CEP council on economic policies

Integrating Climate Risks into Credit Risk Assessment

Current Methodologies and the Case of Central Banks Corporate Bond Purchases

Pierre Monnin

December 2018

Discussion Note 2018/4

Abstract

Climate change and the transition to a low-carbon economy to mitigate it engender significant economic costs. These costs are ultimately borne by households and firms, affecting their cash flows and wealth, which are key determinants of their credit worthiness. Climate-related costs are thus a source of credit risk.

An accurate assessment of all credit risks, including climate credit risk, is central for creditors including central banks. If they underestimate it, they are exposed to financial losses and to the risk of holding assets of inadequate credit quality.

Assessing climate risks requires methodologies based on forward-looking scenarios, on complex cause-and-effect linkages and on data that has not been observed in the past. Such models are at their infancy, but already offer meaningful insights. This note provides an overview of key components that such models are built on and illustrates them with examples of the analytics that are already available. It also applies one of the available methodologies to assess transition risk to the corporate bond holdings of the European Central Bank.

About the Author

Pierre Monnin is a fellow with the Council on Economic Policies (CEP), where his work focuses on the distributive effects of monetary policy and on the role that central banks can play in the transition toward an environmentally sustainable economy. Before that,

he was with the Swiss National Bank (SNB) in various roles for 10 years, counselling SNB's board members on issues concerning financial markets and monetary policy as well as developing measures of financial stability and integrating them into the bank's monetary policy framework. He also worked at Man Group as a quantitative analyst, developing asset allocation strategies for alternative investments. Dr. Monnin holds a PhD in economics from the University of Zurich, an MSc in economics from Queen Mary University of London, as well as an MSc in statistics and a BA in economics from the University of Neuchatel.

CEP Discussion Notes

CEP Discussion Notes are published by the Council on Economic Policies (CEP), an international economic policy think tank for sustainability focused on fiscal, monetary and trade policy. The views expressed in these publications are those of the authors and do not necessarily represent those of CEP or its board. Discussion notes describe policy-related analysis and research. They are published to elicit comments and further debate.

CONTENTS

1 INTRODUCTION

Climate change engenders significant economic costs. The most obvious ones are the damages caused by extreme weather events such as storms or floods. Disruptions in supply chains, higher prices following shortages due to droughts or lower labor productivity in extreme heat periods are further examples. These *physical costs* are already affecting our economies today and will be increasing with time.

The transition to a low-carbon economy, which is necessary to mitigate these physical costs, also comes with a price: investments in low-carbon technologies must be made, carbon prices will reduce margins and existing polluting productive assets must be written-off. Such *transition costs* will also be substantial

Physical and transition costs are ultimately borne by households and firms. They translate in higher expenses and lower revenues – i.e. they decrease households' and firms' cash flows. They can also trigger significant assets revaluation and impact households' and firms' wealth. Cash flows and asset wealth, as well as their volatility, are key determinants of households' and firms' financial soundness and thus of their ability to service their debt; lower cash flows and lower asset values worsen their creditworthiness. Physical and transition costs are thus a source of credit risk – i.e. a *climate credit risk*.

An accurate assessment of credit risks, including climate credit risk, is key for creditors, such as banks and bond holders. If they underestimate this risk, creditors are exposed to unexpected and potentially large financial losses. Such losses, if large and simultaneous, can become systemic and generate financial instability. An accurate assessment of credit risk is also important for central banks. One fundamental principle of central banking is that, when providing liquidity to financial markets, central banks must require low-risk assets as collateral. If central banks underestimate risks by overlooking climate-related credit risk, they might breach this rule, by accepting assets as collateral that do not meet these stringent risk standards.

Currently, financial markets do not adequately reflect climate risks. For example, the Central Banks and Regulators Network for Greening the Financial System (NGFS) highlights that "climate- or environmental-related criteria are not yet sufficiently accounted for in internal credit assessments or in […] credit agencies' models" (NGFS 2018, p. 9).[1] Climate credit risk is thus likely to be significantly underestimated in current credit risk analysis. This has serious consequences: as mentioned above, first, it exposes creditors to potentially large losses and second, it could result in central banks accepting collateral of inadequate credit quality. In addition, if credit prices do not adequately reflect climate credit risk, they send signals and

[1] See also Mathiesen (2018) for a discussion on how credit agencies are likely to underestimate climate risks, or Monnin (2018, p.2) for a more general discussion on why financial markets do not fully reflect climate risks.

incentives to investors that lead to a misallocation of capital and drive investments away from an environmentally sustainable path. These signals and incentives are amplified by monetary policy operations, if central banks also fail to adequality reflect climate credit risk in their monetary policy operations (see Monnin 2018).

One reason why current credit markets do not reflect climate credit risk is that climate costs are not captured by the asset valuation models that market participants use – in particular because these models are calibrated on past data, which give poor or no indication on future climate costs. Assessing climate risks requires forward-looking scenarios that are based on complex cause-and-effect linkages and data that has not been observed in the past. Such models are at their infancy, but already offer meaningful insights. Enhancing and mainstreaming them is a critical next step for financial markets to safeguard current risk standards.

Against this background, this note provides an overview of key components that such models are built on and illustrates them with examples of the analytics that are already available. It is not meant to be exhaustive but rather to outline starting points and pathways to accelerate momentum in the field. Section 2 briefly introduces the notion of climate risks and how it turns into credit risk. Section 3 dives deeper into the methodologies available to estimate physical and transition risks and to reflect them in credit assessments. To illustrate how integrating climate credit risk could change central banks' operations, Section 4 applies one of the available methodologies to assess transition risk in the corporate bond holdings of the European Central Bank (ECB). This example illustrates how the integration of climate risks would lead to a downgrade of certain assets below the investment grade rating that the ECB requires for both its asset purchases as well as its collateral framework. Section 5 concludes.

2 From Climate Risks to Credit Risk

Climate risks are a source of credit risk. To better understand why, we first introduce the notion of climate risks and the different types of risk that it includes and then explain how these risks translate into credit risk.

2.1 What are climate risks?

The NGFS, as well as the G20 Sustainable Green Finance Study Group (formerly the G20 Green Finance Study Group – GFSG), identify two main sources of financial risks emerging from climate change: *physical risks* and *transition risks* (see GFSG 2016 and NGFS 2018).[2] Both types of risk can potentially impact households' and firms' cash flows, as well as the

[2] Some authors add liability risks as a source of risk stemming from climate change (see e.g. Batten *et al.* 2016). In this note, following the example of the NGFS and the GFSG, we focus on physical and transition risks.

value of the assets they own. Changes in both cash flows and asset values affect households' and firms' credit risk.

Physical risks

Physical risks correspond to the potential economic and financial losses caused by climate-related hazards. They are divided into two categories: acute hazards and chronic hazards. Climate-related hazards are considered acute when they arise from extreme climate events such as droughts, floods and storms; they are chronic when they arise from progressive shifts in climate patterns such as increasing temperatures, see-level rise and changes in precipitation. Risks from acute and chronic hazards comprise both their direct impacts (like e.g. damages to property or disruptions of firms' operations) and their indirect impacts (like e.g. disruptions in the supply chain or lower aggregate demand from affected markets).

Transition risks

Transition risks can be defined as the risks of economic dislocation and financial losses associated with the process of adjusting toward a low-carbon economy. Three sources of transition risks are usually considered as relevant for the financial sector: changes in policy (e.g. higher carbon prices or limits on carbon emissions), changes in technology (e.g. low-carbon technologies becoming more competitive than carbon-intensive ones) and changes in market preferences (e.g. households switching toward greener consumption due to environmental concerns). All three types of change will require financial efforts for firms to adapt their business models to the new economic conditions.

At the same time, not all firms will be equally impacted; winners and losers will emerge both at the sectoral and at the firm level. The availability of low-carbon alternatives to a sector and the preparedness of individual firms within a sector are key factors to consider in that context.

2.2 HOW DO CLIMATE RISKS TRANSLATE INTO CREDIT RISKS?

Credit risk is the risk of a financial loss resulting from a borrower's failure to repay part of or all the interests and the principal of a loan. Credit risk is calculated based on the borrower's ability to repay and service its debt. Three dimensions play a key role in determining credit risk: a borrowers' capacity to generate enough income to service and repay its debt, as well as the capital and collateral that back the loan. The first dimension depends on a borrower's cash flow, the second on its financial wealth, the third on the value of the collateral. The higher the cash flows, the overall financial wealth and the value of the collateral, the lower the credit risk. Climate risks affects all three dimensions and may thus lead to both higher probabilities of default and higher losses given default.

Climate risks and cash flows

Physical risks can negatively impact on firms' cash flows through several channels such as reduced revenue from decreased production capacity (e.g. due to supply chain interruptions and worker absenteeism) and lower sales (e.g. due to demand shocks and transport difficulties), as well as increased operating costs (e.g. due to the need to source inputs from alternative more expensive supplies) and increased capital costs (e.g. due to damage to facilities).

Transition risks can also affect cash flows in several ways, including, for example, research and development expenditures in new and alternative technologies, costs to adopt and deploy new practices and processes, reduced demand for carbon-intensive products and services, as well as increased production costs due to changing input prices (e.g. for energy and water) and output requirements (e.g. for carbon emissions and waste treatment).

If not properly assessed, the increase in costs and decrease in revenues associated with climate change will result in lower than expected cash flows. Depending on its financial conditions, lower cash flows may impair a firm's capacity to service and repay its debt. Both physical and transition risk are thus a source of credit risk through their impact on cash flows.

Climate risks, capital and collateral

Physical risk can reduce the value of households and firms' assets both through direct damages e.g. to houses and factories during extreme weather events, but also through write-offs of assets situated in high-risk locations. The transition to a low-carbon economy can also significantly affect the value of households' and firms' assets: potential re-pricing of stranded fossil fuel assets is a case in point. Changes in real estate valuation due e.g. to stricter energy efficiency standards provide further illustration. Changes in asset valuations affect both the capital as well as the collateral that underpin credit and thus add a further channel through which climate risks are a source of credit risk.

3 How to Assess Climate Credit Risk

As highlighted by the NGFS, the tools and methodologies to assess climate financial risks are at an early stage. There are a number of analytical challenges and there is a need to build intellectual capacity in translating the science into analytics that can be integrated into financial decision-making (NGFS 2018). Against this background, this section first lays out the main building blocks that such tools rely on. It then describes general principles that should guide the development of adequate methodologies and then provides an overview on tools and data already used by financial market participants today.

3.1 BUILDING BLOCKS: FROM CLIMATE SCENARIOS TO FINANCIAL RISK MEASURES

To assess the impact of climate change on credit risk, the methodologies used by market participants usually follow three steps:

1. *Defining climate scenarios*: the estimation of the impact of climate change and of the transition to a low-carbon economy on credit risk relies first on the definition of physical scenarios for climate change and for the transition. These scenarios define how climate change will impact the variables that are relevant for economic activities, how a transition will mitigate these impacts and which measures are taken to steer the transition.
2. *Estimating economic and financial impacts*: once the impact of climate change on the variables relevant for economic activities has been estimated, its consequences must be translated into economic terms though macro and microeconomic simulations. This step basically assesses the direct and indirect repercussions of climate change and the transition to a low-carbon economy in economic terms and identifies which actors are affected by them and by how much. Once the economic effects on actors have been identified, the next step is to estimate the impact of these effects on both their cash flows and their balance sheets.
3. *Translating financial impacts into credit risk measures*: based on this assessment of financial impacts on firms and households, the next step is to compute how changes in cash flows and balance sheets will affect their credit worthiness in terms of probability of default and loss given default – and thus also in their credit ratings.

The different options used by market participants to implement these building blocks are described in more detail below. They however face similar methodological challenges that are briefly discussed in the next section.

3.2 METHODOLOGICAL CHALLENGES

Tackling five challenges is common to all methodologies estimating the credit risk impact of climate change, in terms of both physical and transition risks: 1) addressing the limitations of historical data, 2) expanding the horizon of credit risk models, 3) finding the right level of data granularity, 4) identifying the relevant climate risk exposure metrics and 5) translating economic impact into financial risk metrics.

Addressing the limitations of historical data

Past data, whether physical, economic or financial, are a poor indication of future developments related to climate change. Its usefulness to forecast future credit risk is thus limited. To tackle this problem, most methodologies developed so far rely on scenarios that estimate the impact of different greenhouse gas emission pathways and related mitigation measures on temperatures and further physical indicators (e.g. change in precipitation patterns, sea level rise) and on economic variables (e.g. change in productivity, stranding of assets, change in firms' costs). One aspect to keep in mind in that context is the fact that – as always in scenario-based analysis – several configurations and thus outcomes are possible. Different scenarios with different pathways will result in different analytics. Clarity on the underlying assumptions of each scenario is thus critical for a meaningful debate and comparison of results. Whether analysts choose a scenario that is aligned with the objective to limit global warming at 1.5 °C above pre-industrial levels, with the pledges that countries have made in the Paris Agreement, or with their view on what the most plausible outcome is, matters significantly.

In that context, it is imperative to remain conscious that climate scenarios are based on complex models that rely on many hypotheses, on physical and economic relationships that have not yet been observed and on possible feedback loops and non-linearities between the different physical and economic components. As a result, the output of different scenarios is very sensitive to the hypotheses underlying them. The value of the discount rate, the timing and magnitude of the transition, as well as the evolution of policies and technologies are key parameters that crucially influence their results.

Expanding the horizon of credit risk models

Assessing climate risks also requires extending the traditional horizon of credit analysis. One major reason why climate risks are not already considered by market participant is that climate change related risks are assumed to lie behind their traditional analysis horizon of one to three years. An adequate assessment of climate risks should go beyond this timeframe and extend the analysis to a horizon of at least 15 years. We see two reasons why using a shorter horizon is not satisfactory: first, because "while the financial risks may be realized in full over extended time horizon, the risks call for action in the short-term to reduce impact in the long-term." (NGFS 2018, p. 3) and second, because "it is delusional to think that when risks become perceptible, everyone will be able to cut their exposures at the same time and in an orderly fashion" (Villeroy de Galhau 2018).

Finding the right level of data granularity

Ideally, to assess the climate-related risk of a bond or a loan, we should assess the climate risks that the firm (or household) issuing the bond or getting the loan faces. Firms and households are all differently affected by both physical and transition risks. Physical risks are linked to the geographical location of household assets and of the firm's factories and suppliers, as well as to the resilience of these assets to cope with climate change. Transition risks are a function of households' and firms' assets and business models as well as their ability to align themselves with the transition to a low-carbon economy.

Against this background, the assessment of climate credit risk is ideally based on household and firm-level data. At the same time, access to that level of granularity is limited. As a result, estimations of transition risks are currently often made at the industry level and thus do not account for winners and losers within a sector (e.g. between oil companies with different exposures to renewable energy). Similarly, analytics of physical risks are frequently based on assessing the impact across an entire region and thus do not reflect different degrees of resilience of assets within the region (e.g. to account for different degrees of flood resilience in buildings). Yet, comprehensive granular data at the corporate and household level is not easily available and getting it is potentially associated with high cost. There is thus a trade-off between the accuracy of the assessment and costs of the underlying data. Where to strike the balance will depend on the use case and will change over time as data becomes more readily available. In that context, some studies have chosen the approach to rely on very granular data and an extensive analysis for a sample of firms for a specific sector or region and then to extrapolate its results to the rest of the economy (see e.g. UNEP Finance Initiative and Oliver Wyman, 2018).

Identifying the relevant climate risk exposure metrics

There is a vast array of metrics to assess climate related exposures. For physical risks, the location of household assets as well as a firm's production sites, suppliers and customers provide initial insights, but do not offer information on the resilience of these assets. For transition risks current carbon emissions give an indication of exposures but remain mute on the ability of households and firms to reduce their emissions and, in the case of companies, to pass on higher carbon costs to their customers.

Carbon footprints are currently the main indicator used by financial market participants to integrate climate change in their valuation models. This metric, however, provides only a very incomplete, if not misleading, picture. On the one hand, carbon footprints do not deliver any information about the physical risks that households and firms face, on the other, they neither reflect information of a firm's possibilities to switch to low-carbon technologies, nor of its preparedness to do so and its ability to pass on higher costs to its customers.

In addition, current measures of corporate carbon footprints often only comprise a firm's direct emissions (Scope 1) and the emissions for the energy it uses (Scope 2) and thus fall short of covering emissions across the entire value chain of a firm including those by its suppliers and its customers (Scope 3).

To move beyond current carbon footprints providers of climate risk analytics have started integrating further metrics into their methodologies. Examples include firms' investment plans (2° Investing Initiative 2016), green technology patents that have been filed (Carbon Delta 2018), qualitative information on corporate climate strategies (UBS 2018), as well as price elasticities reflecting the ability of companies to pass on cost increases (Schroders 2017).

Translating economic impacts into financial risk measures

A final challenge is to translate estimations of economic impacts into concrete and useful measures of credit risk such as probabilities of default, loss given default and thus credit ratings. To do so, we must consider the initial financial situation of firms and households, the financial consequences of the economic impact of climate change through changes in cash flows and asset values, and the type of asset under scrutiny.[3]

The key step is to translate economic costs into financial impacts on households and firms. Once the financial impact is estimated, traditional credit assessment tools, which rely on financial data as input, can be used to measure changes in credit risk. The integration of financial impacts into a Merton model is a case in point.

3.3 DEVELOPING CLIMATE SCENARIOS

The factors to consider in the development of climate scenarios are quite different depending on whether we seek to assess physical risks or transition risks. Both sets of variables are described separately below. Note however that physical and transition risks are linked as the latter determines the magnitude of the former.

Physical risk scenarios

Defining physical risk scenarios requires to make four key choices: 1) which type of climate-related hazards are modelled, 2) which regions are studied, 3) which regional granularity is used, and 4) which climate change severity and trajectory is assumed.

The types of climate-related hazards that are usually considered are:

- Heat stress and changes in temperature patterns,
- Water scarcity and droughts,
- Extreme precipitation,
- Floods,
- Wildfires,
- Sea level rise,
- Cyclones, hurricanes and typhoons.

[3] Changes in cash flows and asset values do not have the same impact on credit ratings for loans, bonds or asset-backed securities. Cash flows matter for all of them. Changes in the collateral value impacts credit ratings for loans only. The structure of asset-backed securities is important to understand how cash flows and collateral value affect the credit rating of a security.

Ideally, to fully capture physical risk, all hazards should be included into the analysis, but in practice, several scenarios focus on one or a few of these hazards only. Similarly, a comprehensive assessment of physical risk would require a worldwide assessment as climate hazards in one region can affect firms in other parts of the globe, e.g. through their supply chain and through factories that they own abroad. In practice, however, most studies focus on a specific geographical area. Narrowing the focus to a specific area can make sense if a study zooms in on economic actors whose exposure is concentrated in that area (e.g. households in a specific region who face the risk of their real estate values being affected).

A further aspect to define is the level of granularity within regions. Projections for climate-related hazards at a disaggregated geographical level are key for assessing physical risk. Such granularity is already provided by several providers based on historical data. Examples include the UNEP Global Risk Data Platform, ThinkHazard!, Princeton Climate Analytics, Swiss Re's CatNet or Munich Re's NatCatSERVICE. Data from e.g. the International Panel on Climate Change and the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) already includes scenarios for different regions. Specific studies, such as De Nederlandsche Bank (2017), are already based on scenarios that provide data on a disaggregated level within a country.

Scenarios also differ in the severity and trajectories of global warming that they assume. A business-as-usual scenario where greenhouse gas emissions continue to rise at current rates is expected to lead to global warming of 4°C. Scenarios that reflect commitments under the Paris Agreement still leave the world with temperature increases of more than 3°C. Scenarios with more ambitious reductions in emission pathways and in line with the objective that was agreed in the Paris Agreement limit temperature increases to 2°C or 1.5°C. On that note, the assumptions on the trajectories through which the scenarios evolve are also key. The fact that many physical impacts that scientists had originally anticipated over a much longer time horizon are already being observed today across the globe, is a case in point.

Note also that some studies focus on specific economic sectors that are particularly exposed to physical risk. The agricultural sector, the energy and utilities sector and the real estate sector are often studied separately, as they are very sensitive to weather conditions and floods (see, e.g. case-studies in UNEP Finance Initiative and Acclimatise 2018). A comprehensive assessment of physical risks would however require a sector-wide assessment as climate hazards in one sector can affect firms in other sectors, e.g. through their supply chain.

Transition risk scenarios

Like physical risk scenarios, the definition of transition risk scenarios also requires decisions on several parameters – in particular answers to the following three questions: 1) what is the level of ambition in terms of emission reduction and limiting global warming, 2) what is its speed and 3) what are the drivers of the transition?

The first choice to make is to determine the level of ambition of the transition in terms of emission reductions and warming above pre-industrial levels. Widely used goals include the following:

- *An increase in global temperatures of 1.5°C*. This scenario is the most ambitious and the one that minimizes the physical damages of climate change among the ones used. It is studied in depth in e.g. IPCC (2018).
- *An increase in global temperatures of 2°C.* This scenario corresponds to the objectives of the Paris Agreement, which as of December 2018 was signed by 195 countries.
- *Emission reductions in line with current reduction pledges*. This scenario corresponds to the increase in global temperatures that will occur given the emission reductions that countries have individually pledged in the Paris Agreement. It is estimated to lead to an increase in temperatures higher than 3°C.
- *Scenario based on countries' emission reduction targets*. This scenario is based on countries targets as defined in national laws and policies. These emission reductions sometimes differ from countries' pledges (see Grantham Research Institute on Climate Change and the Environment 2018)

The second choice to make is to determine the speed of the transition. The path toward a reduction of emissions can have significant consequences for transition risks. For an identical level of cumulative emission reductions, an early and smooth transition is likely to result in lower transition risk, compared to a late and sudden transition.

The third and last choice to make is to determine the main drivers of the transition. Three levers are usually considered:

- *Policy change*: this driver covers a variety of policy measures, including higher carbon prices, setting limits to emissions, reducing subsidies to carbon-intensive technologies, increasing those for low-carbon alternatives, or banning certain products and technologies. Often, the policy change is simulated with an increase in carbon prices. The size of this increase can be set exogenously (see e.g. Vermeulen *et al*. 2018) or it can be calibrated to trigger the desired amount of emissions reduction (see e.g. Carbon Delta 2018).
- *Technological change*: this driver reflects unanticipated technological advances and cost reductions in low-carbon technologies which lead to a larger market share of these technologies than currently expected. Such a development would also imply that certain parts of carbon-intensive capital must be written-off.

- *Preference change*: this driver is based on a shift in consumer preferences towards low-carbon goods and services.

While all these drivers can and are likely to underpin the transition to a low-carbon economy, they have different impacts on different sectors (see Vermeulen *et al.* 2018). Accounting for these differences and for the way these drivers interact is critical for an assessment of transition risks.

3.4 ESTIMATING ECONOMIC IMPACTS

Once scenarios are defined, they provide the starting point to estimate how climate change and the transition to a low-carbon economy impact on debtors' – i.e. households' and firms' – economic situation. The impact on firms will influence credit risk for bonds, loans and asset backed securities, the impact on households will affect credit risk for loans and asset backed securities, such as those underpinned by mortgages and car loans.

In practice, most analytics that are available today focus on firms' exposure to physical and transitions risks. We outline three elements that must be considered in this context and that are applicable analogously to households below:

- *Direct impact*: firms are directly impacted by climate risks through, e.g., disruptions in their own operations or direct damages to their assets from physical hazards and through, e.g., higher carbon prices or investment costs in low-carbon technologies as a result of transition measures.
- *Indirect impact*: firms can also be affected by the consequences of climate change through the impacts on their supply chains or on their customers. Physical risks can generate disruptions for their suppliers or create changes in their input prices. They can also affect their customers and thus demand for a firm's product and services. Similarly, transition risks can induce higher input costs and alter demand patterns.
- *Macroeconomic impact*: finally, physical and transition risks have a broader impact on macroeconomic conditions. At the macroeconomic level, climate change can affect capital and labour productivity, prices of inputs or the aggregate demand from households.

All three elements must be taken into account to measure the full impact of physical and transition risks on credit risk. The methodologies to assess them is however different for physical and transition risks. Both are described separately in the next sections.

Physical risks

Climate-related hazards are not a new phenomenon. Financial institutions have a long history of assessing and managing physical risks – especially in the insurance and the reinsurance sectors which have extensive data sets on past events and related economic costs. Their insights provide a useful starting point to estimate future risks. However, an important element to consider is that climate change is accelerating and exacerbating risk trends – both in terms of frequency and the gravity of shocks. These trends must be reflected in combination with historical data to give a robust picture of future climate costs.

In that context, a key parameter to assess physical risks is geographical data. For direct risks, it is critical to know the geographical location of factories; for indirect risks, the location of suppliers and customers is important. These locations must be mapped against the regions in which climate-related hazards are likely to happen. Geographical data on factories, suppliers and customers is seldom publicly available, but is increasingly provided through proprietary databases. 2° Investing Initiative (2017) provides a useful overview of the data available at the asset level.

For direct physical risks, the most important information is the location of the factories of a firm. Four Twenty Seven, a US-based provider of analytics on the economic risk of climate change, has, for example, identified the location of over 68'000 facilities (manufacturing plants, distribution centres, warehouses, offices, etc.) of the firms included in the CAC40 stock index (see Deutsche Asset Management 2017). They then mapped the location of these facilities with geographical projections for heat stress, water stress, extreme precipitation, wildfires, sea level rise as well as hurricanes and typhoons to calculate a score between zero and 100 that reflects each firm's exposure to physical risk. TD Bank Group, Bloomberg and Acclimatise conducted a similar analysis for the power and utilities sector in North America using data on asset locations, observed extreme weather events and expected changes in power production capacity due to climate change impacts provided by Bloomberg MAPS (see UNEP Financial Initiative and Acclimatise 2018). The input data underpinned a calculation of changes in revenues and costs of goods sold for each borrower. According to their results physical risks induce a one-notch downgrade for most borrowers.

For indirect physical risks, the key element to know is the location of a firm's suppliers and customers. We are not aware of a database that currently provides this information. One alternative used by studies to gauge the impact of indirect physical risks is to turn to geographical input-output tables.[4] This approach does not offer a precise assessment but gives a rough estimation of the regions they depend on for their supply chain and sales.

A last dimension that must be accounted for to assess the physical risks of a firm is its specific degree of sensitivity to climate-related event – i.e. to which degree its infrastructure can

[4] Carbon Delta (2018) uses a similar approach with economic input-output tables to assess transition risks.

resist to climate hazards better than others – and its adaptative capacity – i.e. how fast it can adjust to hazards or respond to their consequences. Analysts can provide such an input. Data on how firms coped with past climate hazards can also give an indication on their sensitivity and their adaptive capacity (this is the option chosen by Four Twenty Seven, see Deutsche Asset Management 2017).

Transition risks

Transition risks arise from the impact of the transition to a low-carbon economy on firms' revenues and costs. Three main sources of costs are key to consider in this context: higher carbon prices on emissions, investments to reduce emissions and to adapt to stricter low-carbon standards, and write-offs of stranded assets.

The total direct costs resulting from higher carbon prices are a function of a firm's emissions and its investments to reduce them. Higher carbon prices will also induce indirect costs through increased input costs associated with the emissions of a firm's suppliers. On that note, it is important to remain conscious that carbon prices are likely to remain different from one country to another. As a result, the geographical spread of a firm's emissions according to the location of its production facilities and its suppliers is an important data point to estimate total carbon costs. In view of the limited availability and granularity of Scope 3 emission data some studies use country-level input-output tables to estimate where emissions of a firm come from, which carbon price it thus faces on them and how this will affect its cash flows over the next years (see e.g. Carbon Delta, 2018, and Schroders, 2017).

In addition to the costs for their emissions, firms are likely to face investments costs to reduce emissions and to adapt their production as well as their products and services to stricter low-carbon standards. The magnitude of these costs will depend on the price of low-carbon technologies as well as a firm's capital costs.

The transition to a low-carbon economy will make many existing assets obsolete. Writing-off such assets will induce additional costs for firms and affect their balance sheets. The stranding of fossil fuel reserves is an illustration, but not the only one: the transition to a low-carbon economy will require many production processes as well as products and services to be adapted. Some economic activities will not be profitable anymore – thus expanding the notion of "stranded assets" to "stranded business plans".

A key dimension to consider when estimating the impact of these transition costs on firms' financials is the extent to which they can pass them on to their clients. Higher costs decrease firms' margins but may at least partially be offset through higher prices. The impact of transitions costs on firms' cash flows is thus dependant on how the demand from consumers will change in response to price increases – i.e. the impact on cash flows is a function of the price elasticity that firms face. Accounting for such price elasticities and thus the effect of price increases on sales is a further component of estimating transition risks (see e.g. Schroders 2017).

Finally, in addition to these quantitative inputs, a growing number of providers have started integrating qualitative measures to assess the preparedness of companies for a transition to a low-carbon economy. Examples include indicators that reflect a firm's investment plans (see e.g. 2° Investing Initiative 2016), the number of patents in low-carbon technologies that it owns (see e.g. Carbon Delta 2018), as well as commitments it has made and organizational capacity it has built to lower its emissions (see e.g. RobecoSAM 2018 and UBS 2018).

3.5 FROM ECONOMIC IMPACTS TO CREDIT RISK MEASURES

Once climate costs have been estimated – ideally at the firm level – the next and final step is to translate them into useful risk measures. The risk measures traditionally used by creditors are probability of default loss given default and – as a reflection of these two measures – credit ratings.

Analyst judgement and experience plays a crucial role in that context – especially in cases where climate risks are reflected in scores that denote a relative positioning of a company in its sector, but not yet linked to an estimate of financial impacts.

As for quantitative approaches, the calculation of probabilities of default is commonly based on the Merton model. This framework estimates the likelihood that the value of a firms' assets falls below its liabilities, making it incapable of repaying its debts and thus triggering a default.

To estimate the impact of climate risks on a firm's probability of default with the Merton model starts with estimating how these costs – i.e. changes in cash flows and write-offs – affect its assets. This is computed by subtracting the net present value of all physical and transition costs from the current valuation of the firm to estimate a valuation that accounts for climate risks. The new valuation is then used to compute an amended default probability and thus a credit rating that is sensitive to climate risks. Given the wide use of credit ratings in investment processes such an amendment would provide a "plug and play" approach to integrating climate risks into a broad part of financial markets. The corporate bond purchases of central banks are a case in point.

4 Climate risks and central banks' corporate bond purchases: the case of the ECB

Central banks use credit risk assessments across different monetary policy operations. To conduct conventional monetary policy – i.e. when providing liquidity to financial institutions against collateral – internal and external credit assessments determine which assets are of sufficient credit quality to be accepted as collateral. Similarly, for unconventional monetary policy – e.g. for outright asset purchases – central banks define the universe of eligible assets based on internal and external ratings and confine themselves to buying only low-risk assets.

In its first progress report, the NGFS highlights that "climate- or environmental-related criteria are not yet sufficiently accounted for in internal credit assessments or in […] credit agencies' models which many Central Banks rely on for their operations" (NGFS 2018, p. 9). Accounting for climate risks in central banks' credit risk assessment, either by including them into their internal credit risk systems or by adding them to credit agencies' ratings, is thus likely to change the set of assets that they currently accept as collateral or buy: once climate risks are properly accounted for some securities might not meet the established risk standards for such operations and would thus need to be dropped from the list of eligible assets.

To provide a preliminary illustration of this effect and an input for further discussions, the following section investigates how integrating climate risks could affect the asset purchases of one particular central bank. We focus on the ECB's Corporate Sector Purchase Program (CSPP) and examine how adding the measure of transition risk provided by Carbon Delta to current ratings would change the set of assets eligible for purchase. The example illustrates that integrating climate credit risks into current risk frameworks may indeed have repercussions on central banks' asset purchases.

4.1 ECB's corporate sector purchase programme

The ECB started buying corporate bonds under the CSPP in June 2016. As of end-November 2018, its corporate bond holdings stood at EUR 176bn. The ECB's collateral framework – i.e. the rules that lay down which assets are acceptable as collateral for monetary policy credit operations – is the basis for determining the eligibility of corporate sector securities to be purchased under the CSPP. To be eligible for purchase, debt instruments must fulfil the following criteria:

- they must be eligible as collateral for Eurosystem credit operations;
- they must be denominated in euro;

- they must have a minimum first-best credit assessment of at least credit quality step 3 (rating of BBB- or equivalent) – i.e. they must be investment grade;
- they must have a minimum remaining maturity of six months and a maximum remaining maturity of 30 years at the time of purchase;
- the issuer must be a corporation established in the euro area, defined as the location of incorporation of the issuer;
- the issuer of the debt instrument must not be a credit institution.

The third requirement – i.e. minimum credit quality – is key in our context. According to the NGFS, as referenced in the introduction, climate-related criteria are not yet sufficiently accounted for in the models of credit agencies. Yet, it is these models that underpin the external ratings that the ECB uses to determine whether an issuer meets its credit quality requirement. As a result, the ECB may currently be investing in securities that are rated as investment grade, but that would fall below its own risk standard, if climate risks were properly accounted for. The following sections provide an estimate of the number of securities for which this would be the case based on complementing current external ratings with the transition risk analytics of Carbon Delta.

4.2 METHODOLOGY

The methodology of Carbon Delta is based on the assumption that firms will have to reduce their emissions to limit the increase in global temperatures at 2°C above pre-industrial levels. The transition risk reflects the costs of these reductions. The methodology follows three steps:

1. *Quantification of emission reductions by company:* to quantify emission reductions at the company level, Carbon Delta first determines the global level of emission reductions that is necessary to achieve a 2°C increase in global temperatures above pre-industrial levels, they then divide this amount among countries, based on the level of their emission reduction targets for the next 15 years embedded within policies that have been proposed within the Nationally Determined Contributions (NDCs). Second, country emission reduction targets are broken down by sectors based on details within the NDCs as well as recently proposed national level climate regulations. Third, sectoral emission reductions are broken down by production facilities within a sector using Carbon Delta's production facilities database. After these three steps, the emission reductions for each company are available at the country and sector level by aggregating the emission reductions of the facilities that the company owns in each country and sector.

2. *Quantification of emission reduction costs by company*: to estimate the costs of emission reductions for each company, Carbon Delta first estimates the price per ton of CO_2 equivalent in each country that is necessary to reach the emission reduction objectives of this country. To estimate this price, Carbon Delta uses the REMIND model developed by the Potsdam Institute for Climate Impact Research (PIK). These prices per country are then used to estimate the costs that a firm will face given the level of emission reductions that it has to achieve (computed in step 1).
3. *Estimation of company's default probability with transition costs*: Carbon Delta uses Merton's framework to estimate the impact on market capitalization and the theoretical probability of default of a firm within five years. An estimation of the probability of default (PD) of a company can be obtained with Merton's methodology from knowing its level of assets and liabilities and their volatilities. However, Merton's model delivers theoretical PDs that cannot be directly used for credit risk assessments. Therefore, Carbon Delta has developed another model, based on multivariate regression, that links Merton's model's theoretical PDs with PDs observed in market data. This model is estimated on several thousand PDs from market data and is used to translate theoretical PDs given by Merton's model into PDs that are in-line with the values observed on the market. Carbon Delta estimates the impact of transition costs on a firm's PD by comparing its PD based on its initial level of assets with its PD once the emission reduction costs have been deducted from its initial asset level – i.e. Carbon Delta makes the hypothesis that emission reduction costs will be fully reflected in a reduction of the value of the company's assets. The PD obtained with this new balance sheet – i.e. the initial asset level minus the emission reduction costs – is a measure of credit risk that includes transition risk.

4.3 EMPIRICAL RESULTS

Carbon Delta applied its methodology to obtain credit ratings that reflect transition risks for the assets that the ECB bought in its CSPP. The ECB provides a weekly list of all the assets that composes its CSPP portfolio. Carbon Delta used the list of October 12, 2018. This list consists of 1'194 securities. Carbon Delta could analyse covered 875 securities from 166 issuers, which corresponds to 73% of the ECB's CSPP portfolio in terms of number of securities.

The following table gives two examples of the impact of transition risks on credit ratings. The issuers presented in the table are in the utilities sector and the materials sector, respectively. Transition risks are material for both issuers. They represent a loss of 18.7% and 64.5% in the firm's value, respectively. Transition risks translate into a higher probability of default within five years: it increases it by 0.29 and 3.34 percentage points, respectively. According to Carbon Delta, the threshold for being assessed as investment grade is usually 3% in terms of probability of default. In the examples provided below, transition risks would move the probability of default above this threshold for the second issuer. Including transition risks would thus make its credit rating fall from investment grade to non-investment grade. This would exclude it from the list of issuers whose bonds can be bought by the ECB.

Table 1: Transition risks impact on PD (Examples)

	Issuer 1	**Issuer 2**
Industry	Utilities	Materials
Firm value - Pre-shock (in USD bn)	60.5	26.3
Transition shock (in USD bn)	-11.3	-17.0
Firm value - Post-shock (in USD bn)	49.2	9.3
Probability of default - Pre-shock	0.65%	1.43%
Probability of default - Post-shock	0.94%	4.77%

In total, Carbon Delta has identified eight issuers among the issuers it has assessed within the ECB's CSPP portfolio that would fall out of the investment grade category. This represents 4.8% of the issuers analysed. The securities from these eight issuers would not be eligible for purchase in the current ECB framework if transition risks as estimated by Carbon Delta were considered.

5 Conclusion

Climate risks are currently not adequately reflected in credit risk analysis. The methodologies that allow integrating physical and transition risks into credit assessments are however developing at a fast pace. Key building blocks required for them are documented. The data required to assess climate risks and to translate them into credit risks are also expanding rapidly. Their availability at the firm and household level is increasing, which is an important step to achieve the granularity required for assessing credit risk.

At the same time, methodological developments are ongoing and must continue doing so. The need to account for the preparedness of companies for a transition to a low-carbon economy is a case in point.

Such open issues notwithstanding, we believe that the methodologies currently available are advanced enough to deliver a first estimation of climate credit risks. They show that accounting for climate risks can alter the rating of firms and thus their eligibility under current risk management frameworks. Integrating climate risks into credit risk analysis is thus essential to enforce risk standards – including those at central banks. The deciding factor for doing so should not be whether the methodologies that are available are perfect and complete, but whether they offer a better estimate of risk than leaving it completely unaccounted for.

References

2° Investing Initiative (2016) *Transition risk toolbox. Scenarios, data and models*.

2° Investing Initiative (2017) *Asset-level data and climate-related financial analysis: a market survey*.

Batten, S., Sowerbutts, R. and Tanaka, M. (2016). "Let's talk about the weather: the impact of climate change on central banks", Staff Working Paper No. 603, Bank of England.

Carbon Delta (2018) *Carbon Delta methodologies overview*.

Deutsche Asset management (2017) *Measuring physical climate risk in equity portfolios*, November.

De Nederlandsche Bank (2017) *Waterproof. An exploration of climate-related risks for the Dutch financial sector*.

GFSG (2016) *G20 Green Finance Synthesis Report*, September 5.

Grantham Research Institute on Climate Change and the Environment (2018) *Aligning national and international climate targets*, Policy brief, October.

IPCC (2018) *Global warming of 1.5°C*, Intergovernmental Panel on Climate Change, October.

NGFS (2018) *NGFS First Progress Report,* October.

Mathiesen, K. (2018). "Rating climate risks to credit worthiness", *Nature Climate Change*, 8, 454-456.

Monnin, P. (2018) "Central banks should reflect climate risks in monetary policy operations." SUERF Policy Note 41.

RobecoSAM (2018) *Climate strategy* https://www.robecosam.com/en/csa/insights/2018/climate-strategy.html.

Schroders (2017) *Climate change: redefining the risks*, September.

UBS (2018) *Explaining the mechanics: tilting to Climate Aware*.

UNEP Finance Initiative and Acclimatise (2018) *Navigating a new Climate.* July.

UNEP Finance Initiative and Oliver Wyman (2018) *Extending our horizons.* April.

Vermeulen, R., Schets, E., Lohuis, M., Kölbl, B., Jansen, D.-J. and Heeringa, W. (2018) "An energy transition risk stress test for the financial system of the Netherlands," *DNB Occasional Studies*.