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Climate transition risk stress test for the German financial system

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Ivan Frankovic
Tobias Etzel
Alexander Falter
Christian Gross
Jana Ohls
Lena Strobel
Hannes Wilke

Deutsche Bundesbank, Wilhelm-Epstein-Straße 14, 60431 Frankfurt am Main,
Postfach 10 06 02, 60006 Frankfurt am Main

Tel +49 69 9566-0

Please address all orders in writing to: Deutsche Bundesbank,
Press and Public Relations Division, at the above address or via fax +49 69 9566-3077

Internet http://www.bundesbank.de

Non-technical summary

This documents presents the methodology of the Deutsche Bundesbank's climate transition stress test for the German financial system, which was published as part of the Financial Stability Report 2023. The aim of the analysis is to assess potential vulnerabilities related to transition risks for German financial intermediaries and the financial system as a whole.

The analysis includes several steps. The starting point is given by transition scenarios which describe potential co-developments of climate policies (carbon taxes in our case), the economy and climate change. In particular, we study one scenario in which the world as a whole gradually transitions to a net zero emission economy by 2050. A second scenario assumes a large carbon tax hike in the short-run. In the next step we translate the scenario paths of macroeconomic variables into valuation impacts for the assets held by German financial intermediaries. This includes impacts on corporate loans, bonds and equities. Where relevant data is available we consider firm-level information, such as carbon emissions, in order to calculate the scenario impacts on the asset level. Finally, we determine the impact of the scenarios on the balance sheets of German banks, funds and insurers. In doing so, we also investigate how these losses are distributed across different financial institutions.

The analysis is an update of the climate risk sensitivity analysis of the German financial system performed in Bundesbank’s Financial Stability Report 2021. The updated methodology allows for a more robust assessment of overall vulnerabilities. This follows in particular from the consideration of multiple, very distinct climate scenarios and the inclusion of firm-level data.

Nichttechnische Zusammenfassung

Dieses Dokument stellt die Methodik des transitorischen Klimarisiko-Stresstests für das deutsche Finanzsystem der Deutschen Bundesbank vor. Ergebnisse dieser Analyse wurden als Teil des Finanzstabilitätsberichts 2023 veröffentlicht. Ziel der Analyse ist es, potenzielle Schwachstellen im Zusammenhang mit Transformationsrisiken für deutsche Finanzintermediäre und das Finanzsystem als Ganzes zu bewerten.

Die Analyse umfasst mehrere Schritte. Den Ausgangspunkt bilden Transitionsszenarien, die mögliche gemeinsame Entwicklungen von Klimapolitik (in unserem Fall CO_2-Steuern), Wirtschaft und Klimawandel beschreiben. Insbesondere untersuchen wir ein Szenario, in dem die Welt als Ganzes bis 2050 schrittweise zu einer emissionsfreien Wirtschaft übergeht. Ein zweites Szenario geht von einer kurzfristigen und starken Erhöhung der CO_2-Steuer aus. Im nächsten Schritt übersetzen wir die Szenariopfade der makroökonomischen Variablen in Bewertungseffekte für die von deutschen Finanzintermediären gehaltenen Vermögenswerte. Dies umfasst Auswirkungen auf Unternehmenskredite, Anleihen und Aktien. Wo Daten zur Verfügung stehen, berücksichtigen wir Informationen auf Unternehmensebene, wie z.B. Kohlenstoffemissionen, um die Auswirkungen der Szenarien auf Ebene der Vermögenswerte zu berechnen. Schließlich ermitteln wir die Auswirkungen der Szenarien auf die Bilanzen deutscher Banken, Fonds und Versicherer. Dabei untersuchen wir auch, wie sich diese Verluste auf die verschiedenen Finanzinstitute verteilen.

Die Analyse ist eine Aktualisierung der Klimarisiko-Sensitivitätsanalyse für das deutsche Finanzsystem, die im Rahmen des Bundesbank Finanzstabilitätsberichts 2021 veröffentlicht wurde. Die aktualisierte Methodik ermöglicht eine robustere Bewertung der Gesamtanfälligkeit. Dies ergibt sich insbesondere aus der Berücksichtigung mehrerer, sehr unterschiedlicher Klimaszenarien und der Einbeziehung von Daten auf Unternehmensebene.

Climate transition risk stress test for the German financial system

Ivan Frankovic, Tobias Etzel, Alexander Falter, Christian Gross,

Jana Ohls, Lena Strobel, Hannes Wilke[1]

Abstract

This paper presents the methodology applied in the Deutsche Bundesbank's climate transition stress test for the German financial system, see Deutsche Bundesbank (2023). It discusses the construction of the transition scenarios underlying the analysis, including a long-run orderly scenario and a more disruptive short-term carbon price shock. Furthermore, the document shows the methodology for translating scenario impacts onto the asset level, which includes the consideration of firm-level carbon emission data where available. Finally, the impacts on the balance sheets of German banks, funds and insurers are discussed.

Keywords: climate risks, stress testing, climate scenarios, financial stability

JEL classification: G2, H23, Q5

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[1] The opinions expressed in this article are those of the authors and do not necessarily represent the opinions of the Bundesbank or of the Eurosystem. All authors belong to the Bundesbank, Directorate General Financial Stability. The authors would like to thank their Bundesbank colleague Michael Kleemann for supplying methodological inputs.

1. Introduction

This document introduces the methodology applied in the Deutsche Bundesbank's climate transition stress test for the German financial system as presented in the Financial Stability Report, see Deutsche Bundesbank (2023). The aim of the analysis is to identify potential vulnerabilities of the German financial system to transition risks arising from increases in carbon prices.

The methodology presented here is an extension of the carbon price sensitivity analysis performed in the Financial Stability Report from 2021, see Deutsche Bundesbank (2021) and Schober et al. (2021). The general procedure of the current analysis is similar to the previous one: The starting point is given by transition scenarios, which describe the co-evolution of climate policy variables, the economy and the climate. Since transition scenarios are only available at a highly aggregated level, we employ various economic models to downscale the economic impacts of the transition scenario on the asset level. A sectoral model is used to distribute the country-level macroeconomic stress caused by transition policies onto the sectoral level, while financial risk models are used to estimate the impact on individual corporate loans, bonds and equities. Finally, to derive scenario dependent losses in the financial system, the asset-level impacts are applied to current balance sheets of German banks, funds and insurers.

Compared to the previous analysis, the method presented here features a number of methodological extensions. The main goal of the extension is to reduce the uncertainty around our main results and allow for a more comprehensive evaluation of the vulnerability of the German financial system to transition risk. The first extension relates to the transition scenarios. In addition to the long-run orderly transition scenario "Net Zero 2050" developed by the Network for Greening the Financial System (NGFS), we also consider a short-term transition stress scenario. The latter originates from a newly developed macroeconomic model and features a more realistic depiction of the short-run interaction between the real and financial economy. It describes a transition shock in which carbon prices do not gradually increase but jump immediately to a higher level. By considering two very distinct scenarios the analysis allows for a more robust assessment to transition risk. The second extension relative to the previous exercise is the inclusion of firm-level data in the analysis. While previously only sector-level heterogeneity from climate policies was considered, the updated methodology accounts for firm-individual emissions and other data where available. Therefore, the analysis is able to test for potential vulnerabilities arising from the concentration of financial intermediaries' exposures to particularly affected firms. Finally, we consider both, the vulnerability and the resilience of the German financial system to assess the potential impact of transition risk on the stability of the financial system.

In this document we present the methodology employed for the analysis in Deutsche Bundesbank (2023). The interpretation of the results and conclusions are, however, only discussed in Deutsche Bundesbank (2023). The structure of the document is as follows. Section 2 introduces the two transition scenarios underlying the analysis. Section 3 discusses the derivation of asset-level effects of the scenarios, while section 4 presents the balance sheet effects for financial intermediaries from the scenarios. Section 5 concludes with a short summary.

2. Transition scenarios

In this section, we present the scenarios underlying our analysis. The scenarios describe pathways of transitioning to a low-carbon economy, where this transition is triggered by an introduction of carbon pricing. We distinguish between two transition scenarios. The first case is given by the *Net Zero 2050* scenario developed by the Network for Greening the Financial System (NGFS).[2] This scenario is characterized by an orderly, global transition to net zero emissions by the year 2050. This outcome, consistent with the 1.5°C goal enacted in the Paris Agreement of 2015, is achieved by a global carbon price, which gradually increases from very modest to very high levels over the course of the century.

The second scenario is characterized, instead, by a sudden jump in carbon prices. We thus refer to it as the *short-term scenario*. It describes a situation in which policy makers are forced to implement a sudden reduction in emissions. Such a sudden and severe political action could follow elections or a climate change-related catastrophe that triggers a sudden reassessment of the urgency of climate policy action. Specifically, we assume that carbon prices in the euro area increase by 200 Euro/ton within one quarter. An increase of this magnitude is only achieved over 5 years in the aforementioned *Net Zero 2050* scenario. The carbon price hike leads to a reduction of carbon emissions by 40% in the euro area (given our calibration discussed below). For the rest of the world we instead assume that carbon prices evolve as is the case in the *Net Zero 2050* scenario. The horizon of this scenario is limited to only a few years. At longer horizons (>5 years) the model cannot be used adequately due to technological adaptation and other channels not modelled in the short-term oriented model.

The consideration of these two greatly differing scenarios allows us to assess more robustly the range of possible implications of carbon pricing for financial stability. The *Net Zero 2050* scenario informs us about the implications of long-term climate actions for the present, whereas the *short-term scenario* generates insights regarding the potential for immediate policy shifts to endanger financial stability.

Moreover, it is not the aim of our analysis to assess how likely various scenarios are. Such an assessment would be impossible to conduct given the large uncertainties in the future path of climate policy choices. However, since we are interested in potential risks for financial stability, we have a preference for scenarios with larger macro-economic impacts. For example, rather than considering NGFS' "Below 2° scenario" or "Nationally determined contributions", which feature more modest increases in carbon prices, we use the more ambitious *Net Zero 2050* scenario to study a transition that imposes higher transition costs. Similarly, the architecture of the short-term scenario, as will become clear further below, is built to reflect a very adverse development. Our choice of scenarios is, thus, not driven by their likelihood but by their degree of severity. In the following two subsections the scenarios will be discussed in greater detail.

[2] There exist several vintages of the NGFS scenarios. We use the most recent one released in late 2022.

2.1 The Net Zero 2050 scenario

Generating Models

The *Net Zero 2050* scenario by the NGFS has been derived by means of Integrated Assessment Models (IAMs). IAMs combine models from various disciplines, including models of the economy, the energy sector as well as the climate system. The models require a number of background assumptions, the most important being trends in GDP and population growth and the availability and cost of various energy technologies. Given these assumptions, the models generate mappings from a given climate policy path to a climate outcome, or vice versa, from a given climate goal to the necessary, cost-efficient and welfare-maximizing climate policy path consistent with this goal. The *Net Zero 2050* scenario falls into the second category, as it describes an efficient global transition in line with the Paris Agreement goal of limiting global warming to 1.5°C relative to pre-industrial levels.

The NGFS uses three different IAMs, all of which contributed to the scenario database by the IPCC (Intergovernmental Panel on Climate Change). Since the IAMs differ in terms of their assumptions and setup of equations, the scenarios of the same narrative feature different variable pathways. For example, a more pessimistic assumption about the cost of renewable energies will imply a higher required carbon price given the same climate goal. From the suite of models employed in the NGFS, we have chosen to select the IAM featuring the highest global carbon price and, thus, the most adverse impacts on GDP (particularly in shorter horizons). This is the case for the MESSAGE-GLOBIOM IAM.

The exclusive use of IAMs is not sufficient for climate risk analysis at central banks as IAMs typically do not cover detailed variables relating to the real and financial economy. For this reason, the NGFS couples the IAM projections with another model that focuses on these variables: the National Institute Global Econometric Model (NiGEM). NiGEM is a macro-econometric model of the global economy and depicts 60 regions. The model covers macroeconomic and financial variables, including those relating to national accounts, trade, the public sector and prices, interest rates and other financial market variables (see Hantzsche et al. (2018) for details). The NGFS combines the IAMs and NiGEM by a top-down link, implying that NiGEM is calibrated in such a way to replicate for each scenario the economic variables that IAMs cover as well: Carbon prices, GDP, energy use and investment. In the process, values for all other macroeconomic and financial variables from NiGEM are obtained for each scenario. Further details on the linking can be found in Schober et al. (2021) and NGFS (2022b).

Narrative & Assumptions

The NGFS *Net Zero 2050* scenario describes an orderly transition to a global CO2-neutral economy by 2050, ultimately achieving a limitation of global warming to 1.5°C by 2100. The transition driver is an immediate but smooth increase in the carbon price.[3] Technological change is assumed to occur at high pace (relative to other NGFS scenarios). The scenario allows for a medium to high use of carbon dioxide removal technology such that about 5-15% of emission reductions are covered through such technologies. Carbon pricing is assumed to be uniform across different economic activities (i.e. a

[3] Carbon prices increase at different speeds across regions initially but later gradually converge to a single global price.

homogenous price across sectors) and to differ only marginally across regions. Further details on the narrative and technical assumptions of the scenarios can be found in NGFS (2022a) and NGFS (2022b).

Overall, the *Net Zero 2050* scenario thus features plausible but relatively benign background assumptions. The costs of transitioning can be larger if technological obstacles are larger, if removal technologies do not become available at the assumed cost and if carbon prices vary more significantly across countries and economic activities.

The NGFS scenarios provide a decomposition of full scenario impacts into those caused by transition policies and those caused by the physical impacts of climate change. We only use the impact caused by transition policies in the following. The reason is that our focus is not the cost-benefit analysis of transition policies.[4] Instead, the purpose of the analysis is to assess whether the German financial system is resilient enough to shoulder the costs induced by the transition. In doing so, we compare the outcomes of the transition scenario relative to a baseline scenario in which no transition occurs, relying on the NGFS *Current Policies* scenario without physical impacts.

Selected variables

Figure 2.1 plots the evolution of carbon prices, CO2 emissions, GDP and equity prices for the *Net Zero 2050* scenario, for the regions EU, Germany and World (transition impacts only). In the *Net Zero 2050* scenario, the *carbon price* rises to approximately 250 Euro / ton (constant 2022 euros) by 2025, with a slightly lower growth rate in the following years, reaching about 750 Euro / ton by mid-century. The carbon price is assumed to evolve uniformly across world regions and sectors.

Emissions fall in response to the rising carbon prices as seen in the second graph of Figure 2.1. Note that the evolution of emissions prior to the increase in carbon prices (2010-2022) is plotted as well. Halving emission levels is reached around 2030, with net zero being reached approximately in 2050.

The transition induced by the rising carbon prices has a negative impact on GDP. The costs to economic output vary across regions. The peak costs for Germany are at around 2-2.5% of real GDP by 2026. The peak impact for the EU as a whole is reached around 2030 at similar levels. The World is affected more strongly with a peak loss of close to 4% of economic output in 2028. The different levels of GDP impacts across regions reflect the varying degrees of emission-intensity in production.

Equity prices are also affected by the transition. They reflect at each point in time the discounted value of future profits (i.e. capital income) accruing in the private sector of the respective region. The impact on asset prices is strongest in the very first years of the transition. The carbon price path change from the baseline to the *Net Zero 2050* scenario is unannounced and thus leads to a sudden revaluation of the existing capital stock as more emission-intensive production methods become less profitable. The losses in equity prices due to carbon prices amount to 14% and 16% in Germany and the EU as a whole. The world impact is not provided in the NGFS scenarios.[5]

[4] Generally, such cost-benefit analysis points to orderly transitions being very cost-effective in the medium- to long-run, both globally and for Germany. This is because the cost of reducing emissions is outweighed by the benefit of avoiding future climate damages.

[5] The equity price impacts on the US, China and Japan amount to 15%, 10% and 23%, respectively.

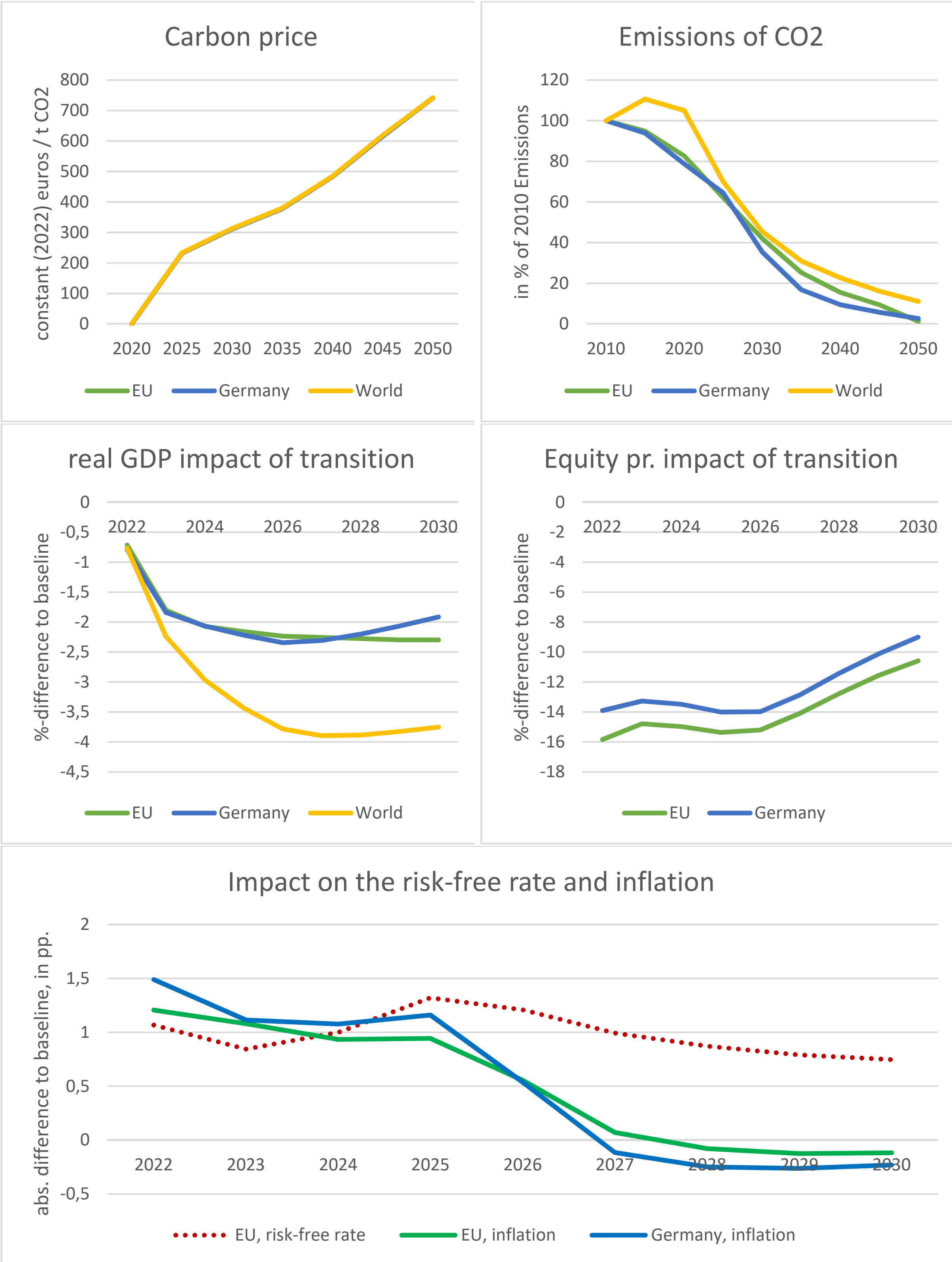

Figure 2.1: Selected variables in the NGFS Net Zero 2050 scenario. Carbon prices and emissions are given in absolute levels. GDP and equity price impacts are provided as percent deviations from the baseline (hypothetical scenario without physical or transition impacts). Risk-free rate and inflation impacts are given in percentage points. Some variables for the world as a whole are not available. Source: NGFS (2022c)

In order to understand the sizeable impacts on bond portfolios derived in Section 4, it is important to analyze the evolution of risk-free rates in the *Net Zero 2050* scenario. Risk-free rates respond to inflation, which is elevated in the EU and Germany for about 4-5 years following the shift in the carbon price path given by the *Net Zero 2050* scenario and the associated emission costs. The impact on inflation is quite noticeable with an increase of up to 150 basis points. Nevertheless, inflationary pressures are much smaller than those that arose during the energy crisis in the wake of Russia's war of aggression against Ukraine. The bottom graph in Figure 2.1 shows how central banks respond to inflation in NiGEM. The central bank's rate (which we interpret as the three-month horizon risk-free rate) increases by about 100 basis points on impact and continues to be elevated throughout the 2020s before beginning to fall towards the end of the decade. This quite persistent impact on risk-free rates also shifts up 10 year risk-free-rates, which increase by about 90 basis points on impact. This has important implications for bonds of longer maturities as we will see further below.

Downscaling using Bundesbank's sectoral model

As discussed, the NGFS scenarios provide macroeconomic variables such as GDP and equity price impacts. These are disaggregated at the country-level. However, the impact of carbon prices differs quite strongly across different economic activities. For this reason we use a sectoral model developed at the Bundesbank to estimate the sectoral impacts of carbon prices, see Frankovic (2022). The model is closely related to the contributions by Baqaee and Farhi (2019) and Devulder and Lisack (2020).

The sectoral model captures inter-sectoral trade between economic sectors across different countries, see Figure 2.2 for a graphical representation. Each sector decides on the amount of inputs purchased from other sectors, including from energy and non-energy sectors, based on input prices and the degree to which the inputs are substitutable with other inputs. It also uses labor from domestic households. A fiscal authority may levy a carbon price. If such a carbon price is introduced, carbon-intensive sectors face higher costs and may need to raise prices, creating an incentive for downstream sectors to reduce inputs and consumers to reduce consumption. This leads to a shift towards less carbon-intensive sectors throughout global supply chains. The model is static, meaning that we can only characterize steady states in the model. The transition from and to these steady states will be informed by the NGFS scenarios, see below.

The model covers seven world regions, including four individual countries (Germany, the US, China, and the UK) and three groups of countries (rest of the euro area, other developed countries, rest of the world). Each region comprises 56 sectors classified by the NACE level 2 system. In the baseline simulation of the model, no global carbon price is implemented and sectoral trade is calibrated to historical estimates from the World Input-Output Database (WIOD). The model is then used to simulate an increase in carbon prices in line with that observed in NGFS' *Net Zero 2050* scenario. For this purpose sectoral emissions are taken from EXIOBASE, a database covering all seven model regions and 56 economic sector as well as the consumer side.[6] The carbon price triggers an endogenous adjustment of global supply chains, leading to changes in sectoral and regional value added.

[6] More details on the datasets used can be found in Frankovic (2022).

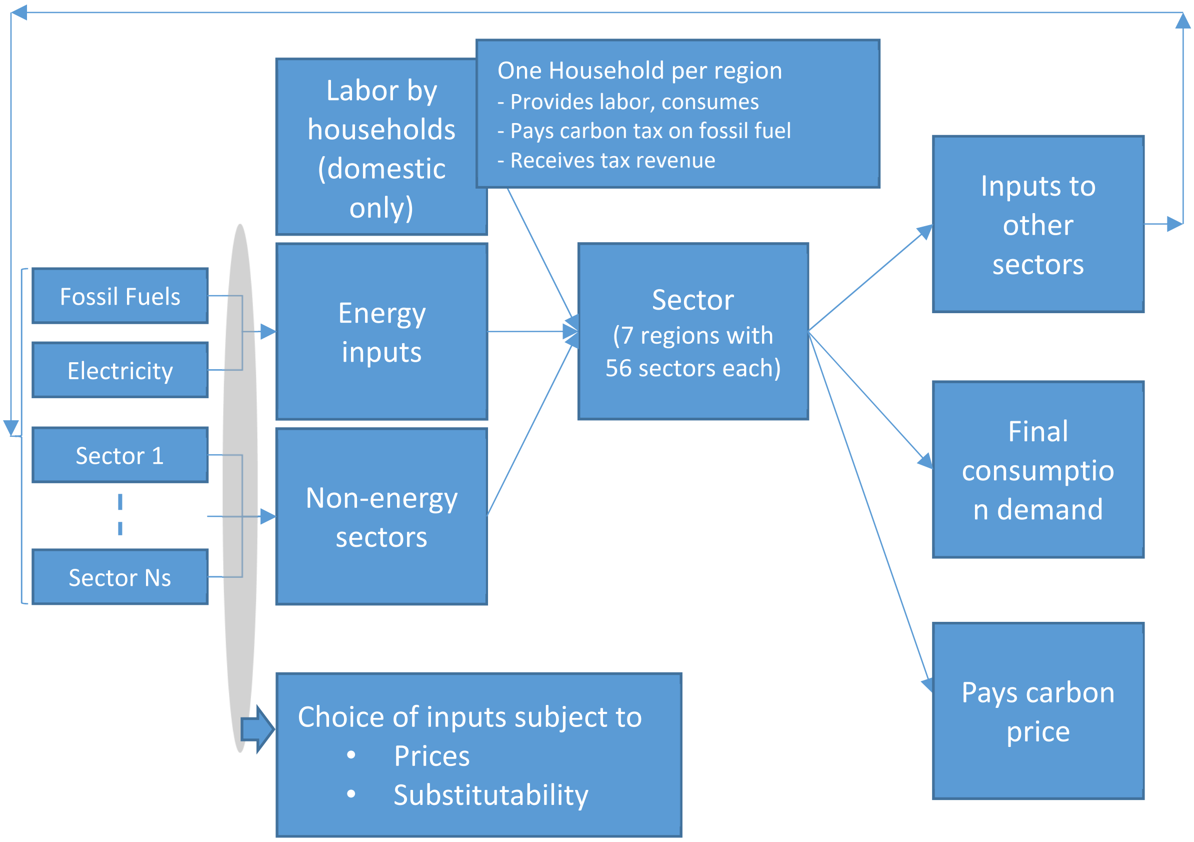

Figure 2.2: A graphical representation of the sectoral model from Frankovic (2022) used to generate the sectoral distribution of transition impacts.

In the next step, we link the dynamic country-level paths from the NGFS scenarios to the static sectoral results of the input-output model to obtain dynamic paths for the 56 sectors and 7 regions covered by the sectoral model. Specifically, we determine for each of the sectors how much value added (VA) loss is caused by the carbon price (in % to the VA when no carbon price was implemented) relative to the aggregate region-level loss. For example, assuming the fossil fuel processing sector loses 20% of its VA, while the aggregate economy to which it belongs loses only 2% of its VA (equal to its GDP), we record a sectoral "scaling factor" of 20%/2% = 10 for this fossil fuel processing sector. We calculate sectoral scaling factors for each of the 56 sectors in 7 regions. We then apply the sectoral scaling factors to the dynamic regional losses obtained in the NGFS scenarios. For example, if GDP losses for a particular region start out at 1% in the first year and rise to 3% in the second year, a sector with a scaling factor of 10 will be assigned a 10% VA loss in the first year and 30% in the second year. This approach is not only implemented for the downscaling of country-level GDP to sectoral VA but also for national changes in equity prices (provided by NiGEM) to sectoral changes in equity prices. The details of the approach are discussed in Frankovic (2022).[7]

[7] Relative to the approach in Frankovic (2022) we apply the scaling factors only during the first five years. Afterwards we distribute national growth in GDP and equity prices across the sectors according to each sector's relative performance during the first five years. This avoids that sectors that have high scaling factors also have the highest growth rates when GDP starts to recover as the economy transitions to less emissions and thus less emission costs. Instead the adjustments ensures that those sectors hit most during the first five years continue to experience low growth going forward. This is in line with some of the available sectoral variables from the NGFS' IAMs, such as fossil energy use, which settle at a much lower level after the transition has been completed.

The results of the sectoral scaling approach from GDP to sectoral VA are shown in Figure 2.3. We focus on the impact after 5 years in the regions Germany, United States and China. We observe that sectoral losses are highest in Agriculture (A01-A03), Mining (B) and Fossil Fuel Processing (C19). Losses in the service sector industries (I-R_S) tend to be smaller than average losses, however they are still noticeable, pointing to important supply chain spillovers from the more energy-intensive electricity (D35) and manufacturing (C) industries. More details on the results can be found in Frankovic (2022).

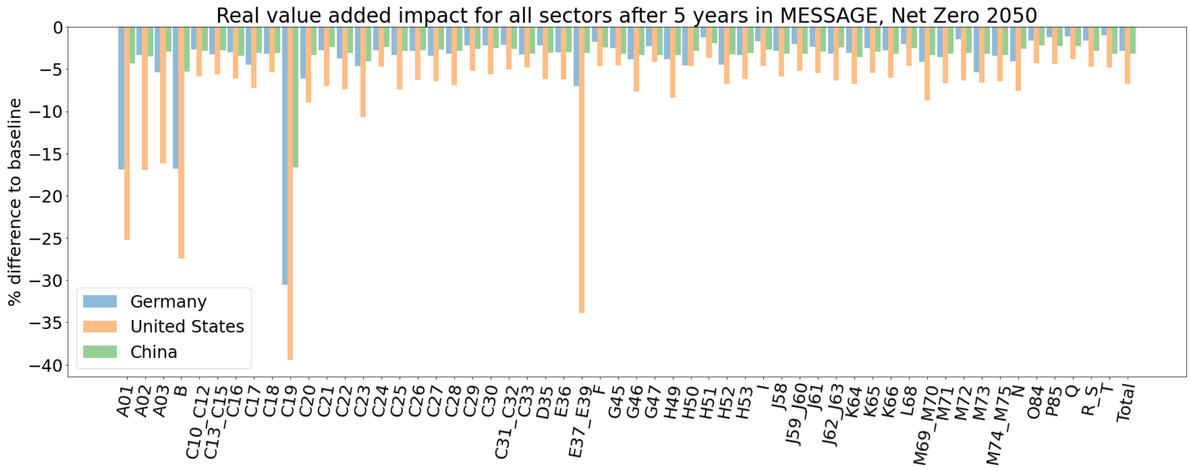

Figure 2.3: Sectoral value added losses in the Net Zero 2050 scenario in Germany, United States and China.

Firm-level impacts in Weth et al. (2024)

As explained above our methodology of scaling down NiGEM's country-level equity price impacts onto the sectoral level only relies on sector-level data. The approach, therefore, misses potentially important firm-level heterogeneity in emissions and energy use. To address this caveat we use firm-level impacts from a forthcoming Bundesbank study of Weth et al. (2024).

Weth et al. (2024) estimate the price impact on 5050 stock corporations (covering half of the global equity market and 17% of global greenhouse gas emissions) for the NGFS *Net Zero 2050* scenario. They first estimate firm-specific discount rates using financial reporting and analyst forecast data. They then calculate the impact of the carbon price and energy mix paths from the *Net Zero 2050* scenario on future profits for each of the 5050 corporations. In doing so they consider various cases of the ability of firms to pass through prices to their clients. The stressed profits are then discounted using firm-specific rates, which yields estimates for equity prices. We apply their estimates to the equity portfolio held by German financial intermediaries in section 4.

2.2 The short-term scenario

Generating Model

The *short-term scenario* is generated within an Environmental Dynamic Stochastic General Equilibrium Model (E-DSGE) derived in Frankovic and Kolb (2023). The model economy, which is calibrated to the euro area, consists of three sectors: i) a low-carbon energy, ii) a fossil energy sector and iii) a non-energy production sector.[8] The low-carbon energy sector uses capital to produce clean energy, while the fossil energy sector also employs fossil resources, whose use is taxed by the government with a carbon tax. The non-energy sector uses capital, labor and energy to produce consumption and investment goods. Financial intermediaries allocate capital across these sectors subject to an endogenous balance-sheet constraint à la Gertler and Karadi (2011), giving rise to a financial accelerator. The fiscal authority in the model imposes a carbon tax on emission activities in the economy, while the central bank sets the nominal interest rate. The household side consists of a standard representative agent that consumes, provides labor and saves via bank deposits (Figure 2.4).

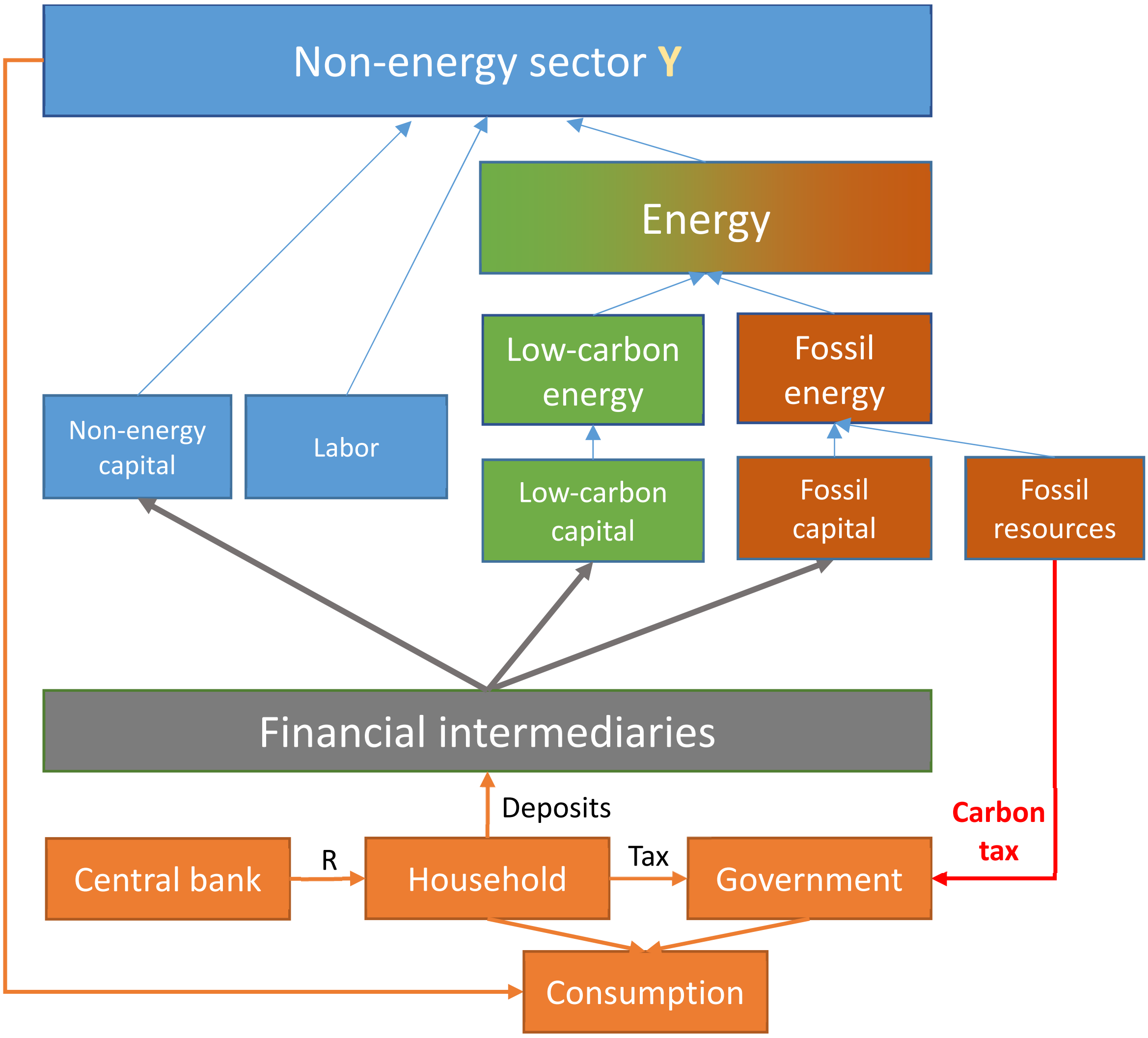

Figure 2.4: A graphical representation of the E-DSGE model from Frankovic and Kolb (2023) used to generate the short-term scenario.

Narrative & Assumptions

The *short-term scenario* is derived specifically for the euro area. For all other countries, we assume that they follow the carbon price path of the *Net Zero 2050* scenario and adopt the macroeconomic variables as derived above. Hence, the *short-term scenario* differs from the *Net Zero 2050* scenario

[8] The fossil energy sector is calibrated to reflect the size of the fossil fuel industry in the euro area. As discussed in Frankovic and Kolb (2023) this amounted to 4% of GDP in 2020. Low-carbon energy encompasses all non-fossil energy sources and is calibrated to 1% of GDP. In total, energy production thus accounts for approx. 5% of GDP.

only for the euro area countries. For the euro area, the scenario assumptions deviate from those of the *Net Zero 2050* scenario in the following four important ways.

First, in the *short-term scenario* the carbon price jumps immediately upon announcement of the carbon price path to a significantly higher level, as opposed to the gradual rise of carbon prices in the *Net Zero 2050* scenario. Specifically, we model an immediate and unanticipated increase of carbon prices in the euro area from 0 Euro / ton of CO2 to 200 euro / ton. An increase of this magnitude is achieved only after 5 years after announcement of the carbon price path in the *Net Zero 2050* scenario. Such a jump in carbon prices could occur if governments want or are forced to reduce emissions strongly and immediately. This strong political action could materialize following a number of events, including i) elections that give rise to a new government with an ambitious climate agenda, ii) a climate change-related natural catastrophe that triggers a sudden reassessment of the urgency of climate policy action among the population and policy makers, or iii) a ruling by some higher court mandating emission reductions. The emission reduction of this policy amounts to 40% in the euro area and is thus considerably lower compared to the Net Zero 2050 scenario, where emissions are reduced by close to 100%. The E-DSGE model used to generate the short-term scenario is not able to account for a full transition as it does not model any technological change. Emission reduction can only be achieved through reductions in output and the substitution to less emission-intensive energy input. As a full decarbonisation can thus not be simulated in the E-DSGE model and larger jumps than 200 euro / ton of CO2 seem unlikely, we do not consider even more adverse short-term simulations.

Second, rather than adopting relatively benign assumptions about the availability and costs of green technologies, we calibrate the E-DSGE model in a more conservative way. This means that we choose parameter values that increase the costs of transitioning to a lower emission intensity. The key parameters in this regard are the elasticities of substitution between low-carbon and fossil energy as well as the elasticity of substitution between capital/labor and energy, for which the empirical literature suggests a wide range of plausible parameter values. Our approach involves the simulation of the GDP impact of a given carbon tax shock for many different parameter value combinations, see Figure 2.5. We then choose the parameter combination of the 5th percentile of GDP impacts (i.e. the parameter combination which is more adverse than 95% of the remaining combinations) as our calibration for the scenario generation. Impacts tend to be larger the lower elasticities of substitution are. This is also consistent with the short-term nature of the scenario, as estimated short-term elasticities tend to be significantly smaller than long-term ones. Specifically, we make the following changes to parameters relative to the documented model version in Frankovic and Kolb (2023). We set the elasticity of substitution between fossil and low-carbon energy to 0.2 (originally set to 3). This is at the very low end of empirical estimates found in the literature and thus captures a very adverse setting. We increase the investment adjustment cost to a value of 40 (originally at 9.5). Higher adjustment costs lead to larger equity price changes for a given shock, since it is more difficult to reduce or increase the capital stock in a given sector within short time. Hence, existing capital is used for a longer time leading to less efficiency and more losses to profits.

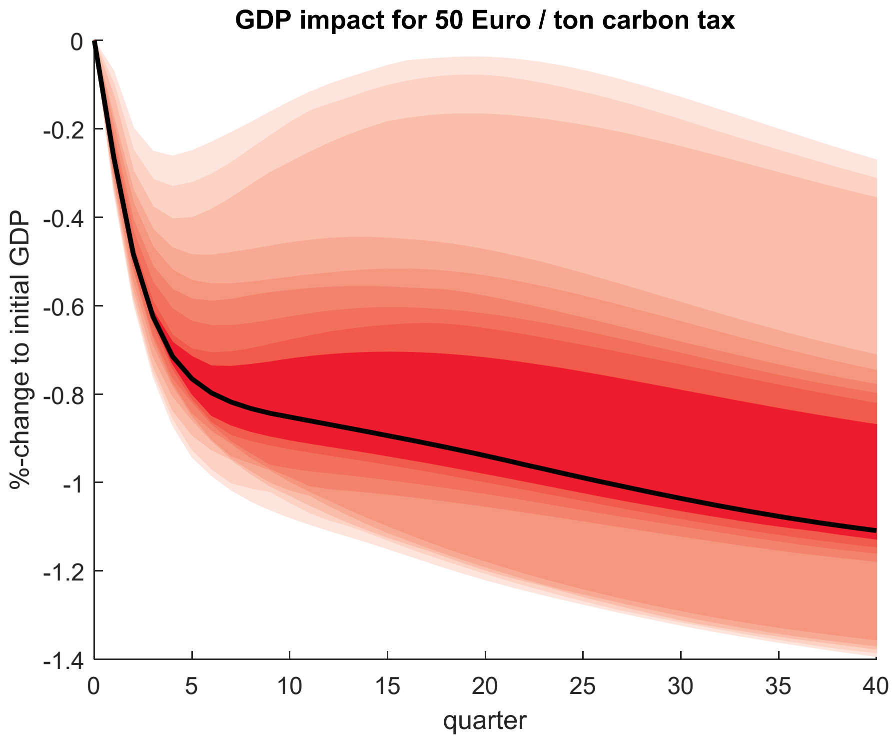

Figure 2.5: The impact of a carbon tax shock of 50 Euro / ton of CO2 in the E-DSGE model by Frankovic and Kolb (2023). The range of possible outcomes is generated by varying values for key elasticity of substitution parameters in line with empirical findings. For this exercise we use a smaller carbon tax shock of 50 Euro / ton to ensure convergence of the simulation for a large set of parameter values. The actual short-term scenario uses a 200 Euro / ton shock.

Third, the E-DSGE model explicitly models the role of the financial sector. The carbon tax shock leads to emission costs in the fossil energy sector, making energy inputs more expensive on average and reducing economic activity. Financial intermediaries holding assets linked to the fossil energy and the non-energy sector, thus, experience balance sheet losses as profits in these sectors fall. Assets held in low-carbon energy can partially but not fully compensate these reductions. The balance sheet losses force banks to tighten credit supply in order to stabilize their asset to net-worth ratio. The reduction in credit supply occurs through an increase in financing costs, which in addition to the emission costs, increase the burden on the economy. Hence, the financial sector effectively amplifies the costs caused by the carbon tax, giving rise to a financial accelerator effect. In contrast, the scenarios as derived in the IAMs of the NGFS, including the *Net Zero 2050* scenario, completely abstract from the role of the financial sector in the transmission of the carbon tax and implicitly assume that financing costs do not rise in times of economic stress. In the E-DSGE model, and as reported in Frankovic and Kolb (2023), the inclusion of the financial accelerator increases the GDP costs of the carbon tax shock by about 27%.

Fourth, rather than assuming a uniform carbon price across all sectors, as in the case of *Net Zero 2050* scenario, a sectoral heterogeneous carbon price regime underlies the *short-term scenario*. As is well known from the literature on carbon taxation, transition costs are lowest when pricing is uniform across different economic activities. This ensures that emissions are reduced where those reductions are achieved in the cheapest way. In contrast, in the *short-term scenario* carbon prices are three times higher in those sectors covered by the European Trading Scheme (ETS) relative to the remaining sectors. This assumption is inspired by the fact that most EU countries are not taxing non-ETS sectors or at significantly lower levels compared to ETS sectors. In case policy makers desire to cut emissions quickly and drastically, they may thus not be able to converge carbon prices across the different sector groups quickly, such that differences in prices prevail for some time. We show below that holding desired emission reductions constant the required carbon price to achieve this reduction is higher by 18 % and leads to 28 % higher GDP costs.

Overall, all four departures from the narrative of the *Net Zero 2050* scenario increase the degree of short-term adversity of the transition to a low-carbon economy. Hence, the *short-term scenario* serves as a more robust test of the vulnerability of the German financial system with respect to short-term risks from the transition. The outcomes of the transition scenario are compared to a baseline scenario in which no transition occurs.

Selected variables

Figure 2.6 shows the *short-term scenario* paths for a few selected variables. The underlying shock to the simulation is an increase of the carbon tax by 200 Euro / ton of CO2 in the first period.[9] The shock causes a recession with output falling by 3% within one year and by 4% after 6 years. The drop in GDP is permanent. Note, however, that we are only interested in the short-term effect since the model is incapable of accounting for medium- to long-run technological change which would allow for cheaper emission reduction measures and thus a recovery of GDP.

The drop in GDP is due to the emission costs that the carbon tax imposes on fossil energy production, which drives up energy prices. While the substitution to low-carbon energy dampens this increase in energy prices, it cannot fully eliminate it. In response to higher energy prices production becomes less energy-intensive (and more labor- and capital-intensive), which again is insufficient to fully compensate the energy price increase, such that output falls.

Inflation and the short-term nominal interest rate increase on impact. Inflation is driven by the increase in energy prices, with a peak impact of 120 basis points. However, since central banks react swiftly and strongly to the increase in energy prices (which is permanent), inflation quickly returns to its long-run value. In fact, inflation is somewhat subdued in the medium-term, with nominal interest rates also falling, as the output-depressing effects of the carbon tax start to dominate its inflationary effects. It is important to note that the 10 year nominal risk-free interest rate in fact slightly drops on impact of the carbon tax shock (by 20 basis points). This is because overall the increase in short-term nominal interest rates is more than compensated by later reductions when the economic output is significantly depressed.

Equity prices reflect the present discounted value of future returns to capital. As carbon prices increase costs (emission or energy costs), income to capital owners falls and, consequently, equity prices are hit. They drop on impact by 17%. In the model capital returns are reinvested in each period with returns flowing now to a much larger extent into low-carbon capital stock such that returns to capital recover over time.

[9] The scenario has no explicit base year. We apply the shock to the balance sheets of German banks, funds and insurers of 2022Q4.

We now turn to the financial side of the model. Since equity prices drop in value, financial intermediaries experience losses in their balance sheets. The endogenous balance sheet constraint embedded in the model leads to a reduction in the supply of capital to the economy as intermediaries need to stabilize their leverage ratio. This necessitates an increase in implied financing costs, as measured by the required return to new capital stock. The increase is very large with 25 percentage points in the first quarter (annualized value), but drops very quickly going forward. Considering the financing costs for a representative investment project financed over a horizon of 7 years, the increase appears more moderate with an increase of 2.3 percentage points in annual financing costs. Finally, we can see that the emission reduction caused by the carbon tax is quite pronounced with a total reduction by close to 40% after 6 years.

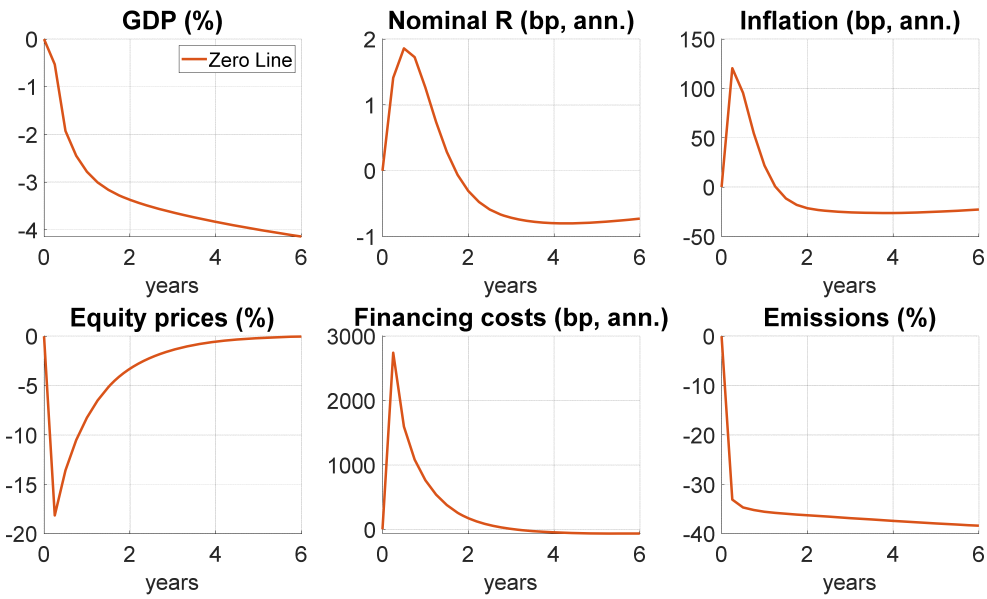

Figure 2.6: The impact of the 200 Euro / ton of CO2 carbon tax shock on the euro area economy in the short-term scenario.

Sectoral downscaling

We employ the identical sectoral downscaling approach as for the *Net Zero 2050* scenario described above, i.e. we use the Bundesbank sectoral model. In line with the narrative of the *short-term scenario* we perform one important adjustment. Instead of assuming a uniform carbon price, we allow for sectoral differences in carbon prices. Specifically, and as motivated above, we impose three times higher carbon prices in the current ETS-sectors relative to the non-ETS sectors.[10]

Table 2.1 shows the simulation of the sectorally-heterogeneous carbon tax for the euro area in the input-output model. We set the average carbon price to 200 Euro/ton in line with the narrative of the *short-term scenario* (implying a 332 Euro/ton price for ETS-sectors and 110 Euro/ton for non-ETS sectors). The model yields an emission reduction of 40 % with a GDP loss of roughly 1 %. If we then

[10] We can only approximate the coverage of the ETS in the NACE 2 classification system since ETS coverage is also determined by firm size and other criteria, which cannot be perfectly replicated by sectors alone. Nevertheless, sectors provide a good approximation for the likelihood of being subject to ETS. Specifically, we chose sectors C17, C19, C20, C23-25, D35 and H51 to have three times higher carbon prices as opposed to the remaining sectors.

revert to the case with sectorally homogeneous carbon prices, we find that a carbon price of only 170 Euro/ton is sufficient to achieve the same emission reduction. As a consequence of the lower average carbon price, GDP losses are considerably lower.

	Emission reduction	Avg. Carbon price	GDP loss
ETS-sector carbon price triple rel. to non-ETS-sectors	-40%	200 Euro/ton	-0.96%
Uniform carbon price	-40%	170 Euro/ton	-0.75%

Table 2.1: Impact of sectorally heterogeneous and uniform carbon prices on GDP losses caused by achieving the same emission reduction target.

Hence, the sectorally-heterogeneous carbon prices significantly increase the costs of the transition. The *short-term scenario* takes this into account by imposing a higher average carbon tax rate and using sectoral scaling factors in line with the non-uniform carbon prices.

3. Breakdown of scenarios

This section discusses the methodologies to disaggregate the sector-level scenario shocks to the level of individual securities (market risk) and individual firms (credit risk).

3.1 Breakdown to individual securities (market risk)

Market value changes in intermediaries' portfolios are derived using a modification of the approach of Falter et al. (2021). Basically, the modelling approach delivers equity and interest rate paths, yet lacks bond market movements. Therefore, we use bridge equations to determine bond spreads corresponding to financial market and real economy projections from the input-output-model of the previous section. Changes in bond spreads in basis points depend on changes in equity value for each sector of the IO model as well as relevant macro variables, such as sectoral economic growth, short- and long-term interest rate developments and inflation. Using large equity or bond indices, value changes at the ISIN level are determined. In a first step, historical empirical data between January 1999 and December 2022 is used to estimate elasticities between bond spreads and the relevant variables. To avoid potential non-stationarity of price data in levels, changes of bond spreads or interest rates are measured in basis points, while equity values and economic growth are measured as relative changes over time in %. This yields the following econometric model:

$$Spread_{i,r,t} = \beta_1 equitygrowth_{i,r,t} + \gamma_1 i_{st,r,t} + \gamma_2\, i_{lt,r,t} + \gamma_3 inflation_{r,t} + \gamma_4 gdp_{i,r,t} + \epsilon,$$

where $spread_{i,r,t}$ measures the changes of credit spreads of a typical bond in period *t* for a corporate in the sector *i* of region *r*; $i_{st,r,t}$ and $i_{lt,r,t}$refer to the short- and long-term interest rate, respectively, in region *r* in period $t.$ $inflation_{r,t}$ denotes the change of the inflation rate compared to the previous period for region r; $gdp_{i,r,t}$ measures the relative change in economic activity in sector *i* of region *r.* Based on historical elasticities for the period from 1999q1 to 2022q4, the projected scenario paths for right-hand side variables are used to derive corresponding spread paths.[11] That is, we use the sensitivities $\beta_1, \gamma_1, \gamma_2, \gamma_3, \gamma_4$ and the model projections for equity, interest rates, inflation and GDP paths in each region to derive the corresponding spread in period h.

$$\widetilde{spread}_{i,r,t+h} = \beta_1 \widetilde{equitygrowth}_{i,r,t+h} + \gamma_1 \widetilde{i_{st,r,t+h}} + \gamma_2\, \widetilde{i_{lt,r,t+h}} + \gamma_3 inflation_{r,t+h} + \gamma_4 gdp_{r,t+h}$$

As a second deviation from the methodology of Falter et al. (2021) the impact of interest rate changes are calculated from a cash-flow approach rather than the modified duration approach. While the modified duration approach is a swift and easy to apply methodology to calculate price changes from changes in yields, it is assumed that the yield curve follows a parallel shift. The cash-flow approach meanwhile considers flattening or steepening of the yield curve as well and is therefore more exact. Changes in the yield curve for each region are determined as linear interpolation between the changes in the short-term central bank rate and changes in the 10 year government bond yield for each region. Maturities beyond 10 years are assumed to shift parallel to the 10 years government bond. In order to provide a measure of price adjustment due to changes in the yield curve of risk-free rates, any fixed income asset is broken down to the level of its cash flows, *CF*. Subsequently, the relative price adjustment, *C*, for an asset, *a*, that is attributed to the change in yield curves is assumed to equal the difference in present values, *PV*, of the underlying cash flows when discounted with the different yield curves. To ease computation, remaining maturities, *p*, are conserved for up to 150 years. When compared to the starting point, *s*, price changes, $C_{a,t}$, are as follows:

$$C_{a,t} = \left(\frac{PV_{\lambda_{p,t}} - PV_{\lambda_{p,s}}}{PV_{\lambda_{p,s}}} \right) * 100$$

Where *PV* for the point in time *t* is calculated as the discounted sum of cash-flows over all remaining maturities p. In order not to distort the comparison by differences in remaining years covered by the cash flows, the whole sequence of cash flows still to be received at the starting-point are considered for both present values. With

$$PV_{\lambda_{p,t}} = \sum_{p}^{150} \frac{CF_{t,p}}{1 + \lambda_{p,t}}$$

where *CF* denotes the cash-flow to be received in year p, discounted with the discount rate λ.[12]

[11] In order to account for different specifications, we use model averaging, weighted by the adjusted R-squared of each specification.

[12] In contrast to a modified duration approach the yield curve parameters can vary both with the time of the present value determination as well as the maturity profile. For the modified duration approach a parallel shift is assumed, i.e. $\lambda_p = \bar{\lambda}$.

3.2 Breakdown to firm's balance sheet items (credit risk)

In order to model credit risk for German banks' corporate loan portfolios (section 4.1), we break down the impact of the climate transition scenarios on firms' balance sheet and profit and loss items.[13] Further details of the approach are discussed in Gross et al. (forthcoming).

For this, we use granular firm-level information:

- Historical balance sheet and profit and loss data of non-financial firms sourced from Deutsche Bundesbank
- Data on carbon emissions: Firm-level data is taken from different sources (European Emissions Trading System, European Pollutant Release and Transfer Register, ISS ESG) where available, remaining data gaps are filled based on sector-level emission-intensities from Eurostat.[14]

The impact of the value added shock $\Delta VA_s^{scenario,t}$ on EBIT (earnings before interest and taxes) of sector *s* is calculated as:

$$EBIT_s^{scenario,t} = F * \left(Sales_s^{scenario,t-1} * \left(1 + \Delta VA_s^{scenario,t}\right) - Cost_s^{scenario,t-1}\left(1 + \Delta VA_s^{scenario,t} * c\right)\right)$$

Where:

- *F* is the sensitivity of sales with respect to value added shocks; t is set to 1, assuming that firms' revenues develop in line with sectoral value added paths.
- *c* is the sensitivity of costs with respect to sales. It is set to 0.9 as firms have some scope to adjust their costs in response to a shock on revenues. On the other hand, firms with growing sales in line with positive value added shocks may become slightly more profitable due to scaling effects.

Given a value added path that is induced by a shock on carbon prices, a high-emitting firm will experience more adverse effects on cost than a low-emitting firm. Hence, additional cost of sector s $\Delta Cost_{s,}^{scenario,t} = Cost_s^{scenario,t} - Cost_s^{scenario,t-1}$ are distributed across the sector's firms not only in line with historical cost (i.e. firms do not only experience a shock on cost equal to $\Delta VA_s^{scenario,t} * c$) but also according to firms' carbon emissions. The degree to which additional cost in sector *s* is distributed according to firms' emissions rather than according to firms' historical cost depends on the degree to which the value added of sector *s* is affected by direct emission cost (first round effects) rather than second round effects, $Ratiofirst_s = \frac{\Delta VA_{s,first}}{\Delta VA_s}$.[15]

[13] See also related approaches in Tressel and Ding (2021) and Demmou et al. (2021).

[14] There are substantial data gaps for firm-level emissions. In our overall sample of 478,650 borrowers firm-level data is available for only 554 firms, representing 10.5 percent of banks' total corporate loan exposures. However, these firms account for roughly 85 percent of overall green house gas emissions in Germany's corporate sector (energy, industry, agriculture, commercial real estate and waste management).

[15] Frankovic (2022) allows for a distinction of first round effects and second round effects when introducing a carbon price shock. First round effects relate to the direct emission cost, which are given by the product of sectoral emissions and the carbon price. Second round effects, in contrast, relate to the general equilibrium effects that lead to price and demand changes in the production network. Second

$Ratiofirst_s$ is used to split the additional cost of sector *s* into additional cost due to first round effects or direct emission cost and additional cost due to second round effects or indirect effects.

$$\begin{aligned}\Delta Cost_{s,}^{scenario,t} &= \Delta Cost_{s,}^{scenario,t} * Ratiofirst_s + \Delta Cost_{s,}^{scenario,t} * (1 - Ratiofirst_s) \\ &= \Delta Cost_{s,}^{scenario,t,first} + \Delta Cost_{s,}^{scenario,t,second}\end{aligned}$$

Additional cost of firm *i* of sector *s* is then calculated as

$$\Delta Cost_{s,i}^{scenario,t} = \Delta Cost_{s,}^{scenario,t,first} * w_{s,i,emis}^{t} + \Delta Cost_{s,}^{scenario,t,second} * w_{s,i,cost}^{t}$$

where $w_{s,i,emis}^{t}$is the weight of firm *i* within sector *s* according to its emission share within the sector's emissions and $w_{s,i,cost}^{t}$is the weight of firm *i* within sector *s* according to its cost share within the sector's cost.

The impact of value added shock $\Delta VA_s^{scenario,t}$ on EBIT of firm *i* is then

$$EBIT_{s,i}^{scenario,t} = Sales_{s,i}^{scenario,t-1} * \left(1 + \Delta VA_s^{scenario,t}\right) - Cost_{s,i}^{scenario,t-1} + \Delta Cost_{s,i}^{scenario,t}$$

The effect of the interest rate shock $\Delta IR^{scenario,t}$on interest expense of firm *i* is calculated as

$InterestExp_i^{scenario,t} = Debt_i^{scenario,t-1} * (InterestRate_i^{scenario,t-1} * \Delta IR^{scenario,t})$, with $InterestRate_i^{scenario,t-1} = InterestExp_i^{scenario,t-1} / Debt_i^{scenario,t-1}$

Starting from firm-specific changes of earnings and interest expenses emanating from the transition scenarios we then model the impact on additional balance sheet metrics of the firm, including debt and liquidity. Notably, it is assumed that a firm will increase debt if available liquidity does not cover cash outflows related to negative EBIT or interest rate expenses. On the other hand, profits may increase liquidity after accounting for taxes and payouts to owners and it is assumed that the firm decides to use parts of excess liquidity to reduce debt.[16]

4. The direct impact on financial intermediaries

This sections describes how the effects on individual loans and securities in the German financial sector that were discussed in the previous sections are mapped to the portfolios of individual German intermediaries. The intermediaries are modelled as price takers in this process. Explicit (dynamic) expectations and/or portfolio adjustments of German banks, funds and insurers are therefore not modelled. This implies that German intermediaries do not sell assets that are subject to climate risks to each other or to foreign market participants.

round effects arise, for example, when an upstream sector increases its selling price, if customers reduce their demand or if the firm itself decides to adjust its output or selling price. $Ratiofirst_s > 1$ if the first round effect of sector *s* is higher than the total effect of sector *s*. This occurs if the sector is able to pass on parts of the CO2 cost to downstream sectors. $Ratiofirst_s < 1$ if second-round effects contribute to overall value added losses. This occurs, for example, if sector *s* is affected by higher cost of intermediate goods from more upstream sectors or if it faces strong demand reductions.

[16] Assumptions taken to model firm-specific decisions can have notable impacts on modelled outcomes. This is why several assumptions on payout rates, the use of excess liquidity etc. are tested to allow for a range of plausible decisions of firms. For more information, please refer to Gross et al. (forthcoming).

4.1 Banks

For German banks, the analysis focuses on selected portfolios as of December 2022 that amount to € 4087 billion or 47% of total assets. These include loans to non-financial companies (€ 1,953 bn), securities portfolios in the banking book (€ 1,017 bn) as well as the trading book in the case of SSM banks (€ 1,126 bn). Within securities portfolios, bonds are the predominant class of securities (80%, of which 57% are financial bonds, 21% are government bonds and 2% are non-financial corporate bonds), followed by fund shares (18%) and equities (2%). German banks covered by the analysis include all CRR (Capital Requirements Regulation) institutions that are monetary financial institutions.

4.1.1 Market risk

The market risk module for the banking sector stress test calculates balance sheet profits or losses from changes in the market prices for banks. For the banking book, profits or losses are approximated at the level of the individual security (ISIN level), where valuation rules under IFRS (International Financial Reporting Standards) and German accounting principles (HGB, *Handelsgesetzbuch*) that differ from mark-to-market valuation are taken into account. For the trading book, trading book sensitivities with respect to market price changes are used. Granular portfolio information as of end-2022 forms the basis for this.

1. Dataset:

- Securities Holdings Statistics (WP Invest): Granular information on the securities held by each bank, including information on whether securities are held in the banking book or the trading book and the carrying amounts of securities.
- Centralised Securities Database (CSDB): Comprehensive information about the securities held by German intermediaries (securities level)
- SSM Short Term Exercise (STE) collected for SREP (Supervisory Review and Evaluation Process) purposes: Sensitivities of the trading book with respect to market risk factors (such as movements of interest rates, spreads or equity prices) as reported by SSM banks
- FINREP, COREP and further regulatory banking statistics: Bank-level information on balance sheet and profit and loss items, capital and capital requirements, hidden reserves or unrealised losses.

2. Mechanics of the model:

Bank j holds individual security s in its securities portfolio in the banking book, which can be assigned to equity instruments, debt instruments or fund shares. In a first step, losses in market value are calculated at the level of the individual security. To do this, for each point in time in scenario horizon t, depending on the type of security, the market value following the market price shock $MV_{js}^{scenario,t}$ is calculated by applying the securities losses from Section 3.1, $MV_{js}^{scenario,t} = MV_{js}^{2022q4} * (1 + \Delta MV_{s}^{scenario,t})$.[17] In a second step, book values following the market price shock $BV_{js}^{scenario,t}$ are

[17] Where possible, fund-specific losses from the market price module are used here for the fund shares held by banks (see also Section 4.2). However, the necessary transparency ("look-through") is not available for all fund shares held by the banking sector (particularly not for

computed, reflecting the accounting treatment of individual securities portfolios.[18] The accounting treatment of securities portfolios is taken into account by drawing on information from two sources. First, the WP Invest provides both book values and market values for individual securities. If for an individual security the book value is higher than its market value, this may indicate a deviation from mark-to-market valuation, for example due to at-cost valuation (IFRS) or due to a long-term investment holding purpose that entails revaluation options for banks that apply the German accounting principles (HGB). Only for those securities portfolios, for which, according to the above reasoning, the accounting treatment would prescribe the realisation of market losses on balance sheets, it is assumed that the market price shock will be reflected on the balance sheet. For such securities portfolios, the balance sheet loss in the banking book $BBLoss_{js}^{scenario,t}$ corresponds to the difference between the current book value and the market value after the market price shock, i.e. $BBLoss_{js}^{scenario,t} = BV_{js}^{2022q4} - BV_{js}^{scenario,t}$, with $BV_{js}^{scenario,t} = MV_{js}^{scenario,t}\ if\ BV_{js}^{2022q4} \leq MV_{js}^{2022q4}$. Second, bank-level information from FINREP and national regulatory bank statistics on securities portfolios provides additional insight into the share of securities not subject to mark-to-market valuation as well as hidden reserves and unrealised losses. Where appropriate, balance sheet losses are scaled accordingly at the bank-level, in order to achieve an overall alignment.

Trading book sensitivities *s* are used to derive trading book losses for SSM banks. These sensitivities convey information on how the value of the trading book changes, given a small change in an underlying market risk factor *RF*. For the purpose of this exercise, the market risk scenario provides changes in the following risk factors: Risk free interest rates, spreads and equity prices (see Section 3.1). Corresponding sensitivities are reported by banks for granular risk buckets *b* that further break down the above risk factors: Interest rate risk sensitivities relate to interest rate risk buckets that are defined by maturities and currencies, while spread risk sensitivities are given for spread risk buckets broken down according to the type of issuer (government, financial, non-financial), the geographic location of issuer and the maturity. Equity sensitivities are available for equity buckets broken down by geographic location. For every bucket *b*, the trading loss is then determined by multiplying the corresponding sensitivity by the change in the underlying risk factor given by the scenario: $TBLoss_{jb}^{scenario,t} = s_{jb} * \Delta RF_{b}^{scenario,t}$.

<u>3. Output:</u>

Balance sheet losses from market risk for individual bank *j* for any point in time *t* of the scenario is given by aggregating balance sheet loss in the banking book across securities portfolios *P* and trading losses across trading portfolios *T*:

$$Marketloss_{j}^{scenario,t} = \sum_{s=1}^{P} BBLoss_{js}^{scenario,t} + \sum_{b=1}^{T} TBLoss_{jb}^{scenario,t}$$

foreign funds). In these cases assumptions are made about market price changes, depending on the type of fund (equity, mixed or bond fund).

[18] For more information, please refer to Falter et al. (2021).

This allows to analyse balance sheet losses from market risk due to climate transition over time by calculating differences in market losses between the respective adverse scenario and the baseline scenario.

4.1.2 Credit risk

The credit risk module of the banking sector stress test estimates scenario-dependent expected losses at the borrower-level.[19] It uses as input the firm-specific balance sheet indicators for the projection horizon as explained in Section 3.2. A panel fixed effects regression model is employed to project firm-level probabilities of default (PDs) conditional on the scenario-dependent balance sheet indicators. Loss given defaults (LGDs) for each corporate borrower are derived by mapping the scenario trajectories for equity prices to starting point LGDs (2022Q4).

1.Dataset

- Bundesbank credit register: Detailed information on key characteristics of German banks' credit portfolios at the level of the individual borrower, including exposure amounts of bank-firm relationships, probabilities of default (PDs) and loss given defaults (LGDs).
- Balance sheet and profit and loss data of non-financial firms as discussed in Section 3.2.
- Data on carbon emissions as described in Section 3.2.

2. Mechanics of the model:

In order to translate the dynamics of the scenarios at macro- and sector-level into credit losses in the banking system, a panel fixed effects model is used to derive projections for PDs at the firm-level over the scenario horizon. We calibrate the projections based on historical elasticities between firm-level PDs and firms' balance sheet and profit and loss items. We employ the following panel regression model:

$$PD_{i,t} = \beta_0 + \beta_k X_{i,t} + FE_s + \varepsilon_{i,t}.$$

$PD_{i,t}$ represents the probability of default for firm *i* in year *t (t=2008, ..., 2020)*. $X_{i,t}$ is a matrix containing key balance sheet indicators, which are typically used in the context of corporate credit risk assessment. We consider return on assets (ROA), leverage ratio, interest expense ratio, liquidity ratio and equity ratio. Sector fixed effects based on NACE codes are included in FE_s. Using the estimates for the parameters $\widehat{\beta_0}$, $\widehat{\beta_k}$ and $\widehat{FE}_s$ and the scenario-dependent values for $X_{i,t}$, we derive projections for firm-level PDs, $\widehat{PD}_{i,t}$. We take median values of projected PDs at sector-level for borrowers for which we cannot project firm-level PDs due to missing data.

We also derive projected LGDs at firm-level, $\widehat{LGD}_{i,t}$, which are modelled by applying the sector-specific equity shocks (in %) in the scenarios to the LGD's starting point value. The rationale behind this approach is the assumption that the depletion of equity due to climate-related shocks reduces the value of collateral to be pledged as protection for loans, hence increasing the loss incurred by banks in case of default.

[19] See Gross et al. (forthcoming) for further details.

3.Output:

Credit losses for each firm-bank relationship *ij*, can be derived for any given point in time *t*, conditional on the type of scenario, with the following formula:

$$Creditloss_{ij}^{scenario,t} = \widehat{PD}_{i,t} * \widehat{LGD}_{i,t} * EA_{ij,t}.$$

$EA_{ij,t}$ represents the exposure amount of bank *j* to firm *i* as reported in the 2022Q4 data of the Bundesbank credit register. The granularity of the approach allows us to aggregate credit risk losses at various dimensions, e.g. bank-, sector- or system-wide level.

Empirical Results

1. *Net Zero 2050 scenario*

Figure 4.1 depicts losses occurred in the banking sector, cumulated over time. The difference between losses in the transition scenario and losses in the baseline scenarios is shown. Banks experience losses of up to 3.2% of their CET1 (Common Equity Tier 1) capital over the scenario horizon of 8 years. Initially, losses are driven by market losses, where maximum losses occur in the first year, stemming from losses from securities in the banking book (2.8% of CET1) and trading losses (0.2% of CET1). Over time, as transition risk is increasingly translated into the balance sheets of borrowers, credit losses rise (maximum of 0.8% of CET1 after eight years).

Figure 4.1: Balance sheet losses of German banks in % of CET1 in the Net Zero 2050 scenario relative to the baseline ("Current Policies") scenario. Losses are expressed as cumulative difference relative to 2022Q4 CET1.

Market risk translates into balance sheet losses in banks' securities portfolio in the banking book of 1.4% in terms of the original portfolio value after the first year, where market loss is highest (Figure 4.2). With 77%, bonds have the highest weight within banks' securities portfolios. This is why the interest rate increase of up to 130 base points as well as risk spread increases mostly translate into balance sheet losses in bonds equal to 1.1% of banks' securities portfolios. Relative to their respective portfolio volumes, equities (8.3%) experience higher balance sheet losses than bonds (1.3%), but their portfolio weight is only 2%. With 1.4%, balance sheet losses in securities portfolios are significantly lower than losses in market prices, which amount to 4.8%. The share of securities in the banking book where losses are not translated into balance sheet losses is currently rather high, at 47% for banks that apply German accounting principles and at 41% for banks that apply IFRS. If market price losses of securities do not translate into balance sheet loss, they increase banks' unrealised losses.

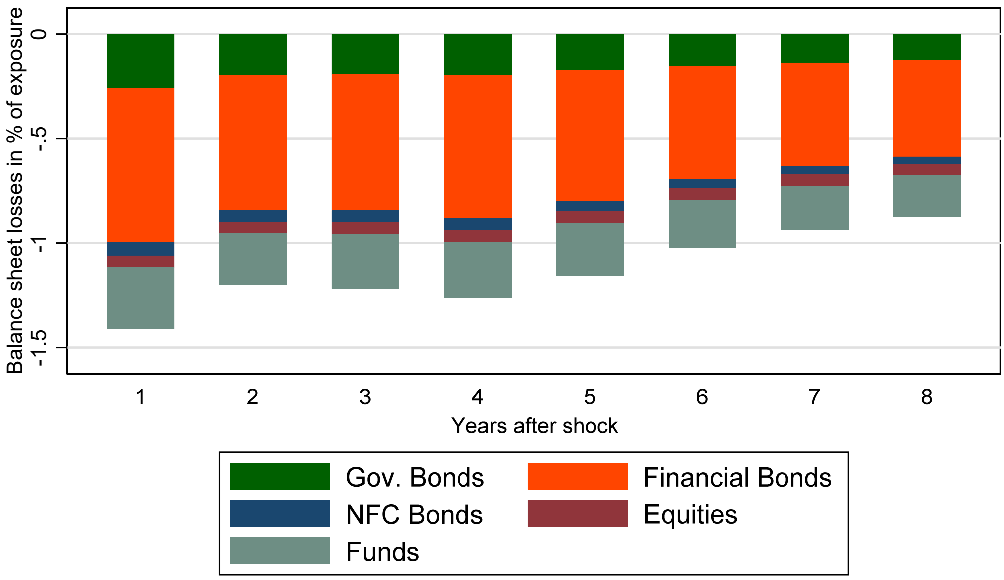

Figure 4.2: Balance sheet losses from market risk of German banks in % of the volume of banking book securities *in the Net Zero 2050 scenario relative to the baseline ("Current Policies") scenario*, by type of security. *Losses are expressed as cumulative difference relative to 2022Q4 exposure.*

Transition-related credit risk losses are heterogeneous across sectors (Figure 4.3). Emission-intensive sectors (e.g. manufacture of coke and petroleum (19), manufacture of transport equipment (30), water and air transport (50 and 51)) tend to have larger losses compared to less emission-intensive sectors. While aggregate credit risk losses are about 0.2% of the stressed corporate loan portfolio, losses in individual sectors may reach more than 5%. This finding highlights that banks' portfolio composition, with respect to borrowers' type of economic activity, ultimately determines a bank's vulnerability towards transition risk.

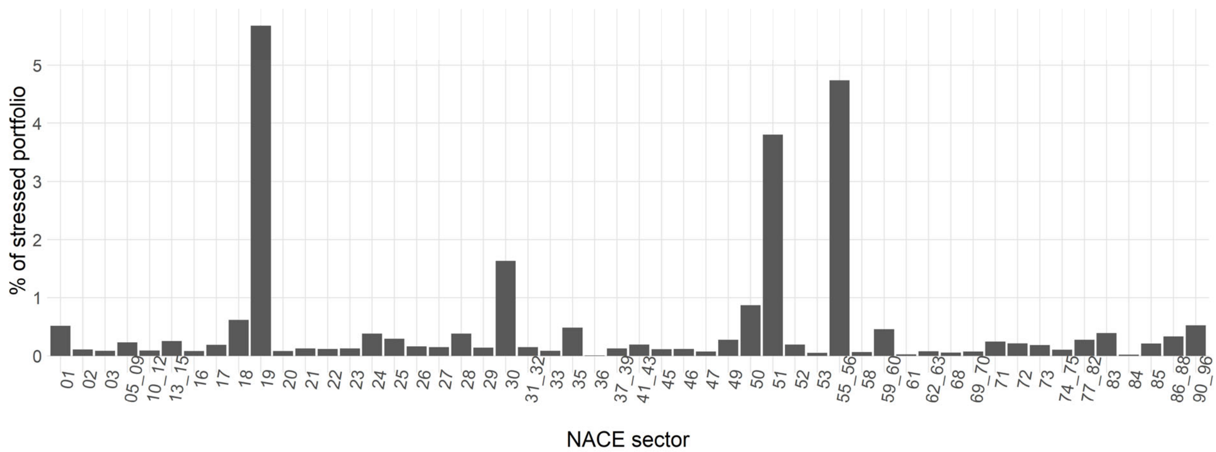

Figure 4.3: Credit risk losses by sector of borrowers, expressed as cumulative difference between adverse and baseline scenario in year 8 of scenario horizon.

Figure 4.4 depicts how climate-related losses affect banks that, originally, have different levels of excess capital, or capital above regulatory requirements. When banks face losses that exceed excess capital they face a choice: They can either breach regulatory requirements (for example by releasing capital buffers) which can be costly in terms of reputation and impose limits on distributions to shareholders or they may deleverage in order to decrease risk-weighted assets (RWA), for example by selling securities or by curbing credit supply. Hence, the amount of excess capital provides information on the distance of banks to such deleveraging behaviour. Figure 4.4 divides banks into quartiles, segmented by banks' original excess capital. For example, the first quartile is composed of banks with excess capital of less than 2.9% relative to RWA and on aggregate these banks have excess capital of 2.1% of RWA (*blue bar*). The *red bar* depicts excess capital of the respective bank segments one year after the climate shock. For the first quartile, excess capital one year after shock is 1.8% of RWA, i.e. a decrease of 0.3 %-points. For each of the quartiles of banks with, originally, higher excess capital, the decrease of excess capital due to climate risk is more pronounced, at 0.6%-points. This indicates that climate transition risk does not disproportionately affect banks which are closer to their regulatory requirements. Hence, the risk of deleveraging behaviour, such as asset-fire sales, is not disproportionately increased by climate risk.

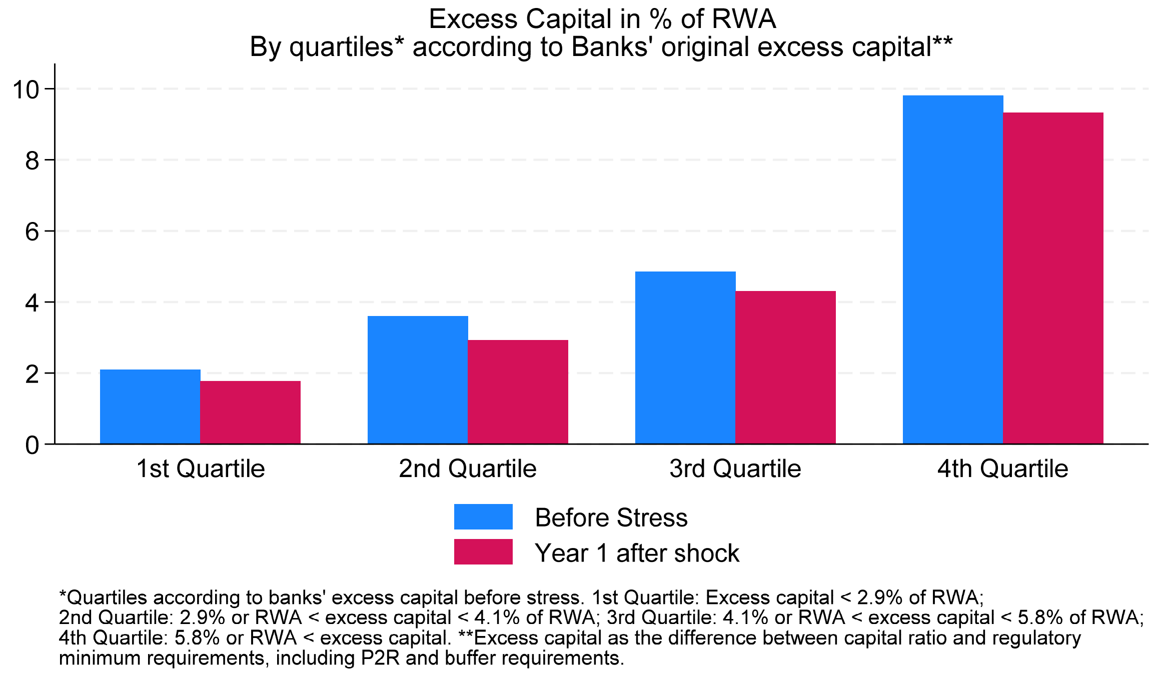

Figure 4.4: Impact of balance sheet losses of German banks on excess capital in the Net Zero 2050 scenario relative to the baseline ("Current Policies") for different quartiles of the banking sector.

2. *Short-term scenario*

In the short-term scenario, losses amount to 2.9 % of CET1 and consist of trading losses of 0.2% of CET1 and balance sheet loss in security portfolios of the banking book of 2.7% of CET1.[20]

[20] The short-term scenario focuses on the short-term impact of a sudden and unexpected CO_2 price increase. As credit risk materialises with a time lag, only market risk that materialises immediately is analysed here.

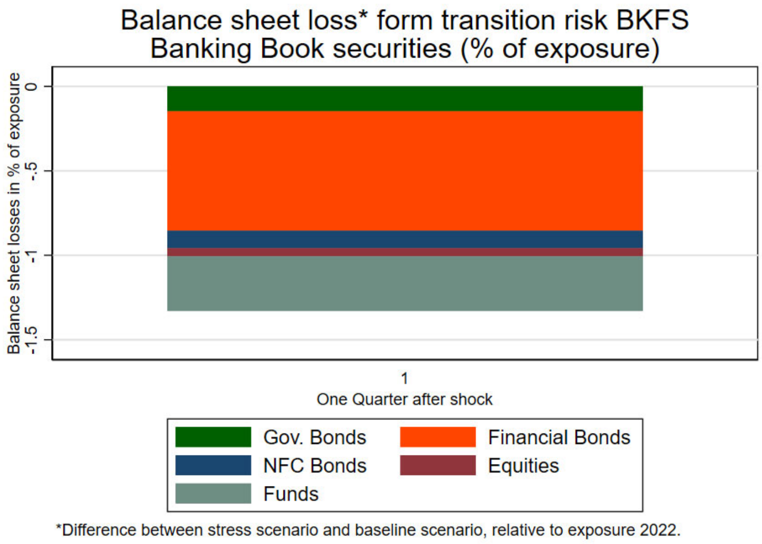

Figure 4.5: Balance sheet losses from market risk of German banks in % of the volume of banking book securities capital in the Net Zero 2050 scenario relative to the baseline ("Current Policies"), broken down by type of security. Losses are expressed as difference between adverse and baseline scenario, relative to 2022Q4 exposure.

Figure 4.5 depicts balance sheet losses in securities portfolios of the banking book in the short-term scenario after one quarter. Overall, balance sheet losses of 1.4% of portfolio value are comparable to market losses in the Net Zero 2050 scenario after one year. Compared to the long-term scenario, the sudden and unexpected shock to the carbon price leads to a higher increase in risk spreads, which is why non-financial corporate bonds experience higher balance sheet losses (0.1% vs. 0.06% of securities' portfolio value). Conversely, interest rate increases are not as pronounced, which is why losses in government bonds are lower compared to the Net Zero 2050 scenario (0.15% vs. 0.26% of securities' portfolio value).

As in the Net Zero 2050 scenario, given magnitude and distribution of losses, there is no indication of an increase in likelihood of second-round effects within the banking sector. However, it is noteworthy that the impact of the short-term scenario is comparable to the impact of the Net Zero 2050 scenario, even though in the short-term scenario no full transition of the economy takes place.

4.2 Funds

The analysis in the fund sector simulates the effects of long- and shorter-term transition scenarios on the assets managed by German funds. This takes place at aggregate level for the fund sector on the one hand and at the level of the individual fund on the other. The granular portfolios of German funds as at the end of 2022 form the basis for this. The simulation uses scenario-dependent relative changes in securities prices for each individual security, calculated on an annual basis, as a key input.

<u>1.Dataset:</u>

- Investment Funds Statistics (IFS): Comprehensive information about the assets and liabilities of German funds. Granular information about the securities held by each fund (securities level)
- Securities Holdings Statistics (WP Invest): Information about the ownership structure of German funds (fund level)

- Centralised Securities Database (CSDB): Comprehensive information about the securities held by German funds (securities level)

Total assets of the German investment fund sector amounted to €2.6 billion at the end of December 2022, of which €2.1 billion are held in securities. The analysis takes into account the securities held by equity, bond and mixed funds as well as funds of funds. 91% of total securities holdings of the German fund sector are stressed, ensuring a high level of coverage of assets. In terms of asset classes held by the fund sector in aggregate, bonds dominate (financial bonds accounting for 20% of the portfolio, sovereign bonds accounting for 16%, non-financial corporate bonds accounting for 10%), followed by fund shares (29%) and equities (25%).

2. Mechanics of the model:

The underlying model is a modified version of the macroprudential stress test model of Fricke and Wilke (2021).[21] Depending on the relevant transition scenario, annual bond and stock price changes are simulated at the level of individual securities for German funds. These changes in value imply:

i. direct changes in the portfolio value of the funds and
ii. indirect changes in the value of portfolios, if the analysed funds hold shares of other funds as well as stocks and bonds (crossholdings).

Let us say there are **N** funds and **K** market-traded assets (stocks and bonds) and cash. Let **F** be the (K+1) vector for the asset-specific annual shocks ($EQP_i^{scenario,t}{}_t/EQP_i^{scenario,t-1} - 1$ for stocks, $BP_i^{scenario,t-1}/BP_i^{scenario,t-1} - 1$ for bonds) and **M** the (NxK+1) matrix for asset-specific portfolio weightings.[22] Let **A, E, D and B** be the respective (NxN) diagonal matrices for the fund assets, equity (= total net assets), debt and the debt/equity ratio(D/E). Let A^{Fund} be the (NxN) crossholdings matrix, whereby $a_{i,j}^{Fund}$ represents the value in euro of the shares that fund i holds of fund j. The value in euro of the fund shares that fund i holds can thus be calculated as A_i^{Fund} = $\sum_j a_{i,j}^{Fund}$. Let the fund assets A comprise the K+1 stocks, bonds and cash held (A^{WP}) and the fund shares held (A^{Fund}): $A = A^{WP}$ + A^{Fund}.

Direct changes in the portfolio value of funds (see i. above): The annual changes in value of K stocks and bonds and cash, depending on the transition scenario chosen, can be calculated as $R^{WP} = M \cdot F$. The fund assets after the initial shock correspond to $A_0 = A^{WP} \cdot (1 + R^{WP}) + A^{Fund}$, which implies a change in the fund assets of R_0^A = $(A_0 - A)/A$ and a change in the total net assets of R_0^E = $(E_0 - E)/E$ = $(\mathbb{I}_N + B) \cdot R_0^A$.

Additional changes in portfolio value due to fund crossholdings (see ii. above): Funds may be directly linked to each other through mutual holdings of fund shares (crossholding network). This means that the share value of a fund may (potentially) depend on the value of *all* other shares issued by funds.

[21] For details of the analysis method, see Fricke and Wilke (2021), pp. 10 ff.

[22] The cash position of funds is always recorded as asset K+1 and is assumed to be constant, as this position is not subject to fluctuations in market prices. Consequently, the cash position of a fund always has an initial shock value of 0.

The crossholding network between German funds is explicitly included in the model. This ensures that direct spillover effects within the fund sector, resulting from direct links between German funds, are taken into account.

After the changes in value of stocks and bonds have spread throughout the German fund sector due to the crossholding network, we can calculate

- the value in euro of fund shares held by fund i as $A_{1,i}^{Fund} = \sum_j a_{i,j}^{Fund}(1 + R_{1,j}^{E})$ and with $A_{1,i}^{Fund} - A_{i}^{Fund} = \sum_j a_{i,j}^{Fund} R_{1,j}^{E}$
- the complete change in value of fund share i as $R_{1,i}^{E} = R_{0,i}^{E} + \frac{\sum_j a_{i,j}^{Fund} R_{1,j}^{E}}{E_i}$.

The complete change in value of fund i is thus calculated as the sum of changes in the value of the stocks and bonds held by fund i ($R_{0,i}^{E}$) and changes in the value of fund shares held by fund i ($\frac{\sum_j a_{i,j}^{Fund} R_{1,j}^{E}}{E_i}$). Due to the crossholding network, the return on fund i may therefore depend on the returns on all other funds in the network.

In this way, the model generates the changes in value of German fund shares for each year, in addition to annual changes in value of stocks and bonds, which are used as an input. These are incorporated into the simulation model for the banking sector. Furthermore, it will also be possible to use these in the future for the calibration of changes in the value of foreign fund shares.

In contrast to classic macroprudential fund sector stress test applications, the portfolios of German funds are fixed at one point in time (end of December 2022) and no active trading by the fund sector is modelled. This is consistent with the assumption that German funds cannot systematically pass on assets that are subject to transition risks to other market participants.[23]

3. Output:

The key output of the simulation, for each of the two transition stress scenarios, is the performance of the portfolios of German funds over time (in each case aggregated across all funds and at the level of the individual fund). The difference in portfolio value between the respective stress scenario and the reference scenario is shown for

a) the entire fund sector; and
b) each individual fund.

This allows us to analyse heterogeneities between different transition scenarios or different fund types (e.g. equity, bond or mixed funds, funds of funds, retail funds or specialised funds) and to identify potential concentration risks for individual funds.

[23] In addition, an ISIN time shock matrix is used as an input instead of an ISIN shock vector, as changes in securities prices fluctuate over time, depending in each case on the transition scenario modelled.

Empirical results:

1. Net Zero 2050 scenario

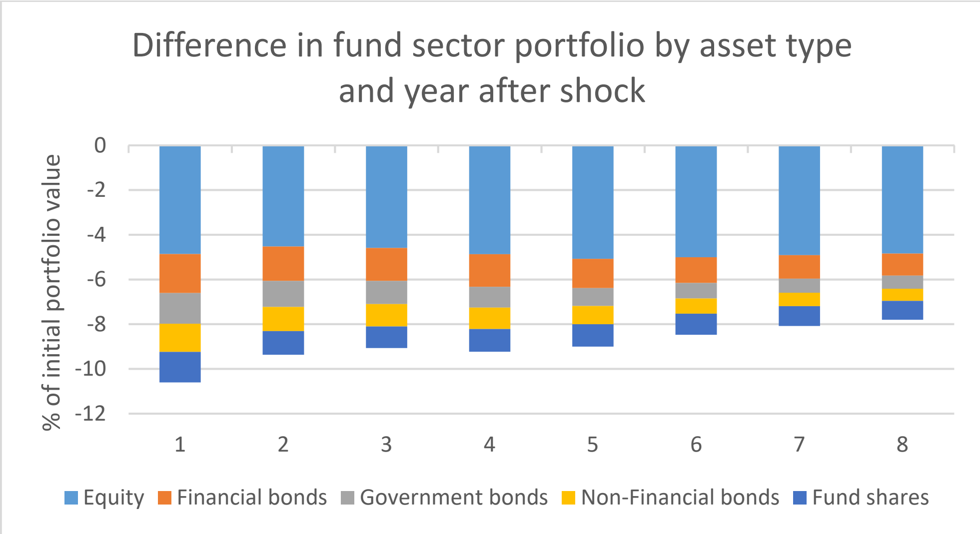

Figure 4.6: Modelled portfolio losses suffered by German funds in the Net Zero 2050 scenario relative to the baseline ("Current Policies"), broken down by financial instruments.

For funds, the transition from the baseline scenario to the more severe *Net Zero 2050* scenario results in portfolio losses of almost 11% of their securities portfolio within the first year, mostly driven by losses in funds' equity portfolios (Figure 4.6). Although these losses are rather material compared to historical market shocks and could lead to redemptions by investors, their dimension must not be impairing the German fund sector's overall functioning per se: e.g., in 2022 German funds lost about 12% of their net assets due to the material interest rate shock without widespread fund instability. The distribution of losses is skewed, indicating that some funds are barely affected by the transition, whereas other funds are highly affected. The average portfolio loss within the quartile of funds least affected is less than 2%, whereas the average loss amounts to 19% within the quartile of funds most affected.

The effect of assumed perfect foresight is very clear: about half of the potential loss is realised directly upon the occurrence of the information shock in 2023.[24] Market participants anticipate future losses and price them into their asset valuations straight away. Subsequent annual changes are each smaller than the initial portfolio loss in 2023. These smaller modelled losses in asset values are mainly attributable to further structural adjustments after the initial shock in 2023, which also come at the expense of profits (changes in carbon price pathways, changes in value added, etc.). The economic recovery after the initial shock in 2023 is partly attributable to the restructuring of the economy and increasingly low-carbon production, which also leads to a lower effective cost burden.

The long-term nature of climate-related risks also becomes clear here and manifests itself in the very long horizons for expectations of a transformation to a low-carbon economy. The bulk of the cost burdens on the real economy is incurred directly in the first year. Discounting of these cost burdens,

[24] The shock occurs in Q1 2023. The losses in Q4 2022 thus come to zero.

and therefore losses, that are expected in the long term, along with the adjustment processes that are expected to take place in the real economy, will lead to only a moderate initial adjustment of asset values in the following years. Therefore, the speed at which the shock initially occurs is rather fast, the extent of the shock itself is medium-sized, while the duration can be classed as extremely long.[25]

2. Short-term scenario

Due to the abrupt and strong increase in carbon prices, the short-term scenario delivers severe market losses to German funds within only one quarter. On an aggregate level, securities holdings decline by 11% (bonds: -3.8%, stocks: -4.7%, fund shares: -2.6%) while the German fund sector suffers a loss worth 10% of aggregate net assets (Figure 4.7). Similar to the Net Zero 2050 scenario, the distribution of losses is uneven across funds. Dividing the losses into quartiles reveals an average loss of less than 2% for the least affected funds, while the funds most affected lose 20% on average.

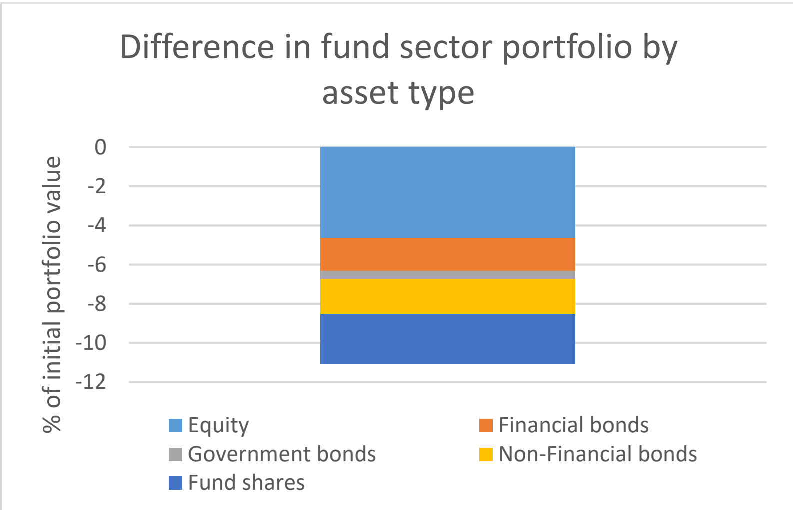

Figure 4.7: Modelled portfolio losses suffered by German funds in the Net Zero 2050 scenario relative to the baseline ("Current Policies"), broken down by financial instruments.

4.3 Insurers

The analysis for the insurer sector simulates the effects of transition scenarios on German insurers' assets. We focus on stocks and participating interests, public and private bonds as well as fund shares. The analysis covers around 93 % of German insurers' security portfolio and 78 % of total assets as of December 2022 (excluding unit-linked policies). Unit-linked policies are excluded since the financial risk from unit-linked investments lies with the household and not the insurance company.

<u>1.Dataset:</u>

- Solvency II: Data from the harmonized EU regulation on insurance supervision, used at solo level (individual companies). Main information on the exposures of German insurers stem from the list of assets (asset-by-asset level). Assets include securities (incl. fund shares) and

[25] We should qualify this by pointing out that the realisation of potential portfolio losses is highly uncertain, especially from the late 2020s onwards.

participations. Characteristics of the security as well as of the issuer are also included. Further insurer level data are collected from Solvency II such as data on the size, line of insurance and solvency capital.

- Centralised Securities Database (CSDB): Comprehensive information about the securities held by German intermediaries (securities level)
- Investment Funds Statistics (IFS): Comprehensive information about the assets and liabilities of German funds. Granular information about the securities held by each fund (securities level).

By combining Solvency II data with the Investment Funds Statistics, we apply the look-through approach in this analysis, i.e. we look through insurers' fund shares to the underlying assets held by the funds. For supervisory and tax reasons, German insurers, and German life insurers, in particular, hold a large share of their assets through funds.[26] Around 80 % of insurers' fund holdings are so called "single-investor funds" where one fund is entirely owned by one insurance company. Hence it is important to look through these funds to the underlying assets when assessing insurers' exposure to transition risk.

Within the assets covered in the analysis, bonds are the predominant class of securities. Financial bonds and government bonds make up 26 % and 25 % of stressed assets, respectively, whereas non-financial corporate bonds amount to 8 % of stressed assets only. Equity instruments, i.e. stocks and participating interests account for 34% of assets, the remaining 7 % consist of fund shares for which the look through approach cannot be applied due to missing data.[27] Within equity instruments, participations in other insurance companies play a prominent role. All German insurers that report Solvency II data are included.

<u>2. Mechanics of the model:</u>

Insurer j holds individual assets i, which can be assigned to equity instruments, debt instruments or fund shares. In a first step, losses in market value are calculated at the level of the individual asset (asset-by-asset). To do this, for each point in time in scenario horizon t, depending on the type of security, the market value following the market price shock $MV_{ji}^{scenario,t}$ is calculated by applying the securities losses from Section 3.1:

$$MV_{ji}^{scenario,t} = MV_{ji}^{2022q4} * \left(1 + \Delta MV_{i}^{scenario,t}\right).$$

As for banks and funds, the asset holdings of German insurers MV_{ji}^{2022q4} are fixed at one point in time (end of 4th quarter 2022) and no active trading by the insurer sector is modelled. This is consistent with the assumption that German insurers cannot systematically pass on assets that are subject to transition risks to other market participants.

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[26] See Deutsche Bundesbank (2017).

[27] When the look-through approach cannot be applied, market price changes are estimated depending on the type of fund (equity, mixed or bond fund).

The losses in market value at time *t* is calculated from the difference between the market value after revaluation $MV_{ji}^{scenario,t}$ and the original market value MV_{ji}^{2022q4}. To reach a sector-wide exposure measure, losses in market value $MV_{loss}^{scenario,t}$ in scenario s are aggregated across all portfolios P of insurers K in the German insurance sector as follows:

$$MV_{loss}^{scenario,t} = \sum_{j=1}^{P} \sum_{i=1}^{K} (MV_{ji}^{scenario,t} - MV_{ji}^{2022q4}).$$

The analysis considers losses in market value in a scenario *s* relative to a baseline scenario. Hence, losses in market value $MV_{loss}^{scenario,t}$ are calculated for three scenarios: the baseline scenario, the Net Zero 2050 scenario and the short term scenario.

3. <u>Output</u>

The key output of the scenario analysis is the loss in market value of German insurers' assets over time in scenario *s* relative to the baseline scenario.

Losses are analysed at different aggregation levels, inter alia on a sector-wide level and a company level. The latter allows us to study heterogeneities between different types of insurers depending on their line of business or on capitalization.

<u>Empirical Results</u>

1. Net Zero 2050 scenario

Moving from the baseline to the Net Zero 2050 scenario (from section 2.1) induces losses in German insurers' security portfolio of roughly 13 % of the securities' market value in the first year after the shock (Figure 4.8). A large part of the losses, almost 6 percentage points, stem from equity instruments, i.e. stocks and participating interests, followed by financial and government bonds. Non-financial bonds play a minor role which reflects the low share of non-financial bonds in insurers' security portfolios. The evolution of insurers' losses over time are similar to that of funds and reflect the dynamics in the stress scenario. The initial loss in year 1 after the shock is largest due to market participants' anticipations of future losses. Subsequently, losses are moderated by the restructuring of the economy and increasingly low-carbon production which all in all lowers the effective cost burden.

The losses in market value in year 1 after the shock amount ceteris paribus to 63 % of own funds of the median insurer and are therefore substantial. These losses on the asset side would however not translate 1:1 into losses in own funds since long-term risk-free interest rates also increase due to the transition to the Net Zero 2050 scenario. This increase in interest rate in turn would lower the market value of insurers‘ liabilities. For life insurers which tend to have long-term liabilities this moderating effect will be particularly pronounced. As of now, we are not able to quantify this effect. But even without considering the moderating effect of rising interest rates on insurer' liabilities, all German insurers are ceteris paribus still able to meet their solvency capital requirements after the initial shock in the Net Zero 2050 scenario.

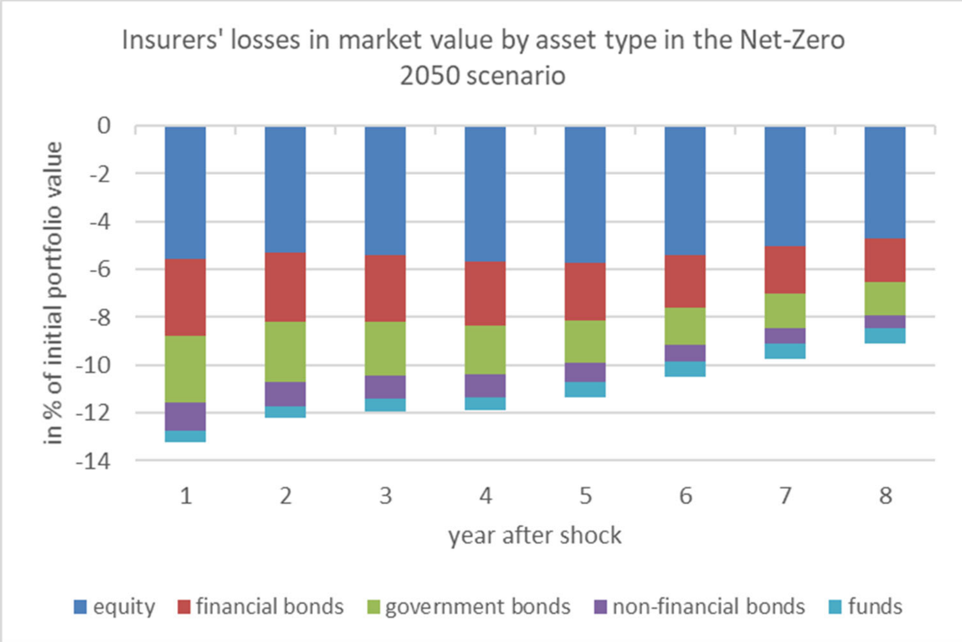

Figure 4.8: Modelled portfolio losses in German insurers' security portfolios in the Net Zero 2050 scenario relative to the baseline ("Current Policies")

However, liquidity risks of German life insurers would increase. This is because the increase of risk-free interest rates would lead to hidden losses in insurers' balance sheet under the German Commercial Code (Handelsgesetzbuch – HGB).[28] Hidden losses in turn limit the fungibility of assets. At the same time rising interest rates may increase lapse risks for life insurance contracts.[29]

2. *Short-term scenario*

In terms of magnitude, losses in the short-term scenario are similar in the insurer and the fund sector. German insurers loose around 11 % of their security holdings' market value in the short term scenario relative to the baseline in the first quarter after the shock (Figure 4.9). The majority of the losses stem from bonds, private and public bonds, reflecting the prominence of fixed income investments in insurers' security portfolio. In contrast to the Net-Zero 2050 scenario, the increase in interest rates is only temporary in the short-term scenario. Hence the trade-off between solvency and liquidity risk of German life insurers following an interest rate hike as discussed for the Net-Zero 2050 scenario plays less of a role in the short-term scenario.

[28] See Deutsche Bundesbank (2023).
[29] See Deutsche Bundesbank (2023).

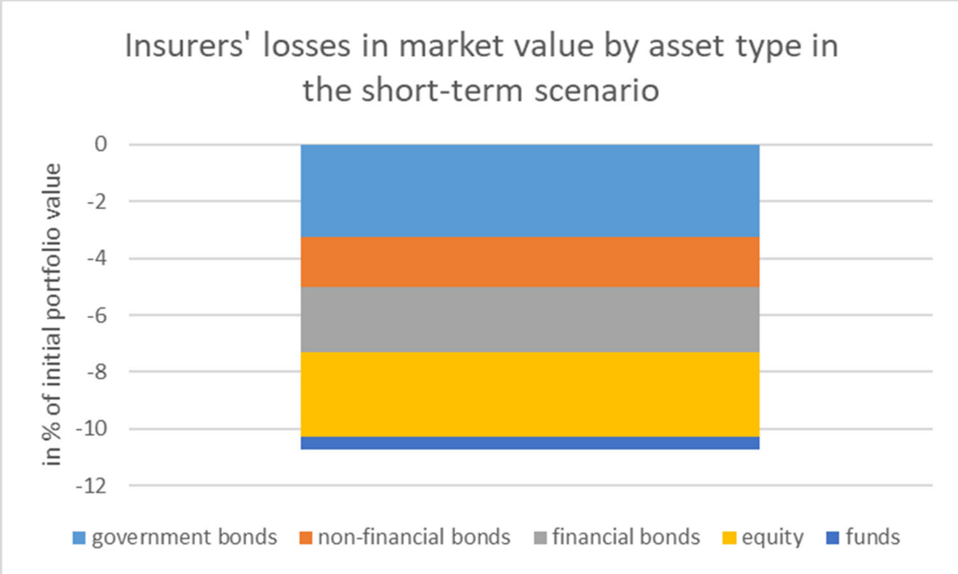

Figure 4.9: Modelled portfolio losses in German insurers' security portfolios in the short-term scenario relative to the baseline ("Current Policies") in the first quarter after the shock.

4.4 Deep dive: Using firm-level equity price impacts

As discussed in section 2, Weth et al. (2024) estimate the impact on equity prices for the stocks of 5050 firms worldwide based on the NGFS *Net Zero 2050* scenario. Specifically, they derive equity price impacts for two cases: i) Firms are able to pass through 80% of their emission costs to their clients and ii) firms are not able to pass on costs at all and carry the full emission costs. We refer to these cases as "PT80" (for pass-through of 80%) and PT0 (pass-through of 0%).

In this subsection, we analyse how our results discussed above change when we consider the equity-price impacts of Weth et al. (2024) rather than those derived in our methodological setup, see Section 2.1. Both their approach and this paper consider the NGFS *Net Zero 2050*-scenario.[30] The main difference in the approaches is that Weth et al. (2024) consider firm-level emission and energy-related revenue data to estimate the impact on the future profitability of firms given the carbon price and energy mix path in the *Net Zero 2050*-scenario, while we consider sector-level emission data and empirical elasticities of substitution between different energy forms. As mentioned above, the pass-through rate of the cost of GHG emissions in Weth et al. (2024) is exogenous. In our study, the pass-through rate of each sector is endogenously determined within the input-output model. Depending on the position of these sectors in supply chains and the ease at which sectors can substitute away to alternatives, sectors are more or less able to pass on costs to their clients, see Frankovic (2022). To make the two approaches comparable, we thus add a third variant to Weth et al. (2024) called "PTvar". In this case we select the pass-through rate for each firm individually, depending on its sectoral

[30] We select the scenario generated by the IAM MESSAGE, in line with the rest of the analysis presented in this document, see section 2.

classification. For firms that belong to a sector with high pass-through rates (>50%), we select the PT80-estimates, while other firms are assigned the PT0 case.[31]

Since Weth et al. (2024) study only equity price impacts we restrict our analysis to the equity portfolio of German financial intermediaries (excluding holdings of funds). Table 4.1 shows the size of the equity portfolios as reported in the CSDB (of 2022Q4) by financial sector. It also shows how much each sector holds in those stocks covered in Weth et al. (2024). Note that in total 4048 of the 5050 stocks from the study are actually held by at least one German financial intermediary.

	Total equity portfolio (bil. euros)	Held in stocks covered in Weth et al. (2024) (bil. euros)	Share of covered stocks in equity portfolio
Banks	46.5	33.6	72.3%
Funds	530.3	328.7	62.0%
Insurers	140.5	32.2	22.9%
Total	717.3	394.5	55.0%

Table 4.1: Amount of stocks covered by Weth et al. (2024) held in the equity portfolio of German financial intermediaries.

Table 4.1 reports the losses in the portfolio of stocks covered in Weth et al. (2024) (i.e. reduced to the 4048 stocks mentioned above) for different cases. We consider unweighted losses, where we counterfactually assume that each stock has the same weight in the portfolio, and weighted losses, where weights reflect the actual portfolio composition. We consider three variants. The first case "Sectoral" represents the results based on our methodology described in section 2.1. Hence, the equity price impacts are derived based on the firm's sector and the sectoral equity price impacts estimated in the sectoral model. The PTvar and PT0 cases follow directly from the estimates in Weth et al. (2024) as described above. We only report losses in the first period of the *Net Zero 2050* scenario.[32]

Focusing first on unweighted losses, see Table 4.2, we observe that our approach is very comparable to the PTvar case. In other words, if firms are assigned pass-through rates in line with our methodology, the total losses for German financial intermediaries are fairly similar (17.3 vs. 16.9 %). This suggests that using firm-level emission data does not materially change the implications for financial intermediaries on aggregate. The PT0 case yields higher losses (by construction) since firms cannot pass on any of the emission costs. However, losses in the portfolio of covered stocks are only modestly higher (17.3 vs 20.4%).

Focusing on the weighted losses, we observe that the loss estimate for the PTvar and PT0 case are smaller relative the unweighted losses. Hence, German financial intermediaries tend to hold more of those stocks that are relatively less affected in Weth et al. (2024). For example, in the PT0 case, the weighted loss amounts to 17.2%, while the unweighted loss is at 20.4%. We observe the opposite pattern for our sectoral approach. Here, correct weighting increases portfolio losses from 17.3% to 21.7%.

[31] The following (NACE2-level) sectors are found to have relatively high pass-through rates in the input-output model (i.e. pass-through rates of > 50%): A01, A02, A03, B, C17, C19, C20, C23, C24, D35, E36, H49, H50, H51, H52. For the PTvar case, firms belonging to these sectors are assigned the PT80 values, while all other firms take on the PT0 estimate.

[32] Repeating the analysis for later periods does not change the conclusions presented here.

Overall, we conclude that the firm-level approach by Weth et al. (2024) does not lead to significantly different losses in equity portfolios in the *Net Zero 2050*-scenario. The reason is two-fold. First, on average losses in covered stocks are only modestly higher in their study and only when considering the very adverse scenario of zero pass-through. Second, German financial intermediaries tend to hold less of those stocks that are estimated to have the largest impacts in Weth et al. (2024).

	Unweighted losses			**Weighted losses**		
	Sectoral	PTvar	PT0	Sectoral	PTvar	PT0
Banks	-13.7%	-11.8%	-14.6%	-15.9%	-22.5%	-24.4%
Funds	-18.2%	-18.1%	-21.8%	-22.2%	-11.9%	-16.5%
Insurers	-11.6%	-10.1%	-12.7%	-22.2%	-11.6%	-16.4%
Total	-17.3%	-16.9%	-20.4%	-21.7%	-12.8%	-17.2%

Table 4.2: Losses in the portfolio of stocks covered in Weth et al. (2024) for three cases: i) Sectoral: approach described in 2.1, equity price impacts from NGFS scenarios are scaled down using the sectoral model; ii) PTvar: estimates from Weth et al. (2024) where pass-through rates depend on firm's sector; iii) PT0 – case from Weth et al. (2024). Unweighted losses capture average losses if each stock is held to the same proportion, while weighted losses consider the actual weighting of the stocks in the portfolios of financial sectors. Losses are reported in negative numbers and expressed in percent of stressed portfolio value.

5. Conclusion

This paper described the methodology underlying the Deutsche Bundesbank's climate transition stress test for the German financial system as presented in the Financial Stability Report, see Bundesbank (2023).

The methodology presented here is a refined version of our previous Technical Paper, see Schober et al. (2021). The changes relative to the previous analysis were made to make the results of the analysis more robust and reliable, so that they can serve as a foundation for the assessment of transition-related vulnerabilities of the German financial system.

Nevertheless, a number of uncertainties remain in the analysis. For example, we do not fully capture all potential international spillovers. While we do take into account losses in assets located outside of Germany, e.g. losses in held equity stocks of foreign firms, we do not calculate losses in other countries' financial systems. If these reach high values, spillovers through international financial linkages might pose risks to the German financial system.

Another remaining source of uncertainty in our analysis lies in the selection of transition scenarios. The consideration of both, a long-run, gradual transition and a short-run, abrupt transition already covers quite distinct potential developments. Still, many other developments could materialize. For example, technological constraints in the adoption of low-carbon technology could turn out to be larger than currently anticipated. Also, we assume a high degree of international cooperation and synchronization of carbon price increases. More heterogeneous carbon prices across the world would tend to increase transition costs.

While methodological developments addressing these caveats would reduce uncertainties of the analysis further, they are beyond the scope of this study.

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