II. CLIMATE CHANGE AND ITS IMPACT ON PRICES AND INFLATION

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Abstract: *As inflation in the euro area and beyond falls from its multi-decade highs of 2022, the focus is now turning to the potentially inflationary impact of ongoing rapid structural transformation. Climate change is transforming the planet in ways that have become ever more disruptive and life-threatening in many parts of the world. As global greenhouse gas emissions continue to grow, amid slow and insufficient mitigation efforts, its impact will become even stronger in the years ahead. This article discusses how prices and inflation will be affected by climate change and efforts to mitigate it and adapt to it. It highlights how relative price adjustments will play a key role in this process. These adjustments may be due to climate-induced shocks to productions factors or preferences, or to some of the policy instruments used. Both climate change and mitigation measures are expected to impact a wide array of prices, particularly food and energy prices. While there is substantial uncertainty about orders of magnitude, inflation is expected to become more volatile and subject to upward pressure. Inflation volatility over time will largely depend on adaptation and mitigation efforts. Overall, inflation is likely to become harder to interpret and forecast. This may in turn affect inflation expectations and create more uncertainty in macroeconomic policymaking.*

Inflation in the euro area and beyond has been severely disrupted by a series of unprecedented global shocks since the outbreak of the COVID-19 pandemic in early 2020. These shocks have pushed inflation to multi-decade highs across the world. As these shocks wane and inflation comes down, the focus is now turning to the inflationary impact of ongoing structural transformations, such as climate change. Unlike the COVID-19 pandemic, climate change is not a sudden shock or single event, but a process that has been building up for decades and that has become ever more disruptive and life-threatening across many parts of the world. As it accelerates, its impact will become even stronger in the years ahead. This article discusses what climate change – and endeavours to mitigate it or adapt to it – may mean for prices and inflation.

II.1. CLIMATE CHANGE: WHERE DO WE STAND?

The global climate is changing dramatically due to human activity. As the Intergovernmental Panel on Climate Change (IPCC) concluded in 2021 (28), [‘It] is unequivocal that human influence has warmed the atmosphere, ocean and land’. In 2023, the global mean surface temperature in 2023 was 1.48°C above the pre-industrial (1850–1900) average, extending the accelerating upward trend observed since the 1970s (Graph II.1, panel A) (29). During that period, Europe has been the fastest-warming continent (30). Daily sea surface temperatures both confirm the steady increase in temperatures over time and further expose the daunting temperature leap in 2023, with record highs on a daily basis since (Graph II.1, panel B) (31). While rising average temperatures are a key indicator of climate change, the IPCC has also

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(28) Intergovernmental Panel on Climate Change (IPCC), 2021: Summary for Policymakers. In: AR6 Climate Change 2021: The Physical Science Basis, https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf.

(29) The average annual temperature increase between 1970 and 2023 has been 0.020 C. Over the period 2010-2023 the average annual temperature increase rose to 0.034 C.

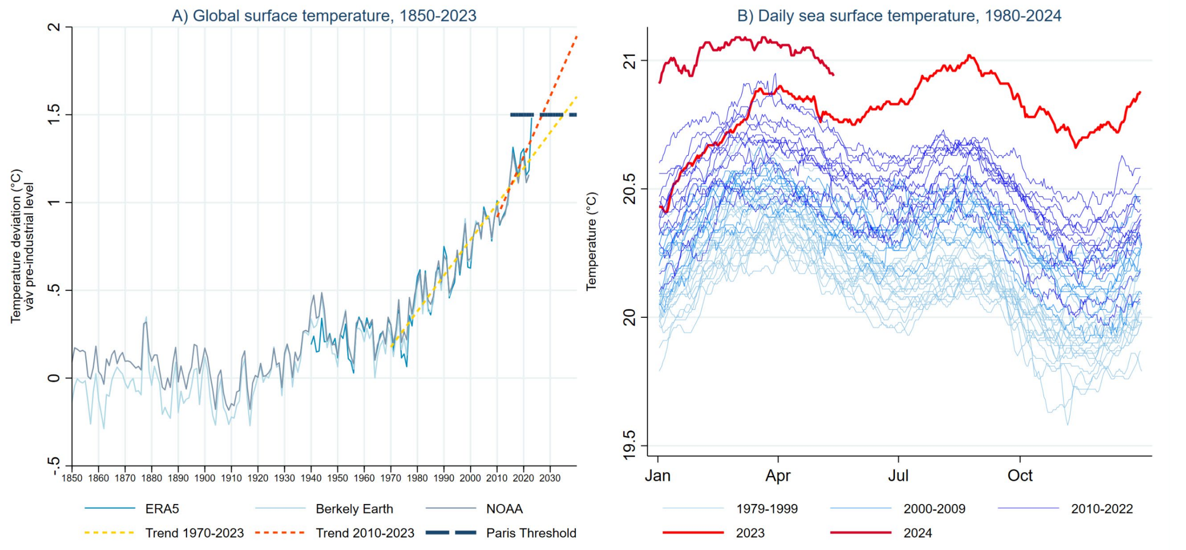
(30) Copernicus Climate Change Service (C3S), 2024, European State of the Climate Report 2023.

(31) While the El Niño event is an important factor behind the high temperatures in late 2023 and early 2024, there have been 12 other El Niño episodes in the sample shown.

identified a series of widespread and rapid changes in the atmosphere, ocean, cryosphere (polar ice caps) and biosphere, which become larger as global warming increases (i.e. impacts are non-linear), as well as weather and climate extremes, such as heatwaves, heavy precipitation or droughts.

Climate change can be clearly attributed to human influence and economic activity (see Box II.1). Global annual greenhouse gases (GHGs) have been emitted at successive annual record levels, although there were brief respites after the global financial crisis in 2009 and in 2020, the first year of the COVID-19 pandemic (Graph II.2, panel A). The growth in GHG emissions is now mainly driven by emerging market economies, which, however, started from a lower basis, and emit less per capita than advanced economies. Meanwhile, GHG emissions by advanced economies, such as the EU or the USA, have been contracting. New emissions expand the large stock (32) of GHGs already accumulated in the atmosphere, which trap heat and cause global temperatures to rise. As GHGs mix in the atmosphere, regardless of their geographic origin, they present a global problem. Addressing it is complex, as the contribution to the GHG stock and the consequences of climate change are often very uneven across regions. This means that incentives to find collective solutions may not always be aligned. Cumulative GHG emissions since 1970 (Graph II.2, panel B) show that regional shares of annual emissions and stock vary. For instance, the EU's and the USA's contributions to the GHG stock are significantly higher than their contributions to annual emissions. Focusing on the EU, annual emissions have declined across all sectors, except for transport, where emissions have continued to increase (Graph II.2, panel C). The main emitters are the power, transport and housing sectors.

Graph II.1: **Global temperature trends**



Notes: ERA5, Berkely Earth and NOAA are different global datasets. The pre-industrial level refers to the period 1850-1900. Last observation in panel B: 13 May 2024.

Source: ERA5, Copernicus Climate Change Service.

Past and future GHG emissions mean that many aspects of climate change are irreversible (IPCC 2021), even in the most optimistic scenarios. This irreversibility requires global society to adapt to a changing climate (*climate change adaptation*) (33). However, it is important to recognise that there are physical

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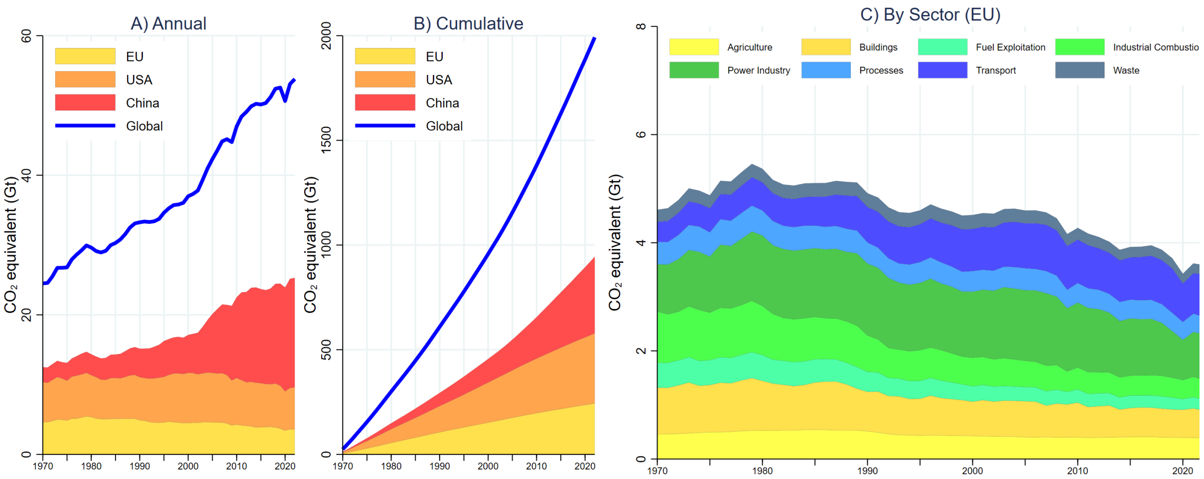
(32) While there is some decay in GHGs, this tends to be very slow and differs depending on the GHG.

(33) Adaptation means anticipating the adverse effects of climate change and taking appropriate action to prevent or minimise the damage they can cause, or taking advantage of opportunities that may arise. Examples of adaptation measures include large-scale infrastructure changes, such as building defences to protect against sea-level rise, as well as behavioural shifts, such as individuals reducing their food waste. Adaptation measures also include, for instance, urban planning, early warning and response systems,

limits to adaptation and that adverse scenarios, including those that breach climate tipping points, would likely exceed such limits. Given the potentially limitless nature of global warming, actions to limit greenhouse gas emissions – by transitioning to a low-carbon economy – are therefore more necessary than ever to contain climate change (*climate change mitigation*) ([34]). The future emission pathways will continue to condition the extent of climate change. The IPCC (2021) has warned that without deep reductions in GHG emissions in the coming decades, the global warming thresholds of +1.5 °C and +2 °C set in the 2015 Paris Agreement, will be exceeded in the 21st century. If the average temperature increases of recent decades were to persist (Graph II.1, panel A), the +1.5 °C threshold would be breached within the next decade.

Graph II.2: **Global greenhouse gas emissions, 1970-2022**



Note: GHG emissions include CO2 (fossil only), CH4, N2O and F-gases.

Source: European Commission, Joint Research Centre (JRC), EDGAR (Emissions Database for Global Atmospheric Research) Community GHG database.

Climate change represents a grave threat to life and livelihoods and has already inflicted severe damage in the form of human and economic losses. The aggregate macroeconomic impacts of climate change are clearly negative (Tol, 2018; Kahn et al., 2021) ([35]) and welfare reducing overall, although they are distributed unevenly across sections of the population, economic sectors, geographic locations and over time. In the EU, economic losses caused by extreme climate events in 2021 and 2022 are estimated at EUR 59 bn and EUR 52 bn, respectively (Graph II.3), broadly equivalent to the GDP of Slovenia. The trend is clear: aggregate economic losses are rising. Their cause, however, varies: while the bulk of damage in 2021 was caused by floods, in 2022 (and 2023) it was due mainly to heat, droughts and wildfires. Historical GHG emissions and socio-economic inertia imply that future

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agricultural adaptation (e.g. adoption of sustainable farming practices), sustainable water management or rehabilitation of ecosystems. In essence, adaptation can be understood as the process of adjusting to the current and future effects of climate change (based on definition provided by the European Environment Agency).

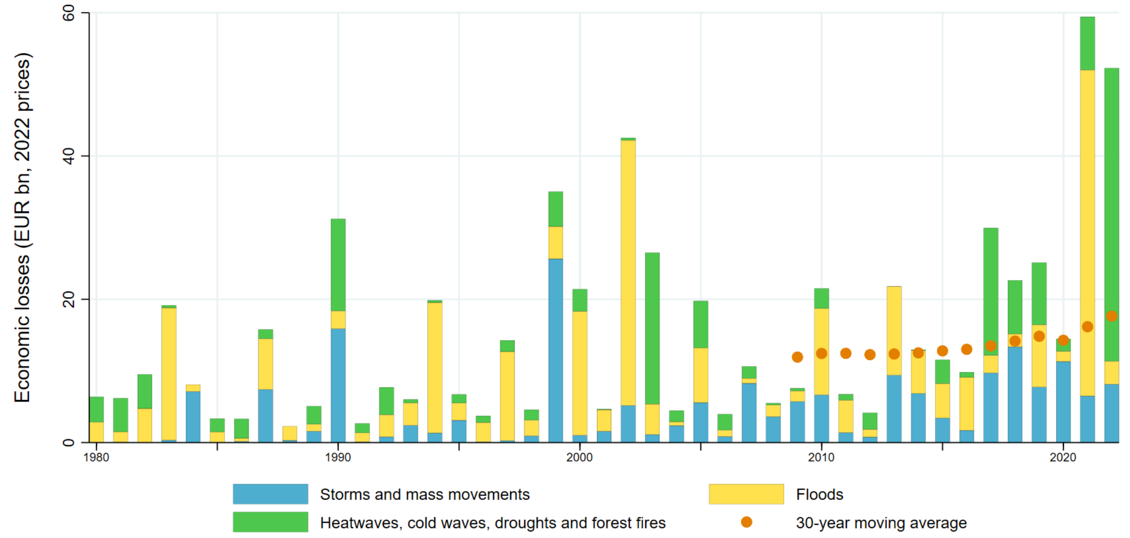
([34]) Mitigation means making the impacts of climate change less severe by preventing or reducing the emission of greenhouse gases (GHG) into the atmosphere. Mitigation is achieved either by reducing the sources of these gases - e.g., by increasing the share of renewable energies, or establishing a cleaner mobility system - or by enhancing the storage of these gases - e.g., by increasing the size of forests. In short, mitigation is a human intervention that reduces the sources of GHG emissions and/or enhances the sinks (definition provided by the European Environment Agency).

([35]) Tol, 2018, The Economic Impacts of Climate Change, Review of Environmental Economics and Policy, volume 12, issue 1, Winter 2018, pp. 4-25; Kahn, Mohaddes, Ng, Pesaran, Raissi and Yang, 2021, Long-term macroeconomic effects of climate change: A cross-country analysis, Energy Economics, Volume 104, 2021.

economic damages are unavoidable. Kotz et al. (2024) ([36]) project sub-national damages from average temperature increases and higher variability in temperatures and precipitation. Their estimates suggest that the world economy is committed to an income reduction of 19% by 2049 (relative to a baseline without climate impacts), independent of future emission choices. Future emission trajectories however matter for projected damages at longer horizons, with high emission pathways leading to greater damage.

With rapidly increasing risks and society's failure to adequately prepare, damage is bound to rise in the future. In its 2024 European Climate Risk Assessment ([37]), the European Environmental Agency (EEA) concludes that out of 36 major climate risks, 21 urgently require more adaptation policies and actions, particularly given the long lead times for such policies and actions. The EEA also points to regional disparities, with southern Europe, low-lying coastal regions and the outermost regions of the EU being most exposed to multiple climate risks.

Graph II.3: **Economic losses caused by weather- and climate-related extreme events in the EU, 1980-2022**



Source: European Environment Agency.

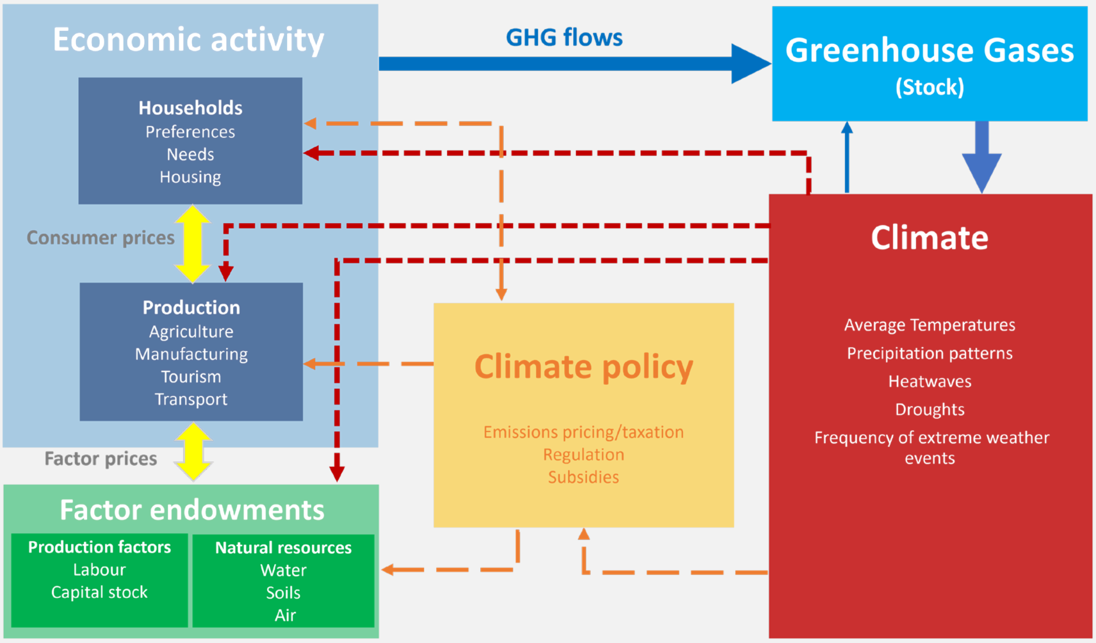
([36]) Kotz, Levermann and Wenz, 2024, The economic commitment of climate change. Nature 628, 551–557 (2024).

([37]) European Environmental Agency, 2024, European climate risk assessment.

Box II.1: **Interactions between the economy and the climate**

The diagram below shows the two-way interactions between economic activity and the climate. The blue arrows show the impact of economic activity, i.e. ways of living and producing, on the climate. Economic activity is determined by household preferences and needs, and businesses' (technology) choices. It is conditional upon on production factors (labour, capital stock) and natural resources at a given point in time, which combine to generate the output that is then consumed by households or added to the capital stock. During the production process, greenhouse gases (GHGs) are emitted that add to the GHG stock already present in the atmosphere. The accumulation of GHGs impacts the climate in various ways, affecting average temperatures, precipitation patterns and the frequency of extreme weather events, such as draughts, for example.

Graph 1: **Interaction between economic activity and the climate**



Note: This diagram shows the two-way interactions between economic activity and the climate. Blue arrows show how human activity affects the climate, while red arrows show how climate change affects human and economic activity. Grey arrows relate to the formation of factor and consumer prices. Orange arrows show drivers of climate policies and the interactions between those policies and the economy (e.g. compliance costs).

The red arrows show the impact of the climate on the economy. There are multiple transmission channels through which the climate impacts economic activity. They can be direct or indirect, physical or non-physical, sudden (frequency of events) or progressive (warming), etc. (This list is not exhaustive).

1. The climate influences some of the characteristics and effective availability of production factors and natural resources. A change in the climate may, for example, impoverish or deplete natural resources, e.g. lower soil fertility or disrupt the water cycle, or it may lead to a more rapid depreciation or destruction of built infrastructure and housing. Likewise, climate change is also expected to directly impact the productivity of labour. A reduction in effective factor endowments and resources will constrain the production process and reduce (potential) output.

2. The climate also has a direct effect on output produced. Examples include the destruction of production, such as crops, or the unavailability of goods due to transport bottlenecks caused by extreme weather events, which are becoming more frequent.

(Continued on the next page)

Box (continued)

3. The climate affects household preferences and human needs (e.g. cooling or warming) and by extension drives demand.

4. Finally, changes in the climate can have self-reinforcing effects, for example heatwaves that lead to wildfires and in turn to GHG releases (represented by a blue arrow).

Left to itself, the system depicted is a closed loop, whereby human and economic activity in the present period, through its effect on the climate, negatively affects human and economic activity in the future. This will also affect the formation prices of production factors and consumer items, represented by the grey arrows and discussed further in Box II.2 and Section II.2.

Breaking – or at least attenuating – this loop hence requires curbing new GHG emissions, and adapting economic activity to shield it as much as possible from the adverse impacts from the existing GHG stock. Climate policies attempt to achieve this. The intensity of those policies in turn hinges on whether governments and societies have the resolve and ability to act, which is likely to depend greatly on the observed, rather than only on the projected extent of climate change. It is also subject to political economy constraints (due to the time lag between emissions and their effects) and global policy coordination challenges. Putting a price on GHG emissions plays a key role in climate change mitigation, as discussed in Box II.3 and Section II.3, and affects production costs and thus prices.

II.2. THE IMPACT OF CLIMATE CHANGE EXPOSURE ON INFLATION

This section discusses how climate change affects prices and inflation. The gradual rise of temperatures, or more frequent extreme weather events, can hit the economy either as supply shocks (e.g. reduced productive capacity) or demand shocks (e.g. declining wealth and confidence), with potentially opposing effects on the general price level. The diversity of climate events and risks means both that many different types of goods and services could be impacted, and that different climate change-induced events will impact individual goods unevenly, causing volatility both in nominal and relative prices (see Box II.2).

Global warming affects all production factors. Temperatures above certain thresholds may reduce working hours, labour productivity and increase heat stress, in particular for outdoor work (e.g. agriculture, construction), but also in indoor settings (e.g. factories or offices) if temperature levels cannot be regulated well. (38) Meanwhile, the diminution in productive capital may occur through capital damage or faster depreciation of built material, notably infrastructure and housing. Losses in economic productivity have been shown to be non-linear in temperature, i.e. the productivity fall for a given increase in temperature will bigger the higher the initial temperature. (39) Warming also disrupts ecosystems and affects natural resources, possibly modifying the water cycle or leading to biodiversity losses.

Extreme weather events generally have a negative impact on short-term output, while their persistence will depend on the type of event (e.g. hurricane versus drought) and the specific context in which it takes place (e.g. vulnerability of built material at the time of the event). Hsiang and Jina (2014) (40)distinguish

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(38) ILO, 2019, Working on a warmer planet: The impact of heat stress on labour productivity and decent work, International Labour Office – Geneva.

(39) Burke, Hsiang, and Miguel, 2015, Global non-linear effect of temperature on economic production. Nature 527, 235–239 (2015).

(40) Hsiang and Jina, 2014. The causal effect of environmental catastrophe on long-run economic growth: Evidence from 6,700 cyclones, NBER Working Paper No. 20352.

between four types of output recoveries following a natural disaster: i) permanent damage (no recovery scenario); ii) recovery to the pre-disaster state (resilience); iii) 'build back better' (e.g. reconstruction enhances 'climate proofing'); and iv) a 'creative destruction' scenario. Understanding the type and persistence of the impact of shocks, including those caused by climate change, is crucial to assessing an economy's cyclical position and inflation drivers, and by extension to making the economic policy decisions that are based on it. The question whether climate change primarily affects the output level, the growth rate, or both, is again shock-specific, (41) but it seems reasonable to consider that both are at risk. The evidence on the long-term output effects of extreme weather events is mixed (see Batten (2018) (42) for a review), partly because it hinges significantly on the no-disaster counterfactual used as a benchmark, but also because it varies by country: economies with higher GDP per capita generally seem better equipped to mitigate the impact of the shock in the short-term and to build more resilient structures afterwards.

Given its dependence on the weather and natural resources, the agricultural sector – and with food as its main end product – is very exposed to the impacts of climate change. Gradual temperature increases, shifting weather patterns and extreme weather events affect crop yields and animal husbandry. While single extreme weather events are likely to lower production and raise prices of affected items (e.g. crop destruction), the effects of gradual changes in the climate are more ambiguous and location-specific. Specifically, they depend on how easily production can be adjusted, for example by substituting the crops grown. Overall, global cereal yields are expected to become more volatile, which also raises the probability of simultaneous global failures of major crops, such as maize (43).

Changing agricultural production constraints will require consumption patterns to adapt, which may in turn entail relative price fluctuations *among* individual food categories. Climate change is therefore highly sectoral by nature. Indeed, many studies on the impact of climate change on inflation focus primarily on the agricultural sector and food prices. Faccia et al. (2021) (44) find that upward temperature anomalies have a swift upward effect on food prices in the short term in a cross-country analysis of 48 advanced and emerging economies. However, the effect is insignificant or even negative in the medium term, which points to negative effects on demand caused by supply disruptions. Focusing on the four largest euro area countries, Ciccarelli et al (2023) (45) find that increases in monthly mean temperatures affect seasonal euro area inflation patterns by raising inflation in summer and autumn, and that higher temperature variability significantly raises inflation. The impact is mainly concentrated in food and services (which include tourism) and is stronger in warmer euro area counties. Kabundi et al (2022) (46) distinguish by type and intensity of climate shocks and find that droughts tend to push inflation up, because of rising food prices.

Meanwhile, floods tend to curb inflation, pointing to a predominance of demand shocks. Likewise, Parker (2018) (47) finds that the impact of natural disasters on inflation differs by type of disaster and inflation sub-index. Storms and floods lead to a short-lived upward effect on food price inflation, while earthquakes (which are unrelated to climate change) reduce core inflation.

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(41) Batten et al. (2020) or Kahn et al. (2021).

(42) Batten, 2018, Climate change and the macro-economy: a critical review, Bank of England Staff Working Paper No. 706.

(43) It is estimated that the probability of a simultaneous loss in maize yields of 10% or more in the top four maize producers (United States, China, Brazil and Argentina) will increase from virtually zero in 2018 to over 6% with a temperature increase of 2 °C. (Tigchelaar, M., Battisti, D. S., Naylor, R. L. and Ray, D. K. (2018), 'Future warming increases probability of globally synchronised maize production shocks', Proceedings of the National Academy of Sciences, 115(26): pp. 6644–6649.).

(44) Faccia, Parker, Stracca, 2021, Feeling the heat: extreme temperatures and price stability, ECB Working Paper No 2626.

(45) Ciccarelli, Kuik and Martínez Hernández, 2023, The asymmetric effects of weather shocks on euro area inflation, ECB Working Paper No 2798.

(46) Kabundi, Mlachila, and Yao, 2022. How Persistent are Climate-Related Price Shocks? Implications for Monetary Policy, IMF Working Paper 22/207.

(47) Parker, 2018, The Impact of Disasters on Inflation. EconDisCliCha 2, 21–48.

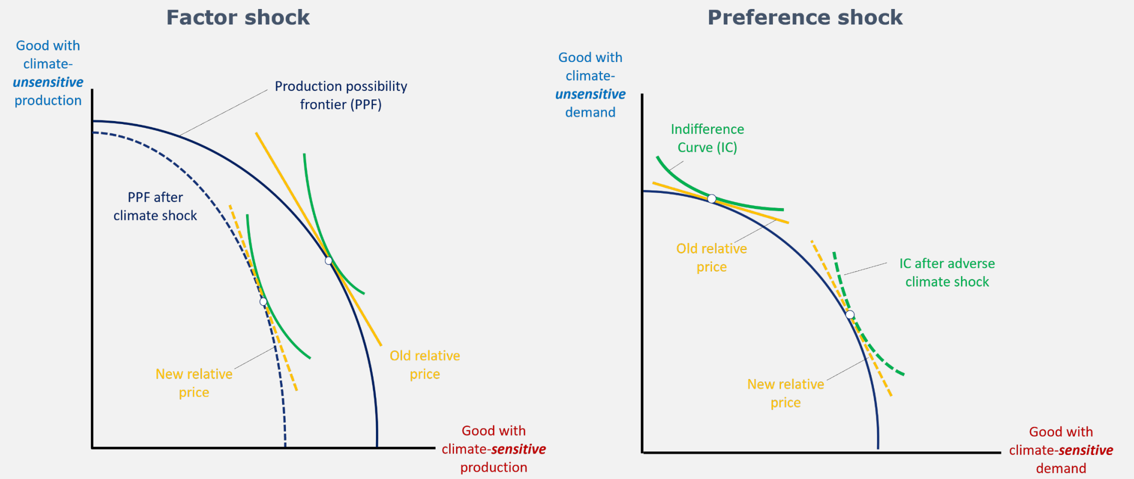
While the impact is generally negligible for advanced economies, it can last for several years in developing economies. Peersman (2022) (48) estimates that shifts in international food commodity prices between 1961 and 2016, caused by harvest shocks, explain 30% of euro-area inflation volatility. An increase in extreme weather events globally would thus plausibly raise euro area inflation volatility. Analysing both high- and low-income countries, Kotz et al. (2023) (49) find that increases in average temperatures have a non-linear and persistent upward effect on inflation, and highlight the risks that climate change poses to price stability.

Box II.2: **Relative goods and factor prices as adjustment variables to climate change**

Where do prices come in? As illustrated in Box II.1, consumer and factor prices are determined by consumer preferences, choices by firms and endowments. Both preferences and endowments are susceptible to change together with the climate, resulting in adjustments to consumer and factor prices.

The figures below illustrate two major channels though which consumer prices may be affected. The figure on the left shows how an adverse climate supply shock affects production factors. It shows a production possibility frontier (PPF) for two goods, one of which relies heavily on a factor that is sensitive to the climate (such as agriculture, which depends on soil fertility and the water cycle). A negative supply shock (like a drought, flood, hurricane or fire) affects relative factor endowments and entails an inward shift of the PPF. For a given set of (unchanged) preferences, the output of both goods will be lower at the new equilibrium, and consumers will be unambiguously worse off. Relative prices will also change, as the price of the good with the more climate-sensitive production rises relative to the other.

Graph 1: **Relative price shocks**

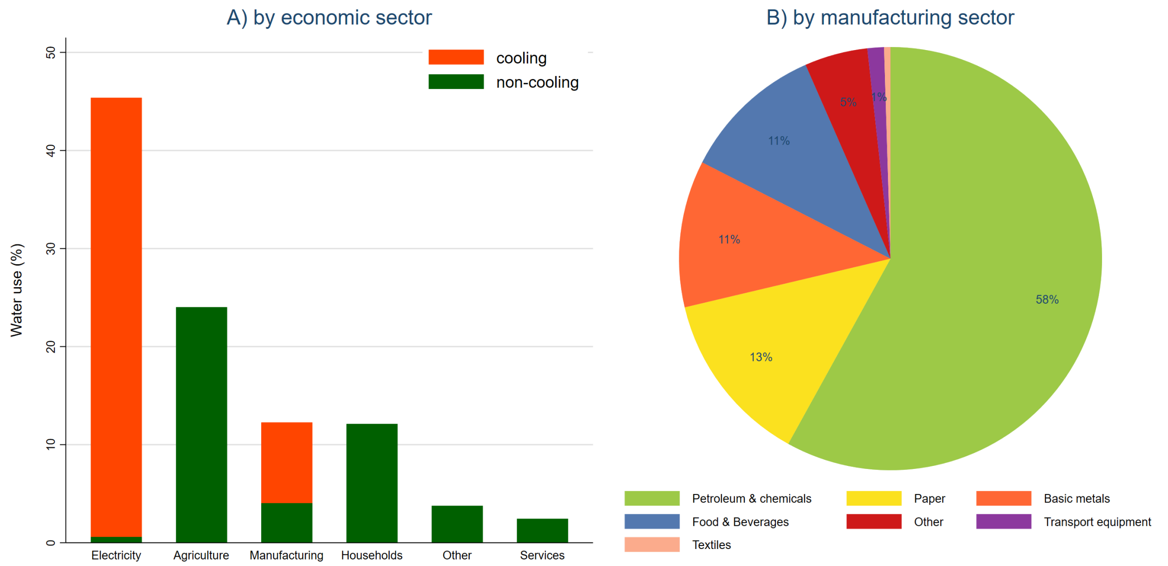

Factor shock

Preference shock

Note: The figure on the left shows how relative prices change as the effective endowment of a production factor is reduced by a climate shock reduces. The figure on the right shows how relative prices change after individual preferences are changed by a climate shock.

The figure on the right illustrates how prices are affected by a climate-induced preference shock. A preference shock is when the utility derived from the consumption of one good rises as the climate changes (e.g. air conditioners) or when consumers become more conscious of the climate impact of their consumption (e.g. preferring certain transport modes over others). While, in this example, the adverse climate shock leaves the PPF unaffected, it changes the shape of the indifference curves and the composition of demand. The economy will now produce more of the good for which demand is climate-sensitive and less of the other, while the price of the former will rise relative to the latter. Supply and preference shocks can of course conflate, and their effects can either offset or reinforce each other.

Graph II.4: **Water use by economic and manufacturing sectors in the EU, 2019**



Note: Water use includes public water supply, and self and other water supply. Due to incomplete data, panel A excludes Ireland, France, Italy, Austria and Finland. Panel B further excludes Greece and Hungary.

Source: Eurostat, own calculations.

The sectoral effects of climate change and disruptive weather events go beyond the agricultural sector, however, and can severely affect many others. This can be illustrated by considering the use of water (excluding precipitation) in various sectors as an example, as climate change is disrupting the water cycle ([50]). As shown in Graph II.4, the electricity sector is the main water user in the EU followed by agriculture and industry. Hence, it is plausible that disruptions to the water cycle, in particular caused by droughts, will have knock-on effects on the prices of goods produced in those sectors. For example, droughts in Taiwan in spring 2021 have compounded pandemic-related shortages of semiconductors, giving a foretaste of how future water stress may impact semiconductor production ([51]). Moreover, with much of the water in the current electricity generation systems and in manufacturing being used for cooling purposes, production efficiency not only depends on the availability of water, but also river temperature. In a case study of Germany, McDermott and Nilsen (2014) ([52]) estimate that electricity prices increase by about 1% per 1% fall in river levels and 1 °C increase in water temperature above 25 °C. Climate related damages are however not limited to economic sectors that intensively rely on natural resources. Floods, for example, do not necessarily affect water-intensive sectors more than other sectors. In a study of the global car industry, Castro-Vincenzi (2024) ([53])that automotive companies react to floods near their assembly plants by reducing production and and partially reallocating it to unaffected plants within the company. While relocating production allows companies to hedge against local risks, it is accompanied by productivity losses and higher consumer prices.

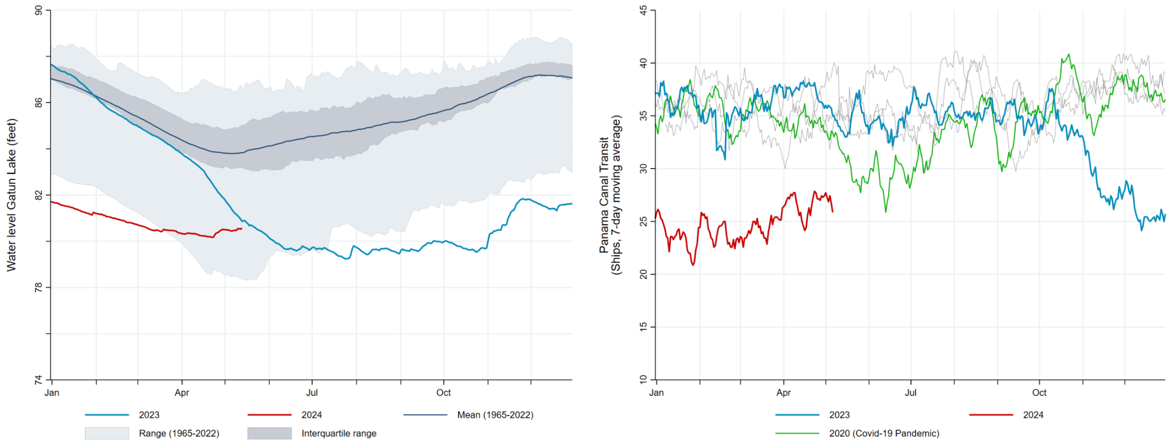
([50]) Note that disruptions to the water cycle and water availability also depend on non-climate factors, such as water management, land use or pollution.

([51]) Lepawsky, 2024, Climate change induced water stress and future semiconductor supply chain risk. iScience. 2024 Jan 5;27(2):108791.

([52]) McDermott and Nilsen, 2014, Electricity Prices, River Temperatures, and Cooling Water Scarcity, Land Economics, February 2014, Vol. 90, No. 1.

([53]) Castro-Vincenzi, 2024, Climate Hazards and Resilience in the Global Car Industry, Working Paper.

Graph II.5: **Panama Canal water levels and ship transit**



Note: Last observation: 7 May 2024.

Source: Panama Canal Authority, IMF Portwatch, own calculations.

Beyond its direct effect on production and production sites, water plays a key role for the transport of inputs and final goods. For example, droughts in Europe have resulted in low water levels of rivers in recent years, severely impeding inland waterway transport, either by making it impossible to navigate or requiring lower loads. Likewise, record low water levels in the Gatun Lake since mid-2023 (Graph II.5) (54), have led to restrictions in the number and type of vessels allowed to transit the Panama Canal. This has cut ship traffic in one of the world's major maritime thoroughfares by about a third – more than at any time during the Covid-19 pandemic – with adverse implications for trade and supply chains. Besides affecting water abundance, climate change also disrupts transport due to more frequent events such as typhoons, which cause ports to close or obstruct sailing. (55)

II.3. THE IMPACT OF CLIMATE CHANGE ADAPTATION AND MITIGATION ON INFLATION

The economic consequences of climate change depend on the vulnerability of production and production factors at a given point in time and place. Expected damage can be expressed as the product of the severity of climate change (e.g. probability of extreme events) and economic vulnerability. Future damage can therefore be minimised by reducing the vulnerability and adapt and adjust the economy subject to the constraints imposed by a changing climate. At the same time, these constraints can be rendered less severe by mitigating climate change (discussed below).

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(54) Note that the figure showing water levels in the Gatun Lake, is almost the reverse image of Graph II.1 (panel B) showing daily temperatures pointing to a close relationship.

(55) Note that while the examples discussed here are restrictive supply shocks, there may be cases where climate change may boost supply, for example melting sea ice opening new trade routes or certain regions becoming more attractive to tourism. However, on balance, the former clearly dominate.

II.3.1. Adapting to climate change

Adapting to climate change is in many ways an exercise in avoiding or limiting future human, natural and material losses. It is necessary due to the unavoidable effects of climate change (56) and focuses on the preservation of essential societal and economic functions, but also on the transformation of ecosystems, infrastructure, industry and society. It is all the more important given the irreversibility and faster-than-anticipated speed of many changes observed (e.g. rising temperatures, extinction of species, melting of glaciers). The fact that some climate trends are predictable should in principle help to prevent some future losses. However, the extent of adaptation efforts is ultimately a societal choice that depends in particular on the discounting of future damage and of life in different climate conditions and other political economy considerations. The rapid transformation of climate change, from an abstract and distant prospect to a present-day reality, implies that there is a significant lack of preparedness for present and future climate risks in the EU, as pointed out in the EEA's 2024 climate risk assessment and in the European Commission Communication on Managing Climate Risks (2024), (57) which expose a need for greater action, also given the long lead times involved.

While adapting to climate change is costly, the costs of inaction are much larger still. Adaptation has many dimensions. It includes for example efforts to ensure that buildings and infrastructure (roads, bridges, power grids) are resilient to shocks from extreme weather events. This can be achieved through public and private investments, subsidies (e.g. for building isolation) or regulatory standards and spatial planning. Other examples are the management of water supplies, the restoration of ecosystems and research to better understand new weather patterns, in particular to create and inform early warning systems. Adaptation also means societies need to prepare for life in a different climate and make changes to their skill sets.

Allocating resources to climate change adaptation means changing the composition of demand and focusing more on investment to strengthen or substitute production factors at risk. It may have aggregate effects on consumer prices (e.g. additional investment boosting aggregate demand) and entail changes in relative prices (see Box II.2). Reducing future vulnerability to climate change will also reduce future price volatility with respect to a counterfactual of no adjustment.

II.3.2. Mitigating climate change

Policies that limit GHG emissions and mitigate future climate change (58) also affect current economic activity and prices (see Boxes II.1 and II.3). A wide range of policy tools exist, such as the pricing of emissions, environmental taxation, regulation and subsidies, which can affect output and prices through various channels. For a given state of technology, curbing emissions puts a burden on current economic activity, as explained in Nordhaus's influential model (1991) (59). Climate action thus involves clear intertemporal trade-offs. The 2015 Paris Agreement provides the legal framework for curbing GHG emissions and limiting global warming to well below 2 °C– and preferably to 1.5 °C –above pre-industrial levels. In the EU, this goal is pursued through the European Green Deal and the European Climate Law (60), which makes climate neutrality in the EU binding by 2050. It includes the 'Fit for 55' legislation

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(56) For the EU climate adaptation strategy see, European Commission Communication (COM(2021) 82 final), Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change.

(57) European Commission Communication (COM(2024) 91 final), Managing climate risks - protecting people and prosperity.

(58) A beneficial byproduct of climate policy is air quality improvement and implications for public health.

(59) Nordhaus analyses the costs and benefits of the emissions effect and policies in terms of two fundamental functions: a *greenhouse damage function*, which describes the costs to society of the changing climate (including the types of costs described in the previous subsection) and an *abatement cost function*, which describes the costs to the economy of preventing or slowing the greenhouse effect. (Nordhaus, 1991, To Slow or Not to Slow: The Economics of The Greenhouse Effect, The Economic Journal, July, 1991, Vol. 101, No. 407 (July, 1991)).

(60) Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law').

package, through which the EU aims to reduce its net emissions by at least 55% relative to the 1990 level, by 2030 (61). As discussed in this sub-section, climate change mitigation will directly affect prices and inflation patterns.

The links between CO2 emissions and the macroeconomy can be better understood through the 'Kaya identity', which decomposes CO2 emissions generated from energy use as follows (see Batten (2016) (62)):

$$CO_2 = Population \times \frac{GDP}{Population} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy}$$

It expresses CO2 emissions as a product of four underlying drivers, namely population, (potential) GDP per capita, energy intensity of GDP and carbon intensity of energy use. It highlights a series of trade-offs, notably between output and emissions. Accordingly, for a given output, lowering emissions would require either lower energy intensity (i.e. higher energy efficiency) or less carbon-intensive energy production (e.g. by switching to renewable sources of energy). The challenge is to continue decoupling economic activity and growth from carbon and emissions, which requires switches in energy production methods and supply lines.

Price signals, and carbon pricing in particular, play an important role in the transition to lower GHG emissions. Changing price signals to better capture the social costs of carbon-intensive goods will reduce demand for such goods and produce more efficient outcomes overall. Internalising the externality through the carbon price – whether implemented as a carbon tax or a market-based cap-and-trade system, as is the case for the EU (63) – is in line with the polluter pays principle and provides an incentive to reduce emissions. Introducing a carbon price acknowledges that carbon emissions (i.e. the right to pollute) are similar to a resource used in the production process. Their cost – just like that of any other input –needs to be covered, instead of being made available available for free (Box II.3) (64). For a fixed emissions cap, the carbon price (or the carbon tax payment for a given carbon tax rate) will largely depend on the marginal abatement cost curve, i.e. the cost of reducing emissions. The additional cost (abatement or permits) borne by firms in sectors covered by the ETS causes the production cost of carbon-intensive goods to rise steadily. The effect on consumer prices will evolve over time, depending both on the emission reduction path and how quickly carbon abatement technologies develop. However, two further effects may be relevant. Firstly, introducing carbon prices or taxes will have a negative effect on income. This will decrease aggregate demand and may have a disinflationary effect. Secondly, reducing dependence on imported fossil fuels, will eventually reduce their role in causing inflation volatility. Indeed, prices of fossil energy sources, such as crude oil and natural gas, have been the main driver of inflation volatility in the recent past and have been the main factor behind the inflation surge in 2022.

Carbon pricing and other incentives to substitute carbon-rich commodities should reshuffle demand. All else being equal, they will reduce demand for carbon-intensive goods and drive-up demand, and prices,

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(61) Up from a previous gross target of 40%. The EU further aims to become climate-neutral by 2050, i.e. achieve 'net zero' emissions. Beyond this, 18 of the G20 countries, as well as many cities and firms have also made that pledge (https://zerotracker.net/analysis/g20-net-zero-stocktake).

(62) Batten, Sowerbutts, and Tanaka, 2016, Let's Talk About the Weather: The Impact of Climate Change on Central Banks. Bank of England Working Paper No. 603.

(63) The EU ETS is a 'cap and trade' system in place since 2005. The cap limits the total amount of GHGs that firms covered by the system are allowed to emit ('allowances'). The cap is reduced every year, ensuring that emissions decrease over time. Firms receive some allowances for free and, within the cap, can buy others on the EU carbon market. This enables governments to generate revenues, which can in turn be allocated to emmissions-reducing investments (e.g., low-carbon technologies). Allowances can be traded among firms on the secondary market, which establishes a market value for them.

(64) The carbon price is subject to repricing risk, because its social cost, which also depends on the discount rate applied, cannot be established with certainty (Tol, 2018).

for non-carbon intensive goods and commodities, or abatement technology (65). Such price increases during the transition process are sometimes referred to as ‘greenflation’. Overall, the introduction of carbon pricing hence changes relative prices, while having a negative income effect. However, the latter is likely be counterbalanced by the large public and private investments that are needed to follow the ‘net-zero emissions pathway’, which will increase demand (66). The impact of carbon pricing on consumer prices (‘carbon pass-through’) hence depends on the level of emission caps and on the share of goods produced by sectors covered in the consumer basket. The introduction of carbon pricing will have a one-off impact on prices and ultimately on inflation (67), which may evolve over time as the carbon price changes and demand adjusts. The effect on consumer prices may be relatively direct (in the case of air transport) or less direct (as with chemicals and maritime transport).

Recent empirical evidence on the carbon pass-through indicates mild inflationary effects so far. Känzig (2023) (68) shows that while a restrictive carbon policy shock causes a persistent fall in overall GHG emissions – consistent with the stated objective – it also leads to a temporary increase in energy prices and a decline in economic activity. Känzig also points out that this does not affect all parts of society in the same way. Thus, poorer households are hit harder as they spend more of their income on energy and experience larger falls in income. Moessner (2022) (69) finds that a USD 10 increase in the price of ETS per tonne of CO2 equivalents raises energy CPI inflation by 0.8 percentage points (pps) after one year, and headline inflation by 0.08 pps, but has no significant effects on food and core CPI inflation. Meanwhile, an equivalent increase in carbon taxes only has a marginal effect on food inflation. Konradt and Weder di Mauro (2023) (70) find that carbon taxes in Europe and Canada have caused relative price changes, increasing the cost of energy. However, they find no evidence for significant increases in headline inflation or spillovers to core inflation, suggesting that central banks can accommodate potential inflationary pressure associated with carbon pricing. Likewise, Konradt et al. (2024) (71) estimate that the EU ETS and national carbon taxation in euro area countries have raised the price of energy but have had limited effects on overall consumer prices. Santabárbara and Suárez-Varela (2022) find strong evidence that cap-and-trade schemes (such as the EU ETS) make headline inflation more volatile. (72)

The limited carbon pass-through found in some recent studies, may not necessarily be very insightful for future. Rather, it could indicate relatively low carbon prices during the periods assessed in the studies, or generous initial ETS allowances, combined with low marginal abatement cost. This would suggest that it has so far been relatively easy to switch technologies, with limited impacts on costs overall. However, the carbon price would need to rise as a result of (i) the need to step up climate policies due to the increasingly strong impact that climate change will put on societies and economies if not mitigated, and (ii) the upward sloping marginal abatement cost curve, which will progressively make it costlier to substitute technologies. Konradt et al. (2024) estimate that for the EU to reach its ‘Fit for 55’

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(65) For instance, reducing emissions by combining higher energy efficiency and energy production that is less carbon-intensive (cf. Kaya identity) implies a switch to a mineral-rich model, as ‘clean’ energies such as solar photovoltaic plants, wind farms and electric vehicles generally require more minerals than their fossil fuel-based counterparts (International Energy Agency, 2021, The Role of Critical Minerals in Clean Energy Transitions). Mineral supply is fixed in the short-term, while longer-term supply expansion requires prolonged and significant investments, which may be challenging depending on their geographic allocation.

(66) The International Energy Agency estimates that that total annual capital investment in energy would need to rise from 2.5% of global GDP to about 4.5% in 2030 before falling back to 2.5% by 2050 (International Energy Agency, 2021, Net Zero by 2050: A Roadmap for the Global Energy Sector). Note that carbon revenues can be used to finance these investments.

(67) An increase in carbon price would thus be similar to a cost-push shock.

(68) Känzig, 2023, The Unequal Economic Consequences of Carbon Pricing. No. w31221. National Bureau of Economic Research.

(69) Moessner, 2022, Effects of Carbon Pricing on Inflation, CESifo Working Paper No. 9563.

(70) Konradt and Weder di Mauro, 2023, Carbon Taxation and Greenflation: Evidence from Europe and Canada, Journal of the European Economic Association, Volume 21, Issue 6, December 2023.

(71) Konradt, McGregor and Toscani, Carbon Prices and Inflation in the Euro Area, IMF Working Paper WP/24/31.

(72) Santabárbara and Suárez-Varela, 2022, Carbon Pricing and Inflation Volatility. Banco de España Working Paper No. 2231.

commitments, carbon prices would need to rise to EUR 150 per tonne of CO2 by 2030, which could add 0.2-0.4 pps to annual euro area inflation per year, depending on the pass-through scenario. (73) Upward carbon price pressures should ease over time as firms adopt new technologies and as the economy decarbonises.

II.4. IMPLICATIONS AND CONJECTURES ON FUTURE INFLATION CHARACTERISTICS

Climate change, caused by an unsustainable carbon-intensive production system, presents a major ongoing and open-ended global challenge. Europe, the continent that is warming most rapidly, is no exception. Regardless of whether it is 'ignored' or actively tackled through adaptation and mitigation actions, climate change will impose and require major structural changes in the global economy. Its impacts are however expected to vary in different places and at different times since regions' contribution to GHG emissions and their exposure to climate change vary. Climate change is a process that has been building up over decades and will continue in the future. It is not a sudden shock or single event like the COVID 19 pandemic. As illustrated in this article, climate change will continue to have a significant effect on prices, which can be viewed both as adjustment variables in response to climate shocks, and as instruments steering the transition to a low-carbon economy and the adaptation to higher temperatures. Thus, climate change can be expected to significantly affect inflation dynamics.

This chapter has explored and illustrated different transmission channels through which climate change can affect prices and inflation. However, its scope does not extend to quantifying the effects of climate change and climate action on inflation, although this clearly warrants further research. Nonetheless, several reasonable qualitative conjectures regarding the nature of future (euro area) inflation emerge from the analysis presented here:

- **Inflation will likely become more volatile** as extreme weather events around the globe become more fraquent and intense or as seasonal price patterns change (Graph II.6). There will be more uncertainty around inflation dynamics, as the type, timing, frequency, and location of extreme weather events cannot be predicted. As negative supply shocks, they will drive up the prices of the affected goods and hence temporarily raise headline inflation. In economies where prices tend not to fall (downward price rigidities), higher inflation volatility could thus lead to upward inflation pressures. However, as many climate shocks result in lower wealth or confidence, they may also have negative demand effects that partially offsett inflation.

- **The transition to a low-carbon economy will likely put upward pressures on inflation and will lead to relative price realignments**. Climate policies that are rigorous enough to achieve the stated objectives are expected to add price pressures in the transition phase to a low-carbon economy. Policies to bring about the phasing out of fossil fuels and of carbon-intensive technologies are likely to result in higher production costs, at least in the short-run. These policies are hence likely to primarily affect consumer prices of energy and of goods falling under the broadening ETS coverage. These effects will last at least for the duration of the supply-side transition to a low-carbon and more resource-efficient economy. Their magnitude is subject to uncertainty, as it will hinge on the resolve both domestically and abroad to implement climate

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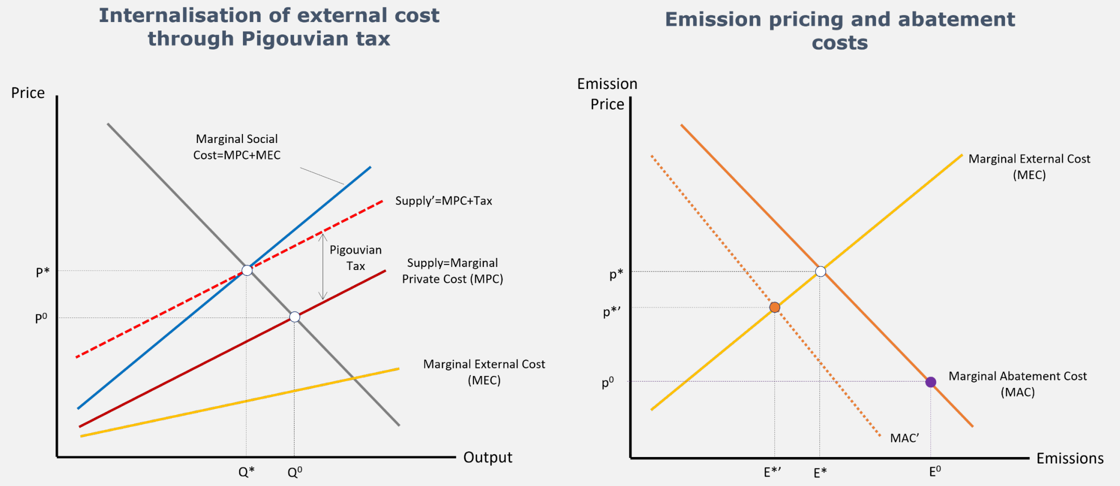
(73) This is marginal when compared to the surge of euro area inflation to 8.4% in 2022, when the energy component contributed 3.8 percentage points after increasing by 37%.

Box II.3: **Pricing mechanism to steer the mitigation of climate change**

To limit climate change of new GHG emissions must be reduced. Pricing mechanisms play a key role in climate change mitigation policies, as illustrated in Box II.1.

Negative production externalities are the underlying economic problem that policy needs to address. If producers ignore the external costs of emissions, there will be more production than is socially optimal. This is illustrated in the figure on the left-hand side of the graph below, which shows that a producer focusing on their private cost only, will produce output Q^0 and charge P^0 per unit of the good. If the producer were also to consider the external cost and focused on social cost instead (the sum of private and external cost), they would scale down production to Q* and raise the price to P*. The negative effect on consumer welfare resulting from a higher price and lower output, would however be offset by the positive effect of reduced emissions. One way to eliminate the negative externality and achieve a socially efficient outcome would be to charge the producer a corrective ('Pigouvian') tax equivalent to the marginal external cost, in line with the polluter pays principle. The socially efficient outcome would therefore result in a higher (relative) price for a good with a production process involving emissions. Addressing the externality through a tax or by selling emission permits would generate fiscal revenues, which could in turn be used to tackle the consequences of climate change or to help mitigate it.

Graph 1: **Climate change mitigation: putting a price on negative externalities**



Note: The figure on the left shows how compensatory taxation addresses a negative production externality to achieve a social optimum. The figure on the right shows how the price of emissions depends on the available abatement technology.

Firms must now either pay for their emission (through a tax or by purchasing a permit) or invest in cleaner technologies to abate their emissions. This is illustrated in the figure on the right-hand side of the graph. For a given abatement cost function, a market outcome would be a level of emissions of E* units, for which a price p* is charged. If a government set an emission price at a level p^0 instead, where $p^0 < p^*$, there would be excess emissions (E^0- E*), for which external costs would exceed abatement cost. The figure illustrates how a positive technology shock would lead to a fall in in abatement costs, i.e. making it less costly to lower emissions. This is represented by an inward shift of the marginal abatement cost curve, which results in a new market equilibrium with both lower emissions (E*') and a lower emissions price (p*').

Compared to a situation in which no policy is implemented, pricing GHG emissions (or limiting them under a market-based cap-and-trade system) lead to higher prices for consumers or an additional production cost which firms may pass on to consumers. Emissions pricing also illustrate the key role of price signals in reducing the negative externality. Price signals ultimately create incentives to decarbonise or to innovate and develop technologies that abate emissions.

policies. Thus, implementation delays and half-hearted climate policies may themselves become a source of inflation volatility.

- **How inflation volatility develops over time will depend on adaptation and mitigation efforts**. Expected inflation volatility over time depends on near-term adaptation and mitigation, which are expected to increase inflation during the transition. While adaptation and mitigation efforts could also result in some near-term inflation volatility, their impact on individual prices could be relatively predictable if they are implemented in an orderly fashion. A benefit of these efforts is that inflation volatility caused by extreme weather events should be lower in a more distant future. Likewise, a successful energy transition will change the drivers of current inflation volatility. Prices of imported fossil fuels have been the main source of inflation volatility in recent years and the main driver of the 2022 inflation surge. Rolling back the dependency on imported fossil fuels should thus also help in reducing their contribution to inflation volatility.

- **Climate change will affect a wide array of prices.** The agricultural sector's dependence on the weather and natural resources means that it is particularly exposed to climate change, and this directly affects food price levels and volatility. However, climate change and disruptive weather events affect the functioning of many other sectors or individual production facilities. This may, for example, be due to vulnerabilities resulting from their reliance on a certain natural resource (e.g. water), or their exposure to weather shocks, which may also result in transport disruptions. In addition, many sectors will be subject to mitigation measures, and thus higher production costs, which they may pass on to consumers.

- **Changing inflation characteristics will affect inflation analysis and economic policy.** Some tentative implications emerge from this analysis to illustrate how climate change could interfere with non-climate issues and policies.

- **Inflation will likely become harder to interpret.** Inflation volatility and shifts in relative prices complicate the interpretation and perception of inflation and could make it harder to separate price signals from noise. The shocks associated with climate change, adaptation and mitigation have different characteristics (supply or demand shock; transitory or permanent; etc.) and transmit to prices through different channels. Disentangling them will be complex, especially if they occur simultaneously. The situation in the euro area is more complex because different regions are affected differently by climate change, with southern Europe and the coastal regions expected to be particularly affected. Climate change could therefore become an additional source of inflation dispersion.

- **Inflation will likely become harder to forecast**. Price volatility and the multiplication and intensification of potential shocks will make it more complicated to quantify their aggregate effects and integrate them into a baseline forecast scenario. All else being equal, forecasts will become more uncertain and will therefore offer households and firms and policymakers less reliable guidance for decision-making. Correspondingly, *ex post* forecast errors are likely to increase, which may affect the credibility of and trust in forecasts and the institutions making them.

- **How inflation expectations are formed may change.** High price volatility, in particular for key prices, such as those of food and energy, could weaken the anchoring of households' inflation expectations to inflation targets (74). One reason for this is that people often attach a higher weight to positive price changes than to negative ones. This could bias inflation perceptions and expectations upwards. Inflation volatility could thus create conditions that are conducive to prolong

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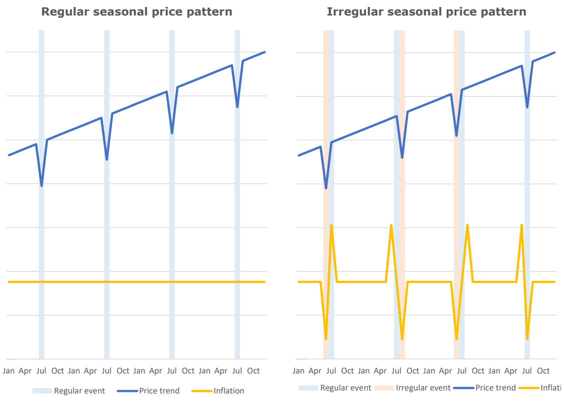
(74) See for example: Cavallo, Cruces and Perez-Truglia, 2017, Inflation Expectations, Learning, and Supermarket Prices: Evidence from Survey Experiments, American Economic Journal: Macroeconomics; D'Acunto, Malmendier, Ospina, and Weber, 2019, Exposure to Daily Price Changes and Inflation Expectations, NBER Working Paper No. 26237.

temporary shocks through second-round effects. A greater irregularity in seasonal price patterns, as illustrated in Graph II.6, could thus potentially accentuate perception biases. Market-based indicators of inflation expectations could become noisier on account of higher risk premimums. And while it would be justified for a central bank to ignore or ‘look through’ adverse temporary supply shocks, the impact on inflation expectations will depend on whether economic agents share its assessment and trust its explanations. (75)

However, communication regarding inflation is likely to become more challenging the longer the supply shock lasts and the more entangled the shocks become (76).

Graph II.6: **Inflation impact of irregular seasonal price patterns**



Note: the graph illustrates the impact on inflation when a seasonal price pattern becomes irregular. If prices have a regular seasonal pattern (left panel), e.g. a drop each July following a harvest, year-on-year inflation is not impacted. If the timing of price drops now alternates between June, July and August (right panel), say because of climate change-induced irregularities in harvest patterns, this will create inflation volatility, even if the price trend remains unaffected.

Source: own illustration.

- **Greater uncertainty may complicate macroeconomic policymaking.** Climate change will affect output and prices. This will make it more challenging to estimate economic potential and growth and, by extension, to determine the cyclical position of the economy, which is a prerequisite for many macroeconomic policies. A growing number of studies discuss the implications of different types of climate shocks for monetary policy (e.g., Batten et al (2020); (77) McKibbin et al. (2020); Rudebusch (2019); ECB (2021); Bank of England (2022); Schnabel (2022); Apel (2022)) (78). As discussed above, when there are downward nominal rigidities, inflation volatility can result in an inflationary bias. However, if inflation volatility is the outcome of relative wage adjustments across sectors as the economy transitions to a low carbon economy, higher inflation could indeed be the byproduct of a smooth transition. (Note that downward wage rigidities are one major reason for pursuing a positive inflation target). A dilemma that could arise for a central bank in such a context of structural adjustment, would be whether to tolerate possible deviations

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(75) An adverse impact of climate change on confidence may also contribute to higher inflation expectations by households, which typically adopt a “supply side view” of macroeconomic shocks.

(76) Higher inflation volatility may also erode the trust in inflation statistics. Anecdotally, this can be illustrated by the recent prominence of the neologism “shrinkflation”, loosely referring to reduced product sizes for an unchanged price. In the context of this article, it is worth noting that the reduction in the size of processed food items (e.g. chocolate bars) may reflect shortages of food commodities (e.g. cocoa) inter alia due to climate change (e.g. Unctad, 2024, Chocolate price hikes: A bittersweet reason to care about climate change).

(77) Batten et al (2020) review several central bank decisions in responses to natural disasters. The US Fed hiked interest rates after Hurricane Katrina in 2005, which it saw as a temporary supply shock. Meanwhile, the Bank of Japan eased its monetary policy following Great East Japan Earthquake, viewing it primarily as a negative demand shock. The Bank of Canada (Lane, 2017) considered the introduction of carbon pricing as a one-off structural change and looked through it in making monetary policy.

(78) McKibbin, Morris, Wilcoxen, and Panton. 2020, Climate Change and Monetary Policy: Issues for Policy Design and Modelling, Oxford Review of Economic Policy 36 (3): 579–603; ECB, 2021, Climate change and monetary policy in the euro area, ECB Occasional Paper No 271; Rudebusch, 2019, Climate Change and the Federal Reserve, FRBSF Economic Letter; Bank of England, 2022, Climate change: possible macroeconomic implications, Quarterly Bulletin 2022 Q4; Schnabel, 2022, A New Age of Energy Inflation: Climateflation, Fossilflation and Greenflation; Speech 17 March 2022; Apel, 2022, How does the climate transition affect inflation? Economic Commentary, No. 13, Sveriges Riksbank.

from its inflation target to help facilitate the transition, or to risk an overly restrictive monetary stance to hit its target (79).

Climate change is causing momentous structural transformations for life on our planet for which there is no precedent. Just as many aspects of it remain subject to great uncertainty, there is also uncertainty on the global resolve to tackle it. Thes uncertainties are due partly to different intertemporal trade-offs, but also to political economy constraints within and across countries and to misaligned incentives. At the same time, the EU and world economies are going through several other structural transformations, such as ageing, geopolitical tensions, changes to globalisation and digitalisation. These transformations will on the one hand interact with climate change and on the other hand affect inflation through their own channels. Inflation disruptions of some form seem unavoidable.

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(79) Guerrieri, Lorenzoni, Straub and Werning, 2021, Monetary Policy in Times of Structural Reallocation (September 15, 2021). University of Chicago, Becker Friedman Institute for Economics Working Paper No. 2021-111.