Network for Greening the Financial System

Technical document

The green transition and the macroeconomy: a monetary policy perspective

October 2024

Central Banks and Supervisors
Network for Greening the Financial System

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Foreword

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As governments across the world implement policies to address the threat posed by unmitigated climate change and seek to transition their economies to net zero by mid-century, these changes will increasingly have macroeconomic consequences over horizons relevant for monetary policy.

This report sets out the channels through which inflation and output may be affected by the transition towards net zero. It analyses three key transition drivers: climate change mitigation policies, such as carbon pricing, green subsidies and regulation, innovation in green technologies, and changes in preferences, and further considers the impacts of increased green investments and transition-related uncertainty.

A key focus of the report is on the impacts of mitigation policies, given their catalytic role in driving the transition. There is a growing body of literature in this field, and policymakers should be aware of the important role that the assumptions underpinning the analysis can play in determining the results. It is evident that the macroeconomic impacts vary across policy levers, even where policies have the same overarching climate goal. For example, some policies might look like negative supply shocks and others like positive demand shocks. The magnitude and sign of the effects also heavily depend on whether other supporting and complementary policies are implemented as part of the wider policy mix, including how policies are funded and/or revenues are recycled.

Policy action around the world has resulted in fairly modest macroeconomic impacts so far, but these effects are likely to grow if governments are to achieve the goals of the Paris Agreement. Even though these policies help to reduce the negative economic consequences of unmitigated climate change over the long term, some may lead to near-term trade-offs for monetary policymakers to manage by increasing inflation and reducing output in the short run. In addition, monetary policy could be facing a profound and prolonged structural change to cope with, which may not be entirely anticipated if the path of future policy is not clear.

We are grateful to the NGFS members, observers and to the NGFS Secretariat for contributing to this work. We would particularly like to thank the co-leads of the subgroup on transition impacts – Solveig Erlandsen (Norges Bank) and Sui-Jade Ho (Bank Negara Malaysia) – for bringing together this report. We hope this publication contributes to deepening the understanding amongst central banks of how the green transition can affect the macroeconomy in the near term and in turn monetary policy.

Executive summary

Climate change and the net zero – or green – transition are already impacting our economies and thus have implications for monetary policy. Governments across the world have been responding to the significant threat posed by climate change by setting targets and introducing policies to reduce greenhouse gas (GHG) emissions and deliver the transition to net zero**.** These policies aim to facilitate major structural changes within economies by changing consumption patterns and production activities towards low-carbon ones, and by scaling up investments in low-carbon sectors. As part of this transition, large-scale investments in renewable energy and other green technologies, higher rates of innovation in these technologies and changes in preferences will be required.

Despite recent progress, there remains a substantial gap between the emissions reduction embodied by current policies and what is needed to achieve the goals of the Paris Agreement (IPCC, 2023). This suggests that further policy action by governments will be implemented to achieve pledged commitments. From a macroeconomic perspective, in addition to the impacts associated with climate change mitigation policies and the other transition drivers, this gap in policy action has the potential to generate uncertainty about the transition pathway that in turn can have macroeconomic effects (e.g. through delaying investment).

While governments are the main actors in setting policies to deliver the transition, central banks will need to understand the macroeconomic effects in order to account for them in their monetary policy assessments and decision-making. While government commitments may typically extend to the medium to longer term, actions will increasingly have macroeconomic effects in the near term. Moreover, if climate policy continues to be scaled up in line with commitments, these macroeconomic impacts are likely to increase. While the transition might give rise to some near-term adjustment costs, the macroeconomic impacts from climate inaction or delayed action – due to more severe and frequent economic damages from physical events – will be significantly larger (NGFS, 2023a).

For central banks, the key first step is to understand how the green transition will impact the economy.

In the short run, the green transition is likely to induce some inflationary pressures, whereas the impacts on output are more ambiguous (Table 1)[1]. In the short run, factors such as increasing carbon prices, stricter climate regulation and shifts in customers' demand can increase firms' costs and put upward pressure on inflation. However, other factors, such as efficiency gains through learning-by-doing, economies of scale and maturing technologies can reduce costs and dampen inflationary pressures. The short-term impact of carbon pricing on output will largely depend on how revenues from these policies are recycled back into the economy. Relatedly, the impact of higher green investment on overall output will depend on whether investments are additional or merely redirected from other sectors; on the multiplier effects on economic activity; and the impact on consumption. Ultimately, the effect of climate change mitigation policies and associated transition drivers on inflation will depend on the balance between aggregate supply and demand, as well as on the monetary policy response.

Different climate policy levers will have different impacts even where policies have comparable effects in terms of emissions reductions. Some will resemble negative supply shocks, while others will look more like demand shocks:

- **In the short run, carbon pricing might look like a negative supply shock**, pushing up inflation and dampening output, but the medium-term effects will largely depend on the policy design, including how carbon tax revenues are used, and how policies affect the expectation formation of different agents.
- **The short run impact of green subsidies will depend on their design and who receives them.** A subsidy to the price of green energy (which would benefit users, primarily consumers) could reduce inflation in the short run, but push up on output through increased demand. Conversely, an investment subsidy may directly push up inflation alongside aggregate demand. In the longer run, the funding arrangements for the subsidy will be a key determinant of its impact.

1 Impacts here are defined against a counterfactual of Business As Usual (BAU) without accounting for the economic impacts of climate inaction or delayed action.

Table 1 **Potential transition impacts on inflation and output over the monetary policy horizon**

		Impacts on output	Impacts on inflation
Transition drivers	**Carbon pricing**	Impact on output depends heavily on revenue recycling.	Headline inflation moves up temporarily, while core inflation may be unaffected.
	Green subsidies	Subsidised sector activity is likely to increase, while overall impact depends heavily on how subsidies are financed.	Prices in subsidised sector are likely to fall, while impact on overall inflation is ambiguous.
	Climate regulation	Some types of regulation can create stranded capital, temporarily lowering output.	Adjustment costs, and hence prices, are likely to increase temporarily.
	Green innovation	Higher productivity and knowledge spillovers can support output.	May reduce costs and dampen inflationary pressures.
	Green preferences	Reallocation across products and sectors, but uncertain impact on aggregate output.	Green price premium and reduced price competition *via* product differentiation affect relative prices.
Other transition impacts	**Increased green investment**[1]	Overall impact depends on whether investments are additional or redirected from other sectors.	Potential volatility and upward price pressures from short-term imbalances in energy markets, critical minerals and labour skills.
	Transition uncertainty	Higher climate policy uncertainty tends to lower aggregate investment and output, but has asymmetric impacts across sectors.	Higher climate policy uncertainty can increase consumer prices.

1 On top of direct public green investments which are captured under mitigation policies.

Some policies are likely to generate challenging inflation-output trade-offs for policymakers. Overall effects on inflation will be influenced by design of the policy, including how any revenues from carbon taxes are recycled, how subsidies are funded, their impact on economic agents' expectations, as well as the structure of the economy. The net effect on inflation will additionally depend on the response of monetary policy. While monetary policy has typically looked through the first-round effects of these types of policies where relative price shifts are small and inflation expectations are well anchored, as the trade-offs become more persistent doing so may become more challenging.

The output-inflation trade-off will depend also on the credibility and pace of implementation of climate policies. Clear, credible policies will smooth the macro impacts and minimise challenges for policymakers. Given the big gap between announced pledges and enacted policies, policy action will likely increase over the coming years. Credible mitigation policies that facilitate an orderly and early transition can minimise adverse macroeconomic impacts of the transition in several ways including by reducing uncertainty. For example, a gradual and predictable carbon price increase results in smaller increases in inflation (Pinheiro de Matos and Gili, 2022).

In contrast, a disorderly transition could lead to increased economic volatility. Disruption to economic activity from a sudden and disorderly transition could arise from multiple sources, both on the supply and the demand side. These include unexpected climate policy changes and associated uncertainty, non-linear technological advancements and sudden shifts in consumer and investor preferences. Such shocks could be amplified by financial feedback effects through the credit and asset price channels. Potential supply-demand imbalances during the energy transition on critical minerals or skilled labour, or challenges associated with green financing could also induce short-term volatility in inflation and output. Overall, an unexpected and sudden policy change would generate additional challenges for monetary policy, making it harder for policymakers to distinguish between temporary and permanent shocks and increasing the risk that inflation can only be contained at a significant cost to real GDP (IMF, 2022).

Overall, while the transition might give rise to some trade-offs for policymakers to manage in the near-term, the macroeconomic impacts from climate inaction or delayed action – *via* more severe and frequent physical damages – will be significantly larger[2]. For instance, Mehrhoff (2023) finds that an orderly net zero transition

2 NGFS (2023b).

by 2050 could result in a 7% boost to global GDP when compared to a scenario with no transition. Notwithstanding the potential for near-term economic impacts, it is important to keep in mind that they are considerably smaller in magnitude than the consequences of unmitigated climate change over the long term.

In addition to policy changes, and partly as a result of these, the transition will give rise to significant structural changes over the long term. As policies become more stringent, economic activities across sectors and geographic regions are likely to be reallocated, impacting long-run total factor productivity and labour flows. Higher rates of green investments, particularly those associated with capital deepening, together with green innovation could also affect the productive capacity of an economy. In addition to affecting countries, sectors and firms differently, such changes are also likely to affect different groups of households differently, which in turn can influence their consumption and saving behaviour. Structural changes in the economy can also affect the natural rate of interest (r*), with implications for the monetary policy stance.

The green transition could induce significant international spillover effects reshaping trade patterns and investment flows. Differences in climate policies across countries may change the comparative advantage of an economy in production and alter competitiveness across industries. In turn, such differences may impact the balance of payment positions and exchange rates, particularly for emerging market and developing economies (EMDEs) whose output tends to be concentrated in carbon-intensive sectors. Furthermore, whilst other EMDEs may gain from developing new areas of competitive advantage for green trade, they may also face challenges from the slow diffusion of green technology and a lack of financing for green energy investments.

For central banks, the findings of this report highlight the importance of understanding the macroeconomic impacts of the green transition and the impacts on the channels relevant for monetary policy. As with any economic change, monetary policymakers will need to distinguish between temporary and permanent effects, and between supply-side and demand-side impacts. Transition-related impacts are expected to be complex, and require more forward-looking analysis. Moreover, the direction and magnitude of the impacts of the green transition on the longer-term structure of the economies and the natural interest rate will ultimately require empirical work and further exploration by central banks, academic researchers and industry.

Introduction

Governments across the world are responding to the threat posed by climate change by setting targets and introducing policies to reduce greenhouse gas emissions and deliver the transition to net zero. As of 2023, 195 nations have committed to the Paris Agreement (UNFCCC, 2024), and more than 130 countries representing over 90% of global GDP have adopted net zero GHG emissions targets (OECD, 2023). Many advanced economies (AEs) have pledged substantial emissions cuts by 2030 and net zero by 2050, while the climate targets of many EMDEs are typically for beyond 2050 (Climate Action Tracker, 2024).

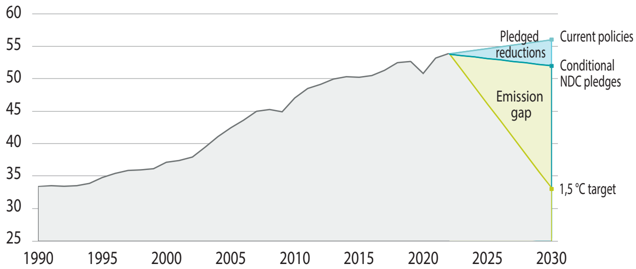
Despite recent progress, there remains a substantial gap between the emissions reduction embodied by current policies and what is needed to achieve the goals of the Paris Agreement (see Figure 1; IPCC, 2023). This suggests that further policy action by governments may be needed to achieve pledged commitments. From a macroeconomic perspective, in addition to the impacts associated with climate change mitigation policies and the other transition drivers, this gap in policy action has the potential to generate uncertainty about the transition pathway that can in turn have macroeconomic effects (e.g. *via* delaying investment).

For central banks, implications for monetary policy will depend on the extent to which the impacts of the green transition affect the macroeconomy over policy-relevant horizons. While governments are the main actors in setting the policies to deliver the transition, central banks will need to understand the macroeconomic effects. Overall, while the transition might give rise to some near-term adjustment costs, the macroeconomic impacts from climate inaction or delayed action – due to more severe and frequent damages from physical events – will be significantly larger (Mehrhoff, 2023; NGFS, 2023a; Hassler, Krusell and Olovsson, 2024).

Transition policies broadly fit into three buckets: carbon pricing; government subsidies and government investment; and non-market-based climate policies, regulations and standards. Examples include the imposition of a carbon tax, or an incentive paid by the government to direct investment towards a green sector.

Figure 1 **Global GHG emissions under different scenarios and the emission gap in 2030**

(measured in $GtCO_2eq$)



Notes: The GHG emission scenarios are the UNEP (2023) median estimates for 2030 of the Current policies and Conditional Nationally Determined Contributions (NDC) scenarios and the median estimate of the level consistent with 1.5 °C. Linearised.
Sources: EDGAR (2023); UNEP (2023).

The introduction of these policies may impact the economy through demand, supply, and financial channels.

In addition to near-term impacts, there will also be deeper, structural changes to our economies due to the transition. These will be relevant for central banks in understanding the potential growth rate of the economy. These transition impacts can take the form of a generational-driven shift in consumer preferences and labour market choices, as well as changing firm behaviour leading to greater investment and innovation.

In some ways, economists and monetary policymakers are familiar with the economic impact of the types of policy instruments used to deliver the transition. For example, an instrument such as a tax or a subsidy. Still, assessing transition impacts presents additional complexities such as second-round effects given the dynamic nature of climate policy shocks over time. For example, a carbon price is intended to shift behaviour, so the boost to government revenues from such a tax becomes less relevant and ultimately irrelevant over time if the policy succeeds.

This work aims to provide a systematic understanding of the implications of the green transition for the macroeconomy and monetary policy. The findings are informed by a review of the literature and set out how the channels through which key macroeconomic variables relevant for monetary policy, such as inflation and output, are affected. The report also looks to outline the differences across economies, particularly by stage of development, e.g. between AEs and EMDEs. Financial stability concerns are not covered in this report. The report begins by presenting an overview of the channels through which the green transition affects economic agents in Section 1. Section 2 focuses on the macroeconomic impact of climate change mitigation policies. Section 3 provides an overview of other transition drivers with a focus on structural changes that may or may not be indirect effects of policies. Section 4 discusses the aggregate effects on the macroeconomy and concludes with a brief discussion on the implications for monetary policy.

1. Propagation of transition drivers to the macroeconomy

This section sets out how the green transition impacts propagate in the macroeconomy. It presents an overview of the shifts the transition introduces and the impacts on agents across the economy. The shift towards a lower-carbon economy to reach net zero global GHG emissions affects how firms produce, how households consume, and has fiscal impacts. It also affects banks' and investors' behaviour, particularly through their management of transition-related risks, and it has international spill-over effects.

1.1 Types of transition drivers

The transition will drive major structural changes within and across economies, shifting consumption patterns and production activities towards low-carbon industries and scaling up investments in these sectors. Some of these changes will be driven by government policy. Others will be driven by market dynamics and shifts in economic agents' expectations, preferences and behaviours.

There are many different policy tools[3] that governments can use to decarbonise their economies, boost green investment and improve energy efficiency. The key policy instruments are carbon taxes, emission trading systems (ETS), investment and innovation subsidies for low-carbon alternatives, direct government investments, regulations and standards. Additionally, financial measures such as climate-related loans and bond issuance, along with "softer" measures such as encouraging private sector green financing and conducting awareness and information campaigns, are used to motivate businesses and households to reduce GHG emissions.

The climate policy choices each government makes depend on their economic, social and political circumstances as well as their climate objectives. For instance, the European Union has emphasised carbon pricing, while the United States and China have favoured subsidy-based approaches (Bown and Clausing, 2023). Overall, the policy measures proposed by most countries so far remain below what is needed to meet the Paris target (Climate Action Tracker, 2024), raising the likelihood that measures will be increased in the future, and the risk that this will occur in a disorderly manner.

Aside from policy shifts, **the transition is also marked by more gradual or "chronic" changes** driven by market forces or shifts in preferences as firms and consumers adjust their expectations and behaviour to the reality of climate change. These include the reallocation towards and scale-up of green investment.

1.2 Transition impacts across economic agents

For firms, the green transition necessitates increased investment in low-carbon technologies and reallocation of existing investment to transition-relevant activities. Ambitious and credible government climate policy, technological innovation, and increasing pressures from customers, investors and employees incentivise firms to transform and adapt their business models. Shifting towards low carbon production may result in existing capital being phased out or even stranded if it cannot easily be redeployed. On the other hand, increased demand for production inputs, such as renewable energy and critical minerals, and for the infrastructure to deploy green technologies, will stimulate investment activity. The introduction of new technologies and new regulatory requirements such as disclosures is also spurring demand for new expertise in the labour market. These changes and the exposure of firms to the transition are impacting their costs and productivity, and in turn also production, profits and their credit and financing operations.

Changes in consumer prices, wages, and asset prices will impact household income, wealth and saving patterns. Carbon pricing can affect consumer prices – both directly through higher energy prices and indirectly through higher costs for firms – and therefore household demand. Effects on productivity and labour market conditions will affect actual and expected household disposable income, impacting household consumption and savings decisions. Separately, households will be affected *via* the wealth

3 See OECD's climate change mitigation policy database for a comprehensive list of policies covering 49 countries (OECD, 2024).

channel as the transition drives shifts in a range of asset prices. Shifts in climate policy, the deployment of new technology or changes in preferences can alter household behaviour in a greener direction. This can take the form of changing consumption baskets, portfolio investment choices and the choice of employer. For households, there are also development co-benefits of climate action, such as direct improvements in human health or reductions in congestion and accidents.

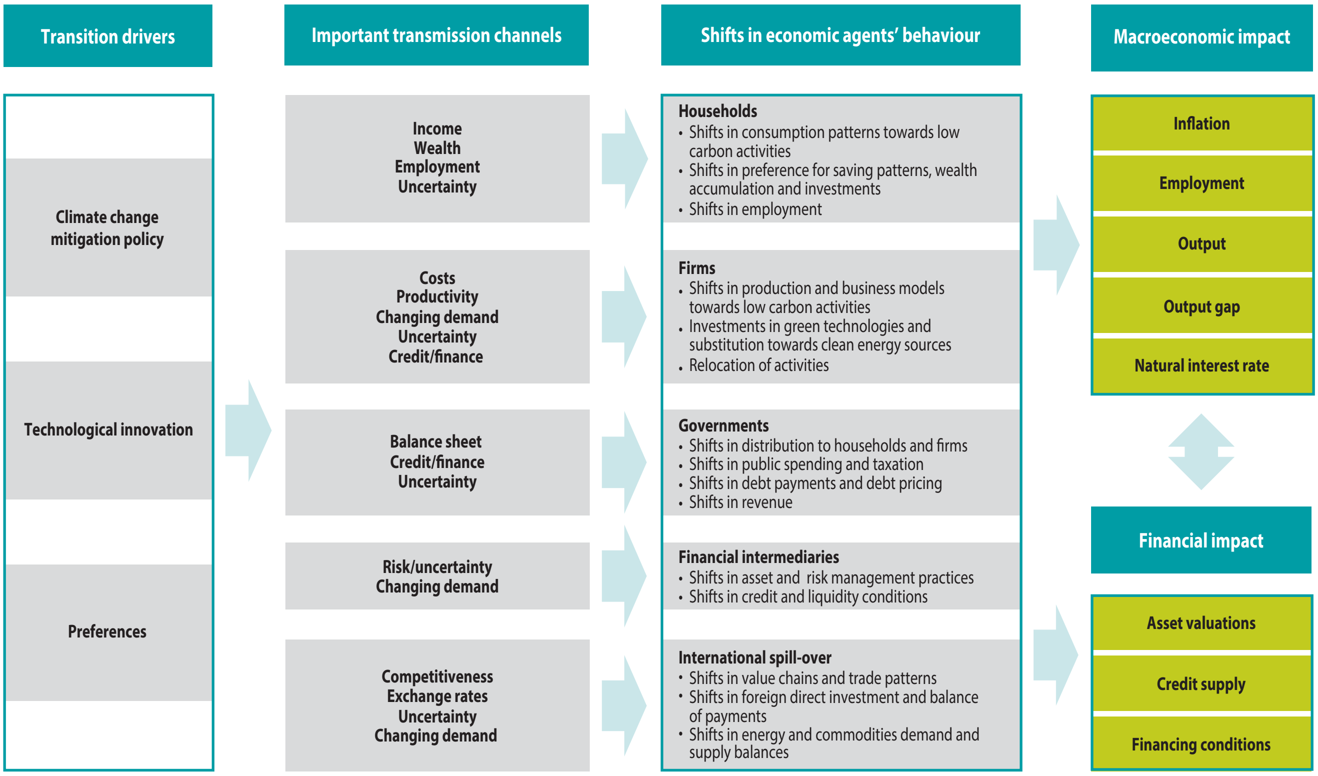
Climate change mitigation measures directly impact government fiscal balances. Carbon pricing generates government revenue, while subsidies for green technologies are financed from other sources of government revenue. The approach to managing these funds – whether recycling revenues or funding subsidies – affects macroeconomic outcomes significantly. The orderliness of the transition also plays a crucial role in influencing income tax revenues, dividends from state-owned enterprises, debt repayment capacity, borrowing costs, trade balances, capital inflows, and exchange rates. For countries that rely on fossil-fuel revenues, managing the green transition could become more challenging for government finances. On the other hand, those endowed with critical minerals or those currently reliant on fossil-fuel imports stand to benefit from important economic opportunities especially as the price of renewables continues a downward trend. The co-benefits of climate action identified above have also been shown to have a positive impact on government fiscal balances given the aggregate improvements in public health and associated reduction in health spending[4].

Financial feedback effects can amplify macroeconomic impacts, with expectations playing a crucial role. Expectations of stricter environmental regulations and changes in business models can lead to a reallocation of capital in financial markets, as investors increasingly begin to favour green investments and move away from carbon-intensive industries. These changes in investment flows can cause volatility in financial markets and affect the valuation of a wide range of assets. Moreover, expectations regarding the impact of future policy changes can influence consumer and investor behaviour, possibly driving precautionary savings or speculative investments which may magnify economic fluctuations, particularly in sectors directly impacted by climate policies. Additionally, expectations about the pace and effectiveness of the green transition can affect long-term interest rates and credit conditions, influencing borrowing costs and investment decisions across the economy.

The green transition could also have important international spillover and cross-border effects. As climate policies will vary in stringency and coverage across countries, this can generate competitiveness impacts and potentially give rise to changes in value chains and trade patterns and in turn domestic production (see Section 4.3).

4 These can be substantial in EMDEs, where air pollution kills millions, and congestion reduces the benefits from agglomeration externalities and urbanisation (Burns, Jooste and Schwerhoff, 2021).

Figure 2 **Propagation of effects from transition drivers to the macroeconomy**



Source: authors' own work.

The nature of the green transition – whether orderly or disorderly – plays a critical role in determining its macroeconomic outcomes. An early and orderly transition offers the potential to minimise the economic costs related to it, while a disorderly or delayed transition is seen to have more pronounced negative macroeconomic effects (IMF, 2022; NGFS, 2023a). The impacts are further influenced by the extent to which changes in transition drivers are anticipated. For example, a sudden, unexpected increase in carbon tax is likely to have more pronounced effects on output and inflation compared to a predictable and gradual one. Moreover, financial market feedback effects on the macroeconomy are magnified when changes in transition drivers are abrupt.

Figure 2 summarises the channels through which the green transition impacts on economic agents' behaviour and hence on macroeconomic variables such as inflation and output. Ultimately, the monetary policy response will also affect the outcomes.

2. Climate change mitigation policies

This section discusses how climate change mitigation policies affect the macroeconomy. Studies provide insights on the specific channels at work for different types of policies including carbon pricing (2.1), subsidies (2.2), and non-market based climate policies, regulation and standards (2.3). Policies work through both demand and supply channels, and can be amplified domestically and internationally through financial and trade linkages.

Climate policies have macroeconomic consequences. Variations in the design, pace, stringency and implementation of such policies, including their transparency, predictability, and degree of coordination across countries will be important determinants of their net impact on the supply and demand side of an economy and in turn what this will mean for output and inflation. Furthermore, uncertainty about the future path of climate policy can impact the macroeconomy through household and firm behaviour as well as through financial markets (FSB, 2020; OECD, 2021). While climate policies are generally set nationally, there will also be important international spillover effects to consider.

There are a few caveats to consider in discussing the results in the following sectors. Given the transition is still at an early stage, it may not be possible to draw conclusions based on backward-looking data. Furthermore, the potential non-linear nature of transition effects poses additional modelling challenges. The variation in how carbon policies are implemented geographically and the differences in the sectoral scope of these policies across countries make the generalisation of results challenging. The model results are also likely sensitive to the assumptions and design choices.

2.1 Carbon pricing

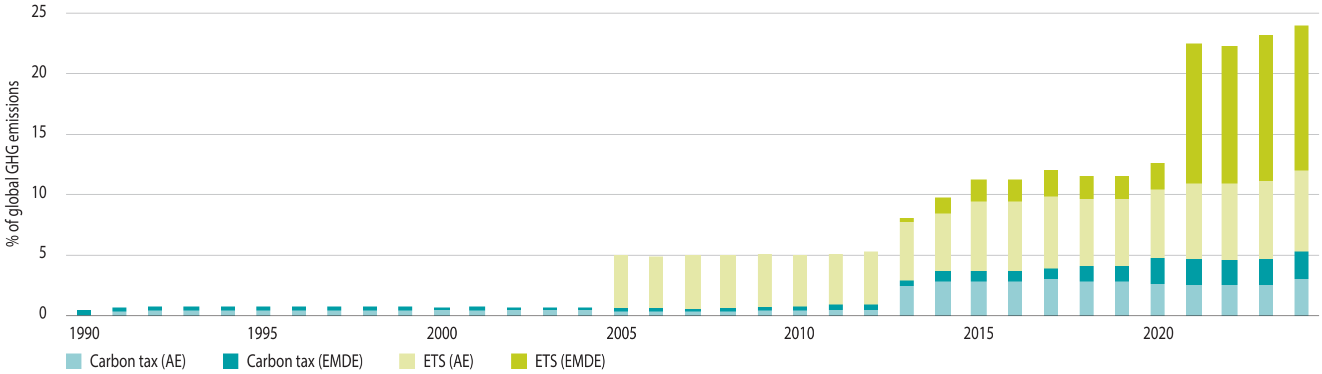
Carbon pricing is increasingly being implemented across many countries and sectors. Empirical evidence suggests that direct forms of carbon pricing will likely create some upward pressure on inflation in the short-term while being disinflationary at longer horizons. The macroeconomic effects of carbon pricing depend on the design of the policy, the size of aggregate demand and supply gap, policy credibility and revenue recycling. In the short run, the implementation of carbon pricing acts like a negative supply-side shock and can potentially induce a monetary policy trade-off.

Explicit forms of carbon pricing such as carbon taxes and emission trading systems are direct policy levers that correct the market failure of GHG externalities[5] by putting a price on emissions. They incentivise firms and households to shift to alternatives with lower carbon content and/or greater energy efficiency. A carbon tax sets the *price* of emissions directly and the market determines the *quantity* of emissions. The resulting revenue can be recycled, for example to compensate lower income households who are most affected by the incidence of the tax. In an Emissions Trading System (ETS), which generally takes the form of a "cap-and-trade" system, the policymaker issues a fixed *quantity* (cap) of emission permits and the market determines the *price*.

Carbon pricing has increasingly been shown to be an effective policy tool for lowering GHG emissions and can be scaled up over time (Moessner, 2022; Kapfhammer, 2023; Känzig, 2023; Metcalf and Stock, 2023; Dubois, Sahuc and Vermandel, 2024). Global coverage and the average carbon price have been increasing over time (Figure 3). Around one quarter of global annual GHG emissions are currently covered by explicit carbon pricing policies, with ETS the most widely used tool (Figure 4). The average global carbon price is around USD 6 per tCO_2e (Black, Parry and Zhunussova, 2022), well below levels required to meet emissions commitments. For instance, IEA (2021a) estimates that AEs would need to achieve a carbon price of USD 140/ tCO_2e by 2030, USD 205/ tCO_2e by 2040 and USD 250/ tCO_2e by 2050. Explicit carbon pricing policies are more prevalent in AEs (e.g. Canada, United Kingdom, European Union) but have been gaining prominence in EMDEs. The sectoral coverage of these policies differs across countries.

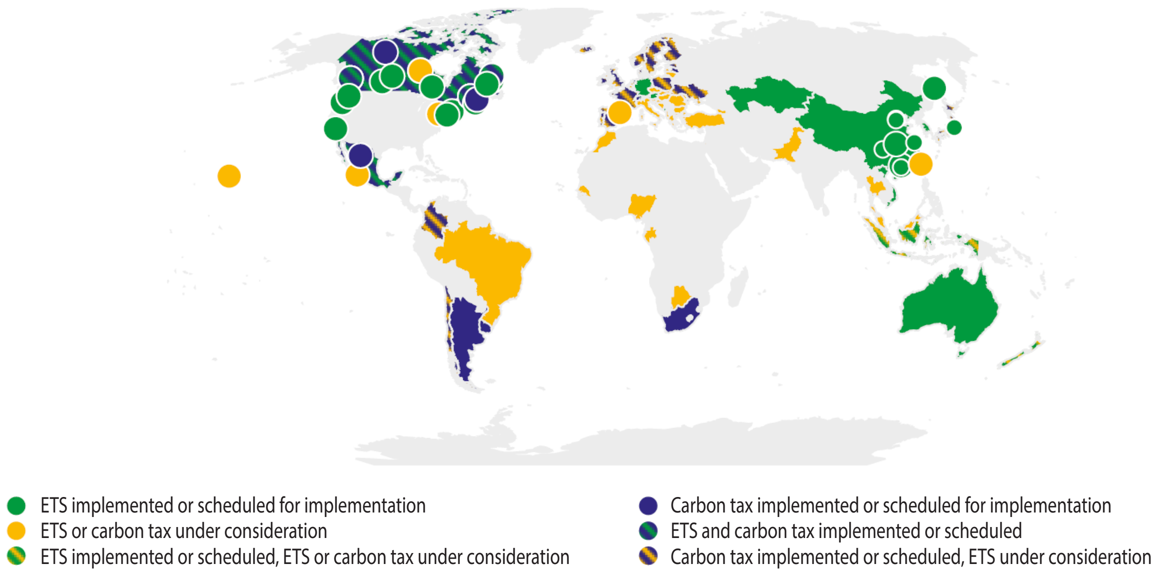
5 GHG externalities are the costs of emissions that the public would otherwise pay (for example as a result of loss of property from flooding due to sea level rise).

Figure 3 **Share of global GHG emissions covered by explicit carbon pricing (1990-2024)**



Note: Only the introduction or removal of carbon taxes and ETS are shown. The chart does not reflect changes in the stringency of the policy post-introduction, such as increased industry coverage or rising per-unit price. Numbers may underestimate the true level of global emissions coverage, as it excludes de facto carbon taxes such as fuel duties (Mann, 2023).
Source: Adapted from the World Bank Carbon Pricing Dashboard (World Bank, 2024).

Figure 4 **Carbon pricing initiatives that are either implemented, scheduled or under consideration around the world as of 2023**



Source: World Bank Carbon Pricing Dashboard (World Bank, 2024).

By making carbon-intensive goods more expensive to produce and consume, carbon pricing impacts agents across the economy:

- For carbon-intensive **firms**, the marginal cost of production increases, which in turn can reduce production and put upward pressure on inflation *via* the cost-push channel. Firms' profit margins can also be impacted due to higher input costs of goods and services that rely on carbon-intensive inputs. Firms could choose to pass through some or all of the higher prices to their consumers, leading to upward pressure on headline prices (Breckenfelder *et al.*, 2023; Känzig, 2023).
- **Households** face higher energy prices and increased prices for goods and services that rely on carbon-intensive products, thereby reducing their disposable income. If households anticipate the introduction of carbon pricing and impact on their future income, they will adjust consumption behaviour in the current period, lowering demand and adjusting their inflation expectations.

- For **governments**, in the short-term, carbon pricing can be a source of revenue that can be recycled back to the economy for various purposes (e.g. rebates to low-income households). Over time and as agents adjust behaviour, the revenues decline.
- **Banks, market participants and other financial intermediaries** will face changes in asset prices, impacting their investment and lending decisions. For instance, more stringent climate policy can hit the prices of carbon-intensive assets in the real economy by introducing the risk of stranding.
- **Internationally**, carbon pricing will also affect the price of traded goods and services for households and consumers, and therefore the terms of trade and the government's current account balance.

In the short run, higher carbon prices can act as a negative supply-side shock leading to a small fall in output. A notable caveat on all empirical work on carbon pricing is that data are constrained by the low level of implemented carbon prices. Metcalf and Stock (2023) find negligible effects on GDP and employment of higher carbon taxes in the short-term, while Känzig (2023) reports that economic activity falls temporarily, and unemployment rises after a carbon pricing shock in the European Union's ETS. Also, Kapfhammer (2023) finds that higher carbon prices dampen GDP in the short run, but the impact subsequently fades. Ferdinandusse, Kuik and Priftis (2024) suggest that the combined effect of the green fiscal measures adopted by the European Union on GDP growth is small over the short-term, and heterogeneous across countries. In a scenario where carbon tax levels increase linearly (in line with the interim carbon price target for AEs with net zero pledges) until 2030, Brand *et al.* (2023) estimate limited negative effects on euro area real GDP.

A rise in carbon prices will usually lead to upward pressures on headline inflation in the short-term, with core inflation largely unaffected. This is particularly the case if monetary policy reacts endogenously and inflation expectations are anchored (IMF, 2022). Konradt and Weder di Mauro (2023) find that countries in Europe and Canada with revenue-neutral carbon taxes and independent central banks do not experience significant increase in inflation in the short run. Moessner (2022) and Känzig and Konradt (2023) find that higher carbon prices can increase inflation in the short-term, more so with an ETS than carbon taxes. On the other hand, Kapfhammer (2023) finds no impact of carbon tax on consumer prices in the Nordics. Forward-looking analysis by the European Central Bank shows that higher European Union carbon pricing only has modest impacts on inflation, diminishing over time to the end of the scenario horizon in 2030 (Brand *et al.*, 2023; Ferdinandusse, Kuik and Priftis, 2024).

Over the medium and longer term, the overall macroeconomic impacts of carbon pricing will depend on policy design. Differences in empirical estimates of medium-term impacts are largely driven by the design of carbon pricing, sectoral coverage and revenue recycling method. Targeted revenue recycling can cushion the impacts of carbon policies. Revenues collected through carbon taxation and ETS can be recycled as lump-sum transfers, tax rebates or investments in the green transition. The recycling method and the proportion of revenue to recycle can have distributional impacts. Recycling revenues by reducing distortionary taxes (i.e. labour, capital) or subsidising green investments can cushion the hit to output from carbon pricing (Chiroleu-Assouline and Fodha, 2014; Caron *et al.*, 2018; McFarland *et al.*, 2018; Bartocci *et al.*, 2022; Estrada and Santabárbara, 2021; IMF, 2022). Targeted lump-sum transfers to low-income households can help address distributional concerns while still reducing macroeconomic impacts.

Carbon pricing can affect employment directly through consumption and investment and indirectly through revenue recycling. For instance, recycling carbon tax revenues to lower social security contribution payments by employers has positive employment implications as it makes labour relatively less costly (Fragkos *et al.*, 2017). A carbon tax increase can lead to varying effects on employment depending on factors such as the level of reallocation across sectors and impacts on firms' profitability: a small positive effect (Yamazaki, 2017; Metcalf and Stock, 2020, 2023), short-lived negative effect (Kapfhammer, 2023; Känzig, 2023) or no significant effect (Martin, de Preux and Wagner, 2014).

Despite creating similar overall incentives, carbon taxes and ETS will differ in their macroeconomic impacts. A credible carbon tax would require a predictable increase in the price of emissions over time, whereas a credible ETS scheme would require a pre-determined reduction in the supply of allowances to generate a carbon price increase[6]. ETS generally have larger macroeconomic impacts as they tend to include sectors with a higher pass-through of costs to prices, such as energy-intensive industries (Moessner, 2022; Känzig and Konradt, 2023). An ETS can reduce GDP volatility because it is countercyclical with respect to the business cycle, in contrast with carbon taxation (Annicchiarico, Di Dio and Diluiso, 2024). Compared to the carbon tax regime, the same shock under an ETS will induce a larger change in prices and an attenuated or even opposite response in aggregate output (Mann, 2023).

Carbon pricing also affects inflation *via* the expectations channel, creating additional challenges for central banks. If households anticipate the introduction of a carbon tax reducing their future income, they will adjust their consumption behaviour in the current period, lowering demand that could, in fact, lead to lower prices (Ferrari and Nispi Landi, 2022). Carbon pricing may also affect firms' inflation expectations, both directly and indirectly through changes in firms' own business conditions such as prices, wages and production constraints (Moretti, Mangiante and Moretti, 2023). Households' inflation expectations may increase if carbon pricing increases short-term energy prices (Wehrhöfer, 2023).

The output-inflation trade-off varies significantly depending on the design and credibility of carbon policies. A gradual and predictable carbon price increase results in smaller increases in inflation (Pinheiro de Matos and Gili, 2022). Conversely, a rapid price increase due to a delayed transition could create greater volatility, requiring central banks to react more strongly with correspondingly greater impacts on output (McKibbin *et al.*, 2020). Other studies find that reducing climate policy uncertainty in general is associated with lower macroeconomic costs.

Carbon pricing is likely to have the largest macroeconomic impacts in countries that are higher carbon-emitters and amongst firms that have the most carbon intensive activities. Berthold *et al.* (2023) report that the macroeconomic impacts of ETS carbon pricing are larger for higher-emitting countries. Furthermore, they document that firms with higher carbon emissions are the most responsive to carbon pricing shocks. Several other studies find evidence that carbon pricing affects firms' financial performance and their stock prices (Ziegler *et al.*, 2018; Millischer, Evdokimova and Fernandez, 2022; Bolton and Kacperczyk, 2023; Hengge, Panizza and Varghese, 2023). The empirical results typically depend on various factors such as the choice of countries, firms, time period and the modelling approach used.

2.2 Green subsidies

Subsidies are increasingly being used as an instrument to reduce GHG emissions by incentivising the adoption, innovation and investment in less carbon-intensive activities. They can take various forms, ranging from subsidised credit, financing assurance, public green investment projects, direct subsidies and tax cuts. They generally function by reducing the cost of capital for low-carbon investments or to directly support public-good type investments in order to then catalyse private investment. They may operate as complementary to policies that increase the cost of carbon-intensive activities (such as carbon pricing) and are especially relevant in sustainable infrastructure and renewable energy investments such as electricity grids or storage, where fixed costs are high and marginal costs low (IEA, 2020). For households, subsidies or tax breaks on low-carbon alternatives (such as electric vehicles) operate by shifting habits and behavioural patterns.

Despite being a less cost-effective tool than carbon pricing in reducing emissions, they are more politically feasible and so are being implemented more widely. The United States introduced the Inflation Reduction Act (IRA) in 2022 (see Box 1), while the European Union launched a green subsidy package (European Commission, 2020) and introduced new tax breaks to boost private sector renewable investment. China has announced large investments in clean technologies (Bian *et al.*, 2024), while India in 2020 put forward the Production Linked Incentive Scheme (Government of India, 2022) to enhance competitiveness in sectors like solar photovoltaics and batteries. Several other countries have also announced subsidised investment plans in green technologies.

6 An example of the latter is the Market Stability Reserve (MSR) of the European Union's ETS, which triggers adjustments to annual auction volumes if the requirements based on the level of the aggregate bank of allowances are met (Dubois, Sahuc and Vermandel, 2024).

The macroeconomic impacts of green subsidy schemes will depend on (i) the way subsidies are designed, (ii) the presence of potential supply bottlenecks, and (iii) the way subsidies are financed. The impact will also depend on the design of the subsidies:

- **When directly subsidising private investments in green sectors, subsidies transmit as a positive demand shock increasing output and inflation.** Subsidies in this case propagate *via* the demand side: by enhancing private investments in the targeted sectors they can increase aggregate demand, and, in turn, output growth and short run inflation (Schnabel, 2022). These effects can dissipate as the price of clean energy and other low-emission goods and services adjusts to a lower permanent level (Del Negro, Di Giovanni and Dogra, 2023).
- **When directly subsidising the price of green inputs, subsidies transmit as positive supply shocks increasing output but reducing inflation.** Subsidies in this case propagate *via* the supply side: they reduce the marginal cost of green goods and increase productive capacity. The associated impact on output is generally found to be positive given the acceleration of clean innovation and productivity (Acemoglu *et al.*, 2012; Bistline, Mehrota and Wolfram, 2023) and increased competition in the abatement equipment sector (Jondeau *et al.*, 2023). However, in this case second-round effects can potentially materialise, leading to an increase in inflation: the demand for the cheaper green goods increases, which in turn leads to an increase in marginal costs in the green sector and potentially to rising prices.

The effect on overall inflation in the medium term will depend on the form the sectoral shifts take and on the impacts on inflation expectations. This includes the patterns of substitution across the green and carbon-intensive sectors, and the effect of increased competition within the green sectors. Depending on the presence of nominal rigidities and the monetary policy response, subsidies to green intermediate inputs may be passed on to final goods and can therefore affect inflation and inflation expectations. Overall, the direct downward pressure on inflation would be partly counteracted by indirect inflationary price effects *via* the positive impact on output. The impacts of green subsidies on the economy will also depend on how they are financed (Benkhodja, Fromentin and Ma, 2023), as it would impact inflation expectations.

Reforming, or removing, existing subsidies to carbon-intensive sectors is also increasingly used as a tool in the transition, with important macro effects. Such subsidies represent a *de facto* negative carbon price, which incentivises consumption and investment in carbon-intensive goods and has been found to have considerable welfare costs (Parry, Black and Vernon, 2021). Globally, the IMF estimates that when accounting for both direct[7] and indirect[8] measures, subsidies for fossil fuel-related activity account for around USD 7 trillion (Black *et al.*, 2023). Ultimately, the overall effect on the macroeconomy of removing such subsidies will partly depend on how the savings from lower fossil-fuel subsidies are used (Damania *et al.*, 2023). In the context of cost-of-living concerns such as during the 2021-23 energy price shocks, fossil fuel subsidies removal has tended to be accompanied by support to affected vulnerable groups[9].

7 Such as budgetary transfers, price support, and investment by state-owned enterprises.
8 Such as foregone consumption taxes.
9 The Canada Carbon Rebate is one example of such a programme (Government of Canada, 2024).

Box 1

The U.S. Inflation Reduction Act

The USD 750 billion U.S. Inflation Reduction Act (IRA) of 2022 represents a significant legislative change to respond to pressing economic and climate needs. It aims to deliver climate resilience by leveraging tax credits to incentivise investments that spur economic activity in clean energy. The White House estimates that one year after the introduction of the policy around 170,000 new jobs were created as a result of additional announced investments at a magnitude of USD 110 billion in clean energy manufacturing and USD 70 billion in electric vehicle supply chains (White House, 2023), while the U.S. Treasury credits the policy with a recovery in business investment and boosting national productivity growth (U.S. Department of the Treasury, 2023).

The direct impact on overall output and inflation is harder to estimate, particularly given the counteracting effect on clean energy investment from underlying macroeconomic conditions and higher interest rates over the time of the policy (Bistline, Mehrota and Wolfram, 2023). Macroeconomic effects of the policy are found to be close to zero over the first year (Huntley, Ricco and Amon, 2022). Over the short to medium term, the estimated effect on prices is like a positive demand shock (Huntley, Ricco and Amon, 2022; Bistline, Mehrota and Wolfram, 2023) and the effect on output tends to be modestly expansionary (Bistline, Mehrota and Wolfram, 2023; De Nederlandsche Bank, 2023).

2.3 Non-market-based climate policies, regulations and standards

Non-market-based direct government interventions are increasingly used to foster the transition in specific activities or economic sectors[10]. Examples include **regulatory standards**, such as efficiency or performance standards; **production quotas or bans**, for instance bans on the sale of cars with internal combustion engines and quotas on electric cars; and **information instruments**, such as green indexes, labelling and disclosures. These measures often apply sector-wide (e.g. energy production, manufacturing, and transportation) and can be impactful as alternatives to pricing measures where price elasticity is low.

Their macroeconomic effects can be contractionary and inflationary in the short run (if they introduce compliance and administrative burdens) but expansionary over time once their intended effects materialise. Understanding these differing short- and long-term impacts is therefore relevant for central banks in formulating their policy.

Working through three main channels, they:

1) **Alter production costs and input prices.** For instance, renewable energy standards can put upward pressure on energy prices by shifting investment into high fixed-cost renewable energy production technologies. Such effects can dissipate or even reverse in the medium term as the benefits of investments and efficiency improvements are realised, and as marginal production costs decline. Administrative and compliance costs associated with disclosure and energy efficiency requirements can push up prices in the short-term. Over time, such measures can introduce cost savings by supporting effective climate risk management and supporting informed investment decisions (through disclosures) and decreasing buildings' energy consumption (through efficiency standards).
2) **Change investment patterns and encourage technological innovation.** Specific or higher standards and/or more stringent regulation in carbon-intensive sectors can incentivise the innovation, development and competitiveness in new markets, such as in renewable energy and electric vehicles. The net effects on productivity from more stringent environmental policy will depend on the balance between the hit to emission-intensive firms and the boost for low-emissions peers (Hamamoto, 2006; Albrizio, Kozluk and Zipperer, 2017; Cohen and Tubb, 2018; Parker, 2023).

10 A comprehensive database on climate laws and policies can be found at www.climate-laws.org.

3) **Affect asset prices and wealth.** Energy efficiency improvements can increase asset prices such as residential real estate (Næss-Schmidt *et al.*, 2016; Reusens, Vastmans and Damen, 2022) and can boost household disposable income given the reductions in energy bills (Bell, Battisti and Guin, 2023). On the flipside, a disorderly transition could result in stranded assets losing value in the transition, which whether realised or not could have negative effects through higher risk premia.

Macroeconomic effects will also manifest *via* the labour market. Regulations that prohibit certain activities, such as coal production, may result in sectoral unemployment unless accompanied by support measures for retraining and reallocating workers to other sectors. The net effects will also depend on the growth of green industries and the extent of transferable skills. Regulations on consumption could also have indirect impacts on the labour market *via* reduced demand for certain products. The European Union's emission limits for cars and vans implemented in 2019, and the bans and quotas for a range of vehicle and fuel types in its Fit for 55 package are designed to shift production technologies to more efficient motors (European Commission, 2023c). This could have extensive impacts on the domestic labour market as electric cars are less labour-intensive to produce and require different skills.

3. Structural transition dynamics

This section discusses the effects of more gradual or structural changes associated with the transition on the macroeconomy including the scale up in green investment (3.1), developments in innovation and technology (3.2) and the evolution of green preferences across economic agents (3.3).

Aside from policy shifts explored in Section 2, the transition is also marked by more gradual changes that are occurring through market forces or by shifts in preferences as firms and consumers adjust their expectations and behaviour to the reality of climate change. While some of these may not at present fall within the monetary policy horizon or take the form of a cyclical shock that monetary policy may be called to react to, they will leave an imprint on real economic activity and inflation dynamics that will be increasingly relevant for central banks as they seek to understand the economy.

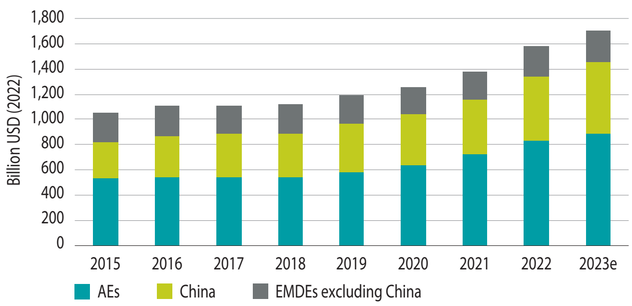
3.1 Green investment

Aside from the short-term impacts of transition policy shocks on the macroeconomy explored in Section 2, the resulting shifts in the patterns and scale of investment will have their own distinct macroeconomic effects that monetary policymakers will need to understand and monitor. A reduction in emissions that achieves net zero in line with the Paris Agreement requires (i) a reallocation of investment and economic activity from carbon-intensive activities to low/zero carbon ones, and (ii) a scale up in investment in low-carbon activities to facilitate continued economic growth.

Delivering the transition will be characterised by investment increasing at a big scale, across sectors, and across geographies. The transformation of the energy sector will take up the lion's share of the increase in investment required to deliver net zero, particularly the electrification and diversification of energy-intensive, high-emissions industries such as oil and gas, and clean energy production. The transition will also allocate substantial investment for electrification and the decarbonisation of transportation, such as investments in sustainable aviation fuel and improved aircraft design and propulsion technologies (Reséndiz and Shrimali, 2023), industrial systems (particularly steel and petrochemicals) and agricultural processes. Overall, the IEA projects that to achieve net zero, clean energy investments as a share of global GDP need to double from 1.8% to 3.6%. (IEA, 2023c)[11], and triple annually for EMDEs (IEA, 2023b)[12]. So far, while green investment reached record levels in 2023, it remains concentrated in AEs and China (Figure 5).

Figure 5 **Global clean[1] energy investment**

(in total and by different groups of countries)



1 *Clean energy includes renewable power, nuclear, grids, storage, low-emission fuels, efficiency improvements and end-use renewables and electrification.*

Sources: Adapted from IEA (2023c).

In the short run, the net effects on overall investment from increased green investment will depend on the extent to which it is additional or redirected investment and on the depreciation cycle of existing assets. Green investments may either displace other investments or contribute towards an increase in the productive capital stock and boost aggregate demand (Victor, 2022). Evidence from green private investment projects in the United States and Norway shows positive impacts on growth (Norges Bank, 2021; Clean Investment Monitor, 2023). Overall, for AEs with aging power generation infrastructure that have fully depreciated, additional investments in

11 Bhattacharya *et al.* (2023) estimate that climate transition and nature-related spending need to accelerate to USD 2.4 trillion per year by 2030, of which most of the investments will be concentrated in delivering the energy transition needs, at approximately USD 1.5 trillion.

12 For EMDEs excluding China, this would be consistent with a historic sevenfold surge in clean energy investments (IEA, 2023b). Other reports project that the annual investment needs in EMDEs are equivalent to 1% to 8% of GDP through to 2030 to reduce GHG emissions by 70% by 2050 and meet other development goals (World Bank, 2022).

renewables will have an incremental impact on capital stocks as they gradually replace existing assets. Conversely, most power plants in EMDEs are still relatively young, and a disorderly transition risks premature obsolescence, potentially reducing the overall capital stock. The lifespan of coal and gas power plants lasts about 40-50 years, compared with 25-30 years for solar photovoltaics (IEA, 2022).

Green investments generate larger investment multipliers than carbon-intensive investments but face higher upfront costs. Batini *et al.* (2022) highlight that renewable energy investment multipliers at 1.2 are almost twice as large as those for fossil fuel energy at 0.5-0.6, both immediately and at a five-year horizon. This reflects their labour-intensive nature, at least in the short run, and their requirement for more direct and indirect spending within the domestic economy – such as building electrical grid systems locally or retrofitting buildings (IRENA, 2016; EPA, 2020). At the same time, they face more obstacles to being launched: in an uncertain policy, cost and demand environment, and without measures to correct market failures, investors are wary of green infrastructure projects that face heightened operational risks such as permit challenges and that require high initial capital expenditure, even if they incur low marginal costs once operational.

Box 2

Green investment and transition uncertainty

Heightened transition uncertainty can adversely impact on green investment and the resulting macroeconomic outcomes. Transition uncertainty can take many forms. Setting aside uncertainty related to the physical impacts of climate change[1], the transition is characterised by uncertainty in relation to:

- *Policies*, including when climate goals will be met, and which combination of tools will be adopted where and at which pace.
- *Technologies*, including where there will be innovation breakthroughs, how costs will evolve, which technologies will dominate and what shape new markets will take (Haas *et al.*, 2023).
- *The behavioural response* of economic agents to the transition, including individuals' green preferences and financial markets' risk management (see sections 3.3 and 4.2).
- *The lack of data,* particularly forward-looking data that can help estimate price elasticities and related substitution effects to understand how different transition drivers will impact the economy.

Higher transition uncertainty can delay or dampen investment the short-term. Uncertainty affects the economy mainly through its impact on households', firms', and investors' decision-making (Bloom, Bond and van Reenen, 2007; Gulen and Ion, 2016). This is particularly true for many investment decisions as large upfront costs, long time-to-build leads, and long lifespans for capital mean that they typically need to be highly forward-looking (Bloom, 2014). Both carbon-intensive and green industries can be affected: by analysing data from 12 OECD countries over the period from 1990 to 2018, Berestycki *et al.* (2022) find that a 10% increase in climate policy uncertainty reduces firm investment on average by about 2-3% in the same year, with the decrease largest for pollution-intensive sectors that are exposed to climate policies and among capital-intensive firms. At the same time, increased regulatory uncertainty can lead to decreased firm investment in renewable energy generation (Fabrizio, 2013) and weigh on decisions for all types of energy investments (Wood, Dundas and Percival, 2019). Generally, evidence points to asymmetric and non-linear impacts from climate policy uncertainty, decreasing investment in carbon-intensive firms, while raising green innovation and investment in other firms (Fried, Novan and Peterman, 2021; Hoang, 2022; Pan *et al.*, 2022; Ren, Shi and Jin, 2022; Yang *et al.*, 2022).

…/…

1 See NGFS report on Acute physical impacts from climate change and monetary policy (NGFS, 2024).

Boosts to long-term productivity from green investments are maximised in an orderly transition. As carbon-intensive industries become displaced from low-carbon ones, the productivity losses they may incur in the short-term dampen the net effect on Total Factor Productivity (TFP). However, the gains from allocative efficiency as renewable energy and other green technologies replace fossil fuels over time increases TFP through (i) innovation spillovers; (ii) new energy market creation and energy efficiency; (iii) higher demand for skilled labour demand in the associated industries; and (iv) a capital deepening effect (Rath *et al.*, 2019; Sohag, Chukavina and Samargandi, 2021). Such positive impacts of TFP from renewable energy were observed for AEs and EMDEs. Potential gains may be limited in the face of challenges such as path dependency[2], high switching cost for firms to use alternative technologies, availability of inputs (e.g. energy, critical minerals, labour), and balance sheet effects from stranded assets. The more orderly and well-managed the transition is, the less relevant these challenges are (Batini *et al.*, 2022; Americo, Johal and Upper, 2023).

2 "Path dependency" refers to when initial conditions and history matter for the outcomes, e.g. due to network effects and high switching costs. Network effects in technology adoption can create path dependence, where the benefits of using a particular technology rise with the number of others using the same technology, and infrastructure assets are often locked in due to the high costs of switching to alternative systems.

The overall impacts on inflation from green investment will be felt predominantly through the energy markets, with increased volatility and inflationary pressures in the short-term giving way to more deflationary medium- and long-term dynamics. As renewable energy investment accelerates and fossil fuel investments are phased down and out in the transition, energy price volatility is likely to increase in the short-term (see Box 3). Challenges related to intermittency in electricity may rise when renewables reach a higher share in the electricity mix. However, as electricity networks become more flexible through better storage options and greater diversification of sustainable energy options, this effect is expected to wane.

In a disorderly transition, pressures on inflation could also build through a spike in demand for critical minerals. Given long lags associated with mining production for minerals such as lithium, nickel and cobalt, a rapid and disorderly increase in demand would put upward pressure on prices. Low-carbon technologies such as renewable energy and electric vehicles contain a higher embodied share of these minerals than their high-carbon counterparts (IEA, 2021b), spurring high demand and putting upward pressures on prices (Boer, Pescatori and Stuermer, 2021). Challenges related to supply chains, including geopolitical fragmentation and concentration of production in a few countries, along with these commodities being traded in financial markets may add to price pressures, while advancement of technology and recycling ability can work in the opposite direction (IEA, 2023a).

In the labour market, shifts in green investment patterns will result in a reallocation of employment with mixed effects on wages and the NAIRU. In the short- to medium-term, greater low-carbon investment will boost employment in the domestic manufacturing, construction, electricity and transport sectors (Chateau, Bibas and Lanzi, 2018; Botta, 2019; Fragkiadakis *et al.*, 2023). As productivity increases and technology cost curves improve over time, economic activity in the sectors will likely become less labour intensive. The overall effect at a given time will depend on a country's industrial structure and on the pace at which the shift from high-carbon to low-carbon activity is achieved following green investments. Green jobs are typically high-skilled and are less prone to automation and attract a wage premium even after considering skill levels, age and geography (Bluedorn *et al.*, 2022; IMF, 2022). In AEs, jobs in both the new green sectors and the carbon-intensive sectors are concentrated among small subsets of workers whereas EMDEs often have a larger employment share in carbon-intensive sectors. These systematic differences in job characteristics may complicate the sectoral reallocation away from carbon-intensive industries, leading to potential economic restructuring, dislocation of green jobs and jobs in supporting industries along the supply chain, with potential distributional effects (Bulmer *et al.*, 2021). There may also be disparity in green job creation across regions within a country, raising concerns about social divides and structural unemployment (OECD, 2023). Over time, this could alleviate risk of hysteresis in the labour market, and in turn affect key monetary policy variables such as the Non-Accelerating Inflation Rate of Unemployment (NAIRU)[13].

Internationally, the rise of green investments could shift patterns of foreign direct investment (FDI) and trade flows, with implications for exchange rates and external investment positions, and in turn inflationary pressures. Countries with carbon-intensive domestic value chains may become less competitive in attracting green FDI (Chau *et al.*, 2023). Fossil-fuel exporters who are not actively planning for the transition may face a dual challenge of declining revenue from fossil exports, while needing to import green technology. All else equal, this would lead to a deterioration of current account balances and an exchange rate depreciation, making imports more expensive and generating inflationary pressures. The net international investment position of fossil-fuel exporters may deteriorate, implying less investment of petrodollars in international financial centres (Svartzman and Althouse, 2020). Such effects work in the opposite direction for green technology-exporting countries, where global demand for capital goods rises and boosts investment and production of green technologies, with positive effects on output and employment. While critical mineral commodity exporters may see a rise in resource-seeking FDI, benefiting from the export boom, there may be crowding-out effects if such investments are not balanced with other FDI and domestic investments into clean energy manufacturing capabilities.

Box 3

The green transition and energy markets

For the energy markets, the transition to a net zero economy translates into a significant transformation marked by the move from fossil fuels to renewable energy. In a disorderly transition, this can result in inflationary pressures and greater volatility for energy prices. This could give rise to several challenges for monetary policy when disentangling temporary from permanent impacts on inflation.

The energy landscape is undergoing a pivotal transformation. Renewable energy development has already accelerated considerably (Figure 5), more recently driven by the impact of the war in Ukraine on the energy market. Geopolitical fragmentation has exposed fragilities in fossil fuel supply chains and introduced a focus on domestic energy security. But there is still a long way to go to align with net zero targets, with some estimates suggesting that the share of renewables in global final energy consumption needs to double between 2020-30 from 18% to 35% (IRENA, 2023). The availability, security and affordability of energy, the rate of technological progress, as well as implementation barriers in renewable energy projects (linked to supply chains, material availability, permitting and licensing, financing, infrastructure, and workforce) will determine the supply and demand balance in the energy market during the transition.

Energy prices will likely remain volatile in the short-term as the sector transitions. The increasing reliance on renewables could lead to intermittent supply issues until the fledgling energy storage sector reaches greater maturity. This may necessitate reliance on flexible fossil fuel-powered backups to mitigate shortfalls in renewable energy production, with impacts on spot electricity prices which may in turn affect prices faced by end-consumers. The increased volatility in both demand (for example from the shift towards electric vehicles) and supply (due to geoeconomic fragmentation) could add further pressures to the energy market.

…/…

13 The NAIRU is the lowest unemployment rate that can be sustained without causing wages growth and inflation to rise. It is a concept that helps gauge how much "spare capacity" there is in the economy.

Volatility and uncertainty in energy prices could in turn exacerbate wider inflationary pressures, including via wage impacts and inflation expectations. Firms facing rising and more erratic energy expenses may react by raising prices, passing increased costs on to consumers and generating inflation (Huang, Hwang and Peng, 2005). Uncertainty can also hinder business investment and planning, disrupting supply chains and production capabilities. Repeated near-term energy price shocks may also push up wages (Auclert *et al.*, 2023; Kilian and Zhou, 2023), with the pass-through from energy prices to wages partly dependent on the structural characteristics of the labour market (wage settings) and the credibility of monetary policy (Baba and Lee, 2022). Additionally, large and persistent energy price shocks can magnify second-round effects through higher inflation expectations. This impact is particularly acute for low-income households (Wehrhöfer, 2023) and in EMDEs where transfers rarely compensate poorer households during times of adverse income shocks.

Over time, the energy transition will become disinflationary as volatility recedes and as renewables become even more cost effective. Increased capacity in renewable energy, technological advancements supporting cost-effective storage solutions, innovation in energy efficiency and lower consumption from behavioural change are all expected to support a downward trend in energy prices. So far empirical evidence for Europe shows that an increase in the share of renewables is already lowering the wholesale price of electricity (Cevik and Ninomiya, 2022; Farhat, 2024). The overall effects will depend heavily on specific market characteristics, including the energy mix and competitive landscape, as well as the regulatory frameworks in place.

The dynamics underpinning changes in energy prices will become increasingly relevant for central banks' monetary policy assessment. Central banks may choose to accommodate at least some of the temporary changes in energy prices (Bandera *et al.*, 2023). The green transition could however also lead to an upward trend in the relative price of energy, resulting in divergences between average CPI and average core inflation over a period time (Bache, 2023). Going forward, it will become increasingly important and challenging for central banks to distinguish between transitory and structural sources of energy price shocks, the persistence of such shocks, as well as the feedback loop to inflation through second round effects through wages and prices.

3.2 Innovation and technology

Technological innovation, such as in renewable energy, electrifying transport or alternative fertilisers, is an important transition driver with likely desirable implications for inflation and output. As firms adjust to the reality of climate change and begin to grasp the economic opportunities the transition presents, they are increasingly investing in innovation for the development and diffusion of new technologies. This is partly driven by climate change mitigation policies explored in Section 2, but also separately and distinctly reflects market forces as firms seek to remain competitive and gain market share in the industries of the future (Fischer and Newell, 2008; Johnstone, Haščič and Popp, 2010; Acemoglu *et al.*, 2012). Over the medium- to long-term, a step-up in the levels of innovation and technological progress can affect the macroeconomy by shifting market and price dynamics relevant for monetary policymakers.

The links between international policy coordination, national climate change mitigation policies, market competition, and technological innovation can create powerful virtuous economic cycles. As policies generate incentives for less-carbon-intensive activities and increase their relative market share, markets respond by shifting research towards cleaner technologies. This in turn lowers input costs for clean sectors and influences the long-run direction of technological change (Acemoglu, 2002). Such shifts can be self-reinforcing[14], with innovation improving productivity and reducing the costs of green investments, thereby accelerating the transition. Building the cycle further, the more cost-competitive green technologies get, the likelier consumers are to develop green lifestyles, values and preferences (Aghion *et al.*, 2023), in turn incentivising firms to invest further in innovation[15]. Increased demand for clean activity from national policies may invite stronger market interest and generate increased competition, boosting

14 See for example the induced innovation hypothesis (Hicks, 1932).

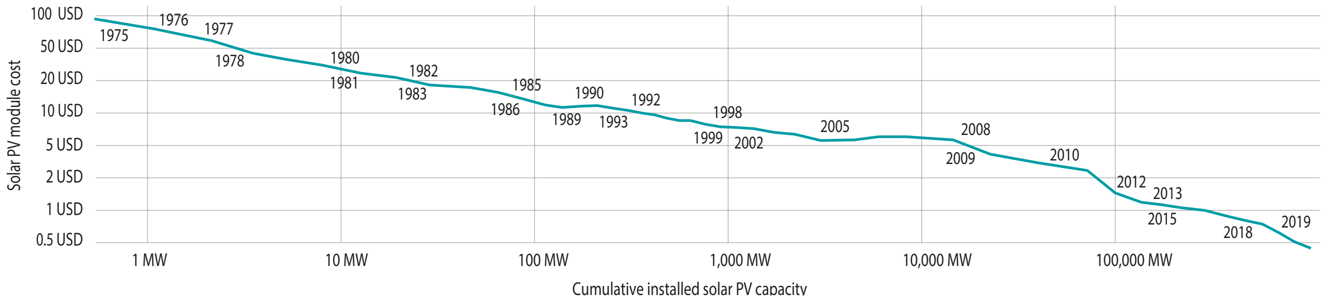
15 Aghion *et al.* (2023) show for instance that realistic increases in environmental preferences and in product market competition can have the same quantitative impact on green innovation as a 17% increase in global fuel prices.

innovation further, including in traditional sectors such as the power sector (Aghion *et al.*, 2005; Stern, 2008; Nillesen and Pollitt, 2019; Jamasb *et al.*, 2020).

Energy markets provide a useful illustrative example. Shifts in the sector[16] are leading to higher research and development and patenting in enhancing existing energy technologies (e.g. oil fuel extraction), energy efficient technologies (e.g. fuel efficiency technologies) and clean technologies (e.g. renewable energy and electric vehicles)[17]. In turn, these are leading to substantial cost reductions in renewable energy: since 2010, the costs for both solar and wind have decreased by 85% and 55% respectively (IPCC, 2023). Improvements have been faster than expected (Figure 6) and have much further still to go (Americo, Johal and Upper, 2023), supported by advancements in artificial intelligence (AI) that enhance the matching of supply and demand in energy systems and strengthen productivity-enhancing network effects (IPCC, 2022; Kaack *et al.*, 2022).

Figure 6 **Solar photovoltaic panel prices vs cumulative capacity from 1975 to 2022**

(prices in constant 2022 USD per Watt)



Source: ourworldindata.org, Our World in Data (2024).

The innovation spur in green sectors can in turn raise aggregate levels of innovation, with implications for the broader macroeconomy (Hasna, Jaumotte and Pienknagura, 2023). This is partly thanks to strong knowledge spillovers to other technology fields, leading to overall higher TFP across the economy and generating economies of scale in production and discovery (Dechezleprêtre, Martin and Mohnen, 2017). In the longer run, the higher productivity gains from green innovation can also affect the natural rate of interest (see Box 6). Demand in green sectors also triggers innovation for other parallel technologies as evidenced in how renewables and electric vehicles spurred innovation in advanced materials and energy storage systems. Still, the aggregate effect on productivity will depend on how sectoral productivity are affected from the reallocation away from carbon-intensive sectors towards those that benefit from the green transition.

The overall impacts on inflation and output from this virtuous innovation cycle will likely be desirable over the medium- to long-term. The shift from finite supplies of fossil-fuel energy sources to increasingly low-cost renewable and low-carbon technologies will dampen inflation *via* lower energy prices, assuming for constant demand[18] (Andersson, Baccianti and Morgan, 2020). In terms of output, a spur in green innovation could temporarily boost economic activity as firms invest in their capacity to absorb new technologies and patents and new firms enter the market (Finkelstein Shapiro and Metcalf, 2023), and as energy efficiency improvements generate cheaper energy sources for firms (Acemoglu *et al.*, 2012; Aldieri and Vinci, 2020). Recent studies (Hasna, Jaumotte and Pienknagura, 2023) further show how a doubling of green patent filings can boost GDP by 1.7% after five years.

16 Partly driven by the COP28 commitment to triple renewable energy production and double the rate of energy efficiency improvements by 2030. Hasna, Jaumotte and Pienknagura (2023) estimate that global and domestic policy synchronisation can contribute towards a 10-18% increase of green patent filing activities within 2-4 years from the policy introduction.

17 For more on energy markets and innovation see Box 3 as well as Newell, Jaffe and Stavins (1999), Popp (2002) and Aghion *et al.* (2016).

18 On a global scale, these shifts will be accompanied by an increase in demand especially in developing economies. Still, inflation will be lower compared with the counterfactual of continued reliance on fossil fuels.

Internationally, changing patterns of innovation could result in shifts in competitive advantages and affect current and capital account balances. Around 70% of the cross-border transfers of Lower Carbon Technologies (LCTs) patents took place among AEs, with almost no transfers to or from EMDEs (Pigato *et al.*, 2020). The slower pace of diffusion in EMDEs is partly attributed to (i) limited absorptive capacity and implicit knowledge; (ii) path dependency and carbon lock-ins; (iii) institutional failures (uncertainty around environmental policy ambitions and administrative barriers); (iv) limited access to financing; (v) issues around Intellectual Property regimes, and (vi) higher trade cost structures (see Box 4 as well as Unruh, 2002; Negro, Alkemade and Hekkert, 2012; Aghion *et al.*, 2016; IPCC, 2022). This can ultimately result in higher adjustment costs for EMDEs when facing international policy spillovers from carbon pricing (see Section 2.1 and Box 5), with implications on the trade balances and foreign exchange earnings of developing countries.

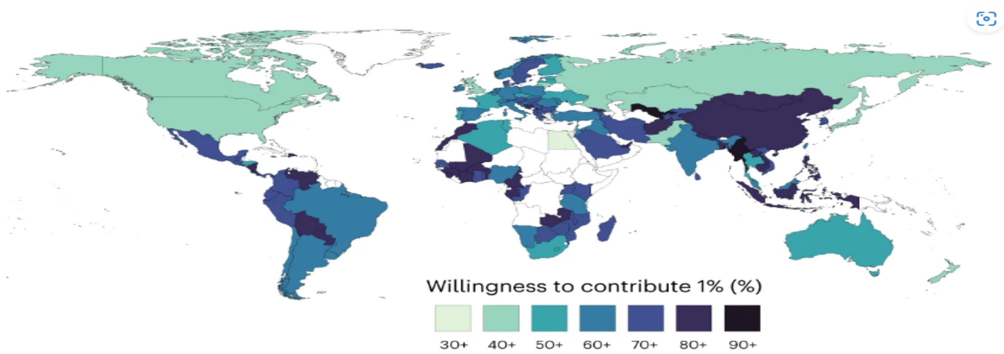
3.3 Green preferences

Another driver of the green transition is changes in economic agents' preferences in a greener direction. There are many examples of green preferences affecting households and firms' behaviour across the world, and such preferences are found to impact inter alia consumer prices and innovation in low-carbon technologies.

As economic agents adjust their expectations and behaviour to the reality of climate change, they are increasingly beginning to express "green preferences" in their choices. This applies to individuals as consumers or labour market participants, with firms and investors doing the same in their business planning and investment choices. While this is partly driven by policy (Santarius and Soland, 2018; Zhou, Sawyer and Safi, 2021; Ardia *et al.*, 2022; Busato *et al.*, 2023), socioeconomic, cultural and technological factors also contribute. These choices can over time impact economic outcomes, particularly consumer prices and levels of innovation in low-carbon technologies (Hoff and Stiglitz, 2016; Mattauch *et al.*, 2022; Besley and Persson, 2023).

Among households, green preferences can affect consumption and in turn influence firm behaviour, prices, and investor choices. Such preferences tend to be stronger in countries more vulnerable to climate change (Figure 7), with households willing to contribute shares of their personal income to support climate action, to adjust their consumption (Ipsos, 2019) or to pay a premium for sustainable products (Bartling, Weber and Yao, 2015; Faelli *et al.*, 2023). As pro-environmental attitudes increase among consumers, they create incentives for firms to foster green innovation and differentiation in product types (Aghion *et al.*, 2023). This in turn can soften price competition and affect price dynamics, for example introducing green *premia* (Bartling, Weber and Yao, 2015; Ammann *et al.*, 2023). Demand and supply also interact *via* the reputation channel: Houston *et al.* (2022) observed that firms in the United States suffering negative ESG reputation shocks saw sales for impacted products fall by 5-10%. Xiao, Zheng and Zheng (2023) report that incidents harming a firm's environmental and social reputation can decrease store visits significantly, especially among more environmentally and socially aware consumers.

Figure 7 **Willingness to contribute 1% of personal income to support climate action**



Source: Andre et al. (2024).

Green preferences can also shift labour supply towards green sectors, affecting wages. A fifth of respondents surveyed in the United Kingdom had turned down a job offer because of the firm's environmental profile (KPMG, 2023) while in Norway firms reported that employees increasingly emphasise climate change considerations when choosing a job (Brekke, Erlandsen and Meyer, 2023). Moreover, workers have been found willing to accept lower wages to work in firms with a sustainable profile (Krueger, Metzger and Wu, 2021).

In investment and finance, green preferences can affect asset pricing by lowering the cost of capital for sustainable firms. There is increasing evidence in the literature that investors with green preferences are willing to pay a premium or receive a lower return on stocks, bonds or bank accounts that are considered green (Fama and French, 2007; Chava, 2014; Zerbib, 2019; Giglio *et al.*, 2023; Aron-Dine *et al.*, 2024). This partly reflects reputation, risk management, and long-term profit considerations, in addition to green preferences (Hart and Zingales, 2017). Pástor, Stambaugh and Taylor (2021) show theoretically that such *premia* lower the cost of capital of green firms, shifting real investment from carbon-intensive to less-carbon-intensive firms. Investors also increasingly follow active ownership strategies, using their shareholder rights to engage with firms to reduce their carbon footprint either directly or through proxy voting (Broccardo, Hart and Zingales, 2022). Another approach involves divesting from carbon-intensive sectors (e.g. City of New York, 2018), which can negatively affect the stock prices of the excluded firms.

Similarly, green preferences among financial institutions can affect bank lending and credit conditions in the macroeconomy. This is particularly relevant for the financing of coal assets as banks increasingly divest from coal (Green and Vallee, 2023), and for fossil fuels more broadly as banks begin to charge higher lending rates in the sector (Delis *et al.*, 2023) or shift credit away from carbon-intensive firms and towards green ones (Kacperczyk and Peydró, 2022). Again, such action partly reflects risk management practices in addition to preferences and is closely related to perceptions and management of transition risk (see Section 4.2).

Overall, these shifts in green preferences are unlikely to manifest as distinct shocks that monetary policy will likely respond to. But they will be relevant for monetary policymakers as they seek to understand how the economy is shifting over the medium- to long-term horizon. So far there is limited empirical literature on the macroeconomic impacts of preference changes. At the sector and country level, the effects in terms of consumption patterns, asset prices and bank lending conditions indicate that preferences can shift economic activity away from sectors and countries heavily reliant on fossil fuels or high emissions, and towards lower-carbon alternatives that are driving the transition.

4. Aggregate effects and monetary policy

This section summarises the effects of the transition on the key determinants of monetary policy and explores how financial feedback effects can amplify them. It further explores how different types of economies will be affected depending on their characteristics and discusses how impacts can spill over internationally. Some preliminary implications for monetary policy are discussed.

4.1 Aggregate impacts in the short and long term

The transition is still at an early phase, and macroeconomic impacts have been modest so far. But these effects will intensify if governments are set to achieve the goals of the Paris Agreement. Over the monetary policy horizon, policies and cyclical shocks may give rise to near-term trade-offs as some policies weight on output and inflation, and monetary policy could be facing a large and prolonged relative price change. In contrast, longer-term structural changes in the economy are likely to expand aggregate supply given the transition represents a big scale up in investment, supporting growth[19].

Different types of climate policy levers will have different impacts even where policies have comparable effects in terms of emissions reductions. Some will function similarly to negative supply shocks, while others may similarly to demand shocks. The effect on inflationary pressures will depend on the balance between the impacts on aggregate supply and demand. The net effect on inflation will additionally depend on the response of monetary policy. While monetary policy may accommodate at least some of the first-round effects of one-off events, where inflation expectations are well anchored, when the impact is larger and more persistent, doing so may become more challenging.

The output-inflation trade-off will depend also on the design, credibility and pace of climate policies. Given the gap between announced pledges and enacted policies, policy action will likely increase over a number of years. Moreover, if the announced path is not credible and can lead to higher emissions and delays in the transition. This in turn may result in larger macroeconomic costs in terms of output as it would require a sudden and more disruptive transition in the future where stabilising inflation would come at a greater cost to real GDP (IMF, 2022). A gradual and predictable carbon price increase results in smaller increases in inflation (Pinheiro de Matos and Gili, 2022). Relatedly, when central banks react strongly to short-term inflationary pressures related to carbon pricing, this could lead to larger reduction in output (McKibbin *et al.*, 2020).

Overall, while the transition might give rise to some trade-offs for policymakers to manage in the near-term, the macroeconomic impacts from climate inaction or delayed action – *via* more severe and frequent physical damages – will be significantly larger (NGFS, 2023b). For instance, Mehrhoff (2023) finds that an orderly net zero transition by 2050 could result in a 7% boost to global GDP when compared to a scenario with no transition. Notwithstanding the potential for near-term economic impacts, it is important to keep in mind they are considerably smaller in magnitude than the consequences of unmitigated climate change over the long term.

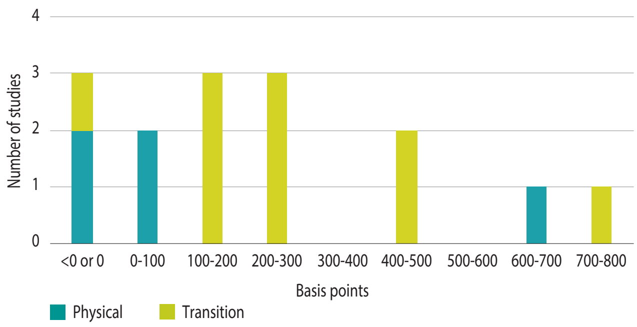
4.2 Transition risks and financial markets

Financial sector feedback effects can amplify the macroeconomic impacts of the transition, especially if it is disorderly. Many studies show that transition risks are to some degree being priced in financial markets as:

- A "carbon premium" on carbon-intensive assets, that serves to compensate investors for exposure to carbon emission risk (Bolton and Kacperczyk, 2021, 2023). de Bandt *et al.* (2023) have summarised the literature and find that the broader transition risk premium on non-green stocks is in a range from 100 to 500 basis points (Figure 8).
- Differences in the performance of green energy stocks and the cost of equity capital relative to fossil-fuel reflecting climate policy uncertainty and regulatory exposure (Kim, An and Kim, 2015; Ilhan, Sautner and Vilkov, 2021; Bouri, Iqbal and Klein, 2022; Sautner *et al.*, 2023).

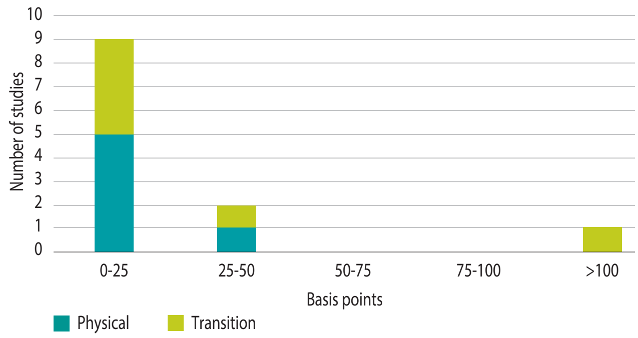
19 This assumes that this effect will not be neutralised by a decrease in supply coming from fossil-based sectors.

Figure 8 **Impact of climate change on risk premium for stocks**



Notes: Authors' calculations, based on the review of 15 academic studies providing an estimate of risk premium on non-green, or carbon-intensive, or non-ESG stocks. The risk premium is not comparable to lending or bond spread.
Source: de Bandt et al. (2023).

Figure 9 **Impact of climate change risk on loan spreads**



Notes: Authors' calculations, based on the review of 12 estimates provided by the academic literature. Impacts is usually measured as the response to a one standard deviation on climate change exposure.
Source: de Bandt et al. (2023).

Still, asset prices and credit spreads can be vulnerable to transition risk especially in the face of heightened uncertainty in a disorderly transition scenario (Pástor and Veronesi, 2012; Nodari, 2014; Kaviani *et al.*, 2020).

Bank lending conditions also reflect transition risk and can be affected by transition uncertainty. Banks are increasingly differentiating household loans with regards to carbon risks, charging for instance lower interest rates for mortgages on energy efficient homes and for electric car purchases. There is also growing evidence that firms' credit conditions are affected by their exposure to climate policy uncertainty. Delis *et al.* (2023) report that banks are pricing the risk of stranded fossil-fuel reserves, while Kacperczyk and Peydró (2022) show that firms' carbon footprints affect their bank lending (see also Section 3.3). In the literature overview of de Bandt *et al.* (2023), they calculate that the transition risk premium on loan spreads in general is found to be between 0 and 25 basis points (Figure 9). Relatedly, Altavilla *et al.* (2023) document that euro area banks charge lower lending rates to firms that have low carbon emissions or firms that have emission reduction targets[20]. Another finding in the literature is that high-carbon borrowers shift the source of financing following increased transition uncertainty (Beyene *et al.*, 2022). Yet another effect of transition risk is that it may affect the cost and availability of insurance to carbon-intensive sectors due e.g. to higher stranded asset risks.

Transition-related distortions in financial markets can generate contagion risk in the macroeconomy. Unexpected transition shocks can create distortions in financial markets (particularly asset prices and credit spreads), in the banking sector (particularly bank lending, see Raunig, Scharler and Sindermann, 2017; D'Mello and Toscano, 2020; Correa *et al.*, 2023; Juelsrud and Larsen, 2023), as well as the functioning of monetary policy including through effects on long-run inflation expectations (Istrefi and Piloiu, 2014) and the monetary policy transmission (Aastveit, Natvik and Sola, 2017). Belloni, Kuik and Mingarelli (2022) show for instance that a large and abrupt change in carbon prices may pose a challenge for the European banking system and increase the contagion risk to the macroeconomy.

4.3 International considerations and spillover effects

Economies will not be affected equally by the transition. The shape, magnitude and direction of impacts will depend on multiple factors, most importantly:

- The economic structure, including whether an economy is a fossil fuel exporter or importer, and whether it is endowed with critical minerals and renewable resources;
- The type of economy, including across advanced economies and EMDEs;
- The fiscal space and cost of capital, given the capital-intensive nature of the transition.

20 Altavilla *et al.* (2023) show also that tighter monetary policy induces banks to reduce their lending to high emission firms more than to low emission ones. Relatedly, Döttling and Lam (2023) find that stock prices of firms with higher carbon emissions are more responsive to monetary policy shocks. Havrylchyk and Pourabbasvafa (2023) document similar results but shows that the differences disappear when controlling for firms' capital tangibility and industry.

Similarly to the physical impacts of climate change, the impact of the transition can have cross- border spillover effects. This makes international climate policy relevant for monetary policymakers to monitor. For example, in the same way that imported inflation may rise in the United States through supply chain effects when a flood occurs in China, exporters in India can be affected when carbon taxes rise in Europe.

Such spillover and cross-border effects can arise in the absence of international climate policy coordination. Climate change is a global issue but policies to address its consequences are set at a national or regional level, based on what is most suitable for the specific economy. Countries can decide to implement different climate policy mixes, with varying degrees of stringency and industry coverage. This has the potential to generate significant spillover and cross-border effects for open economies, depending on the extent to which international policy coordination has occurred (Carton *et al.*, 2023).

One challenge associated with different levels of policy ambitions across countries is "carbon leakage", whereby energy-intensive trade-exposed (EITE) industries relocate to jurisdictions with relatively less stringent climate policies. This will result in changes in competitiveness and can undermine global climate goals as emissions increase in the jurisdictions to which firms relocate, thereby countering the intended decrease in emissions in the jurisdiction implementing the policy (Böhringer, Balistreri and Rutherford, 2012; Fischer and Fox, 2012; Böhringer, Lange and Rutherford, 2014; Mehling *et al.*, 2019). In response, governments and climate policymakers have been exploring a range of international solutions to address carbon leakage, though some countries – who have been early adopters of ambitious policies – have been exploring cross-border adjustment mechanisms (see Box 5)[21].

Some economies have prioritised green industrial policies, through subsidy schemes, to help accelerate their transition to a low-carbon economy. The introduction of these policies can raise concerns about the competitiveness of countries where subsidies are not imposed, including because of limited fiscal space, as is the case for many EMDEs. Subsidies, by reducing the cost of capital for investment, can support production, provide exports with a competitive edge, and attract capital inflows from abroad, including *via* firm relocation effects (WTO, 2022; Bowman, 2023; Smialek and Swanson, 2024). The costs from an escalation of subsidy competition between countries could be large, including *via* potential "green trade wars" (Baschuk, 2022; Ferrari and Ossa, 2023).

Climate regulation and cross-border differences in policies and their stringency can also affect competitiveness across firms and industries participating in international markets. This in turn can shape the new economic geography in the low-carbon economy through the relocation of production facilities, capital flows and possibly even human capital. Andersson, Baccianti and Morgan (2020) suggest that unilateral implementation of environmental regulation has limited effects on competitiveness, showing that worsening trade balances in carbon-intensive industries are likely to be offset by higher exports in sectors with low-carbon intensity. Dechezleprêtre and Sato (2017) find that environmental regulations can lead to statistically significant negative effects on trade, employment, plant location, and productivity in the short run, in particular in energy-intensive sectors, but that these impacts are small relative to general trends in production. Karkatsoulis *et al.* (2016) argue that economies that pursue climate change mitigation policies earlier may see a competitive advantage over those that move later.

Global cooperation can also play a part in supporting the transition, by incentivising innovation, and leveraging comparative advantage in low-carbon technological production across countries. This can take the form of facilitating access to foreign knowledge and technology transfers. In turn, these can enable firms to optimise production processes, and can also help boost both domestic innovation as well as enhance capacity to absorb new technologies (WTO, 2022).

21 A proposed international carbon price floor is another way to address carbon leakage, and the issue of a loss of competitiveness of EITE firms facing higher marginal costs due to climate change mitigation policies, that would arise from unilateral, or uncoordinated action. It is an agreement between countries on a minimum carbon price to put on CO_2 emissions, which can prevent arbitrage opportunities from differences in carbon prices across countries (Parry, Black and Roaf, 2021).

Box 4

Macroeconomic impacts of the green transition for emerging market and developing economies (EMDEs)

Better understanding the distinct channels through which the transition impacts their macroeconomies, will be particularly important for central banks in EMDEs to effectively deliver on their price stability mandates. This is both in terms of their domestic conditions and structural characteristics, and in terms of the ways policy decisions abroad generate spillovers on their domestic output and inflation dynamics.

The transition is impacting and will continue to impact EMDEs differently relative to their AEs peers in several ways. In particular, EMDEs tend to:

- **Be more exposed to the physical damages from climate change,** because of their vulnerable geographies and low resilience thresholds (Fuje *et al.*, 2023). This generates additional important needs for investments in adaptation and resilience, which are over and above the investment needed for mitigation and tend to be trickier when it comes to attracting finance (Buchner *et al.*, 2023).
- **Are generally less diversified** and some rely heavily on **exports of energy commodities and metals**. This generates vulnerabilities for fiscal and current account balances, particularly among fossil fuel exporters. On the other hand, the transition presents economic opportunities for EMDEs richly endowed with critical minerals.
- Enjoy a lower market share when it comes to **green innovation and technology**, and some EMDEs will have limited exposure and know-how in terms of developing green innovation (Pigato *et al.*, 2020; Baffes and Nagle, 2022). Relatedly, they face lower technological knowledge endowments which present barriers for the adoption and diffusion of new low-carbon technologies (Hötte, 2020). At the same time, there are opportunities to leapfrog through innovative.
- Face **pronounced financial barriers.** The cost of capital tends to be significantly higher in EMDEs compared with AEs. Interest rates are typically higher, and domestic capital markets have low depth. Limited financial resources can make financing sustainable infrastructure projects a challenge because of large upfront costs. EMDEs also often lack institutional robustness to support blended finance[1, 2], which can help to address the financing of renewable energy projects and/or to decommission existing coal plants. Some EMDEs with more pronounced investment gaps are also facing debt distress and capital market constraints (Ray and Simmons, 2024). At the same time, underdeveloped financial markets present an opportunity to leapfrog through innovative green financing solutions.
- **Face additional barriers in terms of access to capital and external finance.** Opportunities to attract external finance are limited in EMDEs compared with AEs given high perceived risks[3], with many still lacking investment grade. This impacts investment: despite making up 65% of the global population, EMDEs excluding China accounted for less than 15% of global green investments in 2023 (IEA, 2024).

Reflecting the above, EMDEs are particularly vulnerable to transition uncertainty and volatility in international capital and financial flows. This vulnerability is exacerbated by their substantial need for clean investment linked to their development and adaptation needs, and for some economies by their significant reliance on carbon-intensive production that is more exposed to a disorderly transition (Americo, Johal and Upper, 2023). EMDEs' reliance on international capital and financial flows to support activity further exacerbates vulnerabilities as such flows are adversely impacted by uncertainty effects (Bernal-Ramírez *et al.*, 2022), with

…/…

1 Blended finance is defined as "the strategic use of a limited amount of concessional resources to mobilise financing from public and private financial institutions to achieve climate impacts" (NGFS, 2023b).

2 Other key barriers in scaling up blended financing in EMDEs include data and knowledge gaps and the current lack of climate policies and regulatory clarity. See NGFS (2023b) for more information on these key barriers and policy recommendations.

3 With some priced accurately and others over accounted for by more risk averse investors in the face of poor quality data. Perceptions of risk also reflect a high frequency of political shocks (Bloom, 2014).

the divergence in climate and energy policies across jurisdictions likely redirecting capital and financial flows elsewhere (see also Box 5).

The green transition could influence current account balances, government revenues and access to external finance in EMDEs. For EMDEs reliant on fossil fuel exports, a shift towards a low-carbon economy could impact current account balances and government revenues risk (Kapfhammer, Larsen and Thorsrud, 2020; Bonato *et al.*, 2023)[4]. Conversely, EMDEs that successfully transition to domestic renewable energy sources may experience improvements in their current account positions, although energy importers may experience negative supply shocks during the transition if fossil fuels supply is reduced and the transition lags (Americo, Johal and Upper, 2023). Additionally, as AEs implement their own climate change mitigation policies which form a crucial part of the global climate efforts to mitigate climate change, measures like border carbon adjustment mechanisms may have cross-border effects on EMDEs that have yet to implement carbon pricing[5]. As such, assessments are needed to understand their potential effects on EMDEs, including implications on their real exchange rates and changes in external demand.

Despite challenges, there are promising case studies of green projects in many EMDEs. Notable examples of action include:

- The Chilean Ministry of Energy and the European Investment Bank are collaborating on financing green hydrogen, renewable energies, and other sustainable technologies to accelerate Chile's energy transition (European Commission, 2023b).
- Indonesia is advancing its nickel smelting capabilities to supply processed materials for electric vehicle batteries, with its electric vehicle battery plant scheduled to commence production in 2024.
- The Government of Malaysia has announced ten energy transition flagship projects under the National Energy Transition Roadmap and has allocated a MYR 2 billion (approximatively USD 420 million) seed fund for these projects to enable catalytic blended finance.

4 In some instances, nearly half of EMDE foreign exchange earnings stem from fossil fuels and exports of these products also account for a sizeable part of fiscal revenue. E.g. In the case of Colombia, the sum of refined and unrefined oil, plus coal exports amount to 44% of export earnings (OEC, 2024).

5 For instance, it was estimated that with the introduction of a global CBAM, global real income would fall by USD 3.4 billion annually, with developing economies facing an annual loss of USD 5.8 billion (UNCTAD, 2021).

Box 5

Border Carbon Adjustments

The uneven pace of climate action across jurisdictions, and the associated risks of carbon leakage and competitiveness loss, have prompted some governments to consider Border Carbon Adjustments (BCAs) measures, which can have important macroeconomic effects for affected countries. BCAs apply tariffs on carbon-intensive imported goods based on their emissions content. Their intention is to level the playing field among firms subject to different climate-related regulations and taxes and prevent carbon leakage.

By helping correct negative GHG externalities and limit carbon leakage, effective BCAs can have a positive impact on global output over the medium to longer term, while their effects on prices will vary according to the time horizon and depend on the presence and persistence of frictions. For a country that applies the BCAs, its imposition may trigger a reduction in imports in the short-term due to their higher relative costs and an increase in demand for domestic goods. This could increase domestic production and narrow the output gap in the short-term. Following the immediate import substitution, the BCAs may shift trade patterns over the medium term by incentivising re-shoring and/or short-circuiting of supply chains.

Over the medium and longer terms, BCAs act as a positive supply shock by providing a signal and incentivising investment and innovation in green energy sectors and technologies both domestically and globally, leading to greater availability and reduced costs of low-carbon alternatives. **Effects on prices are likely to be inflationary in the short and medium term** due to frictions associated with shifting trade to more costly suppliers, and deflationary over time as the effect of increased innovation passes through to reduced prices associated with clean technologies.

Countries with weaker climate policies that are on the receiving end of BCAs will experience an initial decrease in exports to the country imposing the tariff, with associated negative impacts on economic activity. This could trigger retaliation from trading partners, reducing global exports, particularly of carbon-intensive products (Clausing and Wolfram, 2023).

The persistence of these macroeconomic effects will depend on the level of convergence in climate policies that can be achieved. For example, if all countries lower the cost of investing into greener technologies. However, in the presence of market failures (such as high cost of capital or limited capacity to meet higher environmental standards in EMDEs – see Box 4) that "lock" comparative advantage for low-carbon technologies in some countries, BCAs and other trade rules that favour "greener" exporters can imply a transfer of market share from EMDEs to AEs (UNCTAD, 2021; Kyriakopoulou, Kyriacou and Pearson, 2023). Unless accompanied by support to respond to the incentive of the BCAs to accelerate decarbonisation in non-BCAs economies, the immediate economic hit from BCAs in EMDEs may further slow their transition (Xiaobei, Fan and Jun, 2022).

Overall, the effectiveness and impacts of BCAs can vary depending on their design and implementation as countries may adopt different approaches. Especially relevant is the variation in the level, the scope and the response of different countries and industries, and the effectiveness of alternative policy measures such as green subsidies and green public investments. Additionally, most studies agree that the introduction of BCAs can lead to behavioural changes by firms and consumers. Capturing these behavioural responses and their subsequent effects on the economy is a complex issue and requires careful analysis and modelling.

The most prominent example of an ongoing BCAs initiative is the European Union's Carbon Border Adjustment Mechanism (CBAM) which entered a transitional phase in October 2023 (European Commission, 2023a). Initially, the CBAM aims to require importers of carbon intensive products such as cement, fertilisers, iron and steel, aluminium, electricity and hydrogen to report GHG embedded in their imports, with a view to subsequently introduce a permanent system from 1st January 2026. This will require importers to declare each year the quantity of goods imported into the European Union in the preceding year and their embedded GHG and provide the corresponding number of CBAM certificates.

4.4 Implications for monetary policy

In exploring the implications of the transition for monetary policy, it is important to **distinguish between** the introduction of a specific policy aimed at climate change mitigation, **and the more gradual, structural shifts that define the transition.** The latter, as explored in Section 3, can also affect agents' economic behaviour and expectations, generating impacts relevant for monetary policy even in the absence of policy near-term shifts (see Box 6).

The overall macroeconomic impact of the enacted climate policies will determine the response of monetary policy. It will also matter how standard the shock is, as well as the predictability and credibility of the shock, including the potential second round effects on expectations. As highlighted in Section 2, the different policies propagate in very different ways to the broader economy.

Carbon prices operate by internalising the externality of carbon emissions. By using a price signal that can be scaled over time, market forces are employed to reduce emissions. Carbon-intensive firms see the marginal cost of their production increase, which puts upward pressure on inflation in the short-term. Households also face higher energy prices and increased prices for other affected goods and services, pushing up inflation and inflation expectations. Revenues can be used to compensate lower income consumers who are affected by the policy. **By contrast subsidies generally function by supporting low-carbon investments or green goods.** When subsidising green sectors, they enhance private investments and can increase aggregate demand. When subsidising green inputs, they reduce the marginal cost of green goods. **Non-market-based direct government interventions are used to target specific activities or economic sectors** as alternatives to pricing measures where price elasticity is low.

In the short run, carbon prices might look like negative supply shocks that reduce output, and **subsidies to green investments more like positive demand shocks** that increase output. Both policies will push up inflation in the short run, though inflation takes longer to return back to its original level under subsidies given the positive near-term impact on aggregate demand. **Some forms of subsidies (e.g. subsidies to inputs used to produce green goods) can also work as positive supply shocks,** pushing up output but reducing inflation. **The medium-term effects will largely depend on the policy design,** including how carbon tax revenues are used and how subsidies are being financed, and how they affect agents' expectations.

The relevance of the policy shock will also depend on the characteristics of the affected economy, particularly (i) the monetary policy regime (e.g. whether the central bank targets inflation or the exchange rate); (ii) the economic structure (e.g. whether the economy is a fossil-fuel exporter or importer, and what endowments it has in resources relevant for the transition, and; (iii) the type of economy, including across AEs and EMDEs. In addition to the jurisdiction affected directly by the climate policies introduced, there will also be spillover effects abroad, and so the openness of the economy will also determine the relevance of an external policy shock for monetary policy.

Even when policy shocks are fully understood and managed, **central banks still face policy challenges from the more gradual and structural changes in the economy.** Shifts in green investment, innovation and technology, and green preferences all alter the consumption, savings, and investment decisions of households and firms. The impact of higher investment on inflation and output will depend on the interplay of supply and demand across various markets, including the extent to which the investment provides capital deepening or crowding out effects. The links between international policy coordination, national climate change mitigation policies, market competition, and technological innovation can create powerful virtuous economic cycles.

Uncertainty about the shape of the transition, including the policy credibility, technological developments, and the behavioural response of economic agents **complicates monetary policymakers' understanding of how different transition drivers will impact the economy.** This is further exacerbated by the lack of forward-looking data that can be used to estimate price elasticities and related substitution effects. **Overall, the less orderly the transition is the greater uncertainty it will introduce in the evolution of key variables for monetary policy.**

Box 6

The green transition and the long-run equilibrium interest rate (R*)

This Box summarises the perspectives offered in Angeli et al. (2022) as part of a Bank of England Quarterly Bulletin article, on how the climate transition might affect the long run equilibrium interest rate. For a discussion on how the physical impacts of climate change could affect R, refer to the referenced material.*

While monetary policy typically focuses on responding to cyclical shocks, it does so within the broader macroeconomic landscape that is shaped by slow-moving structural factors. These slower moving structural changes will influence the long-run equilibrium position of the economy, including the equilibrium real interest rate (R*). While not directly observable, R* is an important guide for monetary policy over the medium to long-run because it is the level of the real interest rate that sustains the actual output level of the economy in line with its potential and inflation at target. Specifically, it provides central banks with a basis against which they can assess and consider whether their monetary policy stance is restrictive or expansionary.

From a theoretical perspective, R* can also be thought of as the price that brings the demand and supply for capital into balance. The demand for capital arises from firms that want to invest in capital for production. The supply of capital is from households accumulating wealth, and who put this wealth into capital by (directly or indirectly) holding corporate shares or bonds, and government bonds. Put another way, under this set up, R* is the risk-free rate of return on government bonds, and, in equilibrium, it is equal to the return to an additional unit of capital minus the "risk premium", which compensates households for the volatility in the return to capital. Given this structure, there are a range of potential determinants of R*, including productivity growth, population growth, longevity, government debt, and the relative price of capital (Cesa-Bianchi, Harrison and Sajedi, 2023) and therefore ways that the climate transition might affect it.

Climate change and the policies designed to mitigate it are expected to give rise to substantive structural changes across the global economy, shaping the longer-term macroeconomic landscape in which monetary policy operates. There are a range of ways that the transition could impact on the determinants of R*:

- The climate transition will be associated with a large increase in investment in new green capital (cf. Section 3). This rise in demand for capital will push up on R*.
- The transition towards green capital and green technologies could have effects beyond just the direct increase in investment. For example, the risk premium on green investments may differ to other investments – if investors perceive them to be riskier, the risk premium may rise, pushing down on R*; the effects on long-run productivity growth could also differ – if green technologies have higher productivity, this will raise the marginal product of capital and push up on R*.
- Large upfront costs to support the transition, such as updating infrastructure, may require a rise in public debt levels. This would increase the supply of government bonds, all else equal, leaving less wealth to finance firm investment, therefore pushing up on R* (NGFS, 2020).

This is by no means an exhaustive list and more work is needed to understand and quantify these various channels, in particular to understand their net effect and whether their relative importance is different at different horizons. Most importantly, we will learn over time how the risks associated with climate change are priced into returns, how productivity develops both in the face of climate events and the transition towards a green economy, and how governments, corporates and households respond to these changes.

Conclusion

The green transition is increasingly impacting macroeconomic outcomes and thus has implications for monetary policy. It affects the behaviour of all agents, sectors and countries, but with large differences across agents and economic horizons. In addition to the near-term impact of policy changes, the transition will also result in deeper, structural changes that will redefine the landscape within which monetary policy operates. More work is needed to concretely assess the implications of the green transition for overall monetary policy strategy.

This report has provided an overview of the implications of the green transition for the macroeconomy and for monetary policy. While governments are the main actors in setting the policies to deliver the transition, central banks will need to understand the macroeconomic effects of the green transition. Such government commitments may typically extend to the medium to longer term, however actions designed to meet them are increasingly being taken now. Moreover, if climate policy continues to be scaled up in line with commitments, the macroeconomic impacts are likely to increase. Overall, while the transition might give rise to some near-term adjustment costs, the macroeconomic impacts from climate inaction or delayed action – due to more severe and frequent damages from physical events – will be significantly larger (Mehrhoff, 2023; NGFS, 2023a; Hassler, Krusell and Olovsson, 2024).

The transition will affect the behaviour of all agents, sectors and countries, but with large differences across agents and time horizons. Changes in consumer prices, wages, and asset prices associated with the impact of transition policies will affect household income, wealth and saving patterns. For firms, investment decisions will be influenced by transition policies aimed at shifting production and investment towards low-carbon activities, as well as by changes to costs, productivity and profits and the financing conditions they face. For governments, carbon pricing will generate revenue whereas subsidising green technology, to the extent that it is financed by debt issuance or taxes, has fiscal implications. Fossil-fuel exporters may face a more challenging transition, while economies endowed with minerals critical for the green transition could benefit from new opportunities.

For central banks, the findings of this report highlight the importance of understanding the macroeconomic impacts of the green transition and the impacts on the channels relevant for monetary policy. As with any economic change, monetary policymakers will need to distinguish between temporary and permanent effects, and between supply-side and demand-side impacts. By fulfilling their mandate of maintaining price stability, central banks can also help to provide a conducive macroeconomic environment that enables and supports the transition.

Overall impacts will depend on the design, credibility, and pace of the transition, on the resulting balance between the impacts on aggregate supply and demand, and on the monetary policy response. For example, the short-term impact of transition measures such as carbon pricing on output will depend to a large extent on how revenues from these policies are recycled back into the economy while impact of higher green investment on overall output will depend on whether investments are additional or merely redirected from other sectors; on the multiplier effects on economic activity; and the impact on consumption. Transition uncertainty will also influence overall impacts: Disruption to economic activity from a sudden and disorderly transition could arise from multiple sources, both on the supply and the demand side, including unexpected climate policy changes and associated uncertainty, non-linear technological advancements and sudden changes in consumer and investor preferences. Such shocks could be amplified by financial feedback effects through the credit and asset price channels.

Transition-related impacts, and the associated uncertainty, will require central banks to adjust their approach to policymaking and communications. Considering the many unresolved questions identified in this report, the green transition will likely cause greater uncertainty about the economic environment in which monetary policymakers operate in pursuit of fulfilling their mandates. More work is needed to better describe the range of transition-related uncertainty relevant for monetary policy, to help formulate concrete options for monetary policy strategy. Moreover, the direction and magnitude of the impacts of the green transition on the longer-term structure of the economies and the natural interest rate will ultimately require empirical work and further exploration. Similarly, more work will be needed to explore transition-related impacts on monetary policy transmission.

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Acknowledgements

The document *The green transition and the macroeconomy: a monetary policy perspective* is a collaborative effort of the members of the NGFS Workstream on Monetary Policy.

The document was prepared under the auspices of the chair of the Workstream, James Talbot (Bank of England). The drafting of the document was coordinated and led by Solveig K. Erlandsen (Norges Bank) and Sui-Jade Ho (Bank Negara Malaysia) with support from the chair's team (Lukasz Krebel, Danae Kyriakopoulou and Michelle Van der Merwe) and the NGFS Secretariat (Benjamin Alford, Daniel Gybas, Léa Grisey and Li Savelin).

This document relies on the analysis and drafting work of a dedicated team of the Workstream members in the subgroup on Transition Impacts. The NGFS is especially thankful to the core drafting team that was composed of Danae Kyriakopoulou and Arjun Mahalingam (Bank of England), Solveig K. Erlandsen (Norges Bank) and Sui-Jade Ho and Grace Punithaa Kylasapathy (Bank Negara Malaysia).

The NGFS is also grateful for the work conducted by the topic team members Ana Arencibia (Banco de España), Eleni Argiri and Ifigeneia Skotida (Bank of Greece), Emiliano Basco and Diego Sebastian Elias (Central Bank of Argentina), Flóra Balázs (Magyar Namzeti Bank), Nathaniel Burkhalter and Maude Rebetez (Swiss National Bank), Natalie Burr, Francesca Diluiso and Niamh Reynolds (Bank of England), Sondre Engebrethsen (Norges Bank), Sandy Eskaros and Farah Sadek (Central Bank of Egypt), Alessandro Ferrari and Johannes Gross (European Central Bank), Etienne Gagnon (U.S. Federal Reserve Bank), Boingotlo Gasealahwe (South African Reserve Bank), Nur Aimi Abdul Ghani (Bank Negara Malaysia), Magnus Jonsson (Sveriges Riksbank), Marcus Jüppner (Deutsche Bundesbank), Cafer Kaplan and Ayşe Sıla Koç (Central Bank of the Republic of Türkiye), Stephen Murchison (Bank of Canada), Marjorie Pampusa (Bank of Mauritius), Andrea Papetti (Banca d'Italia) and Ashot Petrosyan (Central Bank of Armenia).

The chair of the Workstream and the contributors are also thankful to Professor James Stock (Harvard University) for his insightful discussion of the draft report at the November 2023 meeting of the Workstream in London.

Comments and suggestions by all Workstream participants are gratefully acknowledged.

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