Who's Afraid of Carbon Transition Risk?

A Climate Stress Test of Dutch Pension Funds

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Table of contents

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Abstract

This paper presents a climate stress test for the equity and corporate bond portfolios of all 180 Dutch pension funds, based on several scenarios that involve a substantial carbon emissions tax. We apply the finance (valuation) approach to climate stress testing proposed by Reinders, Schoenmaker, and van Dijk (2023). The advantage of this approach is that it is tractable and helps pension funds identify specific sources of carbon transition risk in their portfolios, but the disadvantage is that macroeconomic effects are not considered. We find that, in the baseline €200 per tonne Scope 1 emissions carbon tax scenario, the value of the aggregate equity and corporate bond portfolios of pension funds declines by up to 5.7% and 4.2%, respectively, and by up to 9.1% and 7.4%, respectively, in more severe scenarios. Equity losses for individual pension funds can amount to more than 16% and to almost 22% in more severe scenarios.

Samenvatting

Er is steeds meer belangstelling voor het meten van de impact van klimaatrisico's (zowel fysieke als transitierisico's) op de beleggingsportefeuilles van institutionele beleggers zoals pensioenfondsen en verzekeraars. Recent onderzoek laat zien dat veel institutionele beleggers de impact van klimaatrisico's al terugzien in hun beleggingen en ook dat zij van mening zijn dat deze risico's nog niet of niet voldoende zijn ingeprijsd op financiële markten. Het meten van klimaatrisico's vormt een grote uitdaging, omdat het gaat om een nieuw soort risico's waarover veel onzekerheid bestaat, waarnaar relatief weinig onderzoek gedaan is en waarvoor historische analyses minder zinvol zijn omdat veel van deze risico's waarschijnlijk pas op lange termijn zullen optreden.

In dit paper voeren wij een klimaatstresstest uit voor de aandelen- en bedrijfsobligatieportefeuilles van alle 180 Nederlandse pensioenfondsen op basis van verschillende scenario's met een substantiële CO_2-belasting. We passen de financiële (waarderings)benadering voor klimaatstresstests toe van Reinders, Schoenmaker en van Dijk (2023), die als voordeel heeft dat deze eenvoudig en inzichtelijk is en pensioenfondsen helpt om specifieke bronnen van CO_2-transitierisico in hun portefeuilles te identificeren, maar als nadeel dat macro-economische effecten niet worden meegenomen.

De mate waarin Nederlandse pensioenfondsen zijn blootgesteld aan de drie sectoren met verreweg de grootste CO_2-emissies (nutsbedrijven, materialen en energie) is relatief beperkt, met ongeveer 9% van de aandelenportefeuille en 7,5% van de bedrijfsobligatieportefeuille. Deze blootstelling ligt dicht bij die in de MSCI All Country World Index (MSCI ACWI, een veelgebruikte wereldwijde aandelenbenchmark), maar binnen deze sectoren staan pensioenfondsen duidelijk minder bloot aan de bedrijven met de grootste CO_2-uitstoot dan de MSCI ACWI. Wel wordt ongeveer 50% van de aandelen- en bedrijfsobligatieportefeuilles geïnvesteerd in bedrijven met relatief weinig ambitieuze CO_2-reductiedoelstellingen.

In de basisscenario's met een CO_2-belasting van €200 per ton Scope 1 CO_2-emissies daalt de waarde van de geaggregeerde aandelen- en bedrijfsobligatieportefeuilles van alle Nederlandse pensioenfondsen met respectievelijk maximaal 5,7% en 4,2% (en 9,1% en 7,4% in scenario's met een CO_2-belasting van €400 per ton). Aandelenverliezen voor individuele pensioenfondsen kunnen oplopen tot meer dan 16%, en tot bijna 22% in scenario's met een CO_2-belasting van €400 per ton.

1. Introduction

There is growing interest in the impact of climate risks (including both physical and transition risks) on the investment portfolios of institutional investors such as pension funds and insurance firms. Survey evidence indicates that a substantial fraction of institutional investors conclude that climate risks have already begun to materialize in their investment portfolios (Krüger, Sautner, and Starks, 2020), while a large majority believes that financial markets underestimate climate risks in the pricing of traded financial assets such as stocks and bonds (Stroebel and Wurgler, 2021).

Understanding climate risks is important for individual institutional investors who are concerned about the financial risks inherent in their investment portfolios (especially if these risks are not – or not fully – reflected in the price and are thus not compensated for by an appropriate risk premium). Furthermore, institutional investors are increasingly required by regulations and urged by supervisory agencies to document climate risks. For example, European regulations (e.g., IORP II) and regulatory bodies (e.g. EIOPA) stipulate that pension funds and insurance firms need to include climate risks in their "own risk assessment." Moreover, supervisory agencies such as central banks are concerned about the potential impact of climate risks on financial stability (i.e., macroprudential risks).

Measuring climate risks is challenging because they constitute a novel class of risks that are characterized by substantial uncertainty, relatively little research, and the limited value of historical data, because most of these risks are only likely to materialize in the long term (Giglio, Kelly, and Stroebel, 2021). One prominent way of assessing the climate risks that face a financial institution is a climate stress test (Acharya et al., 2023). Stress tests have long tradition in international policy institutions. They are generally used to assess the vulnerability (tail risks) of individual financial institutions, or the financial system as a whole, to different "severe but plausible scenarios" that contain possible future adverse economic or financial shocks (Ong and Jobst, 2020). In recent years, various specific approaches have been developed for assessing the vulnerability of financial institutions (or the entire financial system) to severe climate transition risks and/or physical risks in particular, each with its own strengths and limitations (Reinders, Schoenmaker, and van Dijk, 2025).

In this paper, we aim to assess the potential impact of carbon transition risk on the equity and corporate bond portfolios of Dutch pension funds. We use the finance (valuation) approach to climate stress testing of Reinders et al. (2023); this examines the impact of several hypothetical carbon tax scenarios on different economic sectors, using a straightforward net present value (NPV) analysis of the financial impact of the tax on corporate valuations, under different assumptions on the degree of pass-through (i.e., the extent to which firms can pass-through the carbon tax to their customers) and the degree of abatement (i.e., the potential of firms to reduce their carbon emissions). The estimated impact of the carbon tax on corporate valuations is then translated into the effects on the value of corporate equity and debt using the Merton (1974) model. These value losses can then be aggregated to the financial institution level using data on the exposure of financial institutions to corporate equity and debt in different sectors within their investment portfolios.

An important advantage of this finance approach to climate stress testing is that it is tractable and can give financial institutions insight into which parts of their investment portfolios are most vulnerable to transition risks and why. Alternative approaches generally use complex macroeconomic models, starting by modeling the impact of climate risk scenarios on the macroeconomy. They then translate the macroeconomic consequences to different economic sectors and ultimately to the value of financial assets, using intricate financial models (Reinders, et al., 2025). These approaches can essentially be characterized as "black box" methods, in which it can be difficult to understand why specific parts of an investment portfolio could be affected by climate risks. Nonetheless, an important advantage of these macro-financial approaches is that they can take macroeconomic and feedback effects into account, which is currently not considered in the finance (valuation) approach of Reinders et al. (2023).

Our focus on carbon transition risk is motivated by the significant economic costs that are expected to result from the transition to a carbon-neutral economy (Acemoglu, Aghion, Bursztyn, and Hemous, 2012; Nordhaus, 1992). Many economists argue that the most effective way to decarbonize the economy is by increasing the price of carbon emissions (through a carbon tax or otherwise), which will likely have substantial financial impact on many firms, possibly leading to "stranded assets" (Leaton, 2011). In turn, the resulting financial losses for firms will reduce the valuations of their stocks and corporate bonds (Smale et al., 2006; Scholtens and Van der Goot, 2014), which is expected to result in non-trivial effects on the investment portfolios of institutional investors. From the perspective of these investors, the transition to a carbon-neutral economy is thus likely associated with important financial risks that are generally not included in traditional risk measurement and management approaches.

Of course, one could argue that, in case carbon transition risk is correctly priced in financial markets (i.e., when markets are "efficient"), investors would receive a risk premium for bearing this risk. However, the recent consensus among investors and researchers seems to be that climate risks are insufficiently priced in financial markets (Stroebel and Wurgler, 2021). And although Bolton and Kacperczyk (2021, 2023) provide evidence that carbon risk is priced in international equity markets, their finding is challenged by Zhang (2025). Furthermore, even if a certain type of risk is fully priced, investors should still be interested in measuring to what extent they are exposed to this risk. And, from a broader perspective, pension funds may want to consider whether running climate risks is in the best interest of their participants, who, after all, may already be exposed to risks in other domains (human capital, housing, health) in scenarios in which climate risks are most likely to materialize.

In our climate stress test, we use proprietary data from De Nederlandsche Bank (the Dutch Central Bank) on the security-specific (line-by-line) global holdings of stocks and corporate bonds of all 180 Dutch pension funds at the end of 2022. Total assets of these pension funds amounted to around €1,500 billion at that time. Of this, €557 billion is included in our sample, since we do not consider other major asset classes such as government bonds and since not all holdings data can be matched with firm-level carbon footprint and financial data. Our final sample contains 883,000 positions in 13,364 different securities around the world. We obtain data on firms' 2022 CO_2-equivalent (CO_2e) Scope 1 and Scope 2 emissions as well as greenhouse gas (GHG) reduction targets from Institutional Shareholder Services (ISS). Scope 1 emissions refer to the GHG emissions that a firm emits directly, while Scope 2 emissions refer to the indirect emissions of a firm associated with purchased energy. Firm-level financial data such as total asset value, total debt value, and stock returns are from Datastream.

Following Reinders et al. (2023), we carry out a carbon transition risk stress test consisting of four steps. First, we specify a number of "severe but plausible" carbon tax scenarios. Next, we estimate the impact of each of these scenarios on the corporate valuations of all firms in our sample by computing the NPV of the carbon tax for each firm using data on its Scope 1 CO_2e emissions, an estimate of their cost of capital, and assumptions about the degree of pass-through and abatement. In the third step, we translate the estimated impact of the scenarios on corporate valuations into value losses for equity and corporate bond holders, using the Merton (1974) contingent claims model. The Merton model is based on the notion that equity is the residual claim on a firm's assets after debt has been repaid. Equity holders thus effectively own a call option on the firm's assets, while bond holders own a risk-free bond and a short put option on the firm's assets. The Merton model allows for the allocation of any loss to the value of the assets of a firm to the losses for equity holders and for bond holders. In the fourth step, we use the line-by-line holdings data of Dutch pension funds to estimate the impact of the scenarios on the value of their equity and corporate bond portfolios. A relevant difference between our paper and Reinders et al. (2023) is that our line-by-line holdings data allow for an analysis at the individual firm-level, while their sector-level debt and equity exposures for Dutch banks necessitate a sector-level analysis.

Our baseline scenarios are based on the introduction of a carbon tax of €200 per tonne of Scope 1 CO_2e emissions, which would come on top of any existing carbon taxes or costs such as those implied by the Emissions Trading System of the European Union. Such a carbon tax seems reasonable (if not modest) in light of estimates of the price of carbon emissions needed to limit global warming to two degrees Celsius, which range from $15 to $360 per tonne of CO_2e in 2030 and from $45 to $1000 per tonne in 2050 (Stiglitz et al., 2017; IPCC, 2018). By comparison, the carbon price in the Emissions Trading System at the time of writing was around €70 per tonne of CO_2e. In a sensitivity test, we raise the carbon tax to €400 per tonne and we also consider Scope 2 emissions.

We generate four different scenarios by combining the baseline carbon tax of €200 per tonne with variations along two dimensions. First, we distinguish between a carbon tax that is introduced overnight ("abrupt") and one that is phased in over a period of ten years. Second, we distinguish between scenarios in which the entire tax is paid by the firms and scenarios in which firms can pass-through 50% of the tax on to their customers.

We start our analysis by documenting the global sector exposures in the equity and corporate bond portfolios of Dutch pension funds. Of the eleven economic sectors in the Global Industry Classification Standard (GICS), five sectors represent more than 60% of the equity exposure of Dutch pension funds (Information Technology, Financials, Health Care, Real Estate, and Industrials), while the corporate bond exposure is largely concentrated in a single sector (Financials). Dutch pension funds thus have relatively limited exposure to the three GICS sectors with the largest carbon emissions by far in Utilities, Materials, and Energy (Visual Capitalist, 2023). This is not surprising in light of the fact that, over the past 5 to 10 years, many Dutch pension funds have formulated explicit targets for the reduction of the carbon footprint of their portfolios (VBDO, 2019).

The exposure to these three sectors is only slightly below the exposure to these same sectors of the MSCI All Country World Index (MSCI ACWI), which is a widely used global equity benchmark, but our analysis indicates that, within these sectors, Dutch pension funds have lower allocations to the top-emitting firms than the MSCI ACWI. We also note that only around 55% of the firms that Dutch pension funds hold in their equity portfolios and 45% of those that they hold in their corporate bond portfolios have either "committed" or "approved" science-based targets (SBTs) to reduce their carbon emissions according to ISS, which indicates that a substantial part of these portfolios represents firms that have relatively less ambitious carbon reduction targets.

Our NPV analysis reveals that the four scenarios can have large effects on corporate valuations, with asset value losses between 30 and 40 percent for the Utilities, Materials, and Energy sectors, which have the greatest carbon footprint. For some of the 162 GICS subindustries in our sample, the estimated asset value losses are even more dramatic, suggesting that nearly the entire value of specific subindustries could be wiped out when a €200 per tonne CO_2e tax were to be introduced (especially abruptly and without pass-through possibility). This would apply, for example, to Independent Power Producers & Energy Traders, Aluminum, Passenger Airlines, Construction Materials, and Industrial Gases. On the other hand, the exposures of Dutch pension funds to the subindustries with the greatest estimated value losses are generally limited. Dutch pension funds have an exposure of at least 0.5% of the market value of their equity portfolio in only three of the top 15 subindustries with the greatest value losses, namely Oil & Gas Refining & Marketing (exposure of 0.5%), Integrated Oil & Gas (0.7%), and Electric Utilities (1.4%).

When aggregating estimated equity losses across all pension funds, we find that total losses in the aggregate equity portfolio of Dutch pension funds could amount to up to €22.5 billion (or 5.7% of their total equity market value) in our baseline scenarios. Equity losses could increase to €35.7 billion (9.1%) in more severe scenarios with a carbon tax of €400 per tonne CO_2e. For individual pension funds, equity losses can be considerably larger than this average. In our baseline scenarios, we find that 30 of the 180 pension funds could face losses in their equity portfolios of 8% or more, with a maximum loss of 16.5% for an individual fund. This maximum equity loss increases to 21.9% for a single fund in the more severe scenarios.

The aggregate losses to corporate bond portfolios of Dutch pension funds are somewhat lower by comparison, at up to 4.2% (with a maximum loss for an individual fund of 23.7%) in the baseline scenarios and up to 7.4% (with a maximum loss of 36.5%) in the more severe scenarios. There are at least two plausible explanations for the more modest losses in corporate bonds compared to equities. First, pension funds have less corporate bond exposure to subindustries with large estimated asset value losses, since corporate bond exposure is concentrated in the Financials sector, which has a relatively small carbon footprint. Second, since equity holders are the residual claimants on firm assets after debt has been repaid, they absorb more of the asset value loss.

How do the estimated equity and corporate bond losses for pension funds in our stress test for carbon transition risk compare to the results of other climate stress tests? In recent years, numerous climate stress tests have been conducted, based on methods ranging from macro- and micro-financial approaches to non-structural studies and stress tests that focus on disaster risk (e.g., European Supervisory Authorities, 2024; Chabot and Bertrand, 2023; Jung, Engle, and Berner, 2021; Reinders et al., 2023, 2025; Vermeulen et al., 2021).

The study most closely related to ours is the carbon transition risk stress test of the Dutch banking sector by Reinders et al. (2023). Their study finds market value losses for Dutch banks corresponding to up to 1.5% of their assets and 29% of their Tier 1 capital in scenarios similar to ours (their Table 8).[1] Asset losses for Dutch banks are thus more limited than we find for pension funds (probably because banks mainly have debt rather than equity exposures), but the impact of carbon transition risk on the balance sheets of banks may be considered to be greater due to their high leverage. Vermeulen et al. (2021) carry out a climate stress test for 80 Dutch financial institutions by examining various energy transition scenarios (including a $100 per tonne CO_2 tax as well as possible innovations

1 Tier 1 capital is generally regarded as the primary measure of a bank's financial strength from a regulator's perspective, and consists of core capital that includes common stock, disclosed reserves, and retained earnings.

in energy technology) in a macro-econometric model. They find that asset-side positions could decrease by as much as 11%. For Dutch pension funds in particular, they obtain larger market value loss estimates than in our study – of up to €65.8 billion for equities in the most severe scenario. The European Supervisory Authorities and the European Central Bank (ECB) recently published their "Fit-for-55" climate stress test, aimed at assessing whether the European financial sector is prepared to achieve the EU objective of reducing carbon emissions by at least 55% by 2030. The stress test considers two adverse climate risk scenarios in a top-down analysis; this includes both "first-round losses" for different economic sectors and "second-round losses" stemming from amplification effects resulting from the impact of the scenarios on the financial sector. The stress test indicates a decline in investment values in the pension fund sector of between approximately 5% and 15% for equities and between 2% and 20% for corporate debt, depending on the scenario. In other words, the results of our analysis are broadly in line with those of other stress tests, but the different approach allows for a new perspective that circumvents black box approaches is tractable, and offers pension funds and regulators direct insights into the sources of carbon transition risk.

In sum, our study provides new insights into the potential impact of climate transition risk on the investment portfolios of institutional investors, in particular Dutch pension funds. We find that in various carbon tax scenarios, pension funds could face serious market value losses, of up to more than €40 billion across their equity and corporate bond portfolios (adding up to €477 billion in our sample). Our finance (valuation) approach to climate stress testing adds to other stress testing approaches by allowing pension funds and regulators to trace the economic sectors, subindustries, and individual firms that constitute the most significant exposure to carbon transition risk for pension funds. Our tractable approach facilitates a discussion about assumptions regarding how individual firms and industries could respond to climate transition risk. That discussion could also serve as input for engagement activities by pension funds with the firms in their portfolios. We note that our findings may underestimate carbon transition risk exposures by Dutch pension funds since our approach does not take macroeconomic and feedback effects into account. That said, we also do not take into account that some firms might be able to profit from the introduction of a carbon tax, which could benefit their investors.

We note that the market value loss estimates in our study may be underestimated since we neither incorporate macroeconomic effects nor second-round losses. Furthermore, carbon transition risk is just one type of climate- or nature-related financial risks for investment portfolios. Aggregation of potential market value losses for pension funds and other institutional investors across a wide array of climate- or nature-related financial risks (including both physical and transition risks and, e.g., carbon, water, biodiversity, and natural disaster risks) is an important avenue for further study.

2. Data and methods

This section describes the data (Section 2.1), the methods (Section 2.2), and the carbon tax scenarios (Section 2.3) used in this study.

2.1 Data

First, we obtain data on the stock and corporate bond portfolios of Dutch pension funds from the confidential Financial Statements (FTK) dataset of the Dutch Central Bank (DNB). This dataset includes detailed quarterly security-level positions held by all Dutch pension funds. These positions span a wide range of asset classes, including government bonds, corporate bonds, equities, and external investment funds. To fully incorporate the external fund positions into the analysis, we apply a "look-through" method, which involves examining the security-level stock holdings of the external investment funds and proportionally allocating these positions to each pension fund, based on its ownership share in the respective investment fund. We only consider equity funds and corporate bond funds. The resulting dataset encompasses 180 Dutch pension funds, along with their holdings of 13,364 unique securities (ISIN codes) across the globe, as of 2022Q4. In total, the dataset includes 883,000 positions across the equity and corporate bond asset classes.

Second, we obtain data from 2022 on the firms' CO_2e emissions, emission reduction target plans related to the Paris Agreement, the Global Industry Classification Standard (GICS) sector and subindustry classifications, and the total market value of equity from Institutional Shareholder Services (ISS). We use the emission reduction targets of individual firms to classify the abatement potential for each firm. We provide further details on this classification process below.

Third, we obtain other firm-specific financial data (total assets, total debt, and the return index that can be used to compute total stock returns including dividends, and accounting for stock splits) from Datastream. These variables serve as inputs for the Merton model formulas. We obtain the total asset value and total debt value of all firms in our sample as of 2022Q4 and match these data with the supervisory pension fund holdings data. We compute the leverage ratio, which is also an input for the Merton formula, as the ratio of total debt to total assets. For firms for which we cannot compute the leverage ratio, we use the average leverage ratio of the corresponding GICS subindustry. The Merton formula also requires firm-level equity volatility; this we compute as the standard deviation of non-overlapping annual returns based on the annual stock return index of each firm from Datastream over the 12 years ending in 2022.[2] If a firm has more than four missing annual stock return index observations within this period, we then use the average equity volatility of the corresponding GICS subindustry instead. As explained in more detail in Section 2.2, we compute a firm's asset volatility from its equity volatility and leverage.

Fourth, to discount future costs associated with the carbon tax, we obtain estimates of industry-level Weighted Average Cost of Capital (WACC) from the website of Aswath Damodaran.[3] We convert the WACC estimates from USD to EUR using a purchasing power parity adjustment based on U.S. and European inflation rates (computed as the average growth rates in the consumer price index for the US and for the euro area over 2001-2022 obtained from the OECD Data Explorer). We match industries for which a WACC estimate is provided to the corresponding GICS subindustries and assign the WACC estimates to individual firms based on their subindustry. For firms for which this mapping is not possible, we use the average WACC across all industries in the dataset of Damodaran, while noting that these firms represent only 0.48% of the total market value of securities in our dataset.

We need to make four parameter assumptions to implement our stress test based on the Merton model. We assume a risk-free interest rate of 2.75%, which reflects the marginal facility rate of the European Central Bank (ECB) at the end of 2022.[4] We assume a time-to-maturity for corporate bonds of 6.6 years, based on the estimate of Cortina, Didier, and Schmukler (2018; see their Table 1) of the value-weighted average maturity of global corporate debt over 1991-2014. We furthermore assume a carbon tax of €200 per tonne of CO_2 equivalent (CO_2e) in our baseline scenarios. Similar to Reinders et al. (2023), we assume that firms have abatement potential (that is, potential to reduce their carbon emissions), although our approach differs in its methodology. To estimate each firm's abatement potential, we use the data on emission reduction target plans related to the Paris Agreement from the ISS dataset, which provides insights into the firm's commitment to the Paris Agreement. Specifically, we assign firms with "No Target" a total abatement potential of 10%. This percentage increases by 2.5% with each higher commitment level, following the categorical order: "Non-Ambitious Target," "Ambitious Target," and "Committed SBT," culminating in a total abatement potential of 20% for firms with an "Approved SBT." The abatement is phased in gradually over five years, meaning that the full potential is realized five years after the introduction of the carbon tax. In a sensitivity analysis, we examine how different assumptions on these four parameters affect the stress test outcomes.

2 The Datastream stock return index is an index (generally starting at 100 at the time the stock is listed) that keeps track of all stock returns stemming from stock price increases and decreases and dividends and that can be used to compute the total returns of a stock over a given time period. We have experimented with other windows of stock returns used to compute the volatility: the findings are not materially affected.

3 https://pages.stern.nyu.edu/~adamodar/; we used the WACC in column K of the dataset "Costs of Capital by Industry Sector" and then the "Global" version (labeled 6. On the website).

4 See: https://www.ecb.europa.eu/stats/policy_and_exchange_rates/key_ecb_interest_rates/html/index.en.html.

Table 1 – Summary statistics

This table shows summary statistics (number of observations, mean, standard deviation, minimum, 25th percentile, median, 75th percentile, and maximum) for the variables used in the stress test for the equity and corporate bond portfolios of Dutch pension funds in 2022Q4. The table is based on the sample of pension fund holdings that are matched with the firm-level carbon footprint data (€400 billion for equity and €157 billion for corporate bonds, see Figure 1). Asset volatility, equity volatility, and leverage are winsorized at the 5th and 95th percentiles to mitigate the impact of outliers. The firm-level CO_2e Scope 1 and Scope 2 data, presented in '000s of tonnes, are derived from the Institutional Shareholder Services (ISS) dataset. The Weighted Average Cost of Capital (WACC) comes from the website of Aswath Damodaran and is matched with the appropriate GICS subindustry for each firm. Data to compute leverage and equity volatility come from Datastream. As described in Section 2.2, we compute a firm's asset volatility from its equity volatility and leverage. Both equity and asset volatility are expressed as annualized values.

	# Obs.	Mean	St.Dev.	Min	25%	50%	75%	Max
(A) Equity								
tCO_2e Scope 1 emissions in '000s	508,120	2,061	11,764	0	3	22	222	373,028
tCO_2e Scope 2 emissions in '000s	508,120	464	2,121	0	8	40	232	76,120
Leverage	508,120	0.255	0.160	0.010	0.122	0.238	0.371	0.582
Asset volatility	508,120	29.7%	18.4%	10.0%	16.5%	24.7%	36.7%	86.6%
Equity volatility	508,120	36.4%	19.0%	14.6%	22.5%	31.6%	45.0%	93.8%
Abatement	508,120	1.432	0.414	1.000	1.200	1.500	2.000	2.000
WACC	508,120	7.6%	1.9%	4.2%	6.2%	7.5%	8.8%	14.6%
(B) Corporate bonds								
tCO_2e Scope 1 emissions in '000s	375,370	4,102	14,434	0	14	58	597	349,890
tCO_2e Scope 2 emissions in '000s	375,370	673	2,024	0	8	64	399	76,120
Leverage	375,370	0.268	0.102	0.035	0.228	0.228	0.320	0.475
Asset volatility	375,370	10.3%	1.3%	8.7%	10.0%	10.0%	10.1%	17.7%
Equity volatility	375,370	23.7%	11.2%	10.7%	15.2%	21.9%	27.2%	64.7%
Abatement	375,370	1.584	0.383	1.000	1.200	1.500	2.000	2.000
WACC	375,370	7.0%	1.7%	4.2%	5.5%	8.0%	8.0%	14.6%

We merge the different data sources with the pension fund holdings dataset using ISIN codes. If ISIN matching is unsuccessful, we then use SEDOL, LEI, or LEI group codes as alternative identifiers. Figure 1 shows an overview of the composition of our final data. The total market value of the investment portfolios across all asset classes of the 180 pension funds in 2022Q4 amounts to €1,517 billion, of which €492 billion is equity and €198 billion is corporate bonds. We succeed in matching 80.1% of the market value of the equity portfolios to the carbon emission and financial data and 41.6% of the market value of corporate bonds. We thus cannot guarantee that our sample is fully representative of all Dutch pension funds' assets, but for equities the coverage is quite good and there are no strong indications that the results would be biased in any direction.

Table 1 shows summary statistics for the variables used in the stress test. To mitigate the influence of outliers, we cross-sectionally winsorize firms' asset volatility, equity volatility, and leverage at the 5th and 95th percentiles. The final dataset for equity consists of 508,120 observations and for corporate bonds of 375,370 observations. The mean values for leverage, asset volatility, equity volatility, and WACC are 25.5%, 29.7%, 36.4%, and 7.6%, respectively.

2.2 Methods

In our stress test, we closely follow the approach proposed by Reinders et al. (2023). In this section, we briefly review this climate stress test method and explain how and why we deviate from Reinders et al. (2023). Their climate stress test model consists of four key steps, which we closely follow, as outlined below. First, we specify four "severe but plausible" carbon tax scenarios. Second, we calculate the asset value loss for each firm under each of the four scenarios. Third, we allocate this asset value loss to the equity and debt holders of each firm using the Merton (1974) model. Fourth, we aggregate the impact of the carbon tax in the different scenarios to the pension fund level, as follows. We compute the product of the equity or corporate bond exposure of each pension fund to a specific firm and the impact of the carbon tax scenarios on the value of the firm's equity and corporate bonds, respectively. We then aggregate these products across all equity and corporate bond holdings of a pension fund. We also aggregate the losses (in terms of market value of the equity and corporate bond portfolios) across all individual pension funds, to arrive at an estimate of overall market value losses for the entire Dutch pension sector.

The market value loss of the investment portfolio of an individual pension fund can be expressed as:

$$Market\ value\ loss = \sum_{i=1}^{N} \Big(\big(1 - \upsilon_{E,i}\big) \times \theta_{E,i} + (1 - \upsilon_{D,i}) \times \theta_{D,i} \Big), \tag{1}$$

where the subscript i (i = 1,..,N) refers to an individual firm (which differs from the industry-level analysis conducted by Reinders et al., 2023); the subscripts E and D refer to equity and corporate debt (corporate bonds in our analysis), respectively; $\theta_{E,i}$ and $\theta_{D,i}$ denote the exposure (that is, holdings in euros) of the pension fund to the equity and debt, respectively, of firm i; $\upsilon_{E,i}$ and $\upsilon_{D,i}$ denote the "stress test coefficients" for the equity and debt, respectively, of firm i, defined as:

$$\upsilon_{E,i} = \frac{MV^*_{E,i}}{MV_{E,i}}; \upsilon_{D,i} = \frac{MV^*_{D,i}}{MV_{D,i}}, \tag{2}$$

where $MV_{E,i}$ and $MV_{D,i}$ denote the market value of equity and debt of firm i before the carbon tax shock, and $MV^*_{E,i}$ and $MV^*_{D,i}$ denote the market value of equity and debt of firm i after the carbon tax shock. Thus, (1-$\upsilon_{E,i}$) and (1-$\upsilon_{D,i}$) are the market value losses per unit of exposure of a pension fund to the equity and debt of firm i.

To estimate the total asset value loss for each firm, we use a discounted cash flow model to determine the total valuation shock ζ_i as a result of the carbon tax shock. ζ_i is defined in such a way that it varies from 0 (meaning no losses to firm i's total asset value as a result of the carbon tax shock) to 1 (meaning a complete loss of the total asset value of firm i).

We calculate the valuation shock ζ_i as the ratio of the net present value (NPV) of the annual carbon tax payments to the total asset value of firm i:

$$\zeta_i = \frac{NPV_{tax,i}}{Total\ asset\ value_i} , \tag{3}$$

where the NPV of the annual carbon tax payments of firm i is:

$$NPV_{tax,i} = \sum_{t=0}^{T} \left(\frac{\gamma_{i,t} \times (1-\alpha_{i,t}) \times \tau_t \times (1-\varphi_{i,t})}{(1+r_{i,t})^t} \right) \tag{4}$$

where $\gamma_{i,t}$ is the carbon footprint in tonnes of CO_2e emissions of firm i in year t $(t$=0,..$T)$; $\alpha_{i,t}$ is the abatement potential (as a fraction of the carbon footprint) of firm i in year t; τ_t is the carbon tax amount (in euros) per tonne of CO_2e emissions in year t; $\varphi_{k,t}$ is the pass-through rate (as a fraction of the carbon tax τ_t) of firm i in year t; and $r_{i,t}$ is the discount rate (WACC) of firm i in year t. In our empirical implementation, we chose T=20 (without terminal value, which unreported tests suggest would not change our inferences) and a carbon tax, pass-through rate, and discount rate that is constant over time.

We allocate the total asset value loss of each firm i as a result of the carbon tax shock between the equity and debt holders using a standard Merton (1974) framework, which we reproduce here following Giesecke (2004) and Reinders et al. (2023). First, we compute the market value of debt and equity of firm i (below, we drop the subscript i for simplicity purposes) before the carbon tax shock as:

$$MV_E = V_t N(d1) - Le^{-r(T-t)} N(d2); \tag{5}$$

$$MV_D = Le^{-r(T-t)} - Le^{-r(T-t)} N(-d2) - V_t N(-d1) , \tag{6}$$

with:

$$d1 = \frac{\ln\left(\frac{1}{R}\right) + \left(r + \frac{\sigma_V{}^2}{2}\right)(T-t)}{\sigma_V \sqrt{T-t}}; \tag{7}$$

$$d2 = \frac{\ln\left(\frac{1}{R}\right) + \left(r - \frac{\sigma_V{}^2}{2}\right)(T-t)}{\sigma_V \sqrt{T-t}}, \tag{8}$$

where N is the probability of the standard normal density function below d. Hence, MV_E and MV_D can be expressed as a function of asset value V, leverage ratio R, contracted repayment L (which can be rewritten as $L = R \times V$), time to maturity T-t, volatility of the firm's total assets (or asset volatility) σ_V, and risk-free interest rate r.

Following Jones, Mason, and Rosenfeld (1984) and assuming that asset values follow a geometric Brownian motion, the volatility of the firm's equity (or equity volatility) σ_E can be expressed as:

$$\sigma_E = \frac{V}{MV_E} N(d1)\sigma_V \tag{9}$$

All parameters containing information about individual firms can be directly retrieved from various data sources, except for V, the firm's asset value, and σ_V, the volatility of total assets. V, the market value of a firm's assets, differs from the total asset value used in equation (3), where the book value of total assets is considered. These two variables are determined by first rewriting equation (5) in the following format:

$$MV_E = \left(N(d1) - Re^{-r(T-t)}N(d2)\right)V_t, \tag{10}$$

after which we use equations (9) and (10) to solve for the unknown parameter σ_V as depicted in equation (11):

$$\sigma_E \times MV_E = N(d1)\sigma_V \times MV_E/(N(d1) - Re^{-r(T-t)}N(d2)) \tag{11}$$

Subsequently, we substitute the obtained σ_V into equation (9) to determine V. The asset value after the carbon tax shock is given by:

$$V^* = (1-\zeta)V. \tag{12}$$

We can then incorporate the asset value after the carbon tax shock into the formula for the original market value of equity, equation (5). By rewriting the equation and dividing by the discounted exposure $Le^{-r(T-t)}$, we derive the following equation to calculate the market value of equity for each firm after the carbon tax shock:

$$MV_E^* = (1-\zeta)N(d1^*) - Re^{-r(T-t)}N(d2^*) \tag{13}$$

where

$$d1^* = \frac{\ln\left(\frac{1-\zeta}{R}\right) + (r + \frac{\sigma_V{}^2}{2})(T-t)}{\sigma_V\sqrt{T-t}} \tag{14}$$

$$d2^* = \frac{\ln\left(\frac{1-\zeta}{R}\right) + (r - \frac{\sigma_V{}^2}{2})(T-t)}{\sigma_V\sqrt{T-t}} \tag{15}$$

Via a similar approach the equation for the market value of debt can be determined as follows:

$$MV_D^* = 1 - N(-d2^*) - ((1-\zeta)/Re^{-r(T-t)})N(-d1^*) \tag{16}$$

Once the market values before and after the carbon tax shock are known for each firm, we compute the stress coefficients by dividing the market value of equity (or debt) before the carbon tax shock by the market value of equity (or debt) after the carbon tax shock:

$$\upsilon_{E,i} = \frac{MV_e^*}{MV_e} = \frac{(1-\zeta)N(d1^*) - Re^{-r(T-t)}N(d2^*)}{N(d1) - Re^{-r(T-t)}N(d2)} \tag{17}$$

$$\upsilon_{D,i} = \frac{MV_D^*}{MV_D} = \frac{1 - N(-d2^*) - ((1-\zeta)/Re^{-r(T-t)})N(-d1^*)}{1 - N(-d2) - (1/Re^{-r(T-t)})N(-d1)} \tag{18}$$

We then use equation (1) to compute the total market value loss for each pension fund by aggregating the individual losses across all firms in the equity and corporate bond portfolios of the pension fund. The aggregate losses across all pension funds provide an overview of the overall impact on the sector.

2.3 Carbon tax scenarios

We closely follow Reinders et al. (2023) in our specification of the carbon tax scenarios. In our baseline scenarios, we use a carbon tax of €200 per tonne of Scope 1 CO_2e emissions. The magnitude of this tax falls within the estimated range of implicit carbon prices needed to limit global warming to less than two degrees Celsius (Stiglitz et al., 2017; IPCC, 2018). In our sensitivity analysis, we also consider scenarios with a carbon tax of €400 per tonne of Scope 1 CO_2e emissions and with a Scope 2 CO_2e emissions tax.

Our main analysis is based on four different carbon tax scenarios that vary in the timing of the carbon tax τ_t as well as in the degree to which firms can pass-through the tax to their customers (that is, parameter $\varphi_{i,t}$ in equation (4) above). In terms of the timing of the tax, we distinguish between a carbon tax that is introduced overnight (“abrupt”) and one that is phased in over a period of 10 years. In terms of the pass-through degree, we distinguish between scenarios in which the entire tax is paid by the firms and scenarios in which firms can pass-through 50% of the tax to their customers.

These variations result in scenarios I through IV. In scenarios I and III, τ_t is set at €200 per tonne of CO_2e for every year t. In scenarios II and IV, τ_t starts at zero and increases linearly over the first 10 years, after which it stabilizes at €200. Thus, scenarios I and III can be seen as an overnight (abrupt) application of the carbon tax, whereas scenarios II and IV involve a phase-in period. Furthermore, in scenarios I and II, $\varphi_{i,t}$ is set to zero for all firms i and across all time periods t, meaning that firms absorb the full carbon tax. In scenarios III and IV, $\varphi_{i,t}$ is set at 0.5 for all firms and time periods, except in the first year where no pass-through occurs, allowing for a one-year delay before firms adjust their prices. These parameter choices result in the following scenarios:

- Scenario I: abrupt, no pass-through;
- Scenario II: phased in, no pass-through;

- Scenario III: abrupt, 50% pass-through;
- Scenario IV: phased in, 50% pass-through.

These scenarios are ranked according to the severity of their impact on corporate valuations, where scenario I is the most severe and scenario IV the least severe.

3. Results

This section discusses the composition of the equity and corporate bond portfolios of Dutch pension funds (Section 3.1), the valuation losses in the equity and corporate bond portfolios of Dutch pension funds in each of the carbon tax scenarios (Sections 3.2 and 3.3), and the results of a sensitivity analysis of the main parameter assumptions in our study (Section 3.4).

3.1 Composition of investment portfolios of pension funds

Before discussing the climate stress test, we present some information on the composition of the investment portfolios of Dutch pension funds. Table 2 presents an overview of the breakdown of these investment portfolios into different asset classes, based on EIOPA data. For purposes of comparison, the table also reports this breakdown for pension funds in the euro area. We note that the total market value of Dutch pension fund assets according to EIOPA (€1,533) differs slightly from the total market value derived from the Dutch Central Bank's holdings data (€1,517 billion), possibly due to differences in definition, timing of the market value measurement, and coverage. The most important asset class for Dutch pension funds is collective investments (40.3%; it includes equity and debt funds and is thus at least partially included in our sample via our look-through approach), followed by government bonds (23.2%), equity (17.8%), and corporate bonds (9.0%). The weight of the other asset classes is considerably smaller. These patterns are by and large similar for euro area pension funds.

Table 2 – Asset classes in investment portfolios of euro area and Dutch pension funds

This table shows the asset classes in the investment portfolios on the aggregate balance sheet of euro area and Dutch pension funds, expressed in terms of both market value (in billions of euros) and the percentage weight of each asset class relative to the total market value. The data are from the quarterly balance sheet statistics as of 2022Q4 from EIOPA: https://www.eiopa.europa.eu/tools-and-data/occupational-pensions-statistics_en. Within the "Collective investments" asset class, investments include subtypes such as equity funds and debt funds. For a detailed explanation of the different asset types, we refer to the official legal documentation.

	Euro area		Netherlands	
Asset class	Market value (€ billion)	% of total	Market value (€ billion)	% of total
Government bonds	516.4	21.4%	355.1	23.2%
Corporate bonds	291.4	12.1%	137.7	9.0%
Equity	431.2	17.9%	273.6	17.8%
Collective investments	960.1	39.8%	618.1	40.3%
Structured notes	5.6	0.2%	0.6	0.0%
Collateralized securities	17.6	0.7%	12.1	0.8%
Cash and deposits	106.7	4.4%	87.5	5.7%
Mortgages and loans	35.5	1.5%	24.1	1.6%
Property	28.3	1.2%	8.1	0.5%
Other investments	19.3	0.8%	16.4	1.1%
Total	2,412.1	100.0%	1,533.3	100.0%

Table 3 – Sector allocation of equity and corporate bond portfolios of Dutch pension funds
This table shows the sector allocation of the equity and corporate bond portfolios of Dutch pension funds, expressed in terms of the market value (in billions of euros) and the percentage weight of each sector relative to the total market value. The table is based on the sample of pension fund holdings that are matched with the firm-level carbon footprint data (€400 billion for equity and €157 billion for corporate bonds, see Figure 1). The sector classification is based on the GICS framework of 11 economic sectors, from the Institutional Shareholder Services (ISS) dataset. Assets for which sector classifications are not available are categorized as "Not available".

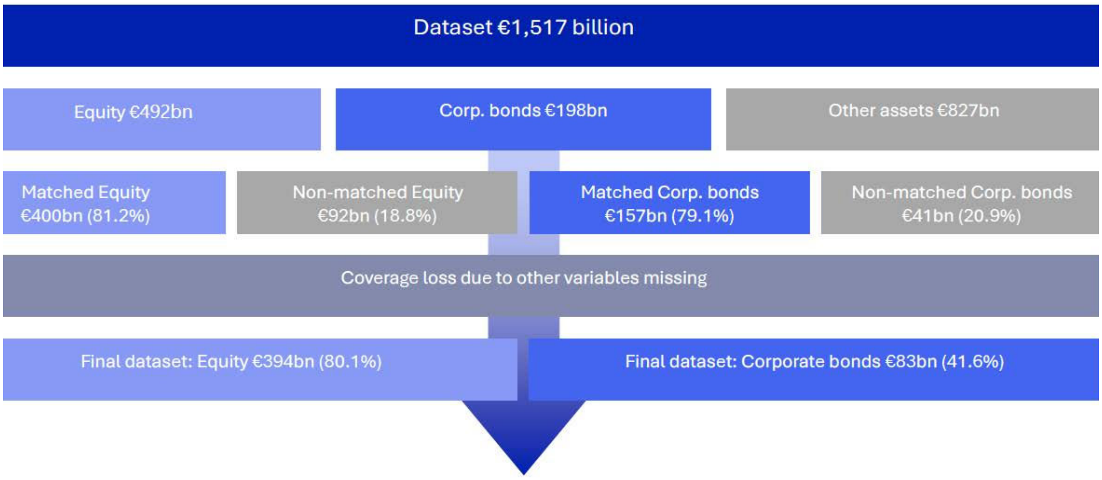
	Equity		Corporate bonds	
Sector	Market value (€ billion)	% of total	Market value (€ billion)	% of total
Information Technology	64.0	16.0%	3.7	2.4%
Financials	63.7	15.9%	42.6	27.2%
Health Care	50.6	12.6%	6.3	4.0%
Real Estate	46.4	11.6%	3.2	2.1%
Industrials	41.5	10.4%	7.2	4.6%
Consumer Discretionary	39.5	9.9%	6.6	4.2%
Consumer Staples	31.9	8.0%	5.4	3.4%
Communication Services	24.1	6.0%	7.9	5.0%
Materials	17.0	4.3%	3.4	2.1%
Utilities	10.7	2.7%	6.2	3.9%
Energy	8.6	2.2%	2.5	1.6%
Not available	1.9	0.5%	61.9	39.5%
Total	400.0	100.0%	157.0	100.0%

Table 3 shows the sector allocation of the equity and corporate bond portfolios of Dutch pension funds, based on the sample of observations that we are able to match with carbon footprint data (the middle row in Figure 1) and based on the GICS classification into 11 economic sectors. As outlined in Figure 1, the total market value across all Dutch pension funds in this sample is €400 billion for equity and €157 billion for corporate bonds. The sectors in Table 3 are ranked based on their weight in the equity portfolios of the pension funds. The top five sectors in the equity portfolios are Information Technology (weight of 16.0%), Financials (15.9%), Health Care (12.6%), Real Estate (11.6%), and Industrials (10.4%). For the bond portfolios, by far the most important sector is Financials, with a weight of 27.1%. The other 10 sectors have a weight of at most 5%. We note that for corporate bonds, we were unable to collect GICS sector classifications for almost 40% of the market value of the portfolios.

One observation based on Table 3 is that Dutch pension funds have relatively limited exposure to the three GICS sectors with by far the largest carbon emissions: Utilities, Materials, and Energy (Visual Capitalist, 2023). These three sectors are the bottom three sector in terms of their weight in the equity portfolios of the pension funds, and also have relatively small weights in the corporate bond portfolios. The combined weight of these three sectors in the equity portfolios is 9.2%, whereas their weight in the current MSCI ACWI is

Figure 1 – Overview of dataset composition

This figure shows an overview of how our final dataset for the equity and corporate bond portfolios of Dutch pension funds is derived from the confidential Financial Statements (FTK) dataset of the Dutch Central Bank. The total market value of the investment portfolios of the 180 pension funds amounts to €1,517 billion in 2022Q4. These portfolios encompass a wide range of asset classes, including equity, corporate bonds, government bonds, mortgages, and other illiquid securities. For our stress test, we only examine equity (€492 billion) and corporate bonds (€198 billion). We are able to match 81.2% of equity market value and 79.1% of corporate bond market value with carbon emissions data. Additional losses in coverage result from the unavailability of other variables required for the analysis, including firm-level data on total asset value, equity volatility, leverage, and market value. The final dataset consists of €394 billion in equity (80.1% of total equity market value) and €83 billion in corporate bonds (41.6% of total corporate bond market value).



9.6%.[5] A likely explanation for the lower weight in the equity portfolios of the pension funds relative to this major global equity benchmark is that, over the past 5 to 10 years, many Dutch pension funds have formulated explicit targets for reduction of the carbon footprint of their portfolios (VBDO, 2019). The underweight of just 0.4% seems remarkably small, but unreported results show that Dutch pension funds have much smaller exposure to the firms with the greatest Scope 1 CO_2 emissions when compared to the MSCI ACWI. For example, the mean weight of the top ten emitters in the MSCI ACWI in the equity portfolios of Dutch pension funds is 0.2% (vs. 1.5% in the MSCI ACWI) and the weight in the top 50 emitters is 1.2% (vs. 2.8% in the MSCI ACWI). It thus appears that Dutch pension funds have reduced the carbon footprint of their portfolios largely by shifting weights within sectors from firms with large footprints to firms with relatively small footprints.

Since the classification into 11 sectors is quite crude, Table 4 shows the top 15 subindustries (out of 162 GICS subindustries in our sample), based on their weight in the equity portfolios (Panel A) and corporate bond portfolios (Panel B) of Dutch pension funds. Diversified Banks are the most important subindustry in both the equity portfolios (weight of 6.6%) and the corporate bond portfolios (12.0%; apart from the category of assets for which subindustry data were not available at 13.5%). For equities, other important subindustries include

5 See https://www.msci.com/indexes/index/892400.

Table 4 – Top 15 subindustries in equity and corporate bond portfolios of Dutch pension funds
This table shows the top 15 subindustries with the greatest allocation within the equity portfolios (Panel A) and corporate bond portfolios (Panel B) of Dutch pension funds, expressed in terms of both market value (in billions of euros) and the percentage weight of each sector relative to total market value. The table is based on the sample of pension fund holdings that are matched with the firm-level carbon footprint data (€400 billion for equity and €157 billion for corporate bonds, see Figure 1). The subindustry classification is based on the GICS framework of subindustries (of which 162 subindustries are included in our sample), from the Institutional Shareholder Services (ISS) dataset. Assets for which subindustry classifications are not available are categorized as "Not available".

Subindustry	Market value (€ billion)	% of total
Panel A: Equity		
Diversified Banks	26.4	6.6%
Pharmaceuticals	19.0	4.8%
Semiconductors	13.9	3.5%
Technology Hardware, Storage & Peripherals	12.8	3.2%
Systems Software	10.0	2.5%
Interactive Media & Services	9.5	2.4%
Packaged Foods & Meats	8.5	2.1%
Broadline Retail	8.2	2.0%
Industrial REITs	7.8	1.9%
Biotechnology	7.6	1.9%
Application Software	7.2	1.8%
Health Care Equipment	7.2	1.8%
Transaction & Payment Processing Services	7.2	1.8%
Life Sciences Tools & Services	6.0	1.5%
Integrated Telecommunication Services	5.9	1.5%
Other subindustries	242.9	60.7%
Total	400.0	100.0%
Panel B: Corporate bonds		
Not available	21.2	13.5%
Diversified Banks	18.8	12.0%
Integrated Telecommunication Services	2.2	1.4%
Pharmaceuticals	1.4	0.9%
Consumer Finance	1.1	0.7%
Electric Utilities	1.0	0.7%
Investment Banking & Brokerage	1.0	0.7%
Cable & Satellite	1.0	0.6%
Multi-Utilities	0.9	0.6%
Diversified Capital Markets	0.9	0.5%
Soft Drinks & Non-alcoholic Beverages	0.9	0.5%
Transaction & Payment Processing Services	0.8	0.5%
Hotels, Resorts & Cruise Lines	0.7	0.4%
Packaged Foods & Meats	0.6	0.4%
Industrial Machinery & Supplies & Components	0.6	0.4%
Other subindustries	103.9	66.2%
Total	157.0	100.0%

Table 5 – Country allocation of equity and corporate bond portfolios of Dutch pension funds
This table shows the country allocation of the equity portfolios (Panel A) and corporate bond portfolios (Panel B) of Dutch pension funds, expressed in terms of both market value (in billions of euros) and the percentage weight of each sector relative to total market value. The table is based on the sample of pension fund holdings that are matched with the firm-level carbon footprint data (€400 billion for equity and €157 billion for corporate bonds, see Figure 1). The country classification is derived from the Institutional Shareholder Services (ISS) dataset.

Country	Market value (€ billion)	% of total
Panel A: Equity		
United States	195.2	48.8%
Japan	22.9	5.7%
United Kingdom	17.6	4.4%
Cayman Islands	13.5	3.4%
France	11.9	3.0%
Switzerland	11.1	2.8%
India	10.3	2.6%
China	10.2	2.6%
Taiwan	10.0	2.5%
Germany	9.8	2.5%
Canada	7.9	2.0%
Korea, Republic of	7.7	1.9%
Australia	7.4	1.9%
Netherlands	7.4	1.9%
Hong Kong	5.7	1.4%
Other countries	51.3	12.8%
Total	400.0	100.0%

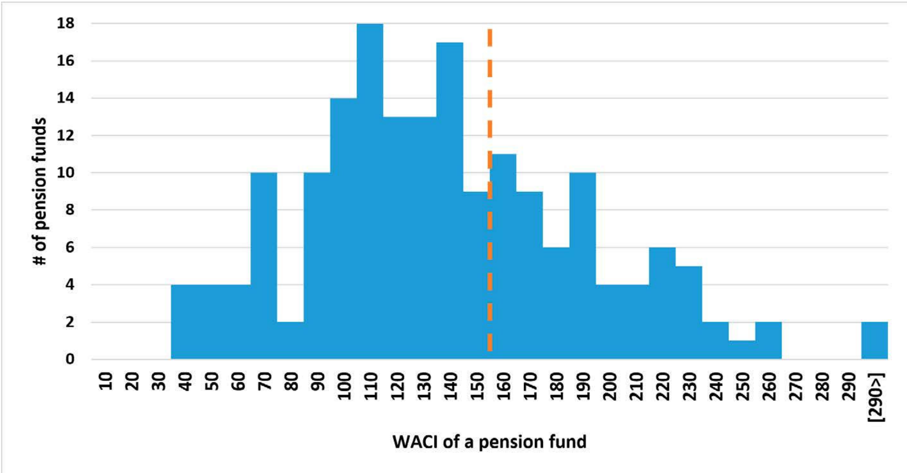
Country	Market value (€ billion)	% of total
Panel B: Corporate bonds		
United States	48.7	31.0%
Netherlands	19.7	12.5%
France	18.8	12.0%
United Kingdom	13.2	8.4%
Germany	8.2	5.2%
Luxembourg	5.8	3.7%
Spain	3.9	2.5%
Canada	3.7	2.4%
Sweden	3.1	2.0%
Italy	2.9	1.9%
Japan	2.5	1.6%
Australia	2.3	1.4%
Ireland	2.2	1.4%
Belgium	2.2	1.4%
Norway	2.1	1.4%
Other countries	17.6	11.2%
Total	157.0	100.0%

Pharmaceuticals (4.8%), Semiconductors (3.5%), Technology Hardware, Storage & Peripherals (3.2%), and Systems Software (2.5%). For corporate bonds, the only other subindustry with a weight above 1% is Integrated Telecommunication Services (1.5%).

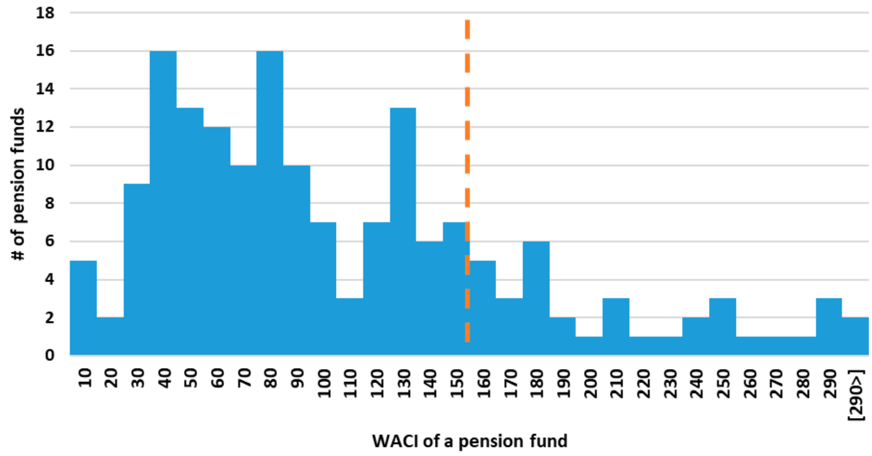
Table 5 shows the country allocation of the equity and corporate bond portfolios. Perhaps not surprisingly, the U.S. has the greatest weight in the equity portfolios (48.8%, compared to 66.4% in the current MSCI ACWI) as well as in the corporate bond portfolios (31.0%). Except for Japan (5.7%), no single other country accounts for more than 5% of the equity portfolios of the pension funds. For corporate bonds, we see weights of 12.5% for The Netherlands (suggesting a non-negligible home bias; French and Poterba, 1991), 12.0% for France, and 8.4% for the U.K.

We now turn to a more detailed analysis of the carbon footprint of the portfolios of Dutch pension funds as of 2022. Figure 2 shows the distribution of the so-called Weighted Average Carbon Intensity (WACI) of the equity portfolios (Panel A) and corporate bond portfolios (Panel B) of the 180 Dutch pension funds in our sample. The WACI of a pension fund's equity or corporate bond portfolio is defined as the sum of the products of each firm's portfolio weight and the carbon efficiency of the firm, where a firm's carbon efficiency is the ratio of its total Scope 1 and 2 greenhouse gas (GHG) emissions to its revenue. The

Figure 2 –Weighted Average Carbon Intensity of equity and corporate bond portfolios of Dutch pension funds
This figure shows a histogram of the Weighted Average Carbon Intensity (WACI) of the equity portfolios (Panel A) and corporate bond portfolios (Panel B) of the 180 Dutch pension funds, based on their Scope 1 and 2 carbon emissions in 2022 from ISS. The WACI quantifies the carbon emissions of a portfolio relative to the revenues of the firms it consists of, adjusted by their respective weights in the portfolio. It is calculated as the sum of the products of each firm's portfolio weight and the carbon efficiency of the firm. The carbon efficiency of a firm is the ratio of its total greenhouse gas (GHG) emissions (expressed in tonnes) to its revenue (expressed in millions of euros). For the purpose of this WACI calculation, we included Scope 1 and 2. As a comparison, the MSCI ACWI had a WACI of 154 as of October 29, 2021. This value is depicted on the graph with an orange dashed vertical line, providing a benchmark for comparison against the WACI scores of other pension fund portfolios in the analysis (from https://www.msci.com/documents/1296102/18370713/MSCI-IndexCarbonFootprintMetrics-cfs-en.pdf/de79973f-2704-4987-bfb0-391e27577b47). The average WACI of the Dutch pension fund sector as a whole (not reported) is 142, and the value-weighted average based on market-cap is 128.



Panel A: Equities



Panel B: Corporate bonds

notion here is that emissions are scaled by a measure of firm size, since larger firms in the same business line are likely to have more emissions without necessarily being less efficient. The resulting WACI numbers cannot be interpreted in a straightforward fashion (they range from 0 to around 300 in our sample), but they do give an indication of the breadth of the exposure of pension funds to carbon efficiency in their equity portfolios. For comparison purposes, we have plotted the WACI of the MSCI ACWI, which is 154, in the same graph.

Table 6 – Climate reduction target allocation of equity and corporate bond portfolios of Dutch pension funds
This table shows the allocation of the equity and corporate bond portfolios of Dutch pension funds to different categories of greenhouse gas (GHG) reduction targets, expressed in terms of both market value (in billions of euros) and the percentage weight of each category relative to total market value. For comparison purposes, the final column shows the percentage weight of each category within the MSCI ACWI equity index. The table is based on the sample of pension fund holdings that are matched with the firm-level carbon footprint data (€400 billion for equity and €157 billion for corporate bonds, see Figure 1). The GHG reduction targets for individual firms come from the Institutional Shareholder Services (ISS) dataset. These targets are classified into five categories, ranging from least to most ambitious: "No Target", "Non-Ambitious Target", "Ambitious Target", "Committed SBT", and "Approved SBT" – where "SBT" stands for Science-Based Targets, which are assessed based on the existence and quality of the greenhouse gas emission reduction commitments of firms. The classification considers both science-based targets and other issuer-set goals. The category "Not Collected" includes firms for which there are no GHG reduction target data.

	Equity		Corporate bonds		MSCI ACWI
Climate reduction targets	Market value (€ billion)	% of total	Market value (€ billion)	% of total	% of total
Approved SBT	170.9	42.7%	53.9	34.4%	36.3%
Committed SBT	47.5	11.9%	19.6	12.5%	12.5%
Ambitious Target	50.5	12.6%	25.3	16.1%	11.3$
Non-Ambitious Target	75.9	19.0%	37.2	23.7%	23.5%
No Target	55.2	13.8%	20.6	13.1%	15.3%
Not Collected	0.0	0.0%	0.4	0.3%	1.1%
Total	400.0	100.0%	157.0	100.0%	100.0%

Figure 2 shows a wide dispersion in the WACI across individual Dutch pension funds, where some funds have an equity portfolio WACI that is well below the WACI of the MSCI ACWI, while others have a WACI that is substantially greater. A small majority of Dutch pension funds have an equity portfolio WACI that is below that of the MSCI ACWI.[6] A similar picture arises from the graph for the corporate bond portfolios in Panel B of Figure 2. Again, we see a wide dispersion across funds, although on average the WACI of the corporate bond portfolios of pension funds is smaller than the WACI of their equity portfolios – possibly because of their relatively large exposure to the Financials sector.

Figure 2 contains information about the current carbon efficiency of the investment portfolios of Dutch pension funds, but it is not very informative about how the carbon footprint of the portfolios might develop in the future. To examine some forward-looking information on the carbon footprint of the investment portfolios of Dutch pension funds, Table 6 shows the allocation in the equity and corporate bond portfolios to different categories of greenhouse gas (GHG) reduction targets (obtained from ISS). We observe that the most ambitious reduction target category (Approved "Science-Based Targets" or SBT) represents a substantial fraction of the equity portfolios (42.7%) and corporate bond portfolios (34.4%). That said,

6 The average WACI of all Dutch pension funds is 142, which is slightly below the WACI of the MSCI ACWI. However, the value-weighted average WACI of the Dutch pension fund sector as a whole is significantly lower than that of the MSCI ACWI (with a value of 128). This indicates that especially larger pension funds have a portfolio with a lower carbon footprint than the MSCI ACWI.

a non-negligible fraction of the portfolios is invested in firms with less ambitious targets, with in total around 45% of the equity portfolios and 55% of the corporate bond portfolios invested in firms with either No Target, a Non-Ambitious Target, or an Ambitious Target that is neither a committed nor approved SBT. When comparing the equity portfolios of Dutch pension funds to the MSCI ACWI (final column of Table 6), it becomes evident that pension funds generally allocate a larger share to firms with Approved Science-Based Targets (42.7% versus 36.3% for MSCI ACWI). However, this finding should be interpreted with caution, as part of the Dutch pension fund portfolio is excluded from our analysis due to missing carbon target information, so that the results may be subject to selection bias.

3.2 Market losses in equity portfolios of pension funds

In this subsection, we discuss how the estimated asset valuation shocks in carbon tax scenarios I through IV translate into estimated market value losses in the equity portfolios of Dutch pension funds. We estimate these valuation shocks for each individual firm in our sample, but we present the results by GICS sector and subindustry. By zooming in on asset valuation shocks and equity market value losses for sectors and subindustries, we provide insight into which sectors and subindustries are most affected by the carbon tax scenarios and which could cause the greatest equity market value losses for Dutch pension funds (taking into account their exposure to these sectors and subindustries). We note that estimating these firm-level asset valuation shocks requires firm-level financial data that limit our final sample to €394 billion in equities and €83 billion in corporate bonds (bottom row in Figure 1).

Table 7 shows the estimated asset valuation shocks (as a percentage of total asset value) in each of the scenarios for all 11 GICS sectors (in Panel A) and for the 15 GICS subindustries (out of the 162 subindustries in our sample) with the greatest asset valuation shocks (in Panel B). It is clear from the table that substantial losses to firm valuations can occur in each of our four carbon tax scenarios. Not surprisingly, the three sectors with the greatest carbon footprint (Utilities, Materials, and Energy) show the greatest potential valuation losses, with 41% of total aggregate firm value in Scenario I for Energy, and 37% for both Materials and Utilities. The valuation shocks for these sectors are somewhat smaller, but still substantial, in the less severe carbon tax scenarios II, III, and IV. For most other sectors, the estimated valuation shocks are considerably smaller, with the exception of Industrials and Consumer Staples, which show value losses in scenario I of 11% and 7%, respectively. The final two columns of Panel A of Table 7 show the aggregate percentage equity exposure of Dutch pension funds to each sector[7] as well as the greatest percentage equity exposure

7 These percentage exposures may differ from those in Table 3 because Table 7 is based on the sample in the bottom row of Figure 1 that is matched to the firm-level financial data, whereas Table 3 is based on the broader sample in the middle row that is matched to carbon footprint data only.

Table 7 – Estimated asset valuation shock by sector and subindustry for equities

This table shows the estimated asset valuation shocks in carbon tax scenarios I-IV for our analysis of the equity portfolios of Dutch pension funds for all 11 GICS sectors in Panel A (sorted from greatest to lowest asset valuation shock in Scenario I) and for the 15 GICS subindustries with the greatest asset valuation shock in Scenario I (out of 162 subindustries in our sample) in Panel B. The shocks are calculated as the net present value losses relative to total firm value, as described in equations (3) and (4). The scenarios, based on Reinders et al. (2023), vary in the implementation paths of the carbon tax (τ) and the extent to which firms can pass the tax burden on to consumers (φ). Scenarios I and III involve an overnight application of the tax, which then remains constant at €200 per tonne of CO_2e. By contrast, Scenarios II and IV assume a gradual phase-in of the tax over 10 years, after which it stabilizes at €200 per tonne of CO_2e. Scenarios I and II assume no pass-through of costs to consumers, whereas Scenarios III and IV assume that 50% of the carbon tax is passed through. The column "PF Sector %" shows the weight of the aggregate equity portfolios of Dutch pension funds in each sector or subindustry. The column "Max PF %" shows the greatest weight in the equity portfolio of an individual pension fund in each sector or subindustry. At the bottom of the table, the averages for subindustries not listed in Panel B are presented, along with the overall averages and medians for all firms in the dataset. The table is based on the sample of pension fund holdings that are matched with the firm-level carbon footprint and financial data (€394 billion for equity, see Figure 1).

Scenario:	I	II	III	IV	PF Sector %	Max PF %
Panel A: Sectors						
Energy	0.41	0.28	0.24	0.15	*2.0%*	*7.6%*
Materials	0.37	0.29	0.27	0.19	*4.3%*	*10.4%*
Utilities	0.37	0.30	0.27	0.20	*2.7%*	*14.4%*
Industrials	0.11	0.07	0.06	0.04	*10.3%*	*21.1%*
Consumer Staples	0.07	0.05	0.04	0.03	*8.0%*	*14.0%*
Not Collected	0.04	0.03	0.02	0.01	*0.0%*	*0.6%*
Consumer Discretionary	0.02	0.02	0.01	0.01	*10.0%*	*16.1%*
Health Care	0.02	0.01	0.01	0.01	*12.8%*	*20.8%*
Information Technology	0.01	0.01	0.01	0.00	*16.2%*	*27.5%*
Communication Services	0.01	0.00	0.00	0.00	*6.0%*	*13.5%*
Real Estate	0.00	0.00	0.00	0.00	*11.7%*	*27.1%*
Financials	0.00	0.00	0.00	0.00	*16.0%*	*22.1%*
Panel B: Subindustries						
Independent Power Prod. & Energy Traders	0.84	0.81	0.78	0.69	*0.0%*	*0.6%*
Aluminum	0.84	0.69	0.65	0.48	*0.0%*	*0.4%*
Passenger Airlines	0.81	0.57	0.49	0.30	*0.1%*	*1.1%*
Construction Materials	0.78	0.73	0.71	0.63	*0.2%*	*0.9%*
Steel	0.73	0.64	0.61	0.44	*0.4%*	*3.2%*
Marine Transportation	0.63	0.43	0.36	0.22	*0.2%*	*1.9%*
Oil & Gas Refining & Marketing	0.59	0.42	0.35	0.23	*0.5%*	*1.6%*
Coal & Consumable Fuels	0.50	0.39	0.36	0.24	*0.0%*	*1.8%*
Industrial Gases	0.47	0.31	0.27	0.16	*0.1%*	*1.7%*
Diversified Chemicals	0.46	0.35	0.32	0.24	*0.1%*	*1.3%*
Integrated Oil & Gas	0.46	0.29	0.25	0.15	*0.7%*	*5.1%*
Paper Products	0.46	0.34	0.29	0.18	*0.1%*	*0.9%*
Electric Utilities	0.43	0.36	0.31	0.22	*1.4%*	*10.0%*
Oil & Gas Storage & Transportation	0.41	0.29	0.24	0.15	*0.2%*	*3.8%*
Fertilizers & Agricultural Chemicals	0.40	0.32	0.29	0.19	*0.3%*	*1.6%*
Average across other subindustries	0.05	0.03	0.03	0.02		
Average across all firms	0.09	0.06	0.06	0.04		
Median across all firms	0.01	0.00	0.00	0.00		

by a single pension fund. The aggregate equity exposure to the top 3 sectors in terms of carbon emissions is relatively modest, at 9.0% for the three sectors combined. That said, the exposure of individual pension funds can be substantially higher. One of the pension funds in our sample has a weight of 10.4% for the Materials sector in its equity portfolio, while another fund has an equity weight of 14.4% for the Utilities sector. The pension sector as a whole has weights of 10.3% and 8.0%, respectively, in the Industrials and Consumer Staples sectors. The valuation shock in Scenario I for these sectors is also non-negligible.

Panel B of Table 7 shows that the asset valuation shocks are even more severe for specific subindustries. For each of the 15 subindustries included in this panel, the asset valuation shock in Scenario I exceeds 40% of asset value, while it is above 80% for three subindustries (Independent Power Producers & Energy Traders, Aluminum, and Passenger Airlines). These numbers suggest that assets in these subindustries would become close to stranded in the most severe of our scenarios. The numbers in the final two columns of Panel B indicate that for most subindustries, the equity exposure of Dutch pension funds is limited, with an aggregate equity weight mostly below 0.5% and the maximum equity weight for an individual pension fund mostly below 4%. The two exceptions are Integrated Oil & Gas and Electric Utilities, with aggregate (maximum individual) equity weights of 0.7% (5.1%) and 1.4% (10%), respectively. These are the subindustries that Dutch pension funds could consider in particular if they wish to reduce their exposure to carbon transition risk in a targeted way.

In Table 8, we translate the asset valuation shocks for different sectors and different subindustries from Table 7 into aggregate market value losses (in € billion) in the equity portfolios of all Dutch pension funds. We again do this for each of the four scenarios and for all 11 GICS sectors (in Panel A) as well as for the 15 GICS subindustries with the greatest equity losses (in Panel B). The table shows considerable equity market value losses, amounting to over €1 billion in total, across a number of sectors and even subindustries and also across multiple scenarios. Among the sectors, the top three with the greatest carbon footprint (Utilities, Materials, and Energy) show up among the top four sectors that constitute equity market losses – even given the relatively low weight of these sectors in the equity portfolios of Dutch pension funds (see Table 7). Industrials and Consumer Staples, sectors with a relatively small valuation shock but with a greater weight in the equity portfolios of the pension funds, also show up among the top five in terms of equity market losses. For each of these sectors, equity market value losses would amount to multiple billions of euros in at least some of the scenarios, up to an estimated €5.14 billion for Materials in scenario I. These estimates indicate non-negligible equity exposures to carbon transition risk in these five sectors.

The corresponding equity market value losses for the 15 subindustries in Panel B of Table 8 are generally lower, which is not surprising since there are 162 subindustries and only 11 sectors. That said, for six of the subindustries the resulting equity market loss for

Dutch pension funds in scenario I would amount to more than €1 billion, namely Electric Utilities, Integrated Oil & Gas, Oil & Gas Refining & Marketing, Environmental & Facility Services, Packaged Foods & Meats, and Multi-Utilities. The first two of these six subindustries (Electric Utilities and Integrated Oil and Gas) stood out in Table 7 for their relatively large weight in the equity portfolios of pension funds.

The bottom of Table 8 shows the aggregate equity market losses across all 180 Dutch pension funds in our sample. These losses amount to around €22.5 billion in scenario I, €16 billion in scenario II, €14 billion in scenario III, and €9 billion in scenario IV. Figure 3 presents these numbers graphically and as a percentage of the aggregate market value of the equity portfolios of Dutch pension funds. The figure shows that pension funds would experience aggregate market value losses in their equity portfolios of 5.7% in scenario I, 4.1% in scenario II, 3.6% in scenario III, and 2.3% in scenario IV. Recent climate stress tests, including those by the European Supervisory Authorities (2024), Reinders et al. (2023), and Vermeulen et al. (2021), obtain market value loss estimates for the European pension sector and the Dutch financial sector that are largely in line with our estimates.

Table 8 and Figure 3 provide information about the equity market losses under different scenarios for the Dutch pension sector as a whole, but do not do justice to the considerable heterogeneity across individual Dutch pension funds in their exposure to carbon transition risk. Figure 4 therefore shows the distribution of equity market value losses in scenario I across the 180 Dutch pension funds in our sample. The figure shows that most of the pension funds (131 out of 180) would experience an equity loss in scenario I of between 4% and 8% of the market value of their equity portfolio. 19 pension funds would experience a loss between 0% and 4%, while 29 pension funds would experience a more severe loss, of between 8% and 12%. One pension fund in our sample in particular is vulnerable to the introduction of a carbon tax as specified in scenario I, as it could face losses of up to 16.5% in its equity portfolio.[8]

Taken together, the results in Section 3.2 suggest that, although the Dutch pension sector as a whole would likely not experience dramatic losses in its equity portfolios under severe but plausible carbon tax scenarios, the aggregate losses of up to 5.7% seem big enough to be taken seriously. Moreover, some individual pension funds are significantly more exposed to such carbon transition risk scenarios.

In Section 3.3, we redo these analyses for the corporate bond portfolios of Dutch pension funds. In Section 3.4, we carry out several sensitivity analyses of our baseline climate stress test, including analyses that involve more severe carbon tax scenarios

8 We have taken a closer look at this fund. It is a relatively small fund with equity and corporate bond portfolios with a sectoral composition that deviates significantly from that of the average fund. However, we see no reason to question the data quality of this fund and this particular result.

Table 8 – Market value losses by sector and subindustry in the equity portfolios of Dutch pension funds (in € billion)
This table shows the total market value losses in the equity portfolios of Dutch pension funds (in € billion) in carbon tax scenarios I-IV for all 11 GICS sectors in Panel A (sorted from highest to lowest equity market value loss in Scenario I) and for the 15 GICS subindustries with highest equity market value loss in Scenario I (out of 162 subindustries in our sample) in Panel B. The bottom of the table shows the total market value loss in the equity portfolios of Dutch pension funds for each scenario, as well as the average and median losses across all subindustries. The scenarios, based on Reinders et al. (2023), vary in the implementation paths of the carbon tax (τ) and the extent to which firms can pass the tax burden on to consumers (φ). Scenarios I and III involve an overnight application of the tax, which then remains constant at €200 per tonne of CO_2e. Scenarios II and IV, on the contrary, assume a gradual phase-in of the tax over 10 years, after which it stabilizes at €200 per tonne of CO_2e. Scenarios I and II assume no pass-through of costs to consumers, whereas Scenarios III and IV assume that 50% of the carbon tax is passed through. The table is based on the sample of pension fund holdings that are matched with the firm-level carbon footprint and financial data (€394 billion for equity, see Figure 1).

Scenario:	I	II	III	IV
Panel A: Sectors				
Materials	5.14	3.82	3.48	2.28
Industrials	4.65	3.29	2.85	1.73
Utilities	4.49	3.70	3.25	2.25
Energy	3.29	2.20	1.88	1.14
Consumer Staples	2.44	1.61	1.36	0.83
Consumer Discretionary	0.95	0.61	0.53	0.31
Information Technology	0.55	0.31	0.31	0.16
Health Care	0.47	0.30	0.27	0.15
Financials	0.24	0.17	0.13	0.08
Real Estate	0.22	0.15	0.12	0.07
Communication Services	0.08	0.05	0.05	0.03
Not Collected	0.01	0.01	0.01	0.00
Panel B: Subindustries				
Electric Utilities	2.79	2.35	2.09	1.46
Integrated Oil & Gas	1.15	0.73	0.64	0.37
Oil & Gas Refining & Marketing	1.15	0.79	0.66	0.41
Environmental & Facility Services	1.14	0.88	0.78	0.46
Packaged Foods & Meats	1.13	0.75	0.63	0.39
Multi-Utilities	1.09	0.88	0.77	0.51
Steel	0.80	0.68	0.64	0.45
Commodity Chemicals	0.76	0.51	0.45	0.27
Rail Transportation	0.69	0.46	0.38	0.24
Diversified Metals & Mining	0.63	0.40	0.35	0.21
Air Freight & Logistics	0.59	0.38	0.33	0.19
Specialty Chemicals	0.56	0.40	0.36	0.21
Construction Materials	0.55	0.51	0.49	0.41
Marine Transportation	0.50	0.34	0.30	0.18
Oil & Gas Exploration & Production	0.45	0.29	0.25	0.15
Other subindustries	8.56	5.83	5.11	3.14
Total equity market value loss	22.54	16.20	14.22	9.05
Average of subindustry	0.14	0.10	0.09	0.06
Median of subindustry	0.14	0.10	0.09	0.05

Figure 3 – Total market value loss per scenario in the equity portfolios of Dutch pension funds
This figure shows the total market value losses in the equity portfolios of Dutch pension funds in carbon tax scenarios I-IV, in € billion as well as in percentage of the aggregate market value of the equity portfolios. The table is based on the sample of pension fund holdings that are matched with the firm-level carbon footprint and financial data (€394 billion for equity, see Figure 1). The scenarios, based on Reinders et al. (2023), vary in the implementation paths of the carbon tax (τ) and the extent to which firms can pass the tax burden on to consumers (φ). Scenarios I and III involve an overnight application of the tax, which then remains constant at €200/tonne CO_2e. Scenarios II and IV, on the contrary, assume a gradual phase-in of the tax over 10 years, after which it stabilizes at €200/tonne CO_2e. Scenarios I and II assume no pass-through of costs to consumers, whereas Scenarios III and IV assume that 50% of the carbon tax is passed through.

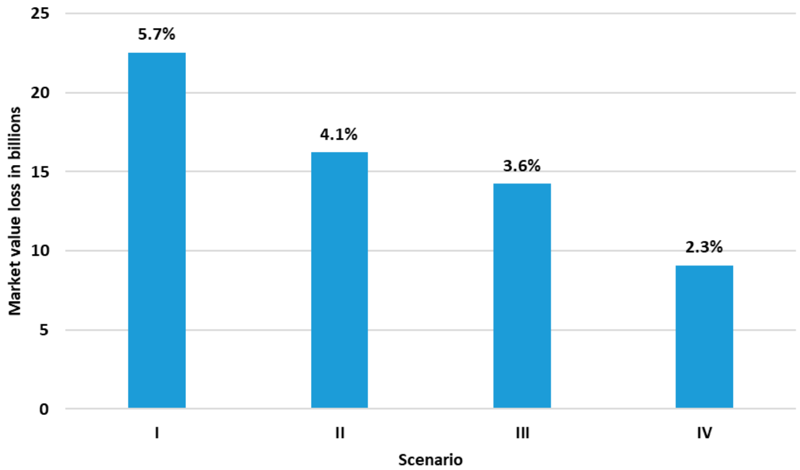
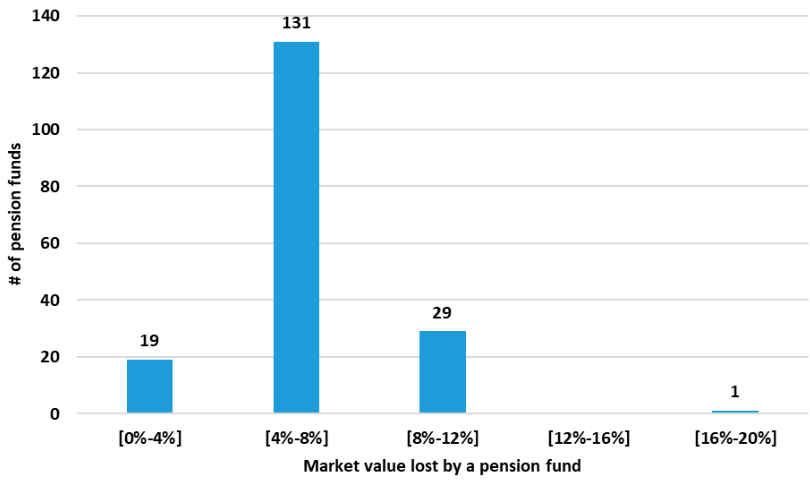


Figure 4 – Distribution of equity market value loss in Scenario I across Dutch pension funds
This figure shows the distribution of the market value losses in the equity portfolios across all Dutch pension funds in carbon tax scenario I. The x-axis represents the range of equity market value losses for each pension fund, and the y-axis shows the number of pension funds within each loss range. The table is based on the sample of pension fund holdings that are matched with the firm-level carbon footprint and financial data (€394 billion for equity, see Figure 1). Scenario I assumes a €200 per tonne CO2e emissions carbon tax applied overnight and remaining constant thereafter, with no pass-through of costs to consumers.



(including a €400 per tonne of Scope 1 carbon emissions tax and a carbon tax that also includes Scope 2 carbon emissions).

3.3 Market losses in corporate bond portfolios of pension funds

We now turn to a climate stress test of the corporate bond portfolios of Dutch pension funds using our carbon tax scenarios I-IV. We carry out our analysis in a similar way as discussed in Section 3.2 for the equity portfolios. Table 9 shows the estimated asset valuation shocks for our corporate bonds sample. The table has the same set-up as Table 7 but then based on our sample of corporate bonds rather than equities. As in Table 7, Table 9 shows the asset valuation shocks (as a percentage of total asset value) in each scenario for all 11 GICS sectors (in Panel A) and for the 15 GICS subindustries with the greatest asset valuation shocks (in Panel B). The results are similar to those in Table 7. Differences between the results in Tables 7 and 9 arise purely because of the different set of firms in the equity and corporate bond samples. The differing samples are the result of the difference in holdings in individual firms in the equity and corporate bond portfolios and by a different fraction of these holdings that can be matched with firm-level carbon footprint and financial data – where we note that the coverage of our corporate bonds sample is considerably smaller (see Figure 1).

Estimated asset valuation shocks for sectors in Panel A of Table 9 can be large under each of the four scenarios, where the top five sectors are the same (although in slightly different order) as in Table 7. The valuation shocks in scenario I are marginally smaller than in Panel A of Table 7, but they still indicate large valuation losses (above 30%) for the top three sectors: Utilities, Energy, and Materials. The final two columns of Table 9 show the aggregate percentage corporate bond exposure of Dutch pension funds to each sector (also presented in Table 3) as well as the greatest percentage corporate bond exposure by a single pension fund. Like for equities, the aggregate corporate bond exposure to the top three sectors in terms of carbon emissions is relatively modest, at 11.9% for the three sectors combined. But individual pension funds have corporate bond exposures that can be much larger. And aggregate corporate bond exposures of the pension sector as a whole are larger for Industrials and Consumer Staples (at 7.5% to 6.3%) that also face substantial valuation shocks.

The asset valuation shocks for subindustries for the corporate bonds sample in Panel B of Table 9 are also comparable to those for the equities sample in Panel B of Table 7. Of the 15 subindustries with the greatest asset valuation shocks in both samples, 12 overlap. In Panel B of Table 9, the estimated asset valuation shocks for some industries are even greater than those in Panel B of Table 7. For example, Panel B of Table 9 suggests that the entire asset value of the subindustries Independent Power Producers & Energy Traders and Industrial Gases would be wiped out (valuation shock of 100%, indicating completely stranded assets) in scenario I. The final two columns show that the corporate bond exposures to the 15 subindustries with the greatest valuation shock tend to be smaller than the equity exposures to these subindustries from Panel B of Table 7. The aggregate corporate

Table 9 – Estimated asset valuation shock by sector and subindustry for corporate bonds

This table shows, in Panel A, the estimated average asset valuation shocks in carbon tax scenarios I-IV for our analysis of the corporate bond portfolios of Dutch pension funds for all 11 GICS sectors (sorted from greatest to lowest asset valuation shock in Scenario I) and, in Panel B, for the 15 GICS subindustries with the greatest asset valuation shock in Scenario I (out of 162 subindustries in our sample). The shocks are calculated as the net present value losses relative to the total firm value, as described in equations (3) and (4). The scenarios, based on Reinders et al. (2023), vary in the implementation paths of the carbon tax (τ) and the extent to which firms can pass the tax burden on to consumers (φ). Scenarios I and III involve an overnight application of the tax, which then remains constant at €200 per tonne of CO2e. Scenarios II and IV, on the contrary, assume a gradual phase-in of the tax over 10 years, after which it stabilizes at €200 of tonne of CO2e. Scenarios I and II assume no pass-through of costs to consumers, whereas Scenarios III and IV assume that 50% of the carbon tax is passed through. The column "PF Sector %" shows the weight of the aggregate corporate bond portfolios of Dutch pension funds in each sector or subindustry. The column "Max PF %" shows the greatest weight in the corporate bond portfolio of an individual pension fund in each sector or subindustry. At the bottom of the table, the averages for subindustries not listed in Panel B are presented, along with the overall averages and medians for all firms in the dataset. The table is based on the sample of pension fund holdings that are matched with the firm-level carbon footprint and financial data (€83 billion for corporate bonds, see Figure 1).

Scenario:	I	II	III	IV	PF Sector %	Max PF %
Panel A: Sectors						
Utilities	0.36	0.27	0.23	0.15	*5.4%*	*67.3%*
Energy	0.36	0.23	0.20	0.12	*2.6%*	*17.4%*
Materials	0.34	0.25	0.23	0.16	*3.9%*	*13.6%*
Industrials	0.13	0.09	0.07	0.04	*7.5%*	*25.0%*
Consumer Staples	0.05	0.03	0.03	0.02	*6.3%*	*31.0%*
Not Collected	0.04	0.03	0.02	0.01	*0.1%*	*3.2%*
Consumer Discretionary	0.03	0.02	0.02	0.01	*7.4%*	*24.0%*
Health Care	0.01	0.01	0.00	0.00	*7.5%*	*15.8%*
Information Technology	0.01	0.00	0.00	0.00	*4.30%*	*18.7%*
Real Estate	0.01	0.00	0.00	0.00	*3.8%*	*11.3%*
Communication Services	0.00	0.00	0.00	0.00	*8.5%*	*24.8%*
Financials	0.00	0.00	0.00	0.00	*42.8%*	*100.0%*
Panel B: Subindustries						
Independent Power Prod. & Energy Traders	1.00	0.87	0.75	0.50	*0.2%*	*11.6%*
Industrial Gases	1.00	0.67	0.58	0.34	*0.1%*	*3.1%*
Passenger Airlines	0.88	0.58	0.50	0.30	*0.4%*	*2.8%*
Construction Materials	0.71	0.65	0.63	0.50	*0.1%*	*1.7%*
Marine Transportation	0.67	0.44	0.38	0.23	*0.0%*	*0.3%*
Steel	0.63	0.59	0.58	0.44	*0.1%*	*1.4%*
Oil & Gas Refining & Marketing	0.48	0.32	0.27	0.16	*0.2%*	*4.9%*
Diversified Chemicals	0.46	0.31	0.27	0.16	*0.4%*	*2.1%*
Oil & Gas Storage & Transportation	0.45	0.31	0.25	0.16	*0.2%*	*3.5%*
Aluminum	0.44	0.32	0.30	0.22	*0.2%*	*2.9%*
Commodity Chemicals	0.43	0.28	0.25	0.15	*0.1%*	*2.1%*
Agricultural Products & Services	0.42	0.28	0.23	0.14	*0.1%*	*1.9%*
Fertilizers & Agricultural Chemicals	0.39	0.35	0.34	0.24	*0.1%*	*0.8%*
Integrated Oil & Gas	0.38	0.24	0.21	0.12	*0.7%*	*7.5%*
Multi-Utilities	0.37	0.25	0.21	0.13	*1.1%*	*30.2%*
Average across other subindustries	0.04	0.03	0.02	0.01		
Average across all firms	0.07	0.05	0.04	0.03		
Median across all firms	0.00	0.00	0.00	0.00		

bond exposure of all pension funds to these 15 subindustries is at most 1.1% per industry, and the individual pension fund exposures are as high as 30.2% but usually considerably smaller.

Table 10 shows the estimated market value losses in the aggregate corporate bond portfolios of Dutch pension funds, stemming from the valuation shocks in Table 9. Table 10 is thus the corporate bonds equivalent of Table 8 for equities. Table 10 shows these corporate bond market value losses (in € billion) in each of the four scenarios and both for all 11 GICS sectors (in Panel A) and for the 15 GICS subindustries with the greatest corporate bond losses (in Panel B). The corporate bond market value losses (in € billion) in Table 10 are considerably smaller than the equity market value losses in Table 8. The difference is due to a combination of four reasons. First, the aggregate market value of the corporate bond portfolios in our final sample (€83 billion, see Figure 1) is much smaller than the aggregate market value of the equity portfolios in our sample (€394 billion).[9] Second, equity is by definition more vulnerable to financial shocks such as a carbon tax since equity holders, as residual claimants, take the first hit of any shock, while debt holders are only affected if the shock brings the firm closer to default. Third, the corporate bond exposures of Dutch pension funds to some of the subindustries with large valuation shocks in particular are smaller than the corresponding equity exposures. Fourth, some of the valuation shocks in Table 9 (corporate bonds sample) are smaller than the corresponding shocks in Table 7 (equities sample). The corporate bond market value losses for the sectors Utilities, Materials, Industrials, and Energy are considerable, ranging from €0.27 billion to €1.75 billion in scenario I, with somewhat smaller losses for the other scenarios. For the other sectors, the corporate bond market values are generally small. Of the 15 subindustries with the greatest corporate bond losses in Panel B of Table 10, only seven were also in the top 15 with the greatest equity losses (in Panel B of Table 8). This finding indicates a notable difference in the subindustries where Dutch pension funds are relatively more exposed to carbon transition risk in their equity and corporate bond portfolios, due to differences in estimated valuation shocks per subindustry and differences in equity and corporate bond exposures of pension funds to these subindustries. The subindustry that experiences the largest corporate bond loss, with €0.62 billion in scenario I, is Electric Utilities, same as for equities.

The aggregate corporate bond market value losses across all sectors and subindustries ranges from €0.57 billion in scenario IV to €3.52 billion in scenario I (see the bottom rows of Table 10), or from 0.7% to 4.2% of the aggregate market value of the corporate bond portfolios of Dutch pension funds (see Figure 5). Figure 6 shows that, even though corporate bond losses are smaller on average than equity losses, individual pension funds may still

9 The smaller aggregate corporate bond market value reflects the smaller portfolio size (€198 billion for corporate bonds vs. €492 billion for equities, see Figure 1) along with the lower coverage of corporate bonds in our sample (41.6% for corporate bonds vs. 80.1% for equities, see Figure 1).

Table 10 – Market value losses by sector and subindustry in the corporate bond portfolios of Dutch pension funds (in € billion)

This table shows, in Panel A, the total market value losses in the corporate bond portfolios of Dutch pension funds (in € billion) in carbon tax scenarios I-IV for all 11 GICS sectors (sorted from greatest to lowest corporate bond market value loss in Scenario I) and, in Panel B, for the 15 GICS subindustries with the greatest corporate bond market value loss in Scenario I (out of 162 subindustries in our sample). The bottom of the table shows the total market value loss in the corporate bond portfolios of Dutch pension funds for each scenario, as well as the average and median losses across all subindustries. The scenarios, based on Reinders et al. (2023), vary in the implementation paths of the carbon tax (τ) and the extent to which firms can pass the tax burden on to consumers (φ). Scenarios I and III involve an overnight application of the tax, which then remains constant at €200 per tonne of CO_2e. Scenarios II and IV, on the contrary, assume a gradual phase-in of the tax over 10 years, after which it stabilizes at €200 per tonne of CO_2e. Scenarios I and II assume no pass-through of costs to consumers, whereas Scenarios III and IV assume that 50% of the carbon tax is passed through. The table is based on the sample of pension fund holdings that are matched with the firm-level carbon footprint and financial data (€83 billion for corporate bonds, see Figure 1).

Scenario:	I	II	III	IV
Panel A: Sectors				
Utilities	1.75	0.87	0.59	0.39
Materials	0.77	0.38	0.31	0.16
Industrials	0.69	0.38	0.17	0.01
Energy	0.27	0.16	0.09	0.01
Consumer Staples	0.02	0.00	0.00	0.00
Consumer Discretionary	0.01	0.00	0.00	0.00
Real Estate	0.00	0.00	0.00	0.00
Communication Services	0.00	0.00	0.00	0.00
Health Care	0.00	0.00	0.00	0.00
Information Technology	0.00	0.00	0.00	0.00
Financials	0.00	0.00	0.00	0.00
Not Collected	0.00	0.00	0.00	0.00
Panel B: Subindustries				
Electric Utilities	0.62	0.46	0.33	0.17
Passenger Airlines	0.57	0.30	0.13	0.01
Independent Power Prod. & Energy Traders	0.44	0.21	0.16	0.20
Steel	0.21	0.05	0.05	0.02
Diversified Chemicals	0.14	0.08	0.08	0.01
Oil & Gas Storage & Transportation	0.14	0.11	0.07	0.01
Construction Materials	0.13	0.11	0.11	0.09
Industrial Gases	0.13	0.03	0.00	0.00
Metal, Glass & Plastic Containers	0.07	0.04	0.01	0.00
Oil & Gas Refining & Marketing	0.07	0.04	0.02	0.00
Environmental & Facility Services	0.06	0.01	0.00	0.00
Industrial Conglomerates	0.05	0.07	0.03	0.00
Fertilizers & Agricultural Chemicals	0.04	0.04	0.03	0.03
Oil & Gas Equipment & Services	0.03	0.00	0.00	0.00
Commodity Chemicals	0.03	0.02	0.01	0.00
Other subindustries	0.80	0.24	0.12	0.03
Total	3.52	1.80	1.17	0.57
Average of subindustry	0.04	0.02	0.01	0.01
Median of subindustry	0.00	0.00	0.00	0.00

Figure 5 – Total market value loss per scenario in the corporate bond portfolios of Dutch pension funds
This figure shows the total market value losses in the corporate bond portfolios of Dutch pension funds in carbon tax scenarios I-IV, in € billion as well as in percentage of the aggregate market value of the corporate bond portfolios. The table is based on the sample of pension fund holdings that are matched with the firm-level carbon footprint and financial data (€83 billion for corporate bonds, see Figure 1). The scenarios, based on Reinders et al. (2023), vary in the implementation paths of the carbon tax (τ) and the extent to which firms can pass the tax burden on to consumers (φ). Scenarios I and III involve an overnight application of the tax, which then remains constant at €200/tonne CO2e. Scenarios II and IV, on the contrary, assume a gradual phase-in of the tax over 10 years, after which it stabilizes at €200/tonne CO2e. Scenarios I and II assume no pass-through of costs to consumers, whereas Scenarios III and IV assume that 50% of the carbon tax is passed through.

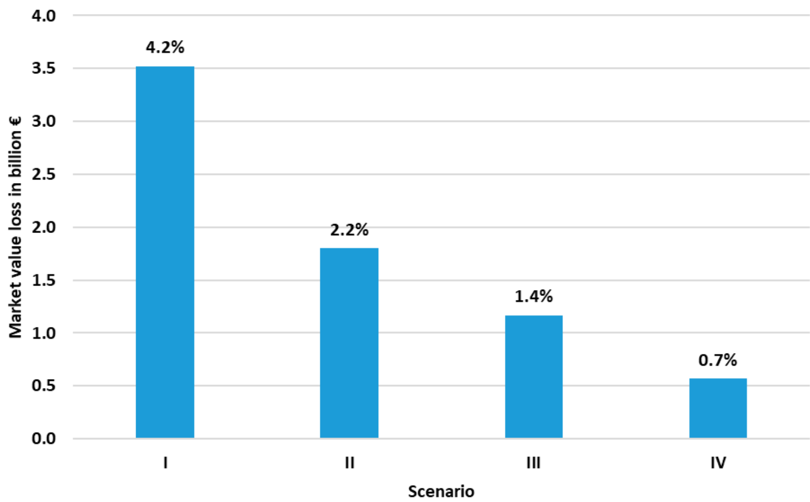
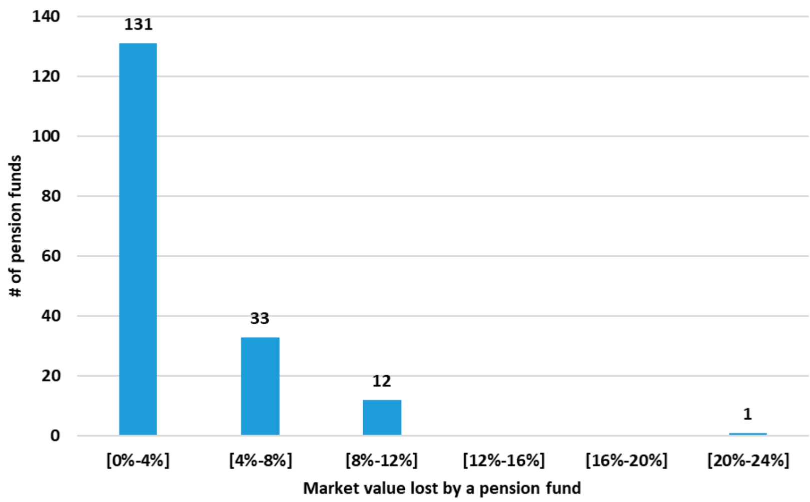


Figure 6 – Distribution of corporate bond market value loss in Scenario I across Dutch pension funds
This figure shows the distribution of the market value losses in the corporate bond portfolios across all Dutch pension funds in carbon tax scenario I. The x-axis represents the range of corporate bond market value losses for each pension fund, while the y-axis shows the number of pension funds within each loss range. The table is based on the sample of pension fund holdings that are matched with the firm-level carbon footprint and financial data (€83 billion for corporate bonds, see Figure 1). Scenario I assumes a €200 per tonne CO2e emissions carbon tax applied overnight and remaining constant thereafter, with no pass-through of costs to consumers.



face substantial losses in their corporate bond portfolios. The vast majority (131 out of 177) of the pension funds in our sample that have corporate bond portfolios would face a loss of less than 4% in their corporate bond portfolios in scenario I, but twelve funds would face a loss of 8% to 12%, with one pension fund facing a loss of no less than 20% to 24%.

3.4 Sensitivity analyses

Our results on the estimated equity and corporate bond losses experienced by Dutch pension funds in the various carbon tax scenarios, as presented in Sections 3.2 and 3.3, may be sensitive to some key assumptions that we make in our analysis. In Table 11, we investigate the sensitivity of our results to five variations in our analysis: the level of the carbon tax (τ) in Panel A; the interest rate assumption in Panel B; the time-to-maturity of debt for the underlying firms in Panel C; the abatement potential in Panel D; and the scope of the carbon tax (Scope 1 emissions vs. Scope 1 + Scope 2 emissions) in Panel E. For each sensitivity analysis, Table 11 shows the aggregate market value losses in the equity and corporate bond portfolios of Dutch pension funds in scenarios I through IV (both in € billions and as a % of portfolio market value). In each panel, the first lines repeat the "main estimate" of these aggregate market value losses based on the baseline scenarios and assumptions (from Tables 8 and 10). To get a sense of the variation in the market value loss estimates across individual pension funds, each panel also shows the largest loss experienced by a single pension fund per asset class and scenario. To get a sense for how much Dutch pension funds deviate from a popular global equity benchmark in terms of their exposure to carbon transition risk, each panel also shows the equity loss for a hypothetical pension fund holding exactly the MSCI ACWI.

In Panel A of Table 11, we compare the aggregate equity corporate bond market value losses in our baseline scenarios with a €200/tonne carbon tax with similar scenarios but then with either a €100/tonne or a €400/tonne carbon tax. The resulting market value losses in the alternative scenarios cannot be directly inferred from the baseline results, since both the equity and the corporate bond market value losses are a non-linear function of the asset valuation shocks. The main finding here is that the aggregate market value losses in the €400/tonne carbon tax scenarios (which may not be unrealistic given the $45-$1000 per tonne carbon tax needed in 2050 according to Stiglitz et al., 2017 and IPCC, 2018) can amount up to 9.1% for equities (21.9% for a single pension fund) and up to 7.4% (36.5% for a single fund) for corporate bonds, considerable greater than the baseline market loss estimates reported in Tables 8 and 10. Panel A of Table 11 also shows how much lower the market value losses are in a scenario of a €100/tonne carbon tax, relative to the baseline (for example, equity losses in scenario I then amount to 3.3% in scenario I).

We note that there are two main reasons why the results in Table 11 are non-linear in the sense that the aggregate market value losses in the €400/tonne carbon tax scenarios

Table 11 – Sensitivity analysis

This table shows the aggregate market value losses in the equity and corporate bond portfolios of Dutch pension funds in carbon tax scenarios I-IV when we vary the assumptions underlying our climate stress test based on the carbon tax scenarios. In Panel A, we vary the level of the carbon tax (τ), considering levels of €100, €200, and €400 per tonne. In Panel B, we vary the interest rate assumption, considering levels of 2.00%, 2.75%, and 3.50%. In Panel C, we vary the assumption on the time-to-maturity of debt for the underlying firms, considering levels of 5 years, 6.6 years, and 7.5 years. In Panel D, we vary the abatement potential, considering levels of 10-20% and 20-40% (by scaling the allocation of abatement potential as outlined in Section 2.2 by a factor of two). In Panel E, we vary the scope of the carbon tax, not only based on Scope 1 CO_2e emissions but also on the sum of Scope 1 and Scope 2 CO_2e emissions. For reference purposes, the first lines of each panel show the "main estimate" of the market value losses based on the baseline scenarios and assumptions, taken from Tables 8 and 10. For each sensitivity analysis, the table not only reports the total market value loss in the equity and corporate bond portfolios of Dutch pension funds (in € billion), but also the percentage loss relative to the aggregate market value of these portfolios. Additionally, the table shows the largest market value loss experienced by a single pension fund for both asset classes across all four scenarios. Furthermore, for comparison, the impact on a portfolio following the MSCI ACWI allocation is also reported for each scenario. The scenarios, based on Reinders et al. (2023), vary in terms of the implementation paths of the carbon tax (τ) and the extent to which firms can pass the tax burden on to consumers (φ). Scenarios I and III involve an overnight application of the tax, which then remains constant at €200 per tonne of CO_2e. Scenarios II and IV, on the contrary, assume a gradual phase-in of the tax over 10 years, after which it stabilizes at €200 per tonne of CO_2e. Scenarios I and II assume no pass-through of costs to consumers, whereas Scenarios III and IV assume that 50% of the carbon tax is passed through. The table is based on the sample of pension fund holdings that are matched with the firm-level carbon footprint and financial data (€394 billion for equity and €83 billion for corporate bonds, see Figure 1).

Scenario:		I	II	III	IV
Panel A: Carbon tax sensitivity analyses					
A.1 – €200 / tonne carbon tax (main estimate)					
Market value loss equities	€	22.5	16.2	14.2	9.1
as % of total market value equities	%	5.7%	4.1%	3.6%	2.3%
Largest loss single pension fund equities	%	16.5%	13.2%	11.8%	8.0%
Loss of MSCI ACWI	%	7.3%	5.5%	4.9%	3.4%
Market value loss corporate bonds	€	3.5	1.8	1.2	0.6
as % of total market value corporate bonds	%	4.2%	2.2%	1.4%	0.7%
Largest loss single pension fund corporate bonds	%	23.7%	12.1%	8.7%	0.8%
A.2 – €100 / tonne carbon tax					
Market value loss equities	€	13.1	8.9	7.7	4.7
as % of total market value equities	%	3.3%	2.3%	1.9%	1.2%
Largest loss single pension fund equities	%	11.1%	7.9%	6.5%	4.1%
Loss of MSCI ACWI	%	4.6%	3.3%	2.9%	1.9%
Market value loss corporate bonds	€	0.9	0.6	0.4	0.1
as % of total market value corporate bonds	%	1.1%	0.7%	0.5%	0.1%
Largest loss single pension fund corporate bonds	%	12.5%	7.7%	1.2%	0.1%
A.3 – €400 / tonne carbon tax					
Market value loss equities	€	35.7	26.9	24.1	16.4
as % of total market value equities	%	9.1%	6.8%	6.1%	4.2%
Largest loss single pension fund equities	%	21.9%	18.7%	17.3%	13.4%
Loss of MSCI ACWI	%	11.0%	8.6%	7.8%	5.5%
Market value loss corporate bonds	€	6.1	3.7	3.5	1.9
as % of total market value corporate bonds	%	7.4%	4.4%	4.2%	2.3%
Largest loss single pension fund corporate bonds	%	36.5%	22.0%	18.2%	8.8%

Scenario:		I	II	III	IV
Panel B: Interest rate sensitivity analyses					
B.1 – Interest rate 2.75% (main estimate)					
Market value loss equities	€	22.5	16.2	14.2	9.1
as % of total market value equities	%	5.7%	4.1%	3.6%	2.3%
Largest loss single pension fund equities	%	16.5%	13.2%	11.8%	8.0%
Loss of MSCI ACWI	%	7.3%	5.5%	4.9%	3.4%
Market value loss corporate bonds	€	3.5	1.8	1.2	0.6
as % of total market value corporate bonds	%	4.2%	2.2%	1.4%	0.7%
Largest loss single pension fund corporate bonds	%	23.7%	12.1%	8.7%	0.8%
B.2 – Interest rate 2.00%					
Market value loss equities	€	22.8	16.4	14.4	9.2
as % of total market value equities	%	5.8%	4.2%	3.7%	2.3%
Largest loss single pension fund equities	%	16.7%	13.4%	11.9%	8.2%
Loss of MSCI ACWI	%	7.4%	5.5%	5.0%	3.4%
Market value loss corporate bonds	€	3.6	2.0	1.3	0.6
as % of total market value corporate bonds	%	4.2%	2.4%	1.6%	0.7%
Largest loss single pension fund corporate bonds	%	23.7%	12.2%	9.0%	1.2%
B.3 – Interest rate 3.50%					
Market value loss equities	€	22.3	16.0	14.0	8.9
as % of total market value equities	%	5.7%	4.0%	3.5%	2.2%
Largest loss single pension fund equities	%	16.4%	13.1%	11.6%	7.9%
Loss of MSCI ACWI	%	7.3%	5.4%	4.9%	3.3%
Market value loss corporate bonds	€	3.5	1.6	1.1	0.5
as % of total market value corporate bonds	%	4.2%	2.0%	1.3%	0.5%
Largest loss single pension fund corporate bonds	%	23.5%	11.9%	8.5%	0.5%
Panel C: Time-to-maturity sensitivity analyses					
C.1 – T2M 6.6 years (main estimate)					
Market value loss equities	€	22.5	16.2	14.2	9.1
as % of total market value equities	%	5.7%	4.1%	3.6%	2.3%
Largest loss single pension fund equities	%	16.5%	13.2%	11.8%	80%
Loss of MSCI ACWI	%	7.3%	5.5%	4.9%	3.4%
Market value loss corporate bonds	€	3.5	1.8	1.2	0.6
as % of total market value corporate bonds	%	4.2%	2.2%	1.4%	0.7%
Largest loss single pension fund corporate bonds	%	23.7%	12.1%	8.7%	0.8%
C.2 – T2M 5.0 years					
Market value loss equities	€	22.9	16.5	14.5	9.3
as % of total market value equities	%	5.8%	4.2%	3.7%	2.3%
Largest loss single pension fund equities	%	16.7%	13.5%	12.0%	8.2%
Loss of MSCI ACWI	%	7.4%	5.6%	5.0%	3.4%
Market value loss corporate bonds	€	3.5	1.9	1.2	0.6
as % of total market value corporate bonds	%	4.3%	2.2%	1.4%	0.7%
Largest loss single pension fund corporate bonds	%	24.0%	12.2%	8.9%	0.9%
C.3 – T2M 7.5 years					
Market value loss equities	€	22.4	16.1	14.1	9.0
as % of total market value equities	%	5.7%	4.1%	3.6%	2.3%
Largest loss single pension fund equities	%	16.4%	13.2%	11.7%	7.9%
Loss of MSCI ACWI	%	7.3%	5.4%	4.9%	3.3%
Market value loss corporate bonds	€	3.5	1.8	1.2	0.6
as % of total market value corporate bonds	%	4.2%	2.1%	1.4%	0.7%
Largest loss single pension fund corporate bonds	%	23.5%	12.0%	8.5%	0.5%

Scenario:		I	II	III	IV
Panel D: Abatement sensitivity analyses					
D.1 – Abatement 10%-20% (main estimate)					
Market value loss equities	€	22.5	16.2	14.2	9.1
as % of total market value equities	%	5.7%	4.1%	3.6%	2.3%
Largest loss single pension fund equities	%	16.5%	13.2%	11.8%	8.0%
Loss of MSCI ACWI	%	7.3%	5.5%	4.9%	3.4%
Market value loss corporate bonds	€	3.5	1.8	1.2	0.6
as % of total market value corporate bonds	%	4.2%	2.2%	1.4%	0.7%
Largest loss single pension fund corporate bonds	%	23.7%	12.1%	8.7%	0.8%
D.2 – Abatement 20%-40%					
Market value loss equities	€	20.1	13.9	12.6	7.6
as % of total market value equities	%	5.1%	3.5%	3.2%	1.9%
Largest loss single pension fund equities	%	15.3%	11.9%	10.7%	6.9%
Loss of MSCI ACWI	%	6.7%	4.9%	4.5%	2.9%
Market value loss corporate bonds	€	3.1	1.2	0.8	0.4
as % of total market value corporate bonds	%	3.7%	1.4%	1.0%	0.4%
Largest loss single pension fund corporate bonds	%	11.9%	2.6%	1.5%	0.2%
Panel E: Scope 1 + Scope 2 carbon tax analyses					
E.1 – Scope 1 carbon tax (main estimate)					
Market value loss equities	€	22.5	16.2	14.2	9.1
as % of total market value equities	%	5.7%	4.1%	3.6%	2.3%
Largest loss single pension fund equities	%	16.5%	13.2%	11.8%	8.0%
Loss of MSCI ACWI	%	7.3%	5.5%	4.9%	3.4%
Market value loss corporate bonds	€	3.5	1.8	1.2	0.6
as % of total market value corporate bonds	%	4.2%	2.2%	1.4%	0.7%
Largest loss single pension fund corporate bonds	%	23.7%	12.1%	8.7%	0.8%
E.2 – Scope 1 + Scope 2 carbon tax					
Market value loss equities	€	32.7	23.2	20.4	12.8
as % of total market value equities	%	8.3%	5.9%	5.2%	3.3%
Largest loss single pension fund equities	%	18.8%	15.0%	13.3%	0.09%
Loss of MSCI ACWI	%	9.5%	7.0%	6.3%	4.2%
Market value loss corporate bonds	€	3.8	2.4	1.6	0.7
as % of total market value corporate bonds	%	4.6%	2.9%	1.9%	0.8%
Largest loss single pension fund corporate bonds	%	23.9%	12.2%	8.8%	0.9%

(e.g., 9.1% for equities in scenario I) are not double losses in the €200/tonne carbon tax scenario (5.7% for equities in scenario I). The Merton model is inherently non-linear, as the relation between a company's equity value and its asset value is modeled as a call option on a geometric Brownian motion, which naturally produces a non-linear payoff structure. In practice, the model determines default probabilities by jointly solving two non-linear equations for the unobservable asset value and asset volatility, which are linked through the observable equity volatility. As a result, even if the total valuation shock (ζ_i, see formula (3)) doubles exactly, the eventual impact on market values does not scale linearly. In addition, some extreme case firms are already fully bankrupt at the €200 tax level since their total asset value shock, ζ_i in formula (3), reaches 1, meaning their asset value is completely eroded. Increasing the tax to €400 therefore does not produce further losses for those firms. While this effect does not apply to most companies, it contributes also to the observed non-linearity.

Panel A of Table 11 also shows that the carbon transition risk exposure of the average Dutch pension fund is below the exposure of the MSCI ACWI index. For example, in the baseline €200/tonne carbon tax scenario, the average equity loss is 5.7% for Dutch pension funds versus 7.3% for the MSCI ACWI. This difference is non-negligible, but also not dramatic. Similar differences apply for the other scenarios analyzed in Table 11.

In Panel B of Table 11, we examine what happens when we change our interest rate assumption from 2.75% to either 2.0% or 3.5%. The findings in this panel indicate that our baseline equity and corporate bond market value loss estimates are not very sensitive to this assumption. Similarly, Panel C shows little sensitivity of our baseline results to changing our assumption regarding the average time-to-maturity of debt for the underlying firms in our sample from the baseline assumption of 6.6 years to either a maturity of 5 years or of 7.5 years.

In Panel D of Table 11, we examine how our market value loss estimates change when we allow for the possibility that firms have a greater potential to abate their carbon emissions than in our baseline scenarios. In this sensitivity test, we double the abatement potential from 10-20% in our baseline scenarios to 20-40% of total emissions, where the abatement pathways of individual firms are again established as discussed in Section 2.1. Not surprisingly, estimated market value losses for equities and corporate bonds are smaller when we assume more abatement potential, but the differences are relatively small. For example, the aggregate equity (corporate bond) market value losses in scenario I decrease from 5.7% (4.2%) in our baseline analysis to 5.1% (3.7%) with the greater abatement potential. This finding suggests that we would need to assume a much higher (and arguably unrealistic) abatement potential to materially reduce our assessment of the carbon transition risk in the equity and corporate bond portfolios of Dutch pension funds.

In Panel E of Table 11, we consider the possibility that a carbon tax could be applied to both Scope 1 and Scope 2 carbon emissions. To this end, we rerun our carbon stress test where we apply the €200/tonne carbon tax to the sum of Scope 1 and Scope 2 GHG emissions of each firm. This analysis is a bit crude in the sense that there is some double counting in such an approach: for example, the emissions associated with electricity production show up as Scope 1 emissions for the electricity producer and as Scope 2 emissions for its corporate customers. A more sophisticated application of a Scope 1+2 carbon tax would likely account for this double counting in practice; hence our equity and corporate bond market value loss estimates may be overstated somewhat - which is why we did not include Scope 2 emissions in our main analyses. Another way of saying this is that the estimates presented in Panel E of Table 11 reflect the more sophisticated application of a carbon tax that slightly exceeds €200 per tonne. A brief summary of the results in Panel E is that including Scope 2 emissions in the carbon tax scenarios increases the market value loss estimates considerably, and more so for equities than for corporate bonds. To illustrate, the aggregate market value losses for equity in scenario I increase from 5.7 in our baseline analysis to 8.3% (and for corporate bonds from 4.2% to 4.6%) in the scenarios in which the tax applies to both Scope 1 and Scope 2 emissions.

All in all, Table 11 indicates that the results of our climate stress test of Dutch pension funds are not critically dependent on our assumptions on interest rate, debt maturity, and abatement potential. But raising the carbon tax from €200 per tonne to €400 per tonne, or including Scope 2 emissions in the carbon tax, does substantially increase our estimates of the vulnerability of, in particular, the equity portfolios of pension funds to carbon tax scenarios.

4. Conclusions

In this paper, we present a climate stress test that focuses on carbon transition risk in the equity and corporate bond portfolios of all 180 Dutch pension funds, using data on their individual security holdings and on the carbon emissions and financial data of the underlying firms as of 2022Q4. We specify four baseline scenarios with a €200 per tonne Scope 1 CO_2e emissions carbon tax. These vary in the timing of the tax (abrupt or phased) as well as in the degree to which firms can pass-through the tax to their customers. We follow the approach of Reinders et al. (2023) to estimate the valuation shock for individual firms, based on the net present value of their annual carbon tax payments under each scenario, and to translate these firm-level valuation shocks to estimated market value losses for equity and debt using the Merton (1974) model. We then aggregate security-level losses to the pension fund level using security-specific data on the equity and corporate bond holdings of each pension fund.

We first provide an extensive overview of the allocation of the portfolios of Dutch pension funds to different asset classes, different GICS sectors, different GICS subindustries, different countries, and different categories of firms, based on the ambition of their climate reduction targets. This overview indicates that the exposure of Dutch pension funds to the three GICS sectors with by far the largest carbon emissions (Utilities, Materials, and Energy) is relatively limited overall, at around 9% for equities and 7.5% for corporate bonds. The equity exposure to these three sectors is close to the exposure of the MSCI All Country World Index (MSCI ACWI, a global equity benchmark widely used by pension funds) to these sectors. However, within these sectors, Dutch pension funds have notably lower exposure to firms with the greatest CO_2 emissions compared to the MSCI ACWI. While that is the case, around 50% of the equity and corporate bond portfolios of Dutch pension funds are invested in firms with relatively unambitious climate reduction targets.

The stress test indicates that the baseline carbon tax scenarios can result in substantial equity losses for the Dutch pension sector as a whole, of up to €22.5 billion (or 5.7% of total equity market value) and up to €35.7 billion (9.1%) in more severe scenarios that involve a carbon tax of €400 per tonne. For individual pension funds, equity losses can reach 16.5% of equity market value and 21.9% in the more severe scenarios. The aggregate losses to the corporate bond portfolios are smaller, up to 4.2% (with a maximum loss for an individual fund of 23.7%) in the baseline scenarios and up to 7.4% (with a maximum loss of 36.5%) in the more severe scenarios.

Taken together, the results of our stress test indicate that the Dutch pension sector as a whole exhibits non-negligible – though perhaps not dramatic – exposure to carbon transition risk, especially in its equity portfolios. For some individual pension funds, the vulnerability of their equity portfolios to carbon tax scenarios is particularly large. Our analysis provides pointers as to which sectors and subindustries contribute most to these overall levels of carbon transition risk, and thus suggests avenues for reducing such risks should pension funds desire to do so. Future research could shed more light on other climate-related risks in the investment portfolios of Dutch pension funds.

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