan exposure to non-financial corporate loans excluding real estate and public borrowers. The residual biodiversity exposure is the part of the biodiversity exposure that is not also included in the climate exposure. Values are reported in percentages. The reporting date is June 2023, the date with the highest absolute expected losses for biodiversity industries above the baseline scenario.

	N Banks	Mean	StDev	25%	50%	75%
Climate	99	22.44%	18.01%	10.75%	20.44%	29.32%
Biodiversity	99	13.25%	8.44%	7.35%	13.24%	19.26%
Residual Biodiversity	99	10.42%	7.04%	5.28%	10.23%	15.00%

Table 2: Descriptive statistics of the market, climate and biodiversity portfolios

This table reports descriptive statistics for the daily portfolio returns in percentage per day. Next to this, we include the average number of firms within each portfolio over time and the average aggregate market cap (bln EUR) of the portfolio firms over time. The sample includes daily observations from January 2010 to December 2023.

Portfolio	Obs	Mean	StDev	Min	Median	Max	N Firms	Mkt Cap
Market	3,595	0.04	1.02	-11.08	0.08	7.76	3,207	7,189
Biodiversity	3,595	0.04	0.96	-9.69	0.08	6.12	596	1,867
Climate	3,595	0.04	1.05	-11.39	0.08	8.14	935	3,115

Table 3: Descriptive statistics of listed banks for top-down stress test

This table reports descriptive statistics for the publicly listed banks that are included in the top-down stress test. We split banks by sub-industry (SIC starting with 60 for Deposit Banks or 61 for Other Banks). We document the number of observations (bank x trading day) and the mean, standard deviation, minimum, median, and maximum values for total assets, total debt, market capitalization, and daily returns. The sample includes daily observation for each trading day from January 2010 to December 2023.

Industry	Obs	Mean	StDev	Min	Median	Max
Total Assets (bln EUR)						
Deposit Banks	402,618	218.27	464.16	0.00	25.94	3,051.30
Other Banks	110,711	36.57	182.84	0.00	0.36	1,282.30
Combined	513,329	179.08	426.35	0.00	14.68	3,051.30
Total Debt (bln EUR)						
Deposit Banks	402,618	206.10	440.26	0.00	23.60	2,883.91
Other Banks	110,711	34.53	173.88	0.00	0.23	1,234.02
Combined	513,329	169.09	404.38	0.00	13.25	2,883.91
Market Cap (bln EUR)						
Deposit Banks	402,618	7.99	17.76	0.00	1.22	179.63
Other Banks	110,711	1.76	7.15	0.00	0.13	64.76
Combined	513,329	6.65	16.27	0.00	0.73	179.63
Returns (% per day)						
Deposit Banks	402,618	0.03	3.04	-90.74	0.00	549.11
Other Banks	110,711	0.07	4.57	-85.66	0.00	245.73
Combined	513,329	0.03	3.43	-90.74	0.00	549.11

Table 4: Bottom-up aggregate losses on peak date and latest date

This table reports the absolute aggregated incremental losses for the most extreme stress test scenario, i.e., expected losses above the baseline scenario. In the extreme stress scenario, PDs are multiplied by three, and collateral values by 0.3. The results are reported for the month with the highest incremental losses following biodiversity stress (2023-06) as well as for the final month of the sample (2023-12). The table further includes total assets and total non-financial credit and the number of banks included at the respective date. Numbers are in billions of euros.

	Date	Climate	Biodiversity	Residual Biodiversity	Total Credit	Total Assets	N Banks
Peak Loss	2023-06	8.05	5.89	3.91	1,105	19,280	98
End of Sample	2023-12	7.92	5.08	3.45	1,117	17,184	96

Table 5: Bottom-up relative losses on peak date in the cross-section of banks

This table presents the distribution of incremental losses for the most extreme stress test scenario, i.e., expected losses above the baseline scenario. We report the cross-section of losses for the month with the highest aggregate incremental losses following biodiversity stress (2023-06). In the extreme stress scenario, PDs are multiplied by three, and collateral values by 0.3. Losses are expressed as a percentage of each bank's total non-financial lending.

	N Banks	Mean	StDev	25%	50%	75%
Climate	99	0.75%	1.49%	0.15%	0.38%	0.79%
Biodiversity	99	0.59%	0.99%	0.11%	0.40%	0.62%
Residual Biodiversity	99	0.44%	0.65%	0.09%	0.25%	0.51%

Table 6: Top-down stress levels on peak date and latest date

This table reports the aggregate BRISK, CRISK, and Residual BRISK above the baseline scenario without equity price shocks. The results are reported for the date with the highest BRISK and CRISK (2022-03-22 and 2022-02-11, respectively) and the final date of the sample (2023-12-29). The table further includes the market capitalization and book value of total debt and assets of the banks in the sample, and the number of banks included on that date. All numbers are in billions of euros.

Date	BRISK	CRISK	Residual BRISK	Mkt Cap	Debt	Assets	N Banks
2022-02-11	15.38	69.91	0.33	1,105	25,700	27,260	142
2022-03-22	22.99	41.76	5.31	939	26,872	28,439	141
2023-12-29	7.69	32.65	0.03	1,076	25,947	27,585	146

A Data appendix

A.1 Exposure to climate and biodiversity risk

We analyze the exposure of the European banking system to corporate borrowers that are heavily exposed to climate and biodiversity transition risk. We identify these borrowers based on whether their industries are targeted by the Climate Action 100 and Nature Action 100 initiatives. Specifically, we obtain SIC codes for the original 100 firms in the Climate Action 100 (CA100) and the Nature Action 100 (NA100) initiatives.[17] We define each two-digit SIC that occurs more than three times in any of the lists as industries highly exposed to climate or biodiversity transition risk. There are smaller industries that do not have many (public) firms targeted by CA100 and NA100. Therefore, we additionally manually assess also industries that do not occur more than three times on these respective lists, and add "coal mining" and "agriculture, forestry, and fishing" to the climate and biodiversity transition risk industries, respectively.[18]

Using this methodology, we proxy high climate transition risk exposure based on 2-digit SICs 10, 12, 13, 28, 29, 33, 35, 37, and 49. The SICs for high biodiversity transition risk exposure are 01, 02, 07, 08, 09, 10, 20, 26, 28, 53, and 58. At first glance, this industry classification seems reasonable. For example, fossil fuel industries such as Oil and Gas Extraction, Petroleum Refining, and Electric and Gas Services have high climate transition risk, while biodiversity transition risk is large for Food, Merchandise, and similar industries with significant land use. There is overlap between the two categories, with Chemicals and Metal Mining being exposed to both climate and biodiversity transition risk.

We focus on exposure to these industries relative to all non-financial corporate loan exposure outside of real estate. Specifically, we filter out SICs 60-67 and 91-97 to exclude loans to the financial sector, as well as real estate and public borrowers.

A.1.1 All loans: AnaCredit Europe

AnaCredit Europe is the most extensive credit registry in Europe, including corporate loans from 25,000 EUR for all banks in the Euro area which are subject to full reporting from June 2019 to December 2023.[19] We use these data for the most comprehensive overview of monthly exposures from European banks to borrowers with high climate and biodiversity transition risk exposure. We include all term loans, drawn credit lines as well as drawn revolving credit which are denominated in euros. Credit with missing interest rates or loan amounts

[17] We observe 99 and 97 firms in Compustat for the CA100 and NA100 firms, respectively.

[18] Coal mining and agriculture do not occur as primary SIC more than three times in the Climate100 and Nature100 firms, but are clearly exposed to these risks. In the next version of this paper, we will apply a more formal method to identify industries that do not occur often in the Climate100 and Nature100 firms, but are exposed to climate and biodiversity transition risk.

[19] Small banks are not subject to the full reporting requirements in AnaCredit. They report to the national central banks but their data is not forwarded to the European Central Bank for AnaCredit Europe, and their exposures are, therefore, outside our sample. In addition to this, banks outside of the Euro area are not included.

below zero are excluded from the sample. In addition, we exclude all non-bank lenders from the sample and keep only the banks which are flagged as being active in the Euro Area. Furthermore, our sample starts June 2019 onwards due which was recommended due to data quality. We currently exclude French lenders due to reporting irregularities. The sample is restricted to internal ratings-based (IRB) banks because these report PDs. Furthermore, defaulted loans and loans with PD=1 are also excluded. Despite these restrictions, we still cover 37% of the Euro Area credit exposure. For syndicated loans, lender shares as provided by AnaCredit are used to assign exposures by lender.[20]

A.1.2 Syndicated loans: DealScan

We report similar output based on syndicated loan origination by EU28 lenders. We use newly originated syndicated loans in DealScan (tranche_o_a equals 'Origination'). We filter out deals with incorrect data (different values for deal or tranche amounts are reported within the same deal, deal amounts do not equal the sum of tranche amounts, or deal amounts are zero) and impute missing lender shares with (i.) For sole lenders: 100%, (ii.) For tranches where available lender shares sum to less than 100%: $(missing\ share)/n\%$ where n is the number of lenders with missing lender share information and *missing share* equals 100 minus the reported lender shares (if any). We then remove any deals where lender shares are still missing after these steps and scale lender shares within each tranche to 100 if needed.

With this cleaned dataset, we compute the new origination exposure of lenders in the EU28 to the climate and biodiversity industries relative to total non-financial corporate loan origination of these lenders. We report the five-year moving average of these numbers to proxy for exposures by these lenders, which is less volatile than originations.

A.1.3 Firm debt: CapitalIQ

Capital IQ decomposes total debt into seven distinct, mutually exclusive categories: commercial paper, (drawn) credit lines, term loans, senior bonds and notes, subordinated bonds and notes, capital leases, and other debt. Bank debt is defined as (drawn) credit lines and term loans (see, e.g., Colla et al., 2013, for details). We use data on an annual basis for firms incorporated in EU28 countries. Country of incorporation is defined base on the Compustat Global "fic" variable. Capital IQ reports information in local currency. We harmonize currencies using FX rates from Compustat Global. To account for outliers (or reporting mistakes), we winsorize firm-level debt items at the 1st and 99th percentile before aggregating by groups.

[20]Because AnaCredit does not report SICs, we translate the SICs above to NACE codes for this analysis. For climate exposures we use NACE codes 5, 6, 7, 8, 9, 19, 20, 21, 22, 24, 25, 26, 27, 28, 29, 30, 35, 36 and 37 and for biodiversity exposures we use 1, 2, 3, 5, 7, 8, 10, 11, 17, 20, 21, 22 and 47. We exclude financial sector, real estate, and public borrowers using NACE codes 64, 65, 66, 68, 84.

A.1.4 Firm debt: Orbis

We analyze annual balance sheet data of large and medium sized firms in the EU28 from Orbis in order to assess their exposure to biodiversity and climate risks. The outstanding amount of debt per firm is the sum of short- and long-term debt (loan + ltdb). The exposures include loans and bonds as Orbis does not allow to distinguish between the two. We use the consolidated version of the balance sheet when available, and the unconsolidated version otherwise. For firms that report two different primary industries and for which one of those sectors is a biodiversity (climate) relevant sector and the other one is not, we attribute half the loan amount to each primary industry.

A.2 Probability of default measure

We estimated the loan weighted average probability of default (PD) across the Euro Area utilizing AnaCredit dataset. The PD is defined as the likelihood that a borrower will default on their obligations over a one-year horizon. Predominantly, these PD estimates are derived from the banks' internal ratings-based approach. Euro Area banks have to report their counterparty's PD on a monthly basis. PDs are either displayed on the loan level or counterparty level. In the former case, the counterparty PD is calculated as a weighted average of the loan level PDs. The weights correspond to the outstanding nominal amount of the loans. We apply a rolling mean over a 3-month window in order to smooth the representation of the data. All observations with PD = 1, defaulted loans and loans that are flagged as unlikely to be paid have been excluded. Currently, our reported figures do not encompass data pertaining to lenders from France, owing to inconsistencies in their reporting.

A.3 Global stock returns and fundamentals

These data are from Compustat Global, using the filtering procedure described here. These filters are a combination of those in Chaieb et al. (2021), Bessembinder et al. (2019) and Alves et al. (2023) with minor adjustments.

- We query data from six tables in Compustat daily (comp_global_daily).

  1. We select prccd, prcld, prchd, trfd, qunit, ajexdi, datadate, gvkey, iid, loc, cshoc, curcdd, conm, gind, isin, exchg, cshtrd from 2005-01-01 until 2023-12-31 from g_secd. We request all observations where: (i.) the prcstd equals 3 or 10, (ii.) the tpci equals 0, and (iii.) the loc is a country that is part of the EU28.[21]
  2. We select information about exchanges (exchgcd, exchgdesc) from r_ex_codes.
  3. We select delisting and primary issue information (gvkey, prirow, dlrsn) and SIC codes (sic) from g_company.

[21]The variable loc must equal one of "AUT", "BEL", "BGR", "HRV", "CYP", "CZE", "DNK", "EST", "FIN", "FRA","DEU", "GRC", "HUN", "IRL", "ITA", "LVA", "LTU", "LUX", "MLT", "NLD","POL", "PRT", "ROU", "SVK", "SVN", "ESP", "SWE", "GBR"

4. We select exchange rate information (curd, datadate, exrattpd, exratd_tousd, exratd_tousd) from wrds_g_exrate.
5. We select accounting standard information (acctstddesc, acctstdcd) from g_fundq.
6. We select Fundamentals Data for book debt (dlcq, dlttq) from r_accstd.

- We merge (left join) the second, third and fourth database to the first one based on (exchg == exchgcd), gvkey, and (datadate & curcdd == curd), respectively.
- We only keep major exchanges. We follow Bessembinder et al. (2019) who consider exchanges within each country (loc) according to trading volume.[22]
- We keep the primary issue for each firm if we observe it. Specifically, within gvkey we filter out observations where 'iid' does not equal 'prirow'; but we keep all observations where prirow is missing. Because of this, there are still firms that have multiple issuances in the data. For those, we take the volume (cshtrd) weighted prices (prccd) as price and only keep one observation for each datadate.
- We filter out observations with missing prices (prccd) and also those where prices are not missing but potentially not reflecting real trading by filtering out observations where none of volume, low, or high is available (cshtrd, prcld, prchd).
- We compute the daily stock returns in EUR as trfd * prccd * exratd_tousd * exratd_fromusd / qunit * ajexdi divided by its lag; minus 1 times 100.
- For firms that either went bankrupt or were liquidated (identified by dlrsn = '02' or dlrsn = '03'), we multiply the last recorded return by -30%. If no return data is available for such firms, we set their final value to -30% (see Jensen, Kelly, Pedersen 2023; Shumway 1997).
- We filter out observations within the lowest 3% of monthly positive trading volume in each year-month. Therefore, we compute the daily positive trading volume in EUR as cshtrd * qunit * prccd * exratd_tousd*exratd_fromusd/ajexdi * qunit. This is used for filtering later, following Alves et al. (2023).
- We compute lagged market value of the equity of each firm as the latest available market value before time t. The computation is prccd * exratd_tousd * exratd_fromusd * cshoc. This is used to compute value weighted returns.
- We add information on book debt via the Fundamentals data from table 6. We keep only historical data (`datafmt = 'HIST_STD'`).

[22]We keep the following exchanges: "Wiener Boerse AG", "NYSE Euronext Brussels", "OMX Nordic Exchange Copenhagen AS", "NASDAQ OMX Helsinki Ltd", "NYSE Euronext Paris", "Deutsche Boerse AG", "XETRA", "Athens Exchange SA Cash Market", "Borsa Italiana Electronic Share Market", "NYSE Euronext Amsterdam", "Oslo Bors ASA", "NYSE Euronext Lisbon", "Bolsa De Madrid", "NASDAQ OMX Nordic", "Swiss Exchange", "Zurich", "London Stock Exchange".

- We add information on book debt with liabilities (ltq) from table six and multiply it by 1000000: ltq * exratd_tousd * exratd_fromusd * 1000000. We merge this data via 'gvkey', 'year', and 'month' with the return data.
- The Fundamentals data contains duplicates for some gvkeys that differ with respect to their accounting standard. We prioritize accounting standards in the following order: 'DI': 1, 'DS': 2, 'US': 3, 'ND': 4.[23]

[23]DI: Domestic standards generally in accordance with or fully compliant with International Financial Reporting Standards (IFRS); DS: Domestic standards; US: United States' standards; ND: Not Determined.