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Assessing climate risk for investment portfolios

An overview for Dutch pension funds

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Assessing climate risk for investment portfolios:
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Abstract

This report's key aim is to provide an overview of available approaches to assess the degree of climate risk in investment portfolios, with a particular emphasis on pension funds. I discuss the key methods underlying a number of the most prominent approaches used by the financial industry, by policy institutions, and in the academic literature, and reflect on their main advantages and disadvantages. I also touch upon the relevant regulation for Dutch pension funds, the various data sources available to support climate risk assessments, as well as potential approaches to mitigate climate risk in investment portfolios.

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1. Introduction

Climate risk is arguably one of the most important sources of financial risk facing institutional investors today. The United Nations' Intergovernmental Panel on Climate Change (IPCC, 2018) estimates that human activity has so far caused around 1.0°C of global warming relative to pre-industrial levels, currently increasing at around 0.2°C per decade due to past and ongoing emissions. Global warming is on course to reach over 3.0°C above pre-industrial levels by 2100 with current policies in place.[1] The consequences of global warming encompass both structural changes (such as rising sea levels, diminishing biodiversity, decreasing crop yields, and fresh water shortages) and an increased frequency and severity of extreme climatic events (such as floods, droughts, storms, and wildfires).

Such consequences are a source of potentially severe ***physical risk*** for companies around the world (Financial Stability Board's Task Force on Climate-related Financial Disclosures; TCFD, 2017). Physical risk may affect companies both directly through damage or loss of assets and indirectly through its effects on supply chains (Institutional Investors Group on Climate Change; IIGCC, 2019ab).

To mitigate the advance and impact of climate change, governments of almost 200 countries signed the 2015 Paris Agreement that aims to limit global warming to 'well below 2°C' above pre-industrial levels (TCFD, 2017). In line with the Paris Agreement, the European Union has committed itself to decreasing greenhouse gasses (GHG) emissions by 40% by 2030 relative to 1990, and to reach net-zero levels by 2050 (Technical Expert Group on Sustainable Finance; TEG, 2019a). These targets provide guidelines for governments to shape their climate policy. The Netherlands has recently presented its Climate Resolution (in Dutch: 'Klimaatwet'), in which it vows to reduce GHG emissions by 49% in 2030 and 95% in 2050 relative to 1990 (De Nederlandsche Bank; DNB, 2018).

The transition to a low-carbon economy entails significant ***transition risk*** for companies across many economic sectors around the world, as governments may implement far-reaching policies and regulations (such as a carbon tax) to reach these targets. The impact of transition risk on companies may range from direct and indirect costs to changing technologies and business models and 'stranded assets'.[2] In a survey among 439 institutional investors globally, 50% of the respondents assert that such regulatory risks have already begun to materialize, while fewer than 10% believe they will only occur in ten years at the earliest (Krüger, Sautner, and Starks, 2019).

[1] Climate Action Tracker, https://climateactiontracker.org/global/temperatures/, accessed February 3, 2020.

[2] TCFD (2017) distinguishes the following other types of transition risk: *legal risk* (stemming from climate-related litigation claims), *technology risk* (stemming from technological innovations that support the transition but disrupt existing technologies or industries), *market risk* (stemming from major shifts in global supply of and/or demand for certain products and services), and *reputation risk* (stemming from changing customer or community perceptions of certain companies).

From the perspective of investors, both physical risk and transition risk imply significant financial risk for their investment portfolios. Climate risk is expected to materialize over a very long period of time and is thus of particular concern for long-term investors such as pension funds. Both types of climate risk are also likely systematic (in the sense that they cannot be easily hedged or diversified away across investments), given the pervasive nature of the effects of climate change and the transition on companies worldwide.

Furthermore, climate risk is difficult to assess for at least three reasons. First, climate risk is distinct from other systematic sources of risk that investors are used to analyze (such as market, credit, and liquidity risk) and is characterized by great uncertainty ('Knightian uncertainty' as opposed to quantifiable risk). Second, historical data are of little use for analyzing climate risk since they neither include realizations of extreme climate change effects nor the types of (government) policies that could emerge going forward. Third, physical and transition risk could interact in a myriad of ways – for example, a rapid transition could result in increased transition risk but reduced physical risk, while unanticipated realizations of physical risk could go hand in hand with greater transition risk.

Notwithstanding the great challenges in assessing the degree of climate risk in investment portfolios, institutional investors around the world are increasingly exploring a host of approaches to analyze their portfolios' exposure to both physical risk and transition risk. New EU regulations for pension funds (IORP II) require pension funds to include climate risk in their 'own-risk assessment'. Central banks and other supervisory bodies of the financial system are interested in assessing climate risk because of financial stability concerns (TCFD, 2017; DNB, 2018; Economist, 2019).

The increasing interest in climate risk builds upon – but is distinct from – the longer-term advent of sustainable or Environmental, Social and Governance (ESG) investing among institutional investors (van Dijk, 2020). In general, four different broad motives for ESG investing can be distinguished: ethical reasons (e.g., not willing to invest in tobacco), impact (aiming to make companies more sustainable), financial return (aiming to enhance portfolio return), and financial risk (aiming to reduce portfolio risk). However, the primary focus of this report is on climate risk as a source of *financial risk* – consistent with the IORP II framework. It is an open question to what extent common approaches in ESG investing (such as exclusion and engagement) are effective in mitigating the financial risk stemming from climate change. I will briefly discuss whether and how climate risk mitigation approaches could also serve other objectives, such as impact.

The key aim of this report is to provide an overview of available approaches to assess the degree of climate risk in investment portfolios, with a particular emphasis on pension funds. I will start with a brief discussion of the relevant regulations and guidelines regarding climate risk from the perspective of Dutch pension funds in Section 2. In Section 3, I review the key underlying principles and methods as well as main pros and cons of four broad categories of approaches to assess climate risk. Section 4 provides an overview of several of the most commonly used data sources to evaluate the environmental impact and policies of individual companies (and of assets such as real estate), which could potentially be used to assess climate risk at the individual asset-level. In Section 5, I briefly discuss potential approaches to mitigate climate risk in investment portfolios. Section 6 concludes.

2. Climate risk regulations and guidelines for pension funds

In 2016, the European Parliament and Council of the European Union published a directive 'on the activities and supervision of institutions of occupational retirement provisions' (revised Institutions for Occupational Retirement Provision Directive or IORP II; Directive 2016/2341/EU). IORP II is aimed at providing security to beneficiaries of European pension funds and establishes rules on governance and risk assessment by pension funds. An important new aspect of IORP II is the compulsory 'own-risk assessment' (in Dutch: 'eigen risicobeoordeling' or ERB) that pension funds must execute triennially. In the own-risk assessment, the fund must investigate material risks (including climate risks), and the possible consequences for the financial position of the fund and its participants. Funds must integrate the findings in their strategy formulation. Furthermore, pension funds must publish on their ESG considerations in investment and risk management policies.

As of 13 January 2019, the EU IORP II regulation is effective in Dutch pension fund law (in Dutch: 'implementatie van de herziene Europese Pensioenfondsenrichtlijn' or 'IORP II-richtlijn'; Edossier E140013). The Dutch Central Bank (DNB) supervises Dutch pension funds' compliance with IORP II. In its outlook for 2019, DNB (2019a) commits to informing pension funds on the new regulations (through sharing good practices and organizing round tables) in the first half of 2019, while executing on-site visits to assess compliance in the second half of 2019. Furthermore, DNB has published guidance on the implementation of the new pension fund law in the form of Q&As and factsheets in 2019. The Pensioenfederatie (federation representing the Dutch pension fund sector) has published a number of 'service documents' (including the 2019 service document ERB; Pensioenfederatie, 2019) to aid pension funds in their own-risk assessment.

Further regulations are on their way. In 2018, the European Commission (EC) adopted the Sustainable Finance Action Plan that is based on the UN's 17 Sustainable Development Goals (SDGs) and is aimed at mobilizing finance for sustainable growth. As part of the action plan, the EC's Technical Expert Group on Sustainable Finance has published a number of reports, including a report on a unified EU classification system to help investors make informed decisions on environmentally friendly economic activities (EU taxonomy; TEG, 2019a), a report on green bond markets (Green bonds; TEG, 2019b), a report on low-carbon investment benchmarks (or indices) and recommendations on ESG disclosures (Climate benchmarks; TEG, 2019c), and a report to assist companies to develop high-quality climate-related financial disclosures (Climate-related disclosures; TEG, 2019d). In 2020, the EC put forward the Green Deal, the consequences of which for the financial sector – and pension funds in particular – are not clear at this stage.

On 8 November 2019, the European Council adopted new legislation that is aimed at supporting the practice of sustainable investing further. The legislation introduces two new benchmarks against which to measure a portfolio's carbon footprint (Regulation 2019/2089/EU) and comes with more disclosure obligations for financial institutions about ESG consideration in their investments (Regulation 2019/2088/EU). The legislation is expected to be implemented in early 2021.

In addition to regulations at the European and national level, there are a number of national and international initiatives and agreements dedicated to creating awareness for sustainable business and investments, establishing collaboration and proposing guidelines:

- The OECD Guidelines for Multinational Enterprises (OECD, 2017) and the UN Guiding Principles on Business and Human Rights or UNGPs (United Nations, 2011) form the basis of the Dutch Pension Funds Agreement on Responsible Investment (in Dutch: 'Convenant Internationaal Maatschappelijk Verantwoord Beleggen Pensioenfondsen' or 'IMVB-convenant'; Sociaal-Economische Raad, 2018). The IMVB agreement aims to bring parties together to collaborate on realizing the OECD and UN guidelines, while complying to IORP II and other new regulations.
- Eumedion (foundation representing Dutch institutional investors on corporate governance and sustainability) has adopted the 'Dutch Stewardship Code', which includes guidelines of responsible ownership by institutional investors in Dutch listed companies in a way that contributes to the long-term value creation.
- VBDO (Dutch Association of Investors for Sustainable Development) carries out an annual benchmark study, ranking Dutch pension funds based on responsible investment.

- The United Nations-supported Principles for Responsible Investment (UN-PRI) is an international network of institutional investors that have signed up to a set of principles to incorporate ESG issues into investment practices across asset classes.
- The Global Sustainable Investment Alliance or GSIA (collaboration of the seven largest sustainable investment membership organizations, including the European Sustainable Investment Forum or Eurosif) aims to deepen the impact and visibility of sustainable investment organizations globally and regularly publishes a report on trends in sustainable investments.

3. Approaches to assess climate risk in investment portfolios

In this section, I discuss a number of approaches to assess the degree of climate risk in investment portfolios, with a particular emphasis on pension funds. I distinguish between four broad categories of approaches: top-down (or 'macro') approaches in Section 3.1; sector-level (or 'meso') approaches in Section 3.2; bottom-up (or 'micro') approaches in Section 3.3; and academic factor model approaches in Section 3.4.

For each category of climate risk assessment approaches, I briefly review the key underlying principles and methods as well as my view on the main pros and cons. I also discuss a few concrete examples within each category. I have based these categories and examples on a review of a wide variety of studies, presentations, and online resources stemming from pension funds and other institutional investors, central banks and other policy institutions, financial advisory companies offering commercial services for climate risk assessment, and academic researchers. My goal here is not to provide a complete overview of all available methods out there, but rather to illustrate the main categories of approaches and their defining features.

3.1 Top-down or 'macro' approaches

Underlying principles and methods

Top-down approaches are characterized by their goal to assess the impact of climate risk on the (global) economy as a whole, as opposed to individual sectors or securities. Top-down approaches commonly rely upon feeding climate projection (or global warming) pathways into an underlying macro-economic model, thereby generating projections for key macro-economic variables such as GDP growth, inflation, and interest rates over prolonged periods of time (sometimes up to the year 2100). These macro-economic projections are then typically translated into the financial impact of climate change on investment portfolios, often by separating out their impact on asset valuations across different asset classes and/or geographic regions. Top-down approaches can incorporate both physical and transition risk, though not all applications involve both.

The Network of Central Banks and Supervisors for Greening the Financial System (NGFS, 2019) reviews a number of these macro approaches and their applicability for central banks and financial supervisors. Integrated Assessment Models (IAMs) – such as the Dynamic Integrated Climate-Economy or DICE model by 2018 Nobel Laureate William Nordhaus (Nordhaus, 1994) – were among the first approaches to assess the economic impact of climate change. Such models typically combine a climate science module (describing how emissions affect temperature) and an economic module (describing how rising temperatures affect the economy). A major criticism of first-generation IAMs was their limited ability to incorporate the large uncertainties inherent in climate change and its economic impact.

Scenario analysis

More recent macro approaches therefore tend to rely upon different scenarios that, for example, specify how a given level of climate change mitigation (for example, resulting in global warming of 1.5°C, 2.0°C, and 4.0°C by a certain date) can be achieved with a given level of probability. Scenario analysis is a well-established method of strategic analysis that accounts for a range of plausible future developments. TCFD (2017) recommends organizations to use scenario analysis in assessing climate-related issues, because it helps to assess the potential (financial) impact of highly uncertain developments. It can also help financial institutions to measure the exposure of their investments to climate risk and, importantly, enhance strategic conversations about such risk. Pensioenfederatie (2019) offers guidelines for the use of scenario analysis in assessing climate risk in the investment portfolios of pension funds.

Stress tests

A stress test is a form of scenario analysis that evaluates the resilience of a financial system (or individual financial institution or investment portfolio) to a particularly bad economic shock or adverse scenario that is 'severe but plausible'. Stress tests of the financial system have become prevalent after the 2007-2009 global financial crisis (Great Recession) as a tool for financial institutions and regulators to evaluate bank balance sheet vulnerability to severe economic shocks as well as financial stability more broadly (see, for example, European Banking Authority; EBA, 2020). In recent years, central banks and other financial supervisory bodies have taken increased interest in stress testing the financial system with respect to climate risk.

Examples of top-down or 'macro' approaches

- DNB (2018) applies a macro approach to carry out what has been described as the first climate risk stress of the financial system by a financial supervisor (Economist, 2019). DNB (2018) reports the results, while Vermeulen et al. (2018) describe the underlying methodology. The stress test is focused on short-term (5-year horizon) transition risk and disregards physical risk. It is based on four scenarios that are deemed severe but plausible:
  1. *Policy shock*: increase of the global price of carbon emissions by $100 per ton of CO_2 (from the current effective price of around $25);
  2. *Technology shock*: doubling of the share of renewable energy in the energy mix;
  3. *Double shock*: combination of the policy shock and the technology shock;
  4. *Confidence shock*: neither the policy shock nor technology shock materializes, leading to a fear of future policies; companies and households postpone investments and consumption.

  The stress test proceeds in three steps. First, DNB uses the macro-econometric multi-country NiGEM model to translate the four scenarios into projections for macro variables such as prices, GDP growth, inflation, and interest rates. Second, DNB models the aggregate effects of each scenario on the valuation of equity and debt in 56 different sectors, based on an assessment of their 'transition vulnerability factor' derived from each sector's 'embodied CO_2 emission' (including emissions by suppliers). Third, DNB uses detailed data on the (security-level) stock and bond holdings of Dutch banks, insurance companies, and pension funds to estimate the losses in the assets of each individual financial institution. In total, €2,200 billion of assets are stress tested, of which €1,067 billion stem from pension funds (of which €583 billion constitute equity investments). The results suggest that the Dutch financial system could face losses between €48 and €159 billion depending on the scenario, with the greatest losses in the double shock scenario. For pension funds, estimated losses range from 3% and 10% of their assets.[3]
- Sprenkels and Verschuren (S&V, 2018) – a financial consulting company – analyze how the four different scenarios developed by DNB (2018) affect the 'coverage ratio' (an indicator of whether the current assets of a pension fund are sufficient to cover its future pension payments) of Dutch pension funds. A key difference with the DNB study is that S&V incorporate the four scenarios in an asset-liability management (ALM) model, and thereby not only examine the impact of transition risk on pension funds' assets, but also on their liabilities. Rather than using actual balance sheet data of Dutch pension funds, S&V analyze a hypothetical pension fund with a representative

[3] DNB (2018) does not examine the impact of these scenarios on pension funds' liabilities, which depends on the interest rate projections. However, Vermeulen et al. (2018, p. 53-54) show that pension funds' coverage ratios actually improve in three out of the four scenarios.

investment portfolio.[4] S&V find that the coverage ratio of the pension fund in the four different scenarios is lower by 5-17 percentage points relative to a baseline scenario. They note that this result is to a large extent driven by the development in interest rates, which are projected to be lower in most scenarios compared to the baseline scenario – thereby negatively affecting the coverage ratio through an increase in the present value of the pension fund's liabilities.

- Ortec Finance (2019) – a financial consulting company – develops a top-down approach to climate risk assessment that incorporates both physical risk and transition risk under four scenarios (1.5°C with an orderly transition, 1.5°C with a disorderly transition, 2.0°C, and 4+°C). Physical risk is modeled both using estimates of the gradual impact of climate change on the economy (based on Burke and Tanutama, 2019) and using estimates of extreme weather impacts (derived from, among others, MunichRE's NatCatService). Transition risk is modeled based on a number of assumptions about developments in both policies (such as the price of carbon) and technologies (such as electricity storage). The climate scenarios and assumptions about physical and transition risk are fed into a macro-econometric model of Cambridge Econometrics, which produces 'climate-adjusted GDP shocks' for each scenario relative to a baseline scenario, differentiating between 59 geographic regions and 70 sectors. Ortec Finance then translates these GDP shocks into projections for a wide range of financial and economic variables (including interest rates, inflation, and impacts on different asset classes) up to 2100 through their 'stochastic financial model'. The model can be used to illustrate the performance of investment portfolios under different scenarios (suggesting, for example, that an early, orderly shift to a low-carbon economy is associated with greater long-term equity returns than the 4+°C 'business as usual' scenario) as well as the development of pension funds' coverage ratios.
- Dietz et al. (2016) use an extended version of William Nordhaus' DICE model to assess the impact of physical risk on global stocks and bonds – in particular, the 'climate value-at-risk' based on a probability distribution of present market value losses due to climate change.[5] They distinguish between two different effects of physical risk: direct impairment of asset values because of extreme weather events and reduced productivity of capital and labor. The DICE AIM's GDP growth projections under different scenarios (relative to a baseline scenario without climate change) are translated into estimates of market value losses for stocks and bonds using assumptions about appropriate discount rates, the growth rate of aggregate earnings relative to GDP, and uncertainty about the productivity growth rate. The findings suggest that the 99% climate value-at-risk of global

[4] It is not clear from the S&V report whether the analysis takes into account the exposure of the pension fund to different sectors (accounting for their 'transition vulnerability factor') or is only based on the projected developments in the macro-economic variables in each of the scenarios.
[5] The concept of 'climate value-at-risk' was introduced by the Economist Intelligence Unit (EIU, 2015), who also use the DICE model to assess the impact of physical risk on the value of global financial assets.

financial assets under a 2.5°C 'business as usual' scenario (compared to a no climate change scenario) is \$24.2 trillion, relative to a current estimated market value of \$143.3 trillion. This approach does not distinguish between different geographic regions or sectors.

- There are several other commercial top-down approaches offered by financial consulting companies to assess climate risk in investment portfolios about which there is limited information available in the public domain. Triple A Risk Finance (2018) develops the 'carbon risk scan' that quantifies carbon-related transition risks for investment portfolios based on three scenarios (1.5°C, 2.0°C, and 3°-4°C), differentiating between different sectors. South Pole (2018) assesses the impact of both physical and transition risk under different scenarios on the value of equity and debt in different geographic regions and sectors.

Pros and cons of top-down or 'macro' approaches

- The main appeal of macro approaches is that they aim to take into account that climate change will likely fundamentally affect the global economy as a whole, as opposed to just individual sectors or companies. Macro approaches can also incorporate feedback loops where economic growth affects climate change, which in turn affects economic growth. Macro approaches have the potential to incorporate both physical and transition risk, and to distinguish between different geographic regions and sectors. They can provide pension funds with a sense of how their entire investment portfolio could be affected by climate risk under different scenarios and over long horizons, and sketch the uncertainty surrounding these scenarios.
- The main drawback of macro approaches in my view is that they tend to be 'black boxes'.[6] Macro approaches generally rely on elaborate macro-econometric models that try to capture the functioning of the global economy in a large number (dozens if not hundreds) of equations describing the demand for labor, real wages, international trade, government spending, etc. The resulting projections for macro-economic variables such GDP growth, inflation, and interest rates are difficult to relate to the underlying scenarios in an intuitive manner.[7] Macro approaches often translate the projections for macro-economic variables into valuation shocks for different financial assets using an additional (financial) model, adding a further layer of complexity. As a result, in my view macro approaches do not facilitate an *informed discussion* about the financial impact of climate risk on different assets.

[6] The Cambridge English Dictionary defines a 'black box' as 'a system or process that uses information to produce a particular set of results, but that works in a way that is secret or difficult to understand'. My description of macro approaches as black boxes does not mean to imply that they are 'secret'; in fact, they are often well-documented and fully transparent. Rather, I mean to say that they tend to be so complex that the way they arrive at results is 'difficult to understand' or intractable.

[7] Table 7 of NGFS (2019) presents an overview of the strengths and weaknesses of various specific macro-economic modelling approaches. Bolton et al. (2020) review macro approaches to assess financial stability risks stemming from climate change, highlighting the limitations (in particular, 'deep uncertainty' and the inherently unpredictable nature of 'green swan' events).

- Another drawback of macro approaches is that – when incorporated into an asset-liability management (ALM) model for pension funds – the resulting effects on coverage ratios are likely to be dominated by the projections for the interest rate. There is great uncertainty about interest rate paths over long periods of time. Interest rates could decline due to climate change since economic activity is hurt. On the other hand, the transition to a low carbon economy requires a huge amount of investments, potentially driving up interest rates.[8]
- Macro approaches are also subject to the 'Lucas critique' by Nobel laureate Robert Lucas (1976), which emphasizes that macro-econom(etr)ic models are based on relations between economic variables observed in past data, and that structural changes (such as the transition to a low-carbon economy or the unpredictable consequences of global warming) may invalidate these relations. In other words, analyzing the impact of structural changes using a macro model is a hazardous exercise.

3.2 Sector-level or 'meso' approaches

Underlying principles and methods

Sector-level approaches are less ambitious than macro approaches in the sense that they do not aspire to assess the impact of climate risk on the (global) economy as a whole. Rather, they aim to assess the extent to which specific economic sectors (or industries) are affected by climate risk, usually without explicitly making projections for macro-economic variables such GDP growth, inflation, and interest rates. Sector-level approaches are based on a less well-developed tradition compared to macro approaches, and tend to be more ad hoc than macro approaches in that they are often not based on formal econom(etr)ic models. Instead, they tend to be built on (qualitative) economic reasoning and stylized analyses that are sector-specific. Sector-level approaches so far mainly focus on transition risk (such as the impact of an increase in the carbon price), but they could also incorporate physical risk.[9]

Three key considerations

The following considerations are of particular importance for sector-level approaches:

- *Sector classifications.* Since sector-level approaches tend to assess the impact of climate risk on entire economic sectors, the classification that is used to distinguish between sectors is crucial. In general, there is a trade-off between a sector classification that is fine enough to analyze the

[8] For example, International Finance Corporation (IFC, 2020) estimates that the Paris Agreement will lead to €23 trillion of climate-related investment opportunities by 2030 in emerging markets alone.
[9] The distinction that I make in this report between macro and sector-level approaches is not based on a formal definition. Some of the macro approaches discussed in Section 3.1 also incorporate an important sectoral dimension. The main criterion I used for classifying certain approaches as macro or sector-level was whether their main level of analysis was the macro economy (through a macro-econometric model) or individual sectors (through more tractable approaches).

heterogenous impact of climate risk on different economic activities, and a classification that is coarse enough to keep individual sector-level analyses manageable and tractable. Battiston et al. (2017) argue that commonly used sector classifications like NACE Rev. 2 or NAICS cannot be readily applied to examine climate risk. They note, for example, that NACE2 sector B (mining and quarrying) includes economic activities unrelated to fossil fuel extraction, while other activities related to fossil fuel extraction are classified in the manufacturing or transportation sectors. They therefore use their own classification to identify five key sectors that are subject to transition risk. Conversely, TEG's (2019a) EU 'Taxonomy' aims to classify *economic activities* that contribute 'substantially to at least one environmental objective and do no significant harm to the other five, as well as meet minimum social safeguards' – thereby moving away from the standard sector classifications.

- *Abatement.* Estimating the impact of transition risk on specific sectors requires an assessment of the sector's flexibility to adjust to the transition (such as an increase in the carbon price) by, for example, switching to alternative, low-carbon production technologies – and, if such flexibility exists, at what cost. The common term for such flexibility is 'abatement' and the associated costs are referred to as 'abatement costs'. McKinsey (2010) provides estimates of 'abatement cost curves' for the reduction of GHG emissions for 10 economic sectors and 21 world regions.
- *Pass-through.* Estimating the impact of transition risk on specific sectors also requires an assessment of the sector's ability to 'pass-through' any cost increases (for example, due to an increase in the carbon price) to its customers by charging higher prices. The sector's ability to do so depends on the degree of competition and market concentration, the extent to which competitors are also affected in the same way by the transition, and – in general – the 'price elasticity of demand' (which indicates the extent to which demand for a product or service decreases when the price is increased, which in turn depends on whether the product or service can easily be substituted by an alternative).

Examples of sector-level or 'meso' approaches

- Battiston et al. (2017) perform a climate stress test by examining euro area financial institutions' equity exposures to five key sectors that are subject to transition risk: fossil fuel, utilities, energy-intensive, transport and housing. These five sectors are constructed from the 4-digit NACE2 classification based on their current direct GHG emissions and their role in the supply chain. They then examine the upper bound of losses that banks would suffer in their equity holdings by assuming the value of the equity in these sectors goes to zero. A key novelty of Battiston et al. (2017) is that they also consider 'second-round effects' due to further losses generated by interbank debt and equity exposures. The results indicate that the equity exposures to climate-policy relevant sectors vary between 20-40% of the portfolios of banks, insurance and pension funds, and investment funds.

- Reinders, Schoenmaker, and van Dijk (2020) carry out a climate stress test by analyzing the impact of different carbon tax scenarios on Dutch banks. A key innovation relative to prior studies (e.g., Battiston et al., 2017) is that they also examine debt exposures, which is important since equity exposures constitute only 1-2% of banks' balance sheets. In particular, they use a 'Merton contingent claims model' to assess the impact of a baseline €100 carbon tax scenario on the market value of corporate debt and residential mortgages.[10] They identify 23 transition-sensitive sectors as all 2-digit NACE sectors with a carbon intensity of more than 0.5 kg CO_2 equivalents / gross value added, and obtain Dutch banks' exposures to these sectors from the Dutch central bank. Asset valuation shocks by sector are based on sector-specific estimates of the carbon footprint, the potential for adaptation or abatement, and the degree of pass-through. Depending on the assumptions, the decrease in the value of bank assets can amount to 4-30% of their core capital (without second-round effects).
- Aegon Asset Management (2019) analyzes the impact of transition risk on equity, bond, and real estate portfolios under a 1.5°C 'abrupt transition' scenario with a carbon price of €480 per ton of CO_2, of which half is effectively passed through to the customer. The costs associated with the carbon price are assumed to decline gradually as companies reduce their carbon emissions to 50% by 2030 and to zero by 2050 (consistent with the estimates of IPC, 2018). In line with McKinsey (2010), abatement costs are assumed to gradually increase over time. The underlying logic is that, initially, it may be relative cheap to reduce carbon emissions by switching to alternative production technologies, but this is likely to become increasingly harder and more expensive as emissions converge to zero (i.e., increasing marginal abatement costs). Aegon Asset Management estimates the value losses by asset class (equity, bond, and real estate for different regions) using asset-level Scope 1 & 2 carbon emissions data and the asset-level 'Carbon Risk Rating' provided by Sustainalytics by means of a stylized dividend discount model for equity and real estate and an assumed impact on credit ratings for bonds. As an example, the study finds a shock to equity valuations in developed (emerging) markets of around -10% (-20%).[11]

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[10] IPCC (2018) estimates that the carbon price for a 1.5°C scenario must be at least $135 per ton of CO2 by 2030, and perhaps as large as $5,500.

[11] Although Aegon Asset Management (2019) builds up the asset valuation shock for different asset classes from individual company-level carbon footprint data and does not distinguish between different economic sectors, I classify this study as a sector-level or 'meso' approach instead of a bottom-up or 'micro' approach. Main reasons are that its underlying reasoning is not purely bottom-up and that its assumptions on pass-through and abatement could naturally be extended to exhibit meaningful variation across sectors.

- A number of other studies highlight the importance of sector-level analyses in understanding the financial consequences of climate risk. Hoogovens Pension Fund (2019) present a parsimonious sector-level analysis of the impact on an increase in the price of carbon on the fund's equity and credit portfolio. Thomä et al. (2017) analyze the equity and debt exposures of 79 Swiss pension funds and insurance companies to the following climate-relevant sectors: energy, electric power, transportation, and cement and steel. For each sector, they present a qualitative and quantitative analysis of how the sector may be affected by transition risk under various scenarios. HSBC (2016) emphasizes the need for formulating investment beliefs on how the transition to a low-carbon economy will develop, and offers an overview of the main effects of physical and transition risk on nine different sectors (see their Table 11). International Renewable Energy Agency (IRENA, 2017) provides estimates of stranded assets for four different sectors and 17 different geographic regions under different scenarios for physical and transition risk.

Pros and cons of sector-level or 'meso' approaches

- The main appeal of sector-level or meso approaches is that they analyze the impact of climate risk at a broader aggregation level than the individual asset-level (or company-level) – thereby taking into account the wider implications of climate change on the economy – while at the same time providing a tractable analysis that can be carried out and understood without relying on a complex macro-econometric model. Of course, assessing how climate risk will affect different economic sectors is very challenging indeed, but the parsimonious sector-level analyses that have been proposed in various studies are transparent and facilitate an *informed discussion* about the financial impact of climate risk on specific sectors.
- An important drawback of sector-level approaches relative to macro approaches is that they do not explicitly assess the impact of climate risk on the global economy as a whole. Relative to bottom-up approaches, sector-level approaches face the limitation that they – in principle – treat all companies within a sector equally, without distinguishing individual companies' ability to mitigate physical and/or transition risk.
- Some of the main challenges of sector-level approaches involve the choices surrounding the three key considerations discussed above: sector classifications as well as the assumptions on abatement and pass-through. More work is needed on developing appropriate sector classifications because, among other things, the global economy is increasingly complex, many companies are active in multiple sectors, and definitions of what constitutes a relevant economic sector may change considerably over time. In my view, there is also significant room for improvement in modeling abatement and pass-through in a more sophisticated way than has

been proposed so far. Interactions between different sectors (for example, along the supply chain) could potentially be considered more explicitly. Finally, current sector-level approaches disregard physical risk and do not distinguish between geographic regions.

3.3 Bottom-up or 'micro' approaches

Underlying principles and methods

The defining feature of bottom-up approaches is that they aim to assess climate risk at the individual asset-level (for example, individual stocks, bonds, or real estate properties). Bottom-up approaches are used both for physical and for transition risk. The common approach is to gather data on asset-level (or company-level) measures for that asset's (or company's) exposure to physical and/or transition risk. For physical risk, such asset-level exposure measures tend to be based on information about the geographic location of the underlying physical assets and on whether this location is in a 'climate-sensitive' region that is either vulnerable to structural climate change effects (such as rising sea levels and fresh water shortages) and/or to extreme climatic events (such as storms and wildfires). For transition risk, such asset-level exposure measures tend to be based on information about the underlying assets' current impact on climate (such as carbon emissions, water use, and waste disposal), and increasingly also on measures of corporate awareness of sustainability issues and on corporate sustainability policies in place. The general idea is that assets with lower emissions and better policies in place are less exposed to transition risk.

Bottom-up approaches vs. ESG investing

The types of data used for bottom-up analyses of transition risk bear significant resemblance with the types of data used in ESG investing (see also the data sources overview in Section 4 below). As discussed in the introduction of this report, a key difference between ESG investing and the bottom-up approaches considered here is that ESG investing is often aimed at enhancing portfolio returns and/or achieving non-financial investment aims (that is, 'social return' or 'impact'). In contrast, the focus here is on the question whether bottom-up approaches can be useful for assessing the degree of climate risk in investment portfolios, which is a subtle but important difference. A common thread to ESG investing and bottom-up approaches to climate risk assessment is that it is standard practice in both to aggregate some of the asset-level measures (for example, carbon emissions) to the portfolio-level (for example, to arrive at an estimate of the carbon footprint of the portfolio as a whole).[12]

[12] A number of Dutch pension funds have formulated concrete targets for reducing the carbon footprint of their portfolios based on an explicit sustainability objective next to a financial risk-return objective. For example, APG (2018) and PGGM (2018) aimed to reduce the aggregate carbon footprint of their equity portfolios by, respectively, 25% and 50% by 2020

Examples of bottom-up or 'micro' approaches

Since bottom-up approaches to climate risk assessment – in contrast to top-down and sector-level approaches – are generally not based on any explicit or implicit modeling choices, there are few systematic studies that propose an overarching framework for bottom-up approaches. Nonetheless, I provide a number of examples of bottom-up approaches below:

- Blackrock (2019) provides a study of the exposure to physical risk for three U.S. asset categories: municipal bonds, commercial mortgage-backed securities, and electric utilities. The analysis based on projections for physical climate change (such as rising sea levels, hurricane damage in terms of GDP, and change in agricultural productivity) for different geographic regions within the U.S. under different scenarios (varying from 'no climate action' to 'decisive climate action') until 2100 obtained using the climate model of Rhodium Group. For municipal bonds, Blackrock translates physical risks into implications for local GDP. For commercial real estate, they examine the risk of hurricanes and flooding as well as projected energy expenses for properties. For utilities, they focus on the risk of hurricanes and wildfires around the physical location of the plants, property, and equipment of 269 publicly listed utilities. The main conclusion is that physical risk is significant for these U.S. asset categories. Furthermore, the study argues that climate risk is currently not fully priced into the prices of municipal bonds and listed utilities (though the report is short on details about these analyses).
- Boermans and Galema (2017) – a study by DNB researchers – measure the carbon footprint (CFP) of the equity portfolios of 41 Dutch pension funds over 2009-2015, based on security-level holdings data available at the Dutch central bank. These holdings data are matched to CFP data from Thomson Reuters ASSET4 for 4,657 unique stocks. The portfolio CFP of Dutch pension funds is considerably smaller than that of the market and has declined over time. The authors document a number of trade-offs in managing portfolio CFP. Decreasing the CFP is associated with a lower dividend yield and a higher systematic risk (market beta). Funds with a funding ratio above the required minimum seem more inclined to trade dividend yield for a lower CFP, perhaps because CFP reduction is considered a 'luxury good'. Further, pension funds with a lower portfolio CFP tend to deviate more from their benchmark. Finally, pension funds that publicly disclose their CFP tend to have a lower portfolio CFP, which is interpreted as possible evidence of public pressure on pension funds to reduce their CFP (but which could also be due to reverse causality).

(relative to 2014). Both APG and PGGM also seek to increase their investments in companies that contribute to the UN Sustainable Development Goals (SDGs) and jointly developed the 'Sustainable Development Investments Taxonomies' that classify investible solutions for each SDG.

- DNB (2017) present a number of initial analyses of the exposure to physical and transition risk for Dutch financial institutions (banks, insurance companies, and pension funds), based on asset-level data of their holdings of equity and debt. For example, the study estimates that two scenarios of a major flooding in the Netherlands ('Rivierenland' and 'Kromme Rijn') could lead to a value loss of billions of euros in mortgages, commercial real estate, and loans to small and medium enterprises. Further, the study finds that Dutch pension funds show an exposure of 12.4% of their total assets to carbon-intensive sectors and an exposure of 17% of their Dutch commercial real estate holdings to assets with poor energy efficiency. At the same time, the study reports that the vast majority of pension funds' assets is invested in countries that are relatively less vulnerable to climate risk.
- DNB (2019b) presents a survey of 25 large and medium-sized Dutch financial institutions (including 10 pension funds) to examine their exposure to environmental and social risks (in particular, water stress, raw materials scarcity, biodiversity loss, and human rights controversies). These financial institutions hold €3.5 trillion in assets, representing 82% of the Dutch financial sector's total assets. Most respondents use the SDGs to guide their sustainability policies, but there is wide variation in the policies in place. Based on data geographic business locations from Four Twenty Seven linked to water stress data from the World Resources Institute, the study finds that Dutch financial institutions have a joint equity exposure of €87 billion to facilities in extremely water-stressed regions. Based on research by the Netherlands Organisation for Applied Scientific Research (TNO, 2015), the study finds that Dutch financial institutions have a joint equity and loan exposure of at least €151 billion to companies that depend on critical raw materials. Overall, the study concludes that Dutch financial institutions have material exposure to environmental and social risks, and need a more holistic approach to measuring and managing these risks.
- A number of recent academic studies apply bottom-up approaches to examine physical risk. For example, Addoum, Ng, and Ortiz-Bobea (2020) find no evidence of a causal impact of temperature shocks on the sales and productivity of U.S. companies based on granular geographic climate data from the PRISM Climate Group and geographic establishment-level data from the NETS database over 1990-2015. Bernstein, Gustafson, and Lewis (2019) find that U.S. houses exposed to sea level rises sell for 7% less than comparable unexposed houses using real estate transaction data from the ZTRAX database and sea level rise exposure data from the NOAA SLR viewer. Murfin and Spiegel (2020) dispute this conclusion using real estate transaction data from CoreLogic and flood risk data from GiraffeGeo.

Pros and cons of bottom-up or 'micro' approaches

- The main appeal of bottom-up or 'micro' approaches is that they are based on detailed measures of the exposure to physical and transition risk of the actual individual assets within a portfolio. In contrast, macro and sector-level approaches are based on a portfolio's broad exposure to geographic regions (such as countries) and/or economic sectors, thereby implicitly assuming that all assets (companies) with a geographic region or economic sector are equally exposed to climate risk. Bottom-up approaches thus have the potential to provide a much more detailed assessment of the degree to which individual assets (e.g., individual stocks / bonds) within the portfolio are exposed to physical and transition risk. Such detailed asset-level analysis is of obvious importance for physical risk, since companies within a region or sector may differ greatly in their exposure to physical risk – depending on the exact location of their physical assets and activities. However, an asset-level analysis can also be relevant for transition risk, since – for example – companies within the same sector may be differentially exposed to transition risk based on differences in their awareness, strategy, and policies in place.
- Another advantage of bottom-up approaches is that they tend to be relatively transparent and only to a limited extent – if at all – based on explicit or implicit modeling choices. As a result, they are more robust and less susceptible to 'model risk' than macro or sector-level approaches.
- The first main drawback of bottom-up approaches is that they fail to take into account the pervasive nature of climate risk by ignoring how climate change and the transition to a low-carbon economy could influence specific geographic regions, particular economic sectors, and the economy as a whole. Bottom-up approaches also tend to consider individual companies as stand-alone organizations, thus ignoring how companies and sectors are linked through competition and supply chains. Related, bottom-up approaches generally do not consider the possibility that certain asset classes may be more or less exposed to climate risk, since they tend to be carried out within an asset class.
- The second main drawback is data quality (see also Section 4 below). There are at least three main issues, which are in part driven by the lack of disclosure requirements for companies (TCFD, 2017):
  (1) The coverage of most ESG data providers is limited (for example, only publicly listed companies, only companies that disclose GHG emissions, only certain countries).
  (2) Different data providers often do not agree on the estimates for the same climate risk exposure measure (such as carbon footprint).
  (3) It is not clear exactly what to measure – given the huge uncertainty about how climate risk will take shape and given the difficulty of constructing forward-looking measures of climate risk exposure.

- The third main drawback is that most pension funds have thousands (if not tens of thousands; including mortgages) individual assets in their portfolio. The peril of bottom-up approaches in such a setting is that they turn into massive data-driven exercises that examine (portfolio-level) climate risk exposure only in an aggregate and quantitative manner, thereby essentially ignoring the intricacies of assessing climate risk exposure for individual assets and thus providing little insight into the underlying economic arguments and mechanisms. It is not clear what the alternative is to quantitatively analyzing large datasets. One view is that a proper bottom-up approach involves traditional fundamental analysis of individual companies or sectors, but the question is whether this is feasible given the number of assets and the trend towards passive investing. I am also not aware of any evidence on the ability of analysts vis-à-vis data providers to assess climate risk.

3.4 Academic factor model approaches

Underlying principles and methods

The current conventional wisdom in the academic 'asset pricing' literature is that an individual asset's (or portfolio's) exposure to different forms of systematic risk can best be captured in a 'factor model'. A factor model describes the (expected) returns on an individual asset as a function of its exposure to various relevant (financial/economic) risk factors and the (expected) returns on these factors. For example, the Capital Asset Pricing Model (CAPM) posits that any asset's expected return can be described as the risk-free rate plus the asset's beta (exposure to the market factor) times the market risk premium. The lack of empirical success of the CAPM has spurred the development of alternative, multi-factor models that allow for multiple dimensions of systematic risk.[13] Since climate risk is likely to be systematic in nature (has pervasive effects on many companies and cannot be readily diversified), an extended factor model that includes one or more factors that capture climate risk could be an appealing way to assess the degree of climate risk in investment portfolios. Nonetheless, there are a number of challenges for factor models to adequately measure climate risk.

Challenges of factor models

Factor models face both general challenges and specific challenges to climate risk applications:

- *General challenges.* There is considerable debate about the interpretation of currently available factor models. Fama and French interpret their factors as true risk factors, while they could also in part be driven by mispricing (Daniel and Titman, 1997; van Dijk, 2011). Hundreds of factors have

[13] For example, the Fama and French (1993) 3-factor model includes two additional factors related to the 'size' and 'value' effects that they interpret as picking up systematic risks that explain why small companies (companies with a low market value of equity) and value companies (companies with a high ratio of book value to market value of equity) tend to have higher returns. More recent factor models include even more factors (see, for example, the 5-factor model of Fama and French, 2015).

been proposed and their empirical validity has been challenged (Harvey, Liu, and Zhu, 2016). Most factor model research focuses on the U.S. equity market only (Karolyi, 2016; Koijen, Lustig, and Van Nieuwerburgh, 2017).

- *Specific challenges to climate risk applications*. The main challenge to assessing climate risk using a factor model is two-fold. First, one needs to define one or more specific risk factors that are successfully able to capture the exposure of individual assets to physical and/or transition risk. Second and related, one needs to be able to estimate such exposure using historical data, which by and large neither include realizations of extreme climate change effects nor of severe transition risk effects.

Examples of academic factor model approaches

- Balvers, Du, and Zhao (2016) introduce a 'temperature shock' factor to the CAPM and Fama-French 3-factor model and estimate these extended factor models using data on U.S. stocks over 1953-2015. Most sectors have a negative exposure to the temperature factor (indicating that their stock returns are hurt by unexpected temperature increases), although some sectors have a positive exposure (suggesting they might act as a hedge against temperature risk). The authors find a small but statistically significant risk premium (0.22% per annum) associated with the temperature shock factor, suggesting that assets with a greater exposure to temperature risk provide investors with some compensation for that risk in the form of a risk premium.
- Hong, Li, and Xu (2019) create a 'drought' factor by comparing the stock returns of food companies based in countries that are increasingly exposed to droughts to those of food companies in other countries (based on the Palmer Drought Severity Index for 31 countries). They find that companies in more drought-vulnerable countries show relatively poor profit growth but also relatively poor stock returns. These results suggest that drought risk hurts food companies' operating performance (that is, physical risk), but that this type of risk is not fully priced into stock prices since a trading strategy focused on food companies that have little exposure to drought risk tends to have predictably higher returns.
- Bansal, Kiku, and Ochoa (2019) model the impact of the physical risk due to long-run temperature increases on current asset prices. Their theoretical model describes how rising temperatures are driven by increasing carbon emissions, and, in turn, increase the probability of temperature-driven natural disasters. The model's prediction that assets with greater exposure to temperature risk offer greater expected returns to compensate for that risk is tested using equity market data from 48 countries over 1970-2015. Consistent with their model, the authors find that equity valuations are generally negatively related to temperature risk exposure. They estimate the temperature risk

premium to be around 0.8% per annum, suggesting that this type of risk is at least partially priced into current stock prices.

- Görgen et al. (2019) introduce a 'Brown-Minus-Green' (BMG) factor by constructing a portfolio that is long in the stocks of 'brown' companies that are likely negatively affected by transition risk and short in the stocks of 'green' companies that are likely positively affected. They construct the factor using ESG data on 1,600 globally listed companies over 2010-2017 from four different data providers (Carbon Disclosure Project, MSCI ESG Stats, Sustainalytics, and Thomson Reuters ESG) on three key company-level characteristics: current emissions, public perception, and adaptability. The average stock returns of green companies exceed those of brown companies over this period, which is inconsistent with a carbon risk premium, but can potentially be explained by 'demand effects' due to the advent of sustainable investing that may have driven up the prices of green stocks.

Pros and cons of academic factor model approaches

- The main appeal of academic factor model approaches is that they are rooted in a well-established academic tradition and that – at least in principle – they enable investors to capture the degree of climate risk in their portfolios by a single number. Just like a portfolio's market beta measures the exposure of the portfolio to broad market fluctuations by a single number that is easily estimated from historical data, an appropriately measured 'climate beta' could capture an entire portfolio's exposure to climate risk (or perhaps multiple climate betas in case climate risk is deemed to have multiple systematic dimensions). Furthermore, in the factor model tradition, such betas are estimated using a recent history of asset return data, which suggests that a portfolio's climate risk exposure could be estimated in a simple manner.
- The key drawback of factor model approaches is that the academic literature on climate risk factors is still in an early stage. There is currently no consensus on what factors might be successful in capturing the relevant dimensions of climate risk, and how they can be constructed. More fundamentally, since factor models tend to be constructed based on historical data, and since historical data may contain little information about possible future realizations of climate risk, it may take years or even decades before the traditional factor model approach using historical data becomes a powerful tool for assessing climate risk.[14]

[14] It might be possible to use factor model approaches without (exclusively) resorting to historical data (for example, by combining historical data with predictions from theory; see, for example, Avramov, Cederburg, and Lučivjanská, 2018), but in my view such approaches are currently insufficiently developed to be applied in practice.

4. Data sources to assess climate risk

The advent of ESG investing and the increasing interest in assessing the degree of climate risk in investment portfolios has resulted in a surge in the demand for data sources to evaluate the sustainability and climate risk exposure of individual companies (and of other individual assets such as real estate properties) – henceforth 'sustainability measures'. In this section, I provide a broad overview of available sustainability measures, I briefly describe a number of examples of commonly used data providers, and I discuss a number of key concerns (including overall data quality) when using these sustainability measures.

Overview of sustainability measures

Measures of companies' sustainability emerged in the 1980s as investors developed an interest in evaluating a company's environmental and social performance next to its financial performance, and the first sustainability rating agencies – Vigeo-Eiris and Kinder, Lydenberg & Domini (KLD) – were established (Berg, Koelbel, and Rigobon, 2019). Broadly speaking, in the past decades there has been a trend from Corporate Social Responsibility (CSR) measures towards Environmental, Social and Governance (ESG) measures. The main difference is that CSR ratings tend to reflect a company's (self-reported) efforts and practices in contributing to environmental and social goals, while ESG ratings tend to be constructed using quantitative (though still mostly self-reported) metrics of the company's social and environmental impact (such as carbon footprint, water use, and waste disposal). In recent years, investors show increasing interest in more direct measures of a company's contribution to the UN's 17 Sustainable Development Goals (SDGs). An appeal of SDG-based ratings is that they aim to measure the broader impact of a company on global sustainable development, whereas ESG measures focus on the company's immediate 'output' (such as carbon footprint). Of course, there is a trade-off here in the sense that measuring a company's contribution to the SDGs is even more challenging than measuring a company's ESG output.

Examples of sustainability measures

Here, I include a brief description of the following data sources that could aid climate risk assessments: ISS-oekom, MSCI, Refinitiv, RobecoSAM, Sustainalytics, and Vigeo Eiris.[15] I do not aim to provide a complete overview of all available data sources, but rather to illustrate several popular data sources.[16]

[15] Several other data providers were acquired by these six in recent years. For example, well-established rating agencies KLD and Innovest were acquired by RiskMetricks in 2009, which was incorporated into MSCI in 2010; ISS and oekom merged to form ISS-oekom in 2018; ASSET4, after being acquired by Thomson Reuters, is nowadays part of Refinitiv; and Sustainalytics comprises of a consortium of smaller agencies (Escrig-Olmedo et al., 2019). S&P Global acquired Robeco SAM in 2020.

[16] Since my information is based on limited public and secondary sources, accuracy of the descriptions cannot be guaranteed.

- ISS-oekom provides a company-level carbon risk score (considering emissions along the value chain) as well as companies' targets and strategies to reduce emissions; a governance score, measuring companies' quality of governance relative to its peers; and an industry-specific all-round corporate rating. Ratings are based on public sources, like the media, as well as on stakeholder interviews (ISS, 2020).
- MSCI reports Scope 1 and 2, and – if available – Scope 3 carbon emissions of listed companies' equity and fixed income assets. Ratings are based on company disclosures. MSCI further provides ratings of companies ranging from AAA (for industry leaders) to CCC (for industry laggards) based on their exposure to and management of 37 ESG-related risks (MSCI, 2019).
- Refinitiv rates listed companies on 10 ESG themes, ranging from emissions to human rights, based on company reports, news articles, and other publicly available information. It covers both equity and fixed income assets, and provides ratings on a scale from D- to A+ (Refinitiv, 2019).
- RobecoSAM rates companies on their awareness of sustainability factors and the implementation, measurement, external audit, and communication of ESG-related risk management strategies. Ratings (total sustainability scores ranging from 0 to 100) are based on an industry-specific questionnaire among large publicly traded companies. The top 10% of each industry is included in the Dow Jones Sustainability Index (RobecoSAM, n.d.).
- Sustainalytics reports Scope 1 and 2 carbon emissions of listed companies, with an extension to private companies using a sector-specific regression model. Ratings are based on company disclosures, but exclude Scope 3 emissions. Sustainalytics further classifies companies into ESG risk categories ranging from negligible to severe, based on management indicators such as corporate policies, and outcomes such as emission levels (Sustainalytics, 2019).
- Vigeo Eiris rates companies on 38 ESG issues, covering both the implementation of policies and their results (in line with international conventions and principles, like those developed by the UN, EU, and OECD). Vigeo Eiris scores companies on a 4-level performance scale from weak to advanced (Vigeo Eiris, n.d.)

Key concerns of sustainability measures

- *Limited coverage and data quality.* Most sustainability measures are based on self-reported metrics and policies taken from the annual reports of publicly listed companies. This gives rise to several concerns. First, data coverage is thus limited to public companies that choose to report. Data providers often 'extrapolate' their sustainability measures to other companies using a statistical model based on other observable company characteristics (Kepler Cheuvreux, 2015), but the quality of such extrapolated measures is disputable. Second, self-reported information (through annual reports, but also surveys) may not be reliable. Third, there is likely to be significant selection bias in which companies choose to report. Fourth, there is little consistency across companies in how they report on sustainability issues. A number of initiatives are underway to improve corporate sustainability disclosures. TCFD (2017) presents recommendations on voluntary, consistent climate-related financial disclosures. The Sustainability Accounting Standards Board (SASB, 2017) develops standards for reporting on 30 broadly relevant sustainability issues. TEG (2019d) issues recommendations to financial institutions and non-financial companies for disclosure of climate-related risks and opportunities. Further development of voluntary and/or mandatory disclosure standards (possibly including formal auditing) is likely to improve the quality of sustainability measures going forward. However, some key concerns are hard to address (coverage likely to remain limited to publicly listed companies, policies and contribution to SDGs even harder to measure than output such as carbon footprint).

- *Disagreement across data providers*. Despite the rapid consolidation in the sustainability rating sector, there is still an apparent divergence between rating methodologies, resulting in considerable disagreement across ratings of different data providers. Chatterji et al. (2016) compare six widely used social ratings and document an average correlation of just 0.30. Berg, (2019) find an average correlation of 0.60 across the ratings of five ESG data providers. For comparison, they show that credit ratings by Moody's and S&P are correlated at 0.99. Berg et al. distinguish between three causes of disagreement: (1) scope divergence (which attributes to measure), (2) measurement divergence (how to measure the attributes), and (3) weight divergence (how to weight the attributes to arrive at a final score). They conclude that 53% of disagreement across rating agencies is due to measurement divergence, while 44% and 3% are due to, respectively, scope divergence and weight divergence.[17]
- *What to measure*. Perhaps the greatest challenge in using sustainability ratings to assess the degree of climate risk is what exactly these ratings should aim to measure. For physical risk, information on the geographic location of physical assets can be combined with location-specific climate projections to arrive at an estimate of potential physical damage. However, accounting for a company's flexibility in moving production locations and for the impact of physical risk throughout the supply chain is much more difficult. For transition risk, the challenges seem to be at least as severe. Climate change is characterized by a great deal of uncertainty, but at least there is a long tradition of climate modeling based on very rich datasets that can produce detailed

[17] I note that, from a diversification and financial stability perspective, imperfect correlations across sustainability measures from different data providers may actually be a good thing. After all, if many financial institutions would base investment decisions on the same or very highly correlated sustainability measures, there could be a greater risk of herd behavior and potential bubbles in the stock prices of companies with a high sustainability rating.

climate projections. Although Integrated Assessment Models (IAMs) and other macro approaches offer a tool for assessing the impact of climate change on the economy as a whole, they fall short in providing a handle on the huge uncertainties in how the different types of transition risk (including potential government regulations, technological innovations, and shifts in global supply of and/or demand) could affect individual sectors or companies. Asset-level sustainability measures like carbon footprint are a relatively straightforward proxy for the transition risk of policies to reduce GHG emissions (such as a carbon tax), but (1) they capture only one dimension of transition risk, (2) they are not forward-looking, and (3) they disregard differences across companies in their ability to adjust to the transition. Ideally, an asset-level assessment of transition risk combines information on current production processes and supply chains with information on the company's suppliers' and competitors' as well as the sector's overall opportunities for abatement and pass-through, in addition to information on the specific's company current and future ability to adjust to (and possibly profit from) the transition. Needless to say, this is a Herculean task.

5. Approaches to mitigate climate risk

This report has so far dealt with the challenge of how to *measure* the degree of climate risk in investment portfolios. How to subsequently *manage* the climate risk embedded in an investment portfolio is an altogether different challenge. Although a thorough discussion of different approaches to climate risk management is beyond the scope of this report, in this section I briefly review a limited number of possible approaches to mitigate climate risk as well their main features. Before doing that, I discuss how climate risk mitigation approaches relate to ESG investing. I also present a brief review of the Efficient Markets Hypothesis and how it relates to climate risk management.

Climate risk mitigation vs. ESG investing

As discussed in the introduction, this report focuses on climate risk as a source of financial risk and this section reviews possible approaches to mitigate such risk. Although these approaches bear considerable resemblance to ESG investment strategies, a key difference is that ESG investing tends to be motivated not only by risk mitigation but also by ethical reasons, the aim to create impact, and/or the aim to enhance portfolio return. Since most pension funds have an interest in these other objectives as well, I will not only discuss the ability of the various approaches to mitigate risk, but also briefly discuss their potential consequences for impact and financial return.

Efficient Markets Hypothesis

The well-known Efficient Markets Hypothesis (EMH; Fama, 1970) defines financial markets as efficient when all relevant information is incorporated into the prices of financial assets. The EMH is relevant for the discussion of climate risk management for two related reasons. First, investors facing decisions about climate risk management should be interested in the question to what extent climate risk is currently priced into the prices of financial assets. If climate risk is perfectly priced in, assets with a greater exposure to climate risk offer investors a risk premium (in the form of a greater expected return) as a compensation for such risk. Investors would then need to decide whether that compensation is high enough for them to be willing to accept the risk. Second, it is conceivable that the increasing emphasis on sustainable investing could lead to financial bubbles in the stock prices of highly sustainable companies (see, for example, Financial Times, 2020). If that is the case, focusing on investments in sustainable companies to mitigate climate risk could actually result in exposure to significant other financial risks, as the bubble might burst at some point in the future. There is a huge body of research on the EMH and sensible people still differ considerably in their views on how efficient financial markets really are. My own view is that financial market prices regularly and significantly deviate from fundamental value, even over prolonged periods of time (see, for example, De Jong, Rosenthal, and van Dijk, 2009; Rösch, Subrahmanyam, and van Dijk, 2017). At the same, it is very hard to profit from market inefficiencies, since abundant evidence indicates that most professional asset managers do not succeed in consistently beating the market.

Is climate risk priced?

The question to what extent financial markets currently incorporate climate risk into asset prices is a difficult one. On the one hand, it is hard to believe that financial markets have correctly priced in a type of risk about there is so much uncertainty and for which there is no historical precedent (Chenet, 2019). This line of argumentation suggests that assets exposed to climate risk do currently not offer a risk premium as a compensation for climate risk, and thus investors could exclude these assets from their portfolios without harming expected returns. On the other hand, the advent of ESG investing has resulted in large capital flows to companies that score well on various sustainability measures. It seems likely that this has – at least to some extent – resulted in a 'demand effect' whereby the prices of sustainable companies have been driven upwards. To the extent that a company's sustainability (or ESG) rating is correlated with its exposure to climate risk[18], this demand effect implies that climate risk has implicitly been incorporated into current asset prices – at least to some extent. Research on the

[18] In this report, I argue that commonly used sustainability measures (or ESG ratings) – such as carbon footprint – are likely positively but far from perfectly correlated with companies' exposure to transition risk, and they probably show little correlation with companies' exposure to physical risk.

pricing of climate risk is still in an early stage and the jury is still out. Various studies cited in Section 4 report mixed results. In their survey of global institutional investors, Krüger, Sautner, and Starks (2019) document these investors' overall belief that the equity valuations of sectors that are most exposed to climate risk do not fully reflect this risk.[19]

Climate risk mitigation approaches

There is no clear classification of the many potential approaches that investors can take to mitigate the climate risk in their investment portfolios. Krüger, Sautner, and Starks (2019) distinguish between 13 different approaches that are not mutually exclusive (ranging from divestment to hedging to engagement). The institutional investors included in their survey rank 'analyzing carbon footprint' and 'analyzing stranded asset risk' as the most popular approaches – without further details on how they are implemented. In the remainder of this section, I briefly discuss the following four main categories of approaches: diversification, exclusion, best-in-class, and engagement.

1. *Diversification*. Diversification across economic sectors, asset classes, and geographic regions is the time-worn approach to reducing the idiosyncratic (non-systematic) risk of an investment portfolio. There likely is considerable heterogeneity in the degree to which different assets are exposed to climate risk. Indeed, while many companies and sectors are likely to be negatively affected by realizations of climate risk, other companies and sectors could be positively affected (Balvers, Du, and Zhao, 2016). The transition to a low-carbon economy is bound to imply a major overhaul of the economic system, disrupting existing business models and sectors and giving rise to altogether new business models and sectors. As a result, there will be winners as well as losers. A broadly diversified portfolio and significant investments in potential winning companies and sectors could thus be effective in reducing the portfolio's overall exposure to climate risk. That said, the power of diversification in reducing climate risk exposure is likely to be limited given the pervasive nature of climate risk. Furthermore, identifying companies and sectors that can be expected to profit from the transition is a difficult task (TEG, 2019a) and climate winners may not be listed companies.
2. *Exclusion.* At a macro level, climate risk is essentially unhedgeable due to its systemic character and the lack of suitable hedging instruments or insurance products (Engle et al., 2019). However, it has been proposed that with an asset class – from a bottom-up approach – investors can hedge against climate risk, while minimizing the tracking error. For example, Andersson, Bolton and Samama (2016) examine a decarbonized MSCI Europe index with a 50% lower carbon footprint than the regular MSCI Europe index. Over 2010-2016, the decarbonized index had a 0.7% tracking

[19] For a more in-depth discussion of the pricing of ESG characteristics and of climate risk, I refer to van Dijk (2020).

error relative to the regular index, with a 0.9% per annum higher return. The authors argue that investing in the decarbonized index implicitly comes with a 'free option on carbon': in a business as usual scenario both indices should offer similar performance, while the decarbonized index should start to outperform once transition risk kicks in. Again, this depends on one's view on market efficiency. This argument only holds if climate risk is currently insufficiently priced in financial markets. In contrast, if climate risk is fully priced – and especially if there already is a bubble underway in the stock prices of low-carbon stocks – the decarbonized index could underperform. The historical outperformance of the decarbonized index over 2020-2016 may well be the result of demand effects caused by investors flocking into low-carbon stocks and driving up their stock prices, possibly resulting in lower returns going forward. Similar arguments apply to exclusion approaches based on other sustainability measures than carbon footprint. They are relatively easy to implement and may improve portfolio-level sustainability measures with a relatively limited tracking error while excluding the worst performing companies or sectors. However, it is unclear to what extent common asset-level sustainability measures truly capture transition risk[20], and the future performance of such strategies depends on the extent to which these sustainability measures are currently priced.[21]

3. *Best-in-class.* An alternative to exclusion is a 'best-in-class' approach, which involves investing in companies that have the highest rating based on one or more sustainability measures within a sector. One appeal of best-in-class approaches is that they more explicitly focus on companies that are in a relatively good position to profit from the transition. Another appeal is that they provide more direct incentives for companies to improve their sustainability performance (to become best-in-class), as opposed to exclusion approaches that tend to eliminate entire sectors (although exclusion could also be done within sectors or 'worst-in-class'). A drawback of best-in-class approaches is that a true identification of 'sustainability leaders' is probably even more challenging than identifying companies with the worst sustainability performance, and require qualitative judgment calls next to quantitative sustainability measures such as carbon footprint. Another drawback is that a relatively narrow best-in-class approach may lead to a substantial loss of diversification by focusing on a limited number of companies. Again, one's view on market efficiency is key. If sustainability performance is priced in, best-in-class investing should be associated with lower expected returns going forward, and individual investors should make the call as to whether the lower expected returns are acceptable in light of the potential reduction in the portfolio's exposure to climate risk.

[20] I am not aware of studies that examine the effect of exclusion of assets that are highly exposed to physical risk.

[21] Bolton and Kacperczyk (2019) find that the stocks of U.S. companies with a greater carbon footprint earn higher returns over 2005-2017, consistent with an implicit risk premium for carbon risk.

4. *Engagement.* While diversification, exclusion, and – to a lesser extent – best-in-class approaches can be described as relatively passive investment strategies, engagement involves active strategies trying to influence the behavior of a limited number of companies through, among other things, shareholder voting and communication with corporate executives. Some argue that engagement is the only way for investors to contribute to the transition and does not need to come at the expense of financial performance (Schoenmaker and Schramade, 2019). Although some initial evidence suggests that engagement could potentially result in better sustainability and even financial performance of the companies involved (Dimson, Karakaş, and Li, 2015, 2019), we currently know little about how effective engagement is in reducing climate risk exposure[22], and engagement likely involves substantial costs as well as loss of diversification. For pension funds solely interested in risk mitigation (and thus not in creating impact), engagement does not seem to be the most obvious approach.

6. Conclusion and recommendations

In this report, I have provided an overview of the importance of climate risk for investment portfolios, of relevant climate risk regulations and guidelines for pension funds, of four main categories of climate risk assessment approaches, of various data sources to assess asset-level climate risk exposure, and of several potential climate risk mitigation approaches. In this section, I synthesize my findings and provide a number of recommendations that reflect my personal viewpoints. In light of the complexity of the issue of climate risk, my recommendations should be viewed as broad directions for thinking about this issue, and as a stimulus for further research and discussion.

Approaches to assess climate risk (Section 3)

Institutional investors show increasing interest in assessing the degree of climate risk in their investment portfolios. Since 2019, Dutch pension funds need to explicitly include climate risk in their 'own-risk assessment' (Section 2). I have distinguished between four broad categories of approaches: top-down (or 'macro'), sector-level, bottom-up, and factor model approaches. In my opinion, current factor models are not fit to properly assess climate risk. Macro approaches are appealing because they aim to account for the far-reaching impact of climate risk on the global economy as a whole. However, macro approaches are essentially black boxes that provide few insights into how exactly an investment portfolio may be affected by climate risk. Hence, they do not facilitate an informed discussion. Also, within an ALM framework, the reported effects on pension funds may be dominated by the interest

[22] Hoepner et al. (2019) present evidence suggesting that ESG engagement is associated with lower downside risk. However, downside risk measures based on historical stock returns over 2005-2018 are a crude proxy for climate risk going forward.

rate projections, which are subject to a great deal of uncertainty. As a result, I believe that the value of macro approaches for understanding climate risk is limited. Bottom-up approaches seem almost inevitable, since it seems hard to obtain a reliable overview of climate risk in an investment portfolio without examining how climate risk could affect individual assets. Bottom-up approaches are also relatively transparent and tractable, and usually do not rely on intricate macro-econometric models that are essentially black boxes. However, data quality is a major concern for bottom-up approaches (Section 4). Furthermore, they do not assess the broader effects of climate risk and run the risk of turning into large data-driven exercises that obscure the economic narrative on how exactly climate risk might influence individual companies or sectors. Therefore, I advocate sector-level approaches as a complement to bottom-up approaches in assessing the impact of climate risk. Sector-level approaches have the advantage that they examine the broader economic impact of climate risk within a tractable framework that makes apparent the different channels through which climate risk could affect various economic sectors. Of course, sector-level approaches also suffer from a number of important drawbacks and challenges (such as sector classifications, assumptions on abatement and pass-through, as well as data quality), but they do facilitate an informed discussion about how climate risk could affect investment portfolios at a broader level.[23]

Data sources to assess climate risk (Section 4)

The advent of ESG investing and the view of climate change as a source of financial risk has spurred the development of a host of databases by different data providers that aim to assess sustainability performance and climate risk exposure at the individual asset-level (e.g., individual stocks / bonds). I have discussed what I view as the three main concerns about these sustainability measures: limited coverage and data quality, disagreement across data providers, and – perhaps most importantly – what to measure exactly in the first place. There is no easy solution here. To assess physical risk, detailed data on the geographic location of physical assets and location-specific climate projections seem indispensable, but hardly sufficient. To assess transition risk, 'output' measures such as carbon footprint likely contain useful information, but paint far from a complete picture of a company's exposure to climate risk – if only because they are not forward-looking. Ultimately, a comprehensive assessment of both physical and transition risk requires a judgment call on what qualitative measures of a company's ability to adjust to climate change effects (as well as the consequences of climate change for the company's supply chain and sector) could supplement quantitative measures such as carbon footprint.

[23] I do not mean to say here that the macro-economic effects of climate change should be ignored altogether, but rather that they could in part be incorporated in sector-level approaches and/or – instead of using a fully-fledged macro-econometric model – could be examined in a more parsimonious and tractable way (e.g., a more discretionary fundamental approach).

Approaches to mitigate climate risk (Section 5)

I have briefly described four prominent climate risk management approaches: diversification, exclusion, best-in-class, and engagement. I have argued that the financial consequences of each of these approaches depend on the degree of market efficiency – in particular, on the extent to which sustainability measures and/or climate risk are priced in financial markets. My descriptions of these approaches serve illustrative purposes about their main features. Concrete recommendations on climate risk mitigation approaches are beyond the scope of this report.

Investment beliefs

In my view, a comprehensive approach to assessing and managing climate risk requires two types of 'investor beliefs' (Slager and Koedijk, 2007). First, given the intricacies of measuring climate risk, formulating explicit beliefs about different climate change scenarios (as an example, see Figure 3 of Global Investor Coalition on Climate Change; GIC, 2015) as well as about how physical risk and transition risk could affect various economic activities is helpful to stimulate informed discussion about climate risk in investment portfolios. Second, evaluating the merits of different approaches to mitigate climate risk requires beliefs about the extent to which sustainability measures and/or climate risk are currently priced in financial markets.

Irrespective of one's specific beliefs, a healthy sense of skepticism is essential in assessing and managing climate risk. There is so much uncertainty that any model or approach is fundamentally flawed and likely ignores 'green swan' events (Bolton et al., 2020).

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