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Climate Change: Policies to Manage Its Macroeconomic and Financial Effects

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ABSTRACT

It is increasingly recognized that climate change generates major macroeconomic and financial risks. There are physical risks associated with the disasters generated by hydrometeorological events, and gradual but persistent changes in temperatures that have structural impacts on economic activity, productivity and incomes. Additionally, the process of adjustment towards a lower-carbon economy, prompted by changes in climate-related policies, technological disruptions and changes in consumer preferences, generates transition risks. After a brief analysis of the macroeconomic, fiscal and tax policies to manage these risks, this paper concentrates on: (i) how financial policies can help improve transparency and climate-related risk disclosure in financial institutions' balance sheets and asset prices, particularly with appropriate prudential regulation and supervision; and (ii) how those risks could be taken into account in monetary policy and central bank balance sheets and operations. The paper ends with some reflections on the COVID-19 pandemic and the will for a 'green' recovery.

Introduction

Humanity has achieved a remarkable reduction in poverty levels and a significant advance in human development in practically all geographies of the planet. Production and consumption patterns, however, have been associated with extremely high energy consumption and increasing use of natural resources, with a strong negative impact on the environment and biodiversity. Energy consumption, which is based largely on fossil fuels, has generated global warming, which already exceeds pre-industrial levels by around 1 degree Celsius.[1]

The Intergovernmental Panel on Climate Change (IPCC 2014, 2018) has estimated that around 50 gigatons of carbon dioxide ($GtCO_2$) are emitted worldwide yearly, in addition to other greenhouse gases.[2] Cumulative anthropogenic CO_2 emissions to the atmosphere between 1750 and 2011 amounted to 2,040 ± 310 $GtCO_2$, about half of which have occurred in the last 40 years (IPCC 2014).[3] If the current emissions trajectory ('business-as-usual') continues, the increase in average temperatures could exceed 2 degrees Celsius in 2030 and 4 degrees Celsius or more in 2100 (Bárcena et al. 2020, p. 49). According to Burke et al. (2018, pp. 13288-9), this would imply "reversing a multimillion years cooling trend in less than two centuries."

To keep the increase in temperature at levels compatible with those agreed in the Paris Agreement of 2 degrees Celsius and, preferably, 1.5 degrees Celsius above pre-industrial levels, it is necessary to adopt immediate mitigation actions. In this regard, the IPCC (2018) has estimated reference limits to the amount of cumulative emissions worldwide compatible with those goals. These limits are known as the 'carbon budget'. The challenge is to reduce CO_2-equivalent emissions per capita from almost seven tons, which is what is emitted today, to approximately three tons in a decade and close to null by the middle of this century, while maintaining or increasing the pace of economic growth (Bárcena et al. 2020, pp. 31-32 and 57).

Despite the compelling need to reduce carbon emissions and curb global warming, the long-term nature of this phenomenon, its short-term costs, the difficulty in quantifying its impact, and the fact that the physical, economic and financial risks related to the climate have only been progressively advancing have led many economic agents, including governments, to delay action. In the words of Carney, "climate change is the Tragedy of the Horizon (…) the catastrophic impacts of climate change will be felt beyond the traditional

[1] According to the IPCC (2018, p. 6), the "observed global mean surface temperature for the decade 2006–2015 was 0.87°C higher than the average over the 1850–1900 period (…) Estimated anthropogenic global warming is currently increasing at 0.2°C per decade due to past and ongoing emissions."

[2] The geographical distribution of emissions has been estimated by Bárcena et al. (2020, p. 34), based on Gütschow et al. (2016) as follows: East Asia and Pacific 38.3 percent, Europe and Central Asia 16.8 percent, North America 14.5 percent, Latin America and the Caribbean 8.3 percent, South Asia 7.5 percent, the Middle East and North Africa 7.4 percent, and sub-Saharan Africa 7.2 percent.

[3] The IPCC (2014, p. 12) states: "About 40% of these emissions have remained in the atmosphere (880 ± 35 $GtCO_2$); the rest was removed from the atmosphere and stored on land (in plants and soils) and in the ocean. The ocean has absorbed about 30% of the emitted anthropogenic CO_2, causing ocean acidification."

horizons of most actors—imposing a cost on future generations that the current generation has no direct incentive to fix" (Carney 2015, p. 4).

This paper analyses the macroeconomic and financial effects of climate change, and the policies that can help mitigate them. It is divided in five sections, the first of which is this introduction. The second section takes a look at the effects of climate change on the macroeconomy and financial sector. The third considers alternative macroeconomic, fiscal and tax policies to mitigate the effects of climate change. The fourth looks, in turn, at financial policies, and the fifth at monetary policy and other possible central bank actions. The paper ends with some reflections on the COVID-19 pandemic and the need for a 'green' recovery. Recommendations are summarized in Appendix I.

Effects of climate change on the macroeconomy and financial sector

Climate change generates widely known *physical risks*, particularly disasters associated with hydrometeorological events such as hurricanes, tornadoes, cyclones and monsoons, floods, avalanches, and, conversely, desertification and increasing aridity. These impacts are wide ranging, since they will affect all agents and sectors of economies in all geographies, although in an uneven way (NGFS 2019a). These major events, as well as gradual but persistent changes in temperatures, have structural impacts on economic activity, consumer preferences and human well-being. In addition, the process of adjustment towards a lower-carbon economy prompted by changes in climate-related policies, technological disruptions and shifts in consumer preferences generates what in the literature are called *transition risks*. There are, thus, multiple mechanisms of transmission of climate change in the macroeconomy and the financial sector, both on the supply and demand side,[4] that are discussed below.

TRANSMISSION MECHANISMS TO THE MACROECONOMY AND SECTORAL EFFECTS

Agriculture, the livestock sector and fishing are particularly sensitive to changes in the climate, and so climate change can become a serious threat to them. Extreme weather events cause crop failures. Gradual warming and more volatile precipitation patterns may intensify soil degradation and desertification, and the loss of the productivity and suitability of certain crops (Batten, Sowerbutts and Tanaka 2016). In the livestock sector, changes in temperature and precipitation are decisive in production and in the quality of different types of pasture and forage, therefore affecting the production of meat and milk. In fishing, warming of the seas, and

[4] NGFS (2019b, pp. 6-10) analyses the mechanisms of the transmission of climate change to the macroeconomy and its effects on financial stability, and provides a survey of methodologies, models and quantitative estimates.

their acidification and overexploitation have substantially reduced biodiversity and put the survival of many species at risk. The latter is also the case for many terrestrial species as a result of the increasing loss of forests and jungles.

For all these reasons, climate change-related events may cause agricultural supply shocks, which could be of a temporary or structural character. These are particularly worrisome for developing economies in which these primary sectors are central pillars of economic activity, and food constitutes a large share of the consumption basket. They can have broad impacts on aggregate income and employment in these economies (Dell, Jones and Olken 2012), and lead to greater volatility of headline inflation rates via increased volatility of food price inflation (Batten, Sowerbutts and Tanaka 2016).

Other productive sectors that can be negatively affected by natural phenomena (physical risks) are transportation, coastal real estate, public utilities, etc. Some can also be hit by policy decisions and technological developments (transition risks), such as oil and coal, as well as those industries with intensive in fossil fuel use, such as steel, aluminium, cement, glass, chemicals, plastics, paper, etc. In contrast, other sectors can take advantage of new opportunities, such as unconventional renewable energy, electric vehicle production and the information industries, among others.

Extreme weather events can also destroy physical infrastructure and productive capacity, generate shortages of resources and products, and cause more frequent disruptions in production processes, trade and supply chains, both domestic and international. This generates a need to divert investment towards adaptation to climate change, and to the possible reconstruction of damaged infrastructure, buildings and machinery (ibid.).

Firms could face a more complex environment, with higher operating costs; possible legal liabilities, and regulatory and reputational risks; and changes in the behaviour of their clients (buyers and suppliers) and in demand for products that are more environmentally friendly. There could also be more uncertain conditions for investment, due to possible distortions in market signals, uncertainty about potential growth and evolution of future demand, anticipated depreciations of existing assets as a result of changes in policies and regulations, lower profitability of existing assets, and higher expenses in adaptation and mitigation, as well as the development of alternative technologies (Batten 2018). These problems could be exacerbated by policy decisions necessary to face climate change, such as carbon taxes, which could increase transition risks.

For their part, households, especially the most vulnerable, could face an impact on the relative prices of food, fuel, transport and basic public utilities such as energy and water, which would affect their consumption capacity. Their properties could also be more exposed to physical risks that would affect their value, possibly inducing them to increase their precautionary savings. Additionally, multiple physical phenomena associated with climate change, such as heat stress, will have impacts on people's health, which would be reflected in

higher rates of morbidity and mortality, and, consequently, would have implications for labour productivity (Tol 2018, Szewczyk et al. 2020).

It is also possible to anticipate structural effects and volatility in the relative prices and traded volumes of many commodities with an important role in international trade (hydrocarbons and minerals, food and other). That could alter the terms of trade and real exchange rates of many emerging and developing countries, in quantities that are difficult to forecast. Taxes, regulations and restrictions on imports and exports resulting from transition policies might also influence trade patterns. Real exchange rates of many countries might also be affected by lower labour productivity. Supply chains could be more frequently hit by geophysical changes and weather events.

It is foreseeable, then, that climate change will have a significant impact on the potential growth of the world economy, although its effects will not be homogeneous in all geographies or sectors. As Bolton et al. have pointed out, quantifying the potential magnitude of these risks and the distribution of financial losses is complex "because of the radical uncertainty associated with an environmental, physical, social and economic phenomenon that is constantly changing and involves complex dynamics and chain reactions. Traditional backward-looking risk assessments (that merely extrapolate historical trends) and existing climate-economic models cannot anticipate accurately enough the form that climate-related risks will take" (Bolton et al. 2020, p. iii). In turn, "climate-related physical and transition risks involve interacting, nonlinear and fundamentally unpredictable environmental, social, economic and geopolitical dynamics that are irreversibly transformed by the growing concentration of greenhouse gases in the atmosphere (…) Exceeding climate tipping points could lead to catastrophic and irreversible impacts" (ibid., p. 1).

QUANTITATIVE ESTIMATES OF THE IMPACT OF CLIMATE-RELATED RISKS ON THE ECONOMY

Although the transmission mechanisms indicated in the previous section are fairly clear, the radical uncertainty of this phenomenon and its forward-looking nature explain why the range of estimation of the impacts of climate change on the economy is very wide, and depends on assumptions in aspects such as climate change scenarios, the future path of climate policies, the timing of reaction, discount rates, the rate of progress in becoming carbon neutral as well as negative emissions technologies (such as carbon capture and storage), feedback loop effects, the level of adaptation and adaptive capacity, and non-linearities or uncertainties related to the nature of climate risks.

Physical risks

Physical risks arise from climate-related hazards. They generate economic costs resulting from the increasing severity and frequency of extreme climate-related weather events, as well as from longer-term progressive shifts of the climate (such as changes in precipitation or extreme weather variability) that reduce productivity, disrupt global supply chains, etc. This issue will be revisited from a financial stability perspective later in this paper.

In reviewing 27 published estimates in 22 academic studies on the impact of climate change on welfare (measured in terms of income loss), Tol (2018, Table 1) reports that the large majority of impacts range around warming of 2.5 degrees Celsius and economic losses of up to 3 percent with a mean value of -1.3 percent, from which the author concludes that "a century of climate change is about as good/bad for welfare as a year of economic growth" (ibid., p. 6). Some outlier estimates are even positive, while a few other studies reckon potential warming up will be up to 5 to 6 degrees Celsius with economic losses up to 6 percent. The author acknowledges, however, that the uncertainty is rather large and that "negative surprises are more likely than positive surprises of similar magnitude" (ibid., p. 8). Kahn et al. (2019) find that a persistent increase in average global temperature by 0.04 degrees Celsius per year (up to around 3 degrees Celsius by 2100) reduces world real gross domestic product (GDP) per capita by more than 7 percent by 2100. Both authors report that effects vary significantly across countries depending on the pace of temperature increases and variability of climate conditions, as we will see later.

The Network for Greening the Financial System's estimates are much more pessimistic (NGFS 2020c). It finds that in a 'hothouse' world scenario,[5] impacts from physical risks (progressively cumulative) result in up to a 25 percent GDP loss by 2100. The NGFS (2019b, p. 7) records a number of research efforts on the subject, among which one by the Organisation for Economic Co-operation and Development (OECD 2015) is located at a midpoint. It calculates losses in world GDP by 2100 of between 2 and 10 percent relative to the no-damage baseline scenario, but amounting even to 12 percent when non-linearities in the climate damage function are strong. Other works include Burke et al. (2015), who calculate falls of over 20 percent of world GDP by 2100 relative to a scenario without changes in the climate. At the other extreme, Nordhaus (2017) estimates falls of 2.1 percent if the average world temperature increases by 3 degrees Celsius, and 8.5 percent if warming rises to 6 degrees Celsius. The NGFS points out, however, that the first generation integrated assessment models that served as the basis for this last calculation generate a possible underestimation of economic losses. Finally, they quote the estimate of Hsiang et al. (2017) for the United States of America, with expected GDP losses that increase quadratically as a function of the increase in temperature, with ranges between -0.1 and 1.7 percent

[5] "Hot house world assumes that only currently implemented policies are preserved. Nationally Determined Contributions are not met. Emissions grow until 2080 leading to 3°C+ of warming and severe physical risks" (NGFS 2020c, p. 6).

of GDP with warming of 1.5 degrees Celsius; between 1.5 and 5.6 percent of GDP with 4 degrees Celsius; and worse at higher temperatures. The most affected economic activity is agriculture (9 to 12 percent losses in yield for each degree Celsius).

Regarding geographic impacts, it is anticipated that climate change will affect tropical countries more harshly (Tol 2018), many of which have the lowest incomes and levels of human development. According to the International Monetary Fund (IMF), "in countries with high average temperatures, an increase in temperature dampens economic activity, whereas it has the opposite effect in much colder climates. The threshold temperature is estimated to be about 13°C to 15°C. (…) Emerging market economies and particularly low-income developing countries tend to have much hotter climates, and a rise in temperature significantly lowers per capita GDP growth. For the median emerging market economy, a 1°C increase from a temperature of 22°C lowers growth in the same year by 0.9 percentage points. For the median low-income developing country, with a temperature of 25°C, the effect of a 1°C increase in temperature is even larger: growth falls by 1.2 percentage points. And even though countries projected to be significantly affected by an increase in temperature produced only about one-fifth of global GDP in 2016, they are home to close to 60 percent of current global population and more than 75 percent of the projected global population at the end of the century" (IMF 2017, pp. 126, 128).

Similarly, by accounting for non-linearity at the macro scale, Burke et al. (2015) show that overall economic productivity is non-linear in temperature for all countries, with productivity peaking at an annual average temperature of 13.6 degrees Celsius and declining strongly at higher temperatures. Deryugina and Hsiang (2014), for their part, using within-county variation in United States counties over a 40-year period, find that productivity declines by roughly 1.7 percent for each 1 degree Celsius increase in daily average temperature above 15 degrees Celsius.

Along these lines, Tol (2018) highlights three main reasons why developing countries are more vulnerable to the impacts of climate change: the important role of agriculture and water resources in their economy, their tendency to be in hotter places and their more limited adaptive capacity. The 2019 *Human Development Report* (UNDP 2019) also points out that developing countries and poor communities have less capacity to adapt to climate change and extreme weather events than richer countries. Therefore, climate change can widen existing socioeconomic inequalities. These heterogeneous social and regional impacts can generate different political manifestations, as well as complex migratory flows and even conflicts, both within countries and internationally.

Transition risks

Transition risks are related to the process of adjustment towards a lower-carbon economy prompted by changes in climate-related policies (taxes, subsidies, regulations), technological disruptions (e.g., in the alternative renewable energy sector) and changes in consumer preferences (e.g., transport demand, diets). They are thus associated with transformation in modes of current production and consumption to reduce greenhouse gas emissions and mitigate climate change. They have macroeconomic effects, analysed here, as well as financial stability implications, discussed in the next section.

The NGFS presents a range of estimates on the impacts of transition risks. They vary between -4 percent of GDP by the end of the century in an orderly scenario (where climate policies are introduced early)[6] and -9 percent of GDP in a hothouse world scenario. The report adds that "some studies from the wider literature suggest that the impacts could be smaller, or even positive, given the rapid reduction in the cost and increased deployment of new technologies. Still, all users of energy and emitters of carbon will be affected, with major fossil fuel exporting regions most at risk" (NGFS 2020c, p. 8).

The NGFS also presents a synthesis of the estimates of various previous studies on transition risks. In brief, "the studies suggest that the economic costs of meeting the requirements to give a likely chance of limiting global warming to 2˚C would be between 1 and 4% of global aggregate consumption levels in 2030. The impact of the transition on GDP depends heavily on the assumptions underlying the analysis, but models generally agree that the speed and timing of the transition is crucial for macroeconomic costs: if it is *orderly and starts early,* costs can be minimized, because it allows for an orderly transition of the existing capital stock and infrastructure. According to Furman et al. (2015) a one-decade delay in addressing climate change would result in a 40% increase in the net present value cost of doing so" (NGFS 2019b, p. 10).

Transition risks can also have heterogeneous regional effects, since it is clearly foreseeable that climate change will have stronger impacts on countries and regions that are more dependent on hydrocarbon and coal exports, which are usually also dependent on these sectors for public sector revenues (taxes, royalties and profits of state-owned enterprises) (IMF 2020).

A concrete example is the study by Huxman, Anwar and Nelson (2019) of South Africa, which is one of the main coal-exporting countries in the world, and where public finances are highly dependent on income from that sector. They estimate that the net present value for this country of the cost of a global transition to a low-carbon economy, for the accumulated period 2013 to 2035, is US $120 billion, approximately a third of its 2019

[6] In the NGFS's orderly scenario, net zero CO_2 emissions are achieved before 2070, giving a 67 percent chance of limiting global warming to below 2 degrees Celsius, thanks to the significant amount of investment to make the transition to a carbon-neutral economy (NGFS 2020c, p. 6).

GDP. Another notable result is that, although the public sector share of those losses is only 16 percent, with investors facing the rest, the latter can become contingent liabilities for the national Government. Thus, when potential bailouts of investors, support to workers who lose their jobs and assistance to struggling municipalities are taken into account, the transition risks borne by the national Government could triple.

CLIMATE-RELATED RISKS FROM A FINANCIAL PERSPECTIVE

From a financial perspective, the increasing severity and frequency of extreme climate-related physical risks may cause damage to household real estate and thus to mortgage portfolios, and losses to firms and to governments, resulting in higher payment of insurance claims, and the devaluation of assets and the guarantees that support loans.

Insured losses may place insurers and reinsurers in a situation of fragility as claims for damages increase. Non-insured losses, which represent 70 percent of weather-related losses (Bolton et al. 2020, p. 17) may affect the value of the financial assets of financial institutions besides insurers, such as banks and pension funds, and reduce banks' abilities to lend to households and corporations. In other words, "climate-related risk is not necessarily a distant possibility in the future but rather a clear and present danger to financial stability since the assets at physical risk are large (for producers, for financial investors, etc.) and the costs of weather-related accidents are also very high and rising, for both insurance companies and their clients, and especially for uninsured parties" (Pereira Da Silva 2019, p. 2). A vivid example of this situation is the case of Hurricane Dorian in the Bahamas in September 2019, which not only devastated properties, but also led to a sudden stop in housing insurance and credit in that country.

Transition risks, prompted by changes in climate-related policies, technological disruptions and changes in consumer preferences, are likely to have significant impacts on asset prices as a consequence of changes in investors' perceptions of the profitability and sustainability of certain companies or economic sectors, and adjustments in the valuations of a wide range of assets. Thus, there will be a good number of "stranded assets and sectors" (due to depreciation/obsolescence/company closings), related to carbon both directly and indirectly. This can affect the cash flow of debtors and impair their ability to pay obligations, impacting banks, bondholders, etc. If the changes are abrupt, a sale could take place "at bargain prices", which could trigger a financial crisis (ibid., p. 2).

A third kind of risk that should be taken into consideration from the financial sector perspective entails liability risks. These may arise from future demands for compensation charges on companies, insurers or lenders by economic agents affected by claims related to physical risk, or related to having financed and supported projects that generate environmental pollution or greenhouse gas emissions, among others. These losses may

affect the financial health of insurers and lenders, as well as the equity value of firms involved in polluting activities.

QUANTITATIVE ESTIMATES OF FINANCIAL RISKS AND THEIR IMPACT ON FINANCIAL STABILITY

Quantifying the potential magnitude of these risks and the distribution of financial losses among economic sectors, firms, banks, insurers, etc. is complex, as discussed in terms of the limitations and uncertainties of existing models.

Nonetheless, the Economist Intelligence Unit (2015) estimated, for physical risks, that the discounted value at risk for private investors through the unmitigated impacts of climate change is $4.2 trillion (between now and the end of the century).[7] This equals 3 percent of current assets. In an extreme (tail) scenario of 6 degrees Celsius of global warming, present value losses in assets under management would amount to $13.8 trillion (equal to 10 percent of current assets). The public sector could incur present value damages of $13.9 trillion on average and up to $43 trillion in a 6 degrees Celsius scenario.

Concerning estimates of transition risks, the NGFS notes: "IRENA (2017) finds that there could be about $10 trillion of stranded value. IEA (2017) on the other hand, finds about $320 billion of stranded capital[8] worldwide over the period to 2050 in terms of fossil-fueled power plants that would need to be retired prior to recovering their capital investment. In both studies, the assumption of an early and smooth transition results in the significant reduction of potential risks. Numbers on stranded assets differ greatly. IEA (2017) estimates that stranded assets could be about $2.3 trillion. IRENA (2017), however, estimates a potential for stranded assets of $18 trillion. Both estimates assume a late and abrupt transition scenario" (NGFS 2019b, p. 16).

Consistent with the first estimate already mentioned, in the specific case of the Netherlands, Vermeulen et al. (2018) report the result of a stress test of Dutch financial institutions in which financial losses are brought about by disruptive policy measures, technological breakthroughs, or a drop in consumer and investor confidence. They estimate losses of up to 3 percent of assets for banks, 10 percent for pension funds and 11 percent for insurers.

Physical and transitional risks interact so that if policy actions to reduce greenhouse gases and induce structural adjustment in the economy are avoided or delayed, then greater physical risks would materialize. But at the

[7] Value at risk measures the loss a portfolio may experience, within a given time horizon, at a particular probability. The stock of manageable assets is defined as the total stock of assets held by non-bank financial institutions. Bank assets were excluded as they are largely managed by banks themselves.

[8] 'Stranded capital' refers to transition risk-related losses of capital spending that went into a project (e.g., the amount invested in oil field exploration). 'Stranded value' represents the transition risk-related losses of the financial *valuation* of a firm (or a project); this is the forward-looking impact on future discounted cash flows that would have been generated by the firm or project (NGFS 2019b, p. 17).

same time, there is a high probability that such policy decisions (such as carbon taxes, regulations, etc.) will increase the risk of transition. This could reinforce financial failures in credit markets or abrupt reallocations of assets from 'brown' to green activities.

It should also be borne in mind that macroeconomic and financial shocks can interact and amplify each other. If natural disasters reduce collateral values of housing and corporate stock, balance sheets would weaken. Household consumption may decline, and increased uncertainty from climate-related events could affect corporate investment decisions and banks' willingness to lend to them.

All of this could result in a "climate Minsky moment" (Carney 2016): a severe tightening of financial conditions for companies that rely on carbon-intensive activities (so-called 'stranded assets'). "A wholesale reassessment of prospects, as climate-related risks are re-evaluated, could destabilize markets, spark a pro-cyclical crystallisation of losses and lead to a persistent tightening of financial conditions" (Carney 2016, p. 2). The paradox is that 'success is failure', where "extremely rapid and ambitious measures may be the most desirable from the point of view of climate mitigation, but not necessarily from the perspective of financial stability over a short-term horizon" (Bolton et al. 2020, p. 7). In any case, as already pointed out, earlier action also allows more time for new technologies to enter the market in response to price signals, leading to a larger green sector and lower transition costs.

Climate-related risks are, therefore, a real threat to financial stability and could originate what Bolton et al. (2020) have called 'green swan' events: potentially extremely financially disruptive events that could be behind a systemic financial crisis, and that can put central banks under pressure to buy a large set of assets that have a devalued value due to physical or transition impacts, in a sense transforming them into 'climate rescuers of last resort'. In their view, however, "Central banks cannot (and should not) simply replace governments and private actors to make up for their insufficient action, despite growing social pressures to do so" (ibid, p. 2). Rather, financial policies should be put in place to prevent such extreme financial instability events.

In brief, central banks and supervisors (and policymakers) have an important role to play in contributing to the development of environment and climate risk management in the financial sector, and to mobilizing mainstream finance to support the transition toward a sustainable economy. Financial policies are reviewed in the next section, followed by a discussion of monetary policy and other central bank alternatives.

TRANSMISSION MECHANISMS IN TERMS OF CENTRAL BANK POLICIES: A FIRST APPROACH

Finally, a brief reference to climate change transmission mechanisms in terms of central bank policies should be added (an issue analysed in more detail later in this paper). From the previous analysis, prices and price variability could be affected through various channels by climate change, including through the increase in the

frequency and severity of extreme weather events. Climate change can also lead to supply side shocks that may cause strong trade-offs for central banks between stabilizing inflation and stabilizing output fluctuations.

In this regard, many authors consider that there is a clear risk that climate change will generate stagflation (Villeroy de Galhau 2019). According to Brainard, these types of supply shocks pose more complex dilemmas for monetary policy than demand shocks, and the policy response is very different in the face of a transitory shock than in the face of a more persistent one. She concludes that "to the extent that climate change and the associated policy responses affect productivity and long-run economic growth, there may be implications for the long-run neutral level of the real interest rate, which is a key consideration in monetary policy", and that "(j)ust on its own, the large amount of uncertainty regarding climate-related events and policies could hold back investment and economic activity" (Brainard 2019, pp. 3-4).

SOME PRELIMINARY TAKEAWAYS

Evidence is ever clearer that the earth will soon exceed climate tipping points, facing the threat of abrupt and irreversible climate changes. The window of opportunity to keep temperature increases to levels deemed safe by scientists is closing rapidly. Strong action is urgently needed to curb carbon emissions and bring them to zero on net globally by mid-century.

As Stern (2007) has stated, climate change is "the greatest market failure the world has seen." As explained by Krogstrup and Oman, "a set of market and governance failures prevent the required transition from taking place in time via the market (…) market prices do not reflect the social cost of carbon and hence over-emit greenhouse gases, or underprovide mitigation (…) market failures include different variants of: common pool and free rider problems, time inconsistency or impatience that leads to short-termism (due to two major sources of risk: uncertainty around their ability to deliver carbon abatement, and uncertainty around the future value of avoided emissions). Market failures interact with government failures: common pool and free-rider problems (since the benefits of carbon abatement mostly accrue to citizens of other jurisdictions or countries), collective action and capture by powerful interest groups" (Krogstrup and Oman 2019, pp. 14-16).

To face this problem, it is imperative to massively transform the structure of the world productive apparatus and consumption patterns to allow development with low greenhouse gas emissions, and to increase global capacity to adapt to the effects of climate change and promote climate resilience. This will require a wide adoption of new technologies, profound adjustments in land use, and changes in consumer behaviour induced by radical adjustments in the costs of greenhouse gases, and particularly CO_2 emissions, complemented by large investments in sustainable infrastructure, construction, research and development, and productive capital, among others (ibid.).

But, as stated by Bolton et al., "changing our production and consumption patterns and our lifestyles to transition to a low-carbon economy is a tough collective action problem. There is still considerable uncertainty on the effects of climate change and on the most urgent priorities. There will be winners and losers from climate change mitigation, exacerbating free rider problems. And, perhaps even more problematically, there are large time lags before climate damages become apparent and irreversible (especially to climate change sceptics): the most damaging effects will be felt beyond the traditional time horizons of policymakers and other economic and financial decision-makers. This is what Mark Carney (2015) referred to as 'the tragedy of the horizon'" (Bolton et al. 2020, p. 5).

The next section explores some macroeconomic, fiscal and tax policy alternatives, followed by discussions of financial and monetary policy and other actions within the reach of central banks and financial regulators.

Alternative macroeconomic, fiscal and tax policies

The objective of mitigating the impact of climate change should be explicitly incorporated in the framework of public policy, particularly macroeconomic, fiscal, tax and financial policies. Regulations that discourage undesirable actions and uses of resources, and that transmit signals that encourage others are fundamental, and must be complemented by large-scale investments, both public and private. Coordination among a large number of state entities with different institutional mandates, and with a large number of stakeholders from the financial markets, the real sectors and civil society, represents a highly complex challenge.

TAX AND FISCAL POLICIES, AND INVESTMENTS IN RENEWABLE ENERGY

There is a broad consensus in the literature that the primary and fundamental action of public policy is to internalize the externalities associated with the social cost of greenhouse emissions. For this purpose, the 'first-best' alternative comprises a path of taxes[9] on emissions (particularly if it is internationally coordinated) along with the elimination of fossil fuel subsidies (which, according to IMF estimates, amounted to 6.3 percent of world GDP in 2017). Carbon pricing is critical to mitigation because higher carbon prices discourage energy use while incentivizing energy efficiency by reallocating resources from high- to low-carbon activities (IMF 2020, p. 87; Batten 2018; Krogstrup and Oman 2019; Tol 2018; Turner 2020; World Bank 2019).

The current level of such taxes is very low in most countries. A large number have not yet implemented them, which makes the world average estimated by the IMF (2019, p. ix and 3) of $2 per ton of CO_2 clearly below the

[9] Carbon taxes reflecting the 'social cost of carbon' would represent the first-best option in a market economy with perfect competition and complete markets. Those assumptions, however, do not hold in the real world, and estimating the expected social cost of carbon is complex (Batten 2018).

minimum considered socially optimal. The IMF (ibid., p. 3) has advocated for international coordination in the prompt setting of a global minimum level[10]—at the very least among the main greenhouse gas emitter countries so that it would provide reassurance against losses in competitiveness and address free-rider issues[11]—and gradually increasing it to levels of $75 per ton in 2030.[12] Of the countries referenced, only Sweden ($127) and Switzerland ($96) have set levels above this value. Close to it are Norway ($59) and Finland ($65). Emerging economies include South Africa ($10 per ton), Chile and Colombia ($5 per ton), and Mexico ($1-3 per ton).

Revenues from carbon pricing can also be used to finance sustainable investments in infrastructure by governments at all levels based on low-carbon, non-conventional renewable energies (power generation, public transport networks, carbon capture and storage, etc.), efficiency retrofits for buildings, prevention and adaptation works with resilience to the adverse effects of climate change, etc., as well as support for research and development subsidies to spur innovation in nascent technologies (including, for instance, negative emissions technologies, such as carbon capture and storage) and others.

The increase in the price of fossil fuel energy (through carbon pricing) relative to clean energy (through green supply policies) would incentivize activities with low carbon intensity, and the reallocation of investment and employment in that direction. The latter can therefore (at least partially) offset the detrimental effects of higher carbon prices on economic activity. The economic costs can also be mitigated by phasing-in carbon taxes, starting at relatively low initial levels, and gradually increasing at preannounced growth rates until reaching a set goal, calibrated as net-zero carbon emissions by 2050 (IMF 2020).[13]

It is evident that higher levels of carbon taxes would have distributional consequences, both within and across countries, and will face controversial political discussions. Voters and particular groups often oppose carbon pricing because it increases energy costs and their cost of living. The IMF estimates, however, "that the revenue

[10] The IMF (2019, pp. 11-13) presents an illustrative carbon tax exercise of $25 per ton for emerging economies and $50 per ton for more developed Group of 20 countries, and concludes that at those levels, the current voluntary commitments of the signatory countries of the Paris Agreement would be reached. However, their calculations show that these levels would not allow countries to meet the goal of keeping the global temperature increase below 1.5 to 2 degrees Celsius, and that it is, therefore, necessary to increase their 'ambition'.

[11] Absent this ideal globally agreed carbon price, Turner (2020) suggests a second-best solution: domestic carbon prices imposed in particular countries plus 'border carbon adjustments', i.e., carbon-related tariffs on imports from countries that do not impose an equivalent carbon price on their producers.

[12] In a more recent publication, the IMF suggests calibrating carbon prices "to achieve the 80 percent reduction in emissions by 2050…A high annual growth rate of carbon prices (7 percent) is assumed to ensure low initial levels of the carbon price and a gradual phase-in of carbon prices. The needed carbon prices start at between $6 and $20 a ton of CO_2 (depending on the country), reach between $10 and $40 a ton of CO_2 in 2030, and are between $40 and $150 a ton of CO_2 in 2050" (IMF 2020, p. 94).

[13] The IMF acknowledges that countries with fast economic and population growth (such as India and, to a lesser extent, China), those with heavy reliance on high-carbon energy (such as China) and most oil producers are likely to bear larger transition costs. Even if the IMF advocates for little or no differentiation of mitigation efforts across countries, it sees room for partial exception "for the group of selected oil-exporting and other economies, which are assumed to keep emissions at current levels because economic activity shrinks substantially" (IMF 2020, p. 93).

from such a tax (1.5% of GDP in 2030, on average, for the G20 countries) could be redistributed, for example, to assist low-income households, support disproportionately affected workers or communities (for example, coal-mining areas), cut other (distortionary) taxes, fund investment in clean energy infrastructure or United Nations Sustainable Development Goals, reduce fiscal deficits, or pay an equal dividend to the whole population" (IMF 2019, p. viii).

In addition to carbon taxes,[14] other carbon pricing policies may be cap-and-trade schemes and emissions trading systems, rebates and tax breaks. The complexity of the subject makes a case for using a broader set of tools, such as regulations, spending and investment policies, public-private partnerships, public guarantees, and concessional loans from development banks, among others.

Obviously, public efforts must be complemented by private sector investments, given the enormous magnitude of the challenge. Financial policy tools are also a necessary and indispensable complement to enable change in the underlying financial asset structure that is needed to transform the productive structure of the economy (Krogstrup and Oman 2019, Bolton et al. 2020, IMF 2019 and 2020, World Bank 2019).

OTHER POLICY ACTIONS

Related programmes, especially in emerging and less developed economies, could include compensation or payments for environmental services such as assisted restoration of natural forest, land-related sequestration (e.g., conservation of standing forests and afforestation), regeneration and conservation of biodiversity, conversion of extensive livestock farming into silvopastoral modalities, and the massive adoption of drip irrigation, among many others. There is ample empirical evidence that these types of investments are cost-effective and help to moderate the negative effects of climate change, in addition to helping to achieve greater social acceptance of carbon taxes. But they will undoubtedly put significant pressure on public finances.

Changes in habits that contribute to modifying consumption patterns will also be required. The voluntary actions of all individual members of society will be decisive in this regard. But these could be insufficient as long as the greater challenge of solving collective action problems is not resolved. For this, it will be necessary to review social contracts, and respect by all citizens for the environment and biodiversity. Political debates would have to reflect necessary changes in production and consumption patterns, and the need for strong

[14] The IMF considers that "if carbon taxation is not feasible, emission trading systems (auctioning or allocating emission permits that are then traded) would be equally effective if applied to as wide a range of economic activities. If neither of these mitigation strategies is available on the necessary scale, 'feebates' (systems of fees and rebates on products or activities with above or below-average emission intensity) or regulations (for example, standards for emission rates and energy efficiency) could generate two thirds of the CO_2 reduction opportunities of carbon taxation" (IMF 2019, p. ix).

coordination between different levels of government and with the private sector and civil society, as has started to occur in several places.

At the international level, all countries should contribute, but following "the principle of common but differentiated responsibilities and respective capacities, in the light of different national circumstances," as well recognized by Article 2 of the Paris Agreement (UNFCCC 2015). New and innovative ideas on how to break political deadlocks on who should bear the burden of climate mitigation policies, both within and between nations, are imperative (Krogstrum and Oman 2019, p. 9). An overhaul of global governance and the search for agreements in international organizations is urgent, including the recognition of needs for technology transfers, increased official development assistance, and increased financial resources for developing countries to undertake their mitigation and adaptation policies. International debates and action should include the participation of local governments, civil society and the private sector.

Finally, it is also essential to develop national accounting that measures in an appropriate way the contribution of natural capital and ecosystem services, and the economic costs of ecological degradation—though recognizing that these concepts are difficult to define precisely (Bolton et al. 2020, pp. 61-64). As the OECD has indicated, "green growth is about fostering economic growth and development while ensuring that the natural assets continue to provide the resources and environmental services on which our well-being relies" (OECD 2011, p. 9).

Financial policy

Article 2 of the Paris Agreement calls on signatory countries to increase "the ability to adapt to the adverse impacts of climate change and foster climate resilience," and make "finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development" (UNFCCC 2015). The dimension of the challenge is truly daunting. According to the International Energy Agency (IEA), "the full implementation of (Paris COP21) climate pledges will require the energy sector to invest $13.5 trillion in energy efficiency and low-carbon technologies from 2015 to 2030, representing almost 40% of total energy sector investment" (IEA 2015, p. 4).[15] This amounts to an increase of 0.6 percent of GDP per year in the global investment rate, which currently is 26 percent of GDP.[16] More broadly, the transition to a low-carbon economy requires shifting trillions from brown to green activities. The Climate Bond Initiative estimates that around $100 trillion[17] will be needed for integral climate change solutions consistent with the 1.5 to 2 degrees Celsius scenario. It should

[15] According to the IEA (2015), about two-thirds of this amount would be needed to improve energy efficiency in the transport, buildings and industry sectors, and the remaining to de-carbonize the power sector.
[16] See: https://research.natixis.com/Site/en/publication/XnVJrpfl5Ft0WrvHUGUSYg%3D%3D?from=share.
[17] See: https://www.climatebonds.net/.

also be underscored that although there are costs, there are also immense new opportunities in several sectors and activities.

Following the Paris Agreement, growing momentum in the private sector has opened up a new phase in the development of green finance. Given that the horizon for the materialization of climate risk is narrowing, however, the need to change scale is becoming more pressing. Inaction, or action that comes late, would come at a significant economic cost through higher physical damages and risks.

Financial policies play a key role to help mobilize mainstream finance, from both the banking sector and the capital markets, to achieve the needed large-scale transformation in the productive structure of the economy, and the concomitant change in the underlying financial asset structure, by leveraging market mechanisms to achieve greater efficiency in the allocation of resources and costs of mitigating climate change (Krogstrup and Oman 2019). Macroprudential, financial regulation and supervision, governance and financial market development policies are considered under the general heading of financial policies. Some of them aim to correct the lack of accounting for climate-related risks for financial institutions, to support mitigation by changing the demand for green and carbon-intensive investments, and to ensure proper pricing, accounting and assessment of climate risk in financial institutions. Others aim to internalize externalities and co-benefits at the level of society.

Following Krogstrup and Oman (2019, p. 18) and the extensive recent literature on the subject, financial policy actions by central banks, regulators and financial supervisors (in what concerns their respective competences if they are not all unified at the central bank[18]) can be grouped around the following criteria: (i) those that aim at improving transparency and risk disclosure in order to redress possible underpricing of climate risks in financial markets and regulatory prudential frameworks; (ii) those aimed at developing a taxonomy of economic activities and the advancement of markets for green financial instruments; and (iii) those that can help reduce the short-term bias and improve the governance frameworks of financial institutions.

In turn, monetary policy instruments, which will be reviewed later, include the financial stability framework, policies related to the central bank balance sheet—such as collateral policy, asset purchases and the access of commercial banks to central bank facilities, and, in some countries, credit allocation policies. These financial and monetary policies to promote green private investments should complement tax and investment policies and broader government responsibilities, but not substitute for them.

[18] In some cases (e.g., a large number of European countries), central banks are responsible for both monetary and foreign exchange policies as well as for financial regulation and supervision, but in others (e.g., more than half of countries in Latin America) the latter are managed by separate agencies, although with interinstitutional coordination mechanisms.

POLICIES AIMED AT IMPROVING TRANSPARENCY AND RISK DISCLOSURE

The first set of policies are aimed at correcting a major market failure: the fact that climate risks may not be adequately reflected in financial institutions' balance sheets and in asset prices. Non-transparent and underpriced climate risks imply that investments subject to climate-related risks are effectively subsidized. Therefore, standardizing climate-related risk disclosures and making them mandatory can help support and improve pricing and transparency of these risks (Krogstrup and Oman 2019). Gathering and disseminating relevant climate-related financial data could also enhance risk assessment in financial regulation and stress tests.

Additionally, it is instrumental to lay solid foundations for the definition of an adequate taxonomy of green and sustainable assets in relation to climate and other environmental considerations, and to achieve consistency in the classification of green versus non-green and brown assets as a basis for the analysis of potential risk differentials between different types of assets, for the development of green bond markets and for carbon pricing.

In this regard, the efforts of the Task Force on Climate Related Financial Disclosure (TCFD) should be particularly highlighted (TCFD 2017 and 2019, see also Appendix II). The Task Force was established by the Financial Stability Board to develop a set of voluntary, consistent disclosures of relevant and prospective information about potential (financial) impacts of climate change, for use by companies (especially those issuing public debt or equity and financial institutions) in providing information to investors, lenders and insurance underwriters.[19] Its recommendations, 'developed by the market for the market', are aimed at ensuring that climate-related risks are understood and discussed at board level, considered in risk management and investment decisions, and embedded in firms' strategies. They may allow investors and external stakeholders to better value assets and investment projects, and to mobilize financial resources to facilitate the transition to more sustainable and resilient activities.

This initiative has been keenly supported by the community of central banks and financial supervisors gathered around the NGFS (2019a, p. 5), which has underscored the importance of robust data on climate-related risks, and its integration into financial stability monitoring and prudential microsupervision. The NGFS (2019a, 2020a) has also recommended that central banks and supervisors gradually develop tools to map physical and transition risk transmission channels within the financial system, conduct quantitative climate-related risk analysis to size risks across the financial system, and include the impact of climate change in macroeconomic modelling and forecasting, and financial stability monitoring. Given the forward-looking nature of these risks, and the inherent uncertainty about future events, innovative methodologies like scenario analysis are being

[19] See: https://www.fsb.org/2017/06/task-force-publishes-recommendations-on-climate-related-financial-disclosures/.

developed to explore the impacts of different possible futures (NGFS 2019b). Some leading central banks are also preparing to apply these tools to stress tests scenarios for financial firms they supervise.[20]

Supervisors should aim at ensuring that individual supervised institutions identify their exposures to climate-related risks, assess the potential losses should these risks materialize, ensure adequate management of them, and take mitigating action where appropriate. For that purpose, authorities should set supervisory expectations based on their understanding of a prudent approach to climate-related and environmental risks (NGFS 2020a).

The relevance of this kind of assessment is illustrated by Battiston et al. (2017). The authors explore how climate policy risk might propagate through the financial system, based on a network-based climate stress-test methodology of the exposures of financial actors to all climate policy-relevant sectors of the economy, as well as exposures among financial actors themselves, across several types of financial instruments. They apply this methodology to large Euro area banks in green and brown scenarios. They find that direct and indirect exposures to sectors that would be affected by climate policy represent a large portion of equity portfolios of investment and pension funds, and that bank loans to climate-sensitive firms are similar to banks' capital. They also conclude that an early and stable policy framework would allow for smooth asset value adjustments, whereas a late and likely abrupt policy framework could have adverse systemic consequences. Interestingly, the authors point out that the transition to a low-carbon economy could have net positive aggregate effects, particularly because the market share of renewable energy and energy efficient sectors is expected to massively increase. In any case, climate policy could lead to winners and losers among financial actors, depending on the composition of their portfolios.

POLICIES AIMED AT SUPPORTING THE DEVELOPMENT OF A TAXONOMY OF ECONOMIC ACTIVITIES AND THE ADVANCEMENT OF MARKETS FOR GREEN FINANCIAL INSTRUMENTS

Financial regulators and supervisors can take a leading role in bringing together relevant stakeholders and experts to develop a taxonomy that enhances the transparency around which economic activities contribute to the transition to a green (low-carbon and environmentally sustainable) economy, and which are more exposed to climate-related risks (brown). Such a taxonomy would facilitate financial institutions' identification, assessment and management of climate and environment-related risks. It would help them gain a better understanding of potential risk differentials between types of assets (green, non-green and brown), identify sustainable companies and assets, and mobilize capital for green and low-carbon investments consistent with the Paris Agreement (NGFS 2019a).

[20] Some of the more emblematic cases cited in the literature are Brazil, China, France, the Netherlands and the United Kingdom.

Policymakers would need to ensure that such a taxonomy[21] is robust and detailed enough to prevent greenwashing[22] and facilitate risk analysis. In this respect, it is worth recalling that the trade in green financial securities is hampered by a lack of transparency, standardization and missing markets. Big challenges remain in defining and certifying credibly and transparently green securities, however, making this a market prone to a problem with lemons (Krogstrup and Oman 2019, p. 27).

A taxonomy of green assets can also be an enabler of the roles of policymakers and supervisors. First, it is a prerequisite for preparing stress-test exercises and assessing financial institutions' risk profile. It is also a prerequisite for scaling up green finance and policymakers' support for identifying market barriers and dysfunctionalities on the supply and demand sides, and best practices to overcome such barriers. Additionally, like any other investor, central banks will benefit from these taxonomies when implementing sustainable investment strategies for their own investment portfolios (an issue to which we will return below), thus leading by example (NGFS 2019a).

Concerning prudential regulation, some analysts have proposed adapting micro- and macroprudential policies to explicitly consider climate-related risks and internalize systemic climate risk. "Tools could include reserve, liquidity and capital adequacy requirements, loan-to-value ratios, and caps on credit growth, as well as sectoral capital buffers targeting credit to particularly climate-exposed sectors" (Krogstrup and Oman 2019, p. 26). They have suggested integrating green-supporting and brown-penalizing factors in capital requirements, or defining minimum amounts of green assets on financial institutions' balance sheets (Dikau and Volz 2019).[23] In this line, "if climate stress tests find that climate-related risks are material, systemic capital buffers could be applied to mitigate the exposure to climate-related risks" (Bolton et al. 2020, p. 51).

There is controversy, however, on the effectiveness of these climate-related prudential regulations. Bolton et al. (2020, p. 53) consider that they "may only very partially contribute to hedging financial institutions from 'green swan' events." Krogstrup and Oman refer to studies that consider that "lowering capital requirements on bank loans to green sectors could undermine macroprudential policy goals and financial risk mitigation; the Basel Committee has consistently adopted an approach in which prudential rules are based only on risk

[21] An example is the European proposal to develop a unified European Union classification system to determine which economic activities can be regarded as environmentally sustainable for investment purposes. The proposal identifies the following environmental objectives for an economic activity to be considered sustainable: (i) substantially contribute to at least one of the environmental objectives, (ii) do no significant harm to any of these objectives, (iii) comply with minimum safeguards and (iv) comply with technical screening criteria by an independent third party. Until now, no regulatory taxonomy has been implemented globally, but there are some market-driven taxonomies as references, like the Climate Bonds Standards (released by the Climate Bonds Initiative) and the International Capital Market Association's Green Bond Principles.

[22] Defined by Investospedia as "an unsubstantiated claim to deceive consumers into believing that a company's products are environmentally friendly." See: https://www.investopedia.com/terms/g/greenwashing.asp.

[23] Prudential regulations in this line have been adopted by the Banco Central do Brasil and Banque Du Liban (Dikau and Volz 2019).

considerations, to shield them from influences like industrial policy goals or political interference in banks' lending practices" (Krogstrup and Oman 2019, p. 29).

As illustrated below, central banks and supervisors have considered that, to further progress in their analysis and recommendations on whether to integrate climate-related or environmental risks into capital requirements, more work is needed on data and assessment methods for quantifying risks and calibrating prudential requirements, a taxonomy of green and brown assets, and, as a result, statistical evidence of a risk differential between green and brown assets. To date the focus has been placed on raising awareness.

In this respect, a recent survey by the Basle Committee on Banking Supervision found that "the majority of its members consider it appropriate to address climate-related financial risks within their existing regulatory and supervisory frameworks…(and) have conducted research related to the measurement of climate-related financial risks, while a number of members identified operational challenges in assessing climate-related financial risks such as data availability, methodological challenges, and difficulties in mapping of transmission channels (…) approximately two-fifths of members have issued, or are in process of issuing, more principles-based guidance regarding climate-related financial risks. However, the majority of members have not factored, or have not yet considered factoring, the mitigation of such risks into the prudential capital framework" (BCBS 2020, p. 1).

In the same vein, the NGFS also notes that "given that methodologies for climate-related and environmental risk quantification are still being developed, most supervisors have not yet imposed (additional) capital or solvency requirements specifically linked to these risks" (NGFS 2020a, p. 5). It argues that more research is needed on the transmission channels and loss potentials of such risks, the potential specific risk profiles of different groups of assets and exposure, and more and higher-quality climate and environmental data and methodologies for better assessing and mitigating climate-related and environmental risks.

POLICY INSTRUMENTS THAT CAN HELP REDUCE THE SHORT-TERM BIAS AND IMPROVE THE GOVERNANCE OF FINANCIAL INSTITUTIONS.

Corporate governance reforms and especially the adoption of environmental, social and governance (ESG) standards in the financial sector, especially among pension funds and other asset managers, are instrumental to promote long-termism and the values of sustainable finance. Due to their specific roles, central banks, financial regulators and supervisors are well-placed to monitor the market dynamics of green finance that help mobilize capital for green and low-carbon investments with a long-term and sustainable perspective. Furthermore, depending on each particular country's institutional framework, some central banks and regulators can also play a role as catalysts for a sound scaling up of green finance (Krogstrup and Oman 2019, Bolton et al. 2020, NGFS 2018b).

Private sector moves to divest from high-carbon assets were initially led by universities in the United States, and followed from 2015 onwards by several of the biggest international banks (Batten et al. 2016). Among wealth managers, it is worth mentioning Blackrock, whose president informed CEOs in his 2020 letter that "the firm has announced a series of initiatives to place sustainability at the epicenter of its investment approach, such as: the integration of sustainability in the construction of portfolios and risk management, the liquidation of investments that present a high risk in terms of sustainability, the launch of new investment products that discard fossil fuels and the reinforcement of our commitment to sustainability and transparency in our responsible investment activities" (Fink 2020). It is also worth noting his commitment to the disclosure guidelines in accordance with TCFD, and his invitation to companies in which BlackRock invests to also adhere to these guidelines.[24]

A study by Blackrock Investment Institute analysed "traditional equity indexes alongside ESG-focused versions" and found that "annualized returns since 2012 (for ESG) matched or exceeded the standard index in both developed and emerging markets, with comparable volatility (…) Early evidence suggests that focusing on ESG may pay the greatest dividends in emerging markets." The study concluded therefore that "ESG can be implemented across most asset classes without giving up risk-adjusted returns" (Blackrock Investment Institute 2018, p. 2).

In contrast with that, in what concerns banking activity specifically, a recent NGFS survey of 49 banks in 18 jurisdictions (plus one supranational) concludes that they "have not established yet any strong conclusions on a risk differential between green and brown" (NGFS 2020b, p. 3). This is explained to a great extent because "the prerequisites for tracking the risk profile of green or brown assets (…e.g. a clear taxonomy and available granular data…), are not yet in place in most jurisdictions" (ibid., p. 5).[25] Given that, most respondent banks have used "an international or national classification in the form of a voluntary classification or principle"[26] or "an internally developed classification" (ibid.).

In spite of all that, "most of the institutions have undertaken an operational commitment towards greening their balance sheets, with 57% of the respondents undertaking commitments that affect their daily operations either by limiting their exposure to brown assets or by setting green or positive-impact targets. However, the

[24] *The Economist* (2020) headlined another broadly referenced investor as "Grantham on divesting from Big Oil—A contrarian investor on the hazards of owning fossil-fuel stocks."

[25] Respondents also highlight that they "encounter different challenges when trying to classify different types of assets (e.g. loans, bonds, investments). For loans in particular, whilst the classification of single purpose loans (e.g. within project finance) may seem quite obvious, loans for general corporate purposes have a weaker direct link to a physical asset or a project and seem more difficult to classify" (NGFS 2020b, p. 4).

[26] Respondents mention the European Union and Chinese taxonomies, and a number of other national ones. Among the international classifications and principles, respondents mention the TCFD Recommendations, the UNEP FI framework (including the Principles for Responsible Banking), the International Capital Market Association's Green Bond Principles, the Green Loan Principles and the Equator Principles, among others (NGFS 2020b, pp. 7-8).

survey responses highlight that the underlying justification is not based on an attested financial risk differential between green and brown assets but rather on a more diffuse perception of risks. Most banks tend to consider their actions to be part of their corporate social responsibility or mitigation measures for reputational, business model or legal risks" (ibid., p. 3).

According to the Climate Bonds Initiative, global green bonds and green loans issuance reached an adjusted $257.7 billion in 2019, marking a new global record. The total is up by 51 percent on the 2018 figure of $170.6 billion. The volume was primarily driven by the wider European market, which accounted for 45 percent of global issuance; the Asia and the Pacific and North American markets followed at 25 percent and 23 percent, respectively. In 2019, there were 1,788 green bonds from 496 issuers, out of which 250 were new issuers, and there were 51 jurisdictions, of which 8 were new.[27] Green bond markets remain small, with the total accounting for just 0.5 percent of the global bond universe, but are growing rapidly.

Additionally, according to the Institute of International Finance (IIF 2020a, p. 1), "with the Covid-19 pandemic serving as a real-life 'stress test' for ESG investing strategies, the relative performance of sustainable assets has been remarkable" during the atypical first half of 2020. In a "sample of 41 sustainable equity indices, over 75% of sustainable indices have outperformed non-ESG peers year-to date, by a substantial 8 percentage points for the median fund. ESG fixed income strategies have also proved resilient during recent market turmoil. Across a commonly used set of 10 fixed-income ESG indices, 70% of them have outperformed their non-ESG counterparts this year" (ibid.).

Monetary policy tools and other actions central banks can take

Central bank mandates, traditions, and legal and institutional frameworks differ across countries. As with many other institutions, their roles and functions, while maintaining their essence, have evolved dynamically in response to changing contexts and societal needs. For most central banks, however, the core responsibility is safeguarding the purchasing power of the legal currency (i.e., a low and stable inflation rate). In several cases, this primary goal is also complemented with aiming to support stable aggregated output and employment around its potential level. As instrumental to these policy objectives, central banks target an inflation level and set a reference interest rate (or directly manage the monetary base), and intervene in the market to guarantee that the short-term market interest rate is close to the monetary policy target. Changes in the reference rate affect inflation and short-term growth through different transmission mechanisms. Additionally, ensuring the

[27] More information is available at: https://www.climatebonds.net/resources/reports/2019-green-bond-market-summary.

smooth functioning of payment systems and safeguarding financial stability has traditionally been the other main concern for central banks, which have historically acted as lenders of last resort.

The effective implementation of monetary policy relies on identifying the nature, persistence and magnitude of shocks impacting the economy as well as on the assessment of potential output, and therefore the output gap, inflationary pressures and natural rate of interest. As discussed in previous sections, environmental factors and climate-related physical risks will bring about more frequent and severe negative supply shocks (e.g., destruction of capital stocks, disruptions to labour productivity, disruption to supply chains) and demand shocks (e.g., damage to household and corporate balance sheets, impact on consumption and investment). Policy-related decisions (i.e., carbon pricing) may also impact sectoral prices, not only affecting price volatility but also unchaining deep and rapid changes in financial markets, threating to trigger so-called green swan events, with sharp declines in the economy and rising unemployment.

Physical and transition risks will increase; therefore, the challenge for central banks is to forecast their impact on price levels and their variability, aggregate demand and supply, actual and potential economic growth and output gaps, all of which are essential inputs for monetary policy design (NGFS 2020d, 2020e).

A number of climate-related shocks might just be transitory. But the probability of structural changes affecting price levels for a longer period, as well as the long-term sustainable level of resource utilization and the long-run real interest rate, raise challenging questions as to how monetary policy can and should react. Climate change might even call into question the long-term ability of central banks to maintain price and financial stability and asset quality. Increasingly, therefore, central banks have to analyse and discuss whether and what they can and should do to confront climate change in order to efficiently and successfully safeguard price and financial stability (Breman 2020).

MONETARY POLICY TOOLS AND THE BOUNDARIES OF CENTRAL BANK MANDATES

Central bank policy reactions to climate-related shocks may depend on the nature and persistence of the shock. While demand shocks are typically more manageable from a monetary policy perspective, supply shocks are generally more challenging as they generate conflicting trade-offs among central banks goals of stabilizing inflation and stabilizing output fluctuations.

In the latter case, transitory events affecting supply and prices might not necessarily force central banks to react, at least in those countries with a credible monetary policy framework and well-anchored inflation expectations, given that effects on inflation are short-lived, and monetary policy cannot affect inflation over that short horizon. Such volatility could, however, complicate the communication of the monetary policy strategy at times (Batten et al. 2016).

Nonetheless, structural changes affecting price levels for a longer period (e.g., food prices due to supply-side shocks or energy prices due to carbon pricing policies), as well as the long-term sustainable level of resource utilization, pose more complex dilemmas for central banks. On the one hand, they risk de-anchoring inflation expectations. On the other hand, they may risk generating stagflation (Villeroy de Galhau 2019). Additionally, and as already pointed out, to the extent that climate change and the associated policy responses affect productivity and long-run economic growth, there may be implications for the long-run neutral level of the real interest rate, which is a key consideration in monetary policy (Brainard 2019).

In this context, as discussed in Dikau and Volz, a policy response that focuses only on the inflationary component (by raising interest rate), without taking decreasing output into account, may lead to unnecessarily large output losses. Concerning the impact of transition risks and climate policies, they also point out that "in a scenario where the introduction of a carbon tax causes aggregate output to decline and inflation to spike (…). In the case of a strict inflation-targeting regime, the central bank would respond to the spike in inflation by raising interest rates, thereby further slowing the economy, but also causing exchange rate appreciation" (Dikau and Volz 2020, p. 10).

These kinds of challenges and dilemmas may motivate, therefore, theoretical reflections on a more suitable monetary policy framework to confront the structural effects of climate change and climate policies. McKibbin et al. (2017) discuss how monetary policy rules that mainly focuses on the inflationary component and on an increasingly difficult to forecast output gap (like inflation targeting and others) would lead to larger output losses than using a monetary policy rule that also aims to keep output and employment high. They conclude that national income targeting is less vulnerable to imprecise information about the nature of climate-related shocks and the current state of the economy than other monetary policy rules, and avoids creating public expectations of higher future inflation.

McKibbin et al. (ibid.) also reflect on the interaction between climate policy and monetary policy. They illustrate how fluctuating prices under a cap-and-trade policy would make inflation forecasting more difficult than a policy such as a carbon tax in which carbon prices are more predictable. They recommend coordination among competent authorities, since considering each regime separately can easily lead to policies that seem fine in isolation but perform poorly in practice.

Other more specific aspects of the discussion on ways in which central banks could proactively support the transition to a low-carbon economy relate to how they can reflect climate risks in their monetary policy frameworks. These include: (i) integrating climate risk analytics into central banks' collateral frameworks (for instance, by adjusting haircuts and valuations on brown assets, and even excluding them from the pool of eligible collateral); (ii) using sustainability criteria in their large-scale asset purchases and refinancing

operations to exclude carbon-intensive assets and favour green assets, thereby boosting their prices (also referred to as green quantitative easing);[28] (iii) implementing parallel asset purchase programmes focused on low-carbon assets; and (iv) communication on forward guidance (Krogstrup and Oman 2019, Dikau et al. 2020, Breman 2020). Schnabel even suggests considering "reassessing the benchmark allocation of CB's private asset purchase programs" because "in the presence of market failures, market neutrality may not be the appropriate benchmark for a central bank when the market by itself is not achieving efficient outcomes" (Schnabel 2020).

Dafermos et al. (2018) show that a green quantitative easing programme can indeed help reduce global warming but cannot by itself prevent severe climate change since the path of global atmospheric temperature is not very likely to change substantially through such a program (many other types of environmental policies and strategies are necessary). Besides, as discussed below, some of these alternative are contentious and raise governability concerns, so that, as of late 2019, among NGFS members, only the People's Bank of China had a dedicated policy to promote green finance via monetary policy (NGFS 2019a, p. 29).

Some others go a step further by proposing better access to central bank funding schemes for banks that invest in low-carbon projects and even allowing central bank credit allocation policies in favour of low-carbon investments (either directly, by extending loans to companies via banks and currency interventions, or indirectly through guarantees, as in the case of Bangladesh, China and India) (see Krogstrup and Oman 2019). As illustrated in more detail in Dikau and Volz, for central banks that employ these type of policies (only a few in developing and emerging economies), "green investment has often been added as an additional priority sector to existing and longstanding credit allocation policy schemes that otherwise pursue developmental objectives" (Dikau and Volz 2019, p. 13).

The list of "central allocative policy instruments" to promote sustainable development could include: (i) preferred (subsidized) loan rates for priority sectors, asset classes and firms; (ii) differential rediscount rates (green targeted refinancing lines by central banks offering refinancing for commercial banks at preferential terms for specified green asset classes); (iii) credit floors and ceilings (requiring commercial banks to allocate a percentage of their loan portfolio to specified classes of assets, industries or geographical areas); and (iv)

[28] According to Matikainen et al., "sectoral analysis of the quantitative easing (QE) corporate bond purchase programmes of the European Central Bank (ECB) and the Bank of England suggests a skew towards high-carbon sectors. Calculations made using publicly available information indicate that 62.1% of ECB corporate bond purchases take place in the sectors of manufacturing and electricity and gas production, which alone are responsible for 58.5% of Eurozone area greenhouse gas emissions, but only 18% of gross value added (GVA). For the Bank of England, manufacturing and electricity production – responsible for 52% of UK emissions – make up 49.2% of the eligible benchmark, but only 11.8% of GVA. Utilities, the most carbon-intensive sector by emissions, also make up the largest share of purchases for both the ECB and Bank of England. Renewable energy companies, already a relatively small portion of the bond market to begin with, are not represented at all in ECB or Bank of England purchases, while oil and gas companies make up an estimated 8.4% and 1.8% of their portfolios, respectively" (Matikainen et al. 2017, p. 1).

assistance to development banks so that they may play a risk-reducing and pioneering role by implementing green finance standards or by developing innovative financial products such as green bonds (ibid., pp. 13-14).

This is very much in line with Werner's Quantity Theory of Credit in that "when bank credit (is) guided towards productive use, high, stable and non-inflationary economic growth (can) be achieved" (Werner 2016, p. 375). It is also consistent with the view of the proponents of the "credit creation theory of banking" who "pointed out that bank credit creation and growth in economic activity are connected, and credit for different types of transactions has a diverging effect on the economy. They have thus favoured bank regulation that directly targets bank credit, both its quantity and its quality (…) whereby economically desirable bank credit is encouraged, and economically harmful credit creation is forbidden or restricted quantitatively" (ibid., p. 377).

The mounting challenge of potential climate-related shocks is leading a growing number of central banks to adopt green finance policies or guidelines. Dikau and Volz examine the extent to which addressing climate-related risks and supporting sustainable finance fit into the current set of central bank mandates and objectives, using the IMF's Central Bank Legislation Database, and compare them to current arrangements and sustainability-related policies central banks have adopted in practice. Of the 135 central banks in their sample, "only 12% have explicit sustainability mandates, while another 40% are mandated to support the government's policy priorities, which in most cases include sustainability goals (...) On the other hand, 48% of central banks have no explicit or implicit sustainability objectives. However, many of them have nonetheless begun to engage in various green activities. Most of these activities aim at incorporating environmental and climate change-related risks into the core policy implementation frameworks (…) in order to efficiently and successfully safeguard macro-financial stability. As a consequence, an integration of ESG factors into central banks' core policy implementation frameworks (…) would be also covered by mandates that make no explicit or implicit reference to sustainability" (Dikau and Volz 2020, pp. 3, 4 and 16).

The mainstream literature maintains, however, that monetary policy is not best suited for long-term climate change mitigation efforts and should remain focused on its short-term stabilization objective, and that the use of central bank balance sheets to tackle green swan events or further green investments and markets is highly controversial. This may imply stretching central bank mandates (at least in most advanced and emerging economies), raising important questions of governance (and thereby undermining their independence). It may risk distorting markets (Pereira Da Silva 2019, Bolton et al. 2020, Krogstrup and Oman 2019).

Dikau and Volz add in this respect that "a potential role of central banks in promoting sustainability in the financial system and 'greening' the economy, however, is more contentious because of the possible distorting effects of such policies (…) While central banks have a potentially large number of instruments to affect the allocation of capital towards green investment, this does not imply that they should necessarily be tasked to

do everything they possibly could" (Dikau and Volz 2020, p. 16). And they recall that "(Mark) Carney has voiced his distaste for a 'surreptitious' approach or implicit guidance through central bank soft power (...) Instead, Carney expressed support for explicit climate change-related regulation or carbon pricing. Regarding a 'promotional' role in enhancing green climate policy, Carney points to the limits of the mandated role of central banks, which, he maintains, cannot 'substitute for governments in climate policy' a view that he shares with virtually all central bankers" (ibid., p. 8).

A balanced conclusion could be that central banks "can contribute to a more sustainable future, but only as a complement to other effective climate policy. Central banks will not be able to replace the need for an effective climate policy that should be focused on setting a price on carbon emissions" (Breman 2020, p. 2).

CONTRIBUTING TO COORDINATION OF MACROECONOMIC POLICIES AND PRUDENTIAL REGULATIONS TO SUPPORT A SUCCESSFUL ENVIRONMENTAL TRANSITION

According to Bolton et al. (2020, p. 2), central banks, regulators and supervisors should be more proactive in calling for broader and more coordinated change, in order to continue fulfilling their own mandates of financial and price stability over longer time horizons than those traditionally considered. They believe that central banks can contribute to coordinating policies to combat climate change. In their opinion, this coordinating role is not incompatible with central banks doing their own part within their current mandates.

For that purpose, central banks need to coordinate their own actions with a broad set of fiscal, prudential and carbon regulations implemented by other players (i.e., governments, the private sector, academia, civil society and the international community) in order to support a successful environmental transition, keeping in mind that, as illustrated in previous sections, this is a collective action problem.

In the first place, their involvement in data collection, research and analysis that sheds light on the economic consequences of global warming is of paramount relevance. A special mention deserves to be made of increased international cooperation on environmental issues among monetary and financial authorities, which can build awareness and intellectual capacity, and encourage technical assistance and knowledge-sharing. For this purpose, a group of central banks and supervisors in December 2017 created the NGFS to, on a voluntary basis, "exchange experiences, share best practices, contribute to the development of environment and climate risk management in the financial sector, and to mobilize mainstream finance to support the transition toward a sustainable economy. Its purpose is to define and promote best practices to be implemented within and outside of the Membership of the NGFS and to conduct or commission analytical work on green finance" (NGFS 2018a). As of November 2020, the NGFS had 75 institutions members and 13 observers (including international financial organizations and standard-setting bodies).

The NGFS has organized its activities around five main workstreams: microprudential and supervisory, macroprudential, scaling up green finance, bridging data gaps and research.

The first workstream focuses on mapping existing country experiences and supervisory practices, encompassing, for example, climate and environmental information disclosure, corporate governance structures for sustainability issues as well as scenario-based risk analyses, around three subareas. These comprise supervisory practices for integrating environmental (climate) risks into microprudential supervision; environmental information (climate risk) disclosure by financial institutions, and options to encourage disclosure; and the extent to which a financial risk differential exists between green and brown assets.

The second workstream, as a medium-term objective, seeks to develop an analytical framework for assessing climate-related risks (including the impact of climate change and policies to mitigate it), the aim of which will be to size the impact of climate-related risks on the economy, both in the central case and in the event of tail scenarios. It will also aim to determine the timeframes in which risks could materialize. It will consider both physical and transition risks, and provide insights on integrating climate risk analysis into macroeconomic and financial stability surveillance.

The emphasis of workstream three is to outline the roles that central banks and supervisors could play in promoting the scaling up of green finance. It will work on a comparative approach to green taxonomies, green bond labelling and the prevention of greenwashing. Its main interests revolve around greening the activities of central banks and supervisors, and understanding/monitoring the market dynamics of green finance and central banks/supervisors as catalysts for greening the financial system.

The fourth workstream on bridging the data gaps is structured around three main topics: identifying a list of data items needed for other NGFS workstreams; determining the availability, sources and limitations for accessing relevant data; and producing a public list of missing data items and calling for external stakeholders to bridge gaps.

Finally, the fifth workstream on research focuses on updating the list of NGFS research questions on a regular basis in relation to the other workstreams, ensuring smooth coordination of research efforts within the NGFS working structures, and developing relationships with NGFS research stakeholders.

In its first comprehensive report, the NGFS issued six main recommendations to the international community of central banks and supervisors to which this document has made several references. Summing up, they are: (i) integrating climate-related risks into financial stability monitoring and microsupervision; (ii) integrating sustainability factors into own-portfolio management; (iii) bridging the data gaps; (iv) building awareness and intellectual capacity, and encouraging technical assistance and knowledge-sharing; (v) achieving robust and

internationally consistent climate and environment related disclosure; and (vi) supporting the development of a taxonomy of economic activities (NGFS 2019a). The first four apply to the work of central banks and supervisors while the last two address policymakers.

INTEGRATING SUSTAINABILITY CRITERIA IN OPERATIONAL ACTIVITIES AS ADMINISTRATORS OF INVESTMENT PORTFOLIOS AND AS CORPORATES

Central banks and supervisors can potentially play a role in 'leading by example' by incorporating sustainability/ESG criteria into their own portfolios and their operational activities as corporates, without prejudice to their mandates and status. This includes aspects such as: (i) management of corporate portfolios and pension funds, integrating some kinds of green requirements in their management or targeting green financing; (ii) reduction of their carbon footprint as companies, including in-house climate/environmentally efficient use of resources such as energy, water or waste management; and (iii) public disclosure of their engagement regarding the previous items (NGFS 2019c).

Central banks can also look into their own investment portfolios and see how vulnerable they would be to climate-related risks and whether climate risks are appropriately reflected, and integrate sustainability factors into their management (Schnabel 2020). There are some notable references that can be mentioned in this respect.

For instance, the NGFS (2019c) has presented results of a survey of its members on how they integrate sustainability factors in their portfolio management. The report shows that some central banks are starting to play their part in scaling up green finance by accounting for climate and environment-related factors in their investment strategies and incorporating sustainability factors.

Central banks typically hold different portfolios with various goals, depending on their respective mandates, distinguishing four types: policy portfolios, own portfolios, pension portfolios and third-party portfolios. Policy portfolios are at the core of central bank mandates and constitute by far the largest pool of assets they manage. They can include portfolios for foreign exchange intervention, the execution of asset purchase programmes or other monetary policy goals. These holdings are subject to strict policy mandates, which typically require investments to meet high standards in terms of liquidity and credit quality (mainly consisting of supranational and high-grade sovereign debt). But, as indicated above, in the case of own and pension portfolios, there is more room to adopt sustainable investment practices.

When granted that possibility, "negative screening and green bond investments are currently the most prominent strategies across central bank portfolios. Both are straightforward to implement as they do not necessarily require a significant adjustment of the asset allocation or the investment process. Some central

banks take a step further and implement a best-in-class approach or integrate ESG criteria in their investment processes. These strategies are mostly applicable to equity holdings (and corporate bonds) within the own portfolios. By their very nature, these strategies are highly dependent on ESG data," as the NGFS concludes (2019c, p. 19).

A case worth noting is Norway's sovereign wealth fund, the world's largest, which manages $1.1 trillion of the country's assets administered by Norges Bank (ibid., p. 23). In September 2019, it announced that it would divest companies solely dedicated to oil and gas exploration and production in a bid to shield itself from a long-term fall in oil prices This decision will have implications in terms of the climate change effects of its investments, and will affect its shares in some 95 companies.[29] Another case is the Banque de France's Responsible Investment Charter, which applies to its portfolio and pension liabilities. In order to identify candidate funds to invest in, the bank took into account, aside from regular financial criteria, non-financial factors, such as the impact of projects financed by the fund vis-à-vis the energy and ecological transition, ESG risks in investments, and the quality and nature of published impact indicators (NGFS, 2019c).

A recent study by researchers at the Bank for International Settlements explores how environmental sustainability objectives might fit within central bank reserve management frameworks. Using the example of green bonds, Fender et al. find that "sustainable investments can be included in reserve portfolios without forgoing safety and return, although their accessibility and liquidity currently pose some constraints" (Fender et al. 2019, p. 50). The results of an illustrative portfolio construction exercise suggest that adding both green and conventional bonds can help generate diversification benefits and, hence, improve the risk-adjusted returns of traditional government bond portfolios, once liquidity requirements at the overall portfolio level are taken care of. Results based on historical returns (over the period from January 2014 to July 2019) are qualitatively similar to those based on prospective returns (ibid., p. 60).

For countries willing to incorporate sustainability elements in their reserve management process but lacking the technical capacity to design them, the Bank for International Settlements, responding to a growing demand for climate-friendly investments, in 2019 launched an open-ended fund for central bank investments in green bonds to help central banks incorporate environmental sustainability objectives in the management of their reserves.[30]

[29] See: https://www.reuters.com/article/us-norway-swf-oil-idUSKBN1WG4R9.
[30] See: www.bis.org/press/p190926.htm.

Some final reflections on COVID-19 and a green-recovery

The COVID-19 pandemic has provided vivid evidence of the fragility of global systems, and has raised awareness of the potential shocks for the global economy in reaching tipping points if nothing is done to reduce greenhouse gases. Both the pandemic and climate change affect human lives and economic well-being, and both have a significant negative distributive impact. They have also made evident the need for policymakers to cooperate on building more holistic approaches to identifying and managing global risks that have been neither fully considered nor priced, in a framework of multilateral cooperation (Pereira de Silva 2020).

The time is now, therefore, for authorities worldwide, both national and international, to actively account for climate change in engineering a green recovery. Coordination is needed, together with businesses and civil society, to align response measures with the Paris Agreement and the Sustainable Development Goals. Different public authorities can undertake a wide variety of policy actions in this direction. A number have already been mentioned in this paper. They include:

First, a policy mix should aim at reducing the carbon footprint by promoting sustainable investments, with a longer-term view of returns on investment projects. In this regard, establishing a floor in the carbon price (or reducing emission ceilings) and phasing out subsidies on carbon-intensive sectors is of foremost importance. As noted, a carbon price policy is a key determinant in the development of the demand for energy and emissions, and an important driver of investment in renewable energy. Public investment programmes to boost recovery could be geared to a global green transition, focused on energy, transportation and housing.

Second, authorities could condition support measures provided to businesses to survive the current crisis upon moving towards a more sustainable future. New technologies and changes in the locus of production, supply chains and work sites could also reduce greenhouse gas emissions. Notable examples of recent stimulus packages that take account of this and previous criteria are ones engineered in Denmark, France and Germany, as well as the European Commission's Next Generation EU recovery proposal (IIF 2020b).

Third, financial authorities could evaluate measures aimed at advancing climate-related prudential regulation, minimizing climate-related risks for regulated financial institutions (Pereira da Silva 2020) and preventing a further build-up of climate risks in their balance sheets. Calls have also been made for mandatory disclosures related to climate change for financial firms. Some financial regulators have already begun implementing policies along these lines (France and the United Kingdom, in particular).

Fourth, in this same line, coordination could also extend to standard setters, by considering more 'ecological' accounting frameworks, with the possible obligation to disclose additional types of exposure, and new

accounting approaches (e.g., natural capital) to capture interactions between the economy and the natural world (ibid.).

Finally, central banks could attempt to more accurately reflect climate risks in their balance sheets and operations, thus contributing to the achievement of climate and sustainability goals. They could amend collateral frameworks to better account for climate change-related and other environmental risks, align asset purchases and refinancing operations with Paris Agreement goals, and adopt sustainable and responsible investment principles for portfolio management, including policy portfolios (Dikau et al. 2020).

Appendix I: Major policy recommendations

Policy area	Policy instrument	Ultimate goal	Authorities responsible and actors involved
Fiscal policy	Carbon tax	Discourage energy use while incentivizing energy efficiency	Government
	Cap-and-trade and emissions trading systems	Discourage energy use while incentivizing energy efficiency	Government
	Subsidies, rebates and tax breaks	Incentivize energy efficiency	Government
	Public investment in energy infrastructure	Incentivize energy efficiency (reduce carbon intensity by switching to low-carbon energy sources)	Government
	Others: public-private partnerships, public guarantees, concessional loans from development banks	Incentivize energy efficiency	Government
Financial policy	Improving transparency and standardizing climate-related risks disclosure	Redressing possible underpricing of climate risks in financial markets and regulatory prudential frameworks; development of green bond markets	Regulatory and supervisory authorities, central bank where applicable
	Developing a taxonomy of economic activities and the advancement of markets for green financial instruments	Assessment and management of climate related risks; better understanding of risk differentials between green and non-green assets; helps to mobilize capital for green and low-carbon investments	Regulatory and supervisory authorities, central bank where applicable
	Improving governance frameworks of financial institutions	Signalling on awareness of the values of long-term sustainable finance; helps to support the dynamics of green finance	Regulatory and supervisory authorities, central bank where applicable
Monetary policy	Integrating climate risk analytics into central bank collateral frameworks (e.g., haircuts, negative screening), asset purchases and refinancing operations	Signalling to help mobilize capital for green and low-carbon investments	Central bank

	Preferential access to central bank funding schemes and credit allocation policies either through loans or guarantees	Credit allocation in favour of low-carbon investments	Central bank
Other central bank actions	Contribute to coordinate macroeconomic policies and prudential regulations in order to support an environmental transition	Help mobilize capital for green and low-carbon investment	Central bank
	Integrating sustainability criteria in operational activities as administrators of investment portfolios and as corporates	'Leading by example' and signalling to help mobilize capital for green and low-carbon investment	Central bank

Appendix II: The Task-Force on Climate-Related Financial Disclosure

The TCFD is a voluntary, market-led initiative aimed at firms making a disclosure of pertinent and prospective information on potential (financial) impacts of climate change, to bring 'to the present' the issues arising from 'future' climate change (through the analysis of various possible scenarios). It puts a strong emphasis on risks and opportunities related to the transition to a lower carbon economy.

The information refers to: (i) the governance structure of a company in terms of risks and opportunities related to climate change; (ii) its strategy in the face of present and potential impacts climate change may have on its business lines and financial planning; (iii) the processes to identify, assess and manage risks associated with climate change; and (iv) estimates and objectives used by the company to assess and manage the most relevant risks and opportunities related to this problem.

Greater transparency in the disclosure of information on climate-related risks allows investors and external stakeholders to have a basis for the proper valuation of assets and investment projects, in order to better guide the market to mobilize financial resources that facilitate the transition towards more sustainable and resilient activities. The TCFD's focus is on commercial companies from various sectors, financial entities and investment fund managers.

Regarding metrics and objectives, the TCFD invites companies to transparently disclose estimates of the impact of production processes with so-called Scope 1 (direct emissions generated by them), Scope 2 (indirect emissions) and Scope 3 (those generated throughout the entire value chain, backwards by its suppliers and outsourced processes, and forward by its consumers and distribution logistics).

The 2019 TCFD Progress Report recognizes the enormous difficulty of revealing information on environmental sustainability, and identifying valid scenarios to carry out its analysis and make forecasts. It also recognizes that the first steps in this direction are only just being taken, that the methodologies for evaluating the financial risk spreads between green and brown assets are incipient, the availability of data is limited, and there are no common standards.

The surveys carried out by the TCFD, however, indicate that the number of companies in the process of implementing the TCFD recommendations is increasing, and that the main motivation is the reputational benefits of proceeding as well as the pressure from investors to provide information on climate-related risks. Thus, although TCFD continues to be a private and voluntary initiative, it is expected that as the need for greater transparency in climate-related risks and opportunities becomes more urgent, financial regulators and supervisors may take additional steps to require that disclosures recommended by TCFD are formally

incorporated as requirements of company reports. Risk-rating firms may also soon begin to incorporate this factor in their evaluations.

As critical challenges to implementing the TCFD recommendations, respondents identified, in particular, the lack of standardized industry metrics and concerns about disclosing confidential business information.

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