Chapter 10

Environmental Economics: A Macroeconomic Framework

Ömer Tanju Durusoy[1]

Abstract

The literature on environmental macroeconomics is still in its early stages and does not yet have a fully defined framework. Therefore, this section examines the theoretical and conceptual foundations of environmental economics and current research on environmental economics from a macroeconomic perspective.

Current macroeconomic theory has so far addressed environmental issues as the relationship between CO2 emissions and growth. However, other macroeconomic variables and environmental issues have recently begun to be associated. The concept of climate change is part of a broader network of environmental issues, such as population growth, problems in agricultural production, water resources, and species loss. To achieve a low-carbon future, it is necessary to control population growth, reduce consumption, and take care to protect the environment. Therefore, macroeconomic theory needs to evolve to respond to these new challenges.

This study briefly summarizes the main concepts and discussions in the literature on environmental macroeconomics. Theoretical and empirical studies on this topic have been reviewed, and the framework of environmental issues has been outlined, showing the global dimension of the problem. In the continuation of the study, the macroeconomic effects of environmental factors are discussed in light of the debates in the literature, with a particular focus on their impact on inflation. Additionally, the study examines how the traditional IS-LM model has been extended to include environmental effects. Finally, this study presents a sustainable economic growth model and demonstrates the relationship between economic growth and the environment using the Environmental Kuznets Curve.

1 Asst. Prof. Dr., AHBV Unv.. Faculty of Economics and Administrative Sciences, Department of Economics, ORCİD: 0009 0009 1299 5600, omer.durusoy@hbv.edu.tr

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1. INTRODUCTION

Climate change is known to cause significant physical risks, including hurricanes, monsoons, floods, avalanches, and increasing desertification and drought. These extensive effects impact all actors and sectors of economies worldwide, albeit to varying degrees. Global temperature changes will naturally impact economic activities. Additionally, environmental events on a global scale will influence consumer preferences and, consequently, well-being.

The greatest economic challenge of the twenty-first century is the disconnect between scientists' warnings about potential disasters caused by uncontrolled carbon emissions and the political and economic implications of rising emissions. This raises the question of whether economic growth can continue when carbon emissions are significantly reduced. Therefore, it is necessary to reassess what economic growth truly means.

Although environmental economics has roots that go back further, it began to develop around fifty or sixty years ago. However, for a long time, there has been almost a complete disconnect between environmental economics and macroeconomic policy. Only recently have policies related to the subject started to be expressed in economic policy reports published by international organizations such as the International Monetary Fund (IMF), the Organisation for Economic Co-operation and Development (OECD), and the European Commission, as well as by national central banks. According to Pisani-Ferry (2021), there are intellectual and political reasons for this long neglect. The intellectual reason is that environmental economics initially developed within the framework of public economics rather than a macro framework. Politically, the reason is that decarbonization has been seen as a longer-term issue.

Climate change is one of the most discussed global issues of the 21st century, with its significance extending beyond physical impacts such as extreme weather patterns, rising sea levels, hurricanes, wildfires, and heatwaves. It also has significant macroeconomic implications. These can be examined through its effects on economic activity, such as the impact of high temperatures on labor productivity, efficiency, mortality, and disease rates. Moreover, severe climate events can disrupt supply chains, potentially affecting prices, particularly for food. The uncertainty surrounding climate change and its policies may also lead to higher carbon prices, increasing production costs, reducing profitability, and lowering the value of company equity (Adediran et al., 2023).

Nearly everyone now acknowledges that global warming threatens both humanity and nature. The economic consequences of climate change are substantial, influencing businesses, households, and government policies. Climate change also disrupts ecosystems, thereby harming economic development by affecting primary resources, human capital, and productivity. At present, nations are enacting measures to lower greenhouse gas emissions and lessen adverse economic effects. Climate risk is a worldwide issue with long-term impacts that become evident over time.

The literature on environmental macroeconomics that we have examined is just beginning to mature and its framework has not yet been fully defined. In this study, we will try to summarize the prominent concepts and discussions in the environmental macroeconomics literature. In the second part of our study, the literature including both theoretical and empirical studies on the subject is reviewed. In the third part, the framework of environmental problems and the issue of global cooperation are discussed. In the fourth part, the macroeconomic effects of environmental factors are discussed within the framework of the literature. In the fifth part, the transmission mechanisms of environmental factors to macroeconomics are examined. In the sixth part, the effects of environmental factors on inflation are discussed. In the seventh part, the traditional IS-LM macroeconomic analysis is expanded to include environmental effects. In the eighth part, the sustainable economic growth model and in the ninth part, the Environmental Kuznets Curve are discussed, concluding the study.

2. LITERATURE

In classical economics, economic activities are associated with natural resources. Malthus highlights the economic growth implications of limited agricultural production areas by drawing attention to the production limits in agriculture and the impoverishment caused by uncontrolled population growth. Ricardo stated that diminishing returns from land would limit both wealth and population growth. Hotelling, on the other hand, advanced the theory of exhaustible resources. In more recent times, Koopmans (1973) highlighted the crucial role of the macroeconomic interest rate by integrating exhaustible natural capital from Hotelling's 'cake-eating' problem with produced capital accumulation in a Ramsey-type growth model (Munasinghe, 2004). Withagen's 1990 study explored various aspects of this approach and paved the way for more advanced studies by Hartwick and colleagues in 1990. Stiglitz (1974) demonstrated through a model that capital, labor, and natural resources can be substituted for each other in production. His study shows that if technological advancements continue to offset the depletion of natural resources, it is possible to achieve sustainable higher levels of consumption.

Daly (1991) argues that appropriate macroeconomic policies can lead to optimal resource allocation, but they fail to address the scale issue when economies exceed environmental limits. Solow (1993) introduces the concept of net national product (NNP) adjusted for the depletion of natural resources and changes in environmental quality as an indicator of the highest sustainable level of consumption.

These points blend neoclassical economic theory with previous studies on environmental economics and national income measurement. England (2000) identifies three factors that will constrain growth and result in a stable economy: the scarcity of natural capital, the inability to substitute produced capital for natural capital in production, and the limitations of technological advancements in enhancing the efficiency of natural capital use.

Another historical approach uses input-output (I-O) analysis developed in the 1930s. Leontieff (1970) provides a basic framework for analyzing pollution outputs from productive sectors and the effects of policies aimed at reducing these externalities in pollution control sectors.

Subsequent research has expanded on the foundational input-output approach by integrating older models that account for labor demand and capital stock, as well as incorporating consumer demand through linear expenditure systems. Advanced models have further developed by making technical input-output coefficients dependent on prices. For environmental macroeconomic analyses, cutting-edge computable general equilibrium models and advanced models for environmental national income accounting utilize the input-output approach (Munasinghe, 2004).

In addition to these developments, environmental factors have been integrated into traditional macroeconomic models used in policy-making. These range from extended Keynesian IS-LM models for comparative static analysis to advanced computable general equilibrium models that include environmental variables. Macroeconomic models are increasingly examining environmental issues, particularly in relation to short-term Keynesian topics such as capacity utilization, unemployment, and economic cycles.

In his study, Girma (1992) included the environmental sector in a traditional macroeconomic model to assess the effects of fundamental macroeconomic policies on the environment. Long-term environmental macroeconomic models for both closed and open economies emphasize supply-side elements like capital accumulation, natural resource depletion, long-term labor supply, discount rates (used to calculate the present value of future cash flows), and technological advancements.

Empirical studies like those by Grossman and Krueger (1995) on the connections between macroeconomics and the environment examine the relationship between per capita income and various air and water pollution indicators. This study investigates whether the 'environmental Kuznets curve,' which suggests an inverted U-shaped relationship between economic growth and environmental pollution, truly exists. According to the results of this study, while it is generally accepted that environmental quality deteriorates with increasing per capita income in the early stages of growth, it remains uncertain whether this trend will reverse with further growth, as the shape of the curve varies significantly between countries and types of environmental degradation.

In another study, Opschoor and Jongma (1996) comprehensively examine the environmental consequences of structural adjustment and stabilization programs implemented by the World Bank and the International Monetary Fund in developing countries. They advocate for the implementation of complementary environmental policies to mitigate the adverse effects of growth-oriented macroeconomic strategies in the short term, while emphasizing the need for a more holistic approach in the long term.

Jorgensen and Wilcoxon (1990) investigate how environmental regulations impact the U.S. economy using a computable general equilibrium (CGE) model. This model focuses on the fundamental energy-economy-environment linkages and uses intertemporal analysis to estimate the proportion of abatement costs within the total costs of industry and transportation, investigating the long-term growth effects. Similarly, Bergman (1990) uses a CGE model to simulate the impact of environmental regulations and energy policies on the Swedish economy. In Bergman's study, environmental market failures are addressed by creating a market for emission permits and integrating these costs into cost functions.

In another study, Kessler and Van Dorp (1998) emphasize the unforeseen impacts of structural adjustment programs, particularly on land, water resources, and forests. They advocate for the proactive assessment of environmental impacts before implementing regulatory policies, highlighting the importance of mitigation efforts.

Holden et al. (1998) conducted simulations on the economies of six Zambian villages, revealing that structural adjustment policies can negatively impact the environment. They noted that eliminating policy distortions doesn't necessarily result in efficient markets due to high transaction costs and imperfect information, particularly in remote regions. Contrary to the previous belief that climate change would mainly impact developing countries, it also affects developed nations. Colacito et al. (2018) found that rising temperatures could reduce U.S. economic growth by one-third by 2100. A rise of 1°F in the average summer temperature leads to a 0.154% decrease in the annual GDP growth rate. Elevated summer temperatures adversely impact not just agriculture but multiple sectors of the U.S. economy. According to Kiley (2021), who analyzed data from 124 countries between 1961 and 2010, climate change heightens the probability and intensity of economic downturns, thereby affecting economic and financial stability and overall well-being.

In their study, Feyen et al. (2020) examined the interaction between climate risks and macro-financial risks. They highlight that both the physical effects of climate change and the shift to a low-carbon economy present major challenges for macro-financial stability. These challenges can disrupt investment, economic growth, fiscal revenues and expenditures, debt sustainability, and the valuation of financial assets, adversely affecting the financial health of governments, households, businesses, and financial institutions. As a result, macro-financial risks can weaken resilience to physical climate risks and hinder the ability to adapt to and mitigate climate change. The study concludes that many countries are simultaneously dealing with high levels of climate-related and macro-financial risks, a situation termed as 'double jeopardy'.

Byrne and Vitenu-Sackey (2024) investigated the impact of climate on macroeconomic activities in their study. They differentiated climate change into global and country-specific climate risks and examined their distinct effects on macroeconomic activities. The study also separates the impact of climate on developed and developing economies to account for country differences. They found that global climate risk has significant and adverse effects on macroeconomic activities in both developed and developing countries.

3 ENVIRONMENTAL ISSUES AND GLOBAL COOPERATION ACTIVITIES

Climate change typically describes the ongoing rise in average temperatures on Earth's surface, a trend that has been tracked since the late 1800s when global temperature data started being consistently recorded. This warming has significantly accelerated globally since the early 2000s.

While per capita greenhouse gas emissions in developing countries like India, China, Brazil, and Indonesia remain lower than those in developed nations, they have surged in recent years due to GDP growth with industrialization. This situation has sparked the argument that developed nations should bear greater responsibility in combating climate change. Meanwhile, developing countries like Mexico, South Korea, and Turkey have experienced notable rises in emissions as they continue to industrialize and urbanize. Although their emissions have not yet reached the levels of developed countries, they are rising faster than those of other developing nations. Small developing island states, despite having the lowest greenhouse gas emissions, are the most vulnerable to climate change impacts like rising sea levels, ocean acidification, and more frequent and severe natural disasters. Many of the least developed countries, especially in Africa and Asia, have minimal greenhouse gas emissions but are highly susceptible to the impacts of climate change. They contend that developed nations, due to their historical contributions to the issue, should take the lead in combating climate change.

Despite the urgent need to reduce carbon emissions and mitigate global warming, the long-term nature of climate change, its high costs, and the difficulty of measuring its impact have prevented the increase in global warming from being halted. However, many economic actors, especially governments, have recently taken action to prevent global warming.

The United Nations reports that the decade from 2011 to 2020 was the hottest on record, with each decade since the 1980s being warmer than the previous one. Arctic temperatures have risen at least twice as fast as the global average. This phenomenon, known as global warming, is primarily due to high levels of carbon dioxide (CO2) and other greenhouse gases in the atmosphere, which trap heat from the sun and increase the Earth's average surface temperature. The elevated levels of CO2 and other greenhouse gases are largely the result of burning coal, oil, gas, and other fossil fuels for energy production and various economic activities. Fossil fuel use alone is estimated to be the largest contributor to climate change, responsible for about 75% of global greenhouse gas emissions and 90% of all carbon dioxide emissions (Bakoup, 2023).

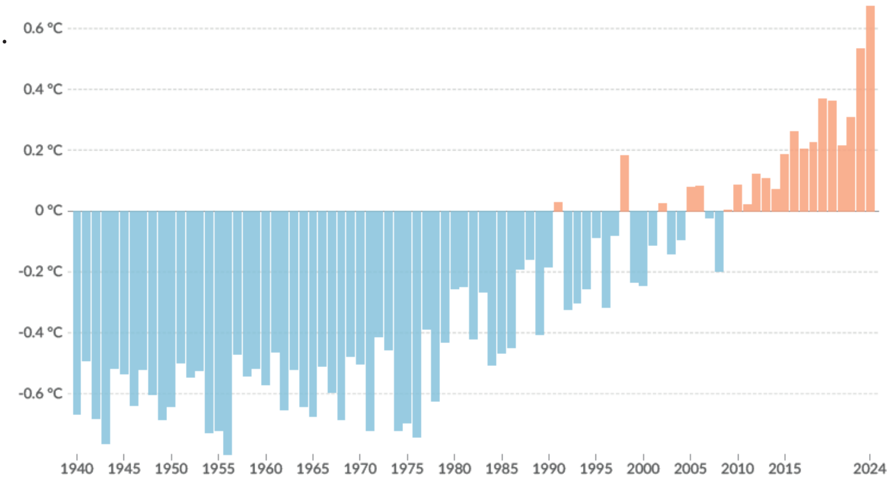

Figure 1. Global Average Temperature (The deviation of the average surface temperature of a specific month from the average temperature of the same month during the 1991-2020 period, measured indegrees Celsius).

Source: Our World In Data, https://ourworldindata.org/grapher/temperature-anomaly (accessed 16.11.2024).

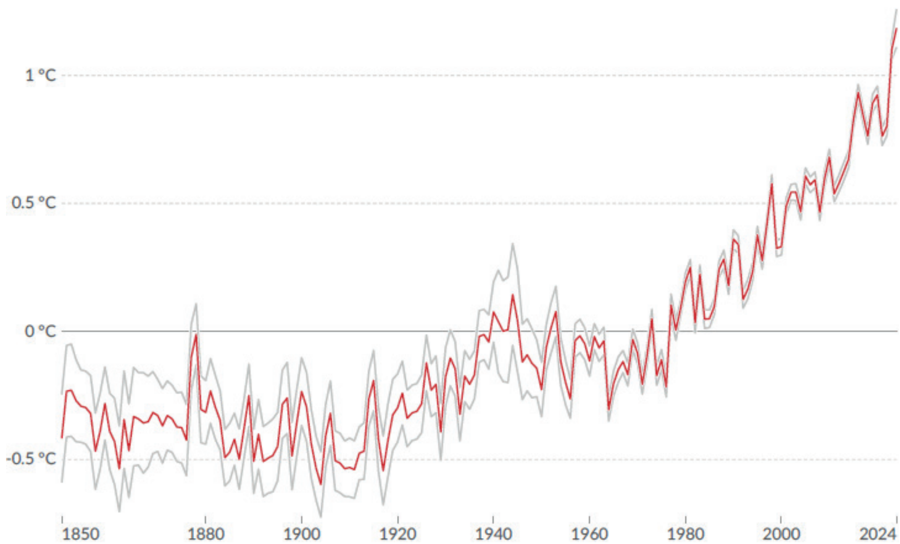

Figure 2. Global average land-sea temperature anomaly relative to the 1961-1990 average temperature reference line.

Source: Our World In Data, https://ourworldindata.org/grapher/temperature-anomaly (accessed 16.11.2024).

In February 2008, climate model studies, including those on deep-sea warming, concluded that carbon dioxide emissions must reach zero by mid-century to prevent a temperature rise of about 7°F by 2100. These conclusions align with the Fourth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC), which advises a 50-85% reduction in carbon emissions by 2050 to keep temperature increases below 2°C (3.6°F) (Harris, 2009).

In the 2015 Paris Agreement, 220 countries committed to creating national climate action plans, known as nationally determined contributions (NDCs), which include long-term emission targets to be revised every five years. The IPCC concluded that to keep temperature increases well below 2°C, with a target of 1.5°C, global annual emissions must be reduced to 50% of 2010 levels by 2030.

Climate change is a global challenge that requires collective action from all countries. The international community, led by the United Nations, is spearheading efforts to mitigate climate change and enhance resilience. Under the Paris Agreement, nations have committed to achieving net zero greenhouse gas emissions by 2050, aiming to limit global warming to no more than 1.5°C above pre-industrial levels. This goal involves reducing new emissions to near zero and ensuring any remaining emissions can be absorbed by natural sinks like forests and oceans.

The Paris Agreement mandates urgent actions to limit temperature rise to 2 degrees Celsius, ideally 1.5 degrees Celsius above pre-industrial levels. The IPCC (2018) has set estimated reference limits for global emissions, termed the 'carbon budget,' to align with these goals. The challenge lies in cutting per capita CO2 equivalent emissions from around seven tons today to about three tons in a decade and nearly zero by mid-century, while sustaining or boosting economic growth. (Bernal-Ramirez & Ocampo, 2020).

The IPCC, in its Sixth Assessment Report, emphasized that climate change is making our climate more variable and that extreme temperature changes are affecting more regions over time. A study covering more than a century and thirty countries shows an increase in both the average annual temperature rise and variability. From 1901 to 1950, the average annual temperature increase was 0.012°C with a standard deviation of 0.279°C. Between 1950 and 2020, this increase rose to 0.015°C, with the standard deviation rising to 0.292°C (Byrne & Vitenu-Sackey, 2024).

4 MACROECONOMIC EFFECTS OF ENVIRONMENTAL FACTORS

Among the factors determining the macroeconomic performance and outlook of countries, climate change has been gaining increasing importance in national and global public policy discussions and thus in macroeconomic policy analyses since the 1990s.

Climate change has both direct physical effects on countries' macroeconomic variables and will affect nations' macroeconomic performance through the transition to low-carbon production processes. Almost all major macroeconomic policy variables and tools are linked to climate change. The variables that will be primarily affected include production and growth rates. In addition, monetary policies and financial stability in the inflationary process will be impacted by these developments. Furthermore, labor markets will be affected in terms of unemployment, income distribution, and labor productivity. Moreover, capital stock, technological progress, and investments will be influenced by climate change and the accompanying preventive policies. Finally, consumption and aggregate demand will be affected by this process. Naturally, all these interactions will impact both exchange rates and the fiscal structure.

Table 1 The process by which climate change affects macroeconomic variables

Shock/impact Type		Physical effects		Transition Risks
		caused by weather events	caused by global warming	
Demand	Investment	Uncertainty arising from climate change		The crowding-out of climate policies
	Consumption	risk of flooding		The crowding-out of climate policies
	Trade	Disruption of international trade due to natural disasters		Distortions resulting from asymmetric climate policies

Supply	Labour Supply	Loss of working hours due to natural disasters	Loss of working hours due to extreme heat	
	Energy, food and other inputs	Possible shortages of food and other inputs		Risks to energy supply
	Capital Stock	Damage caused by extreme weather conditions	Shift of resources from productive investments to depreciation investments	Shift of resources from productive investments to activities aimed at reducing environmental impacts
	technology	Redirecting resources from innovation to reconstruction and renewal	Directing resources from innovation to adaptation capital	Uncertainty about the speed of innovation and the adoption of clean energy technologies

Source: Batten et al., (2020).

Examining the impact of environmental factors on macroeconomic variables, that is, understanding the mutual interaction, requires addressing the following issues. These issues are essentially related to the macroeconomic impacts of climate change. In other words, it concerns how climate change affects economic performance and policy. Additionally, it is an important dimension to consider how macroeconomic policies affect climate change. Another issue is the evaluation of the macroeconomic effectiveness of climate change policies.

When these relationships are considered in terms of developing economies, three main facts need to be discussed. First, although developing economies contribute very little to climate change, they are highly vulnerable to its effects and face significant and disproportionate impacts. Second, while these economies cope with the macroeconomic effects of climate change, they are also dealing with other major global economic, financial, and geopolitical shocks they are constantly exposed to. Third, most developing economies show weak macroeconomic management while dealing with the macroeconomic effects of climate change. As a result, the effects of environmental changes on the macroeconomic variables of these countries will be quite significant. This increases the importance of prioritizing climate change and environmental degradation issues in macroeconomic analysis and policies, especially in the context of developing countries (Bakoup, 2023).

Current macroeconomic theory largely assumes continuous, exponential GDP growth. Historically, GDP growth has been closely linked to increased fossil fuel use and CO2 emissions. Reducing carbon emissions will require significant changes in economic growth models. Climate change is part of a broader set of environmental issues related to growth limits, including population growth, agricultural production, water resources, and species loss. Achieving a low-carbon future will require stabilizing the population, limiting consumption, and making significant investments in environmental protection and social priorities such as public health, nutrition, and education. Macroeconomic theory needs to be adjusted to adapt to these new realities (Harris, 2009).

A distinction will need to be made between goods and services that can continue to grow and those that must be limited to reduce carbon emissions. This new approach offers numerous opportunities for environmentally friendly economic growth. New Keynesian policies that focus on ecological sustainability, meet basic social needs like education and health, and ensure equitable distribution can help rapidly reduce carbon emissions while promoting investment in human and natural capital

Climate change will hinder economic growth through multiple pathways. Extreme weather events like floods, severe storms, and hurricanes will damage physical assets, including productive capital, causing negative supply shocks that reduce production and slow economic growth. Furthermore, as temperatures rise, more of the existing capital stock will need to be used as adaptation capital to protect against heat-related damages (Batten, 2018). This adaptation capital will not contribute to productivity. Consequently, global warming will result in slower economic growth.

Climate change will also impede growth by affecting aggregate demand. Environmental impacts will reduce capital stock and cause significant supply-side shocks, decreasing the productivity of both capital and labor, which in turn will lower output and incomes. Additionally, physical impacts will destroy consumer wealth. According to Keynesian theory, life cycle approach and permanent income hypothesis, which try to explain private consumption, these factors may lead to a decline in real and expected incomes, thus reducing private consumption. Uncertainties about future transition policies, regulations, and market preferences may also negatively affect investment, resulting in a lower growth trend in the short, medium, and long term.

The macroeconomic effects of environmental disaster shocks are similar to cost shocks. A disaster shock reduces the capital stock, leading to a decline in consumption and production. This reduction in capital stock increases the cost of capital and thus raises the real interest rate, leading to higher inflation. Inflation can also be affected by the impacts of environmental change on the agriculture and energy sectors. Changes in the environment affect agricultural yields, which can have long-term impacts on the prices of agricultural commodities. While yields might initially increase in some regions, they could decrease in others, with the overall impact depending on a country's location and sources of agricultural imports. Additionally, rising sea levels and desertification, which lead to land loss, could affect commodity prices. Inflation can also be influenced by extreme weather events. The effects of environmental changes on inflation are further explored in the following sections.

5 TRANSMISSION MECHANISMS OF ENVIRONMENTAL FACTORS TO MACROECONOMICS

According to partial equilibrium analyses, macroeconomic stability is a minimum and necessary condition for environmental protection. Secondly, environmental degradation often results from market, policy, and institutional failures related to the use of environmental resources. Thirdly, macroeconomic policies can have negative effects on the environment, but these adverse outcomes only occur when market, policy, and institutional failures are present, although it is difficult to predict how severe these effects will be in advance (Gandhi, 1996).

The shift to an economy with reduced carbon emissions, driven by changes in climate policies, technological advancements, and evolving consumer preferences, is known as transition risks in the literature. Consequently, there are various ways climate change impacts both the supply and demand sides of the macro economy and the financial sector. At this point, the effects of environmental changes on the overall economy are mainly examined from the perspectives of supply, demand, and productivity.

Andersson et al. (2020) examined how climate change and related policies can affect the macro economy in ways relevant to central banks' monetary policy assessments regarding inflation outlooks. For this purpose, the potential transmission channels and economic impacts of climate change, as well as evidence on mitigation policies that may be of potential importance to macroeconomic policymakers, are reviewed. According to them, early policy efforts to address climate change may entail significant upfront costs but will likely reduce long-term costs.

In their study, Diebold and Yılmaz (2012) developed generalized temperature spillover indices and demonstrated the interconnectedness of climate changes between countries. Therefore, the spread of temperature changes from one country to another and the interconnectedness of countries is an inevitable reality. This interconnectedness suggests that temperature changes share common factors. Given this global interconnection, it is essential to consider these shared climate factors when assessing their impacts on macroeconomic activities.

Climate risk can affect the economy through various channels. Due to uncertainty, firms may delay irreversible investments with option value waiting (Bloom, 2009), leading to a decrease in new working capital and R&D expenditures. Berestycki et al. (2022) discovered that uncertainty surrounding climate policies leads to notable reductions in investments in capital-intensive industries, especially in sectors with high pollution levels that are impacted by changes in climate policies. Comprehensive research emphasizes the need to incorporate the physical aspects of climate threats into economic impact studies. These studies show that climate risks reduce economic growth by negatively affecting labor productivity, capital quality, and R&D expenditures. In summary, climate risks can have a direct impact on both economic production and consumption. (Byrne & Vitenu-Sackey, 2024).

Climate-related risks are divided into two types: physical risks arising from climate changes and transition risks arising from the shift to a low-carbon economy. Physical risks include the effects of more frequent and intense weather events such as tropical hurricanes, droughts, heatwaves, and floods, as well as the gradual impacts of global warming. For example, rising sea levels can significantly reduce the productivity of coastal areas and even cause entire atoll countries in the Pacific, such as Kiribati and Tuvalu, to be submerged. Additionally, increases in temperature and changes in precipitation patterns can negatively affect the productivity of agricultural lands (Feyen et al. 2020).

Agriculture, livestock, and fisheries are highly vulnerable to climate change. Extreme weather conditions can cause crop spoilage; gradual warming and unpredictable rainfall can further degrade soil and exacerbate desertification, reducing crop yields. In livestock, changes in temperature and precipitation affect pasture quality and feed, impacting meat and milk production. In fisheries, rising sea temperatures, acidification, and overfishing significantly reduce biodiversity, threatening many species.

Climate change-related events can temporarily or permanently disrupt agricultural supply. This is particularly concerning for developing economies where agriculture is a significant economic sector and food constitutes a major portion of consumer expenditures. Such disruptions can affect overall income and employment and lead to more volatile inflation rates due to fluctuations in food prices.

Natural events, like physical risks, can negatively impact various productive sectors such as transportation, coastal real estate, and public utilities. Additionally, policy decisions and technological developments (transition risks) can affect industries like oil and coal, as well as those heavily dependent on fossil fuels such as steel, aluminum, cement, glass, chemicals, plastics, and paper. Conversely, some sectors may benefit from new opportunities, such as renewable energy, electric vehicle production, and the information technology industry.

Extreme weather events can also destroy physical infrastructure and production capacity, cause resource and product shortages, and lead to more frequent disruptions in domestic and international production processes, trade, and supply chains. This situation necessitates directing investments towards adapting to climate change and potentially rebuilding damaged infrastructure, buildings, and machinery.

Firms may encounter a more complex environment with increased operating costs, potential legal liabilities, regulatory and reputational risks, and shifts in customer behavior and demand for eco-friendly products. Additionally, market signal disruptions, uncertainties about growth and future demand, expected depreciations of existing assets due to policy changes, and more uncertain investment conditions due to low profitability of current assets can arise. Higher expenditures on adaptation, mitigation, and developing alternative technologies (Batten, 2018) also contribute to these challenges. Necessary climate policy decisions, such as carbon taxes, can further increase transition risks.

It is possible to anticipate structural effects and fluctuations in the relative prices and trade volumes of key commodities, such as hydrocarbons, minerals, and food, which are crucial in international trade. This can unpredictably alter the terms of trade and real exchange rates for many emerging and developing countries. Transition policies, including taxes, regulations, and import/export restrictions, can also influence trade patterns. Additionally, low labor productivity can impact the real exchange rates of numerous countries. Supply chains may face more frequent disruptions due to geophysical changes and weather events.

Although the effects vary by region and sector, climate change is expected to significantly impact global economic growth. Estimating the scale of these risks and financial losses is difficult due to the inherent uncertainty of the evolving environmental, social, and economic problem. Traditional risk assessments and existing climate-economic models fall short in fully predicting the nature of climate-related risks. Physical risks and transition risks arising from climate change involve complex, unpredictable dynamics fundamentally altered by increasing greenhouse gas concentrations. Crossing climate tipping points could lead to catastrophic and irreversible consequences.

Many sectors are expected to suffer from climate change, though agriculture in high latitudes might initially see some benefits. Climate change is anticipated to affect both the European production system and physical infrastructure. Extreme events and rising sea levels may lead to increased global population movements. Agriculture, fisheries, forestry, and bioenergy production are likely to be directly impacted. The agricultural sector will probably experience changes in crop yields, with pests and plant diseases becoming more prevalent. Grain yields in northern Europe may increase, while those in southern Europe are likely to decline.

Climate change will affect the productivity of specific land and water areas. Altered rainfall patterns are likely to increase the need for irrigation. However, in some regions, irrigation might not be enough to prevent crop damage from heatwaves. The amount of water extracted from rivers and groundwater sources may significantly decrease in the context of increasing demand from agriculture, energy, industry, and housing. A warming climate might boost forest productivity in northern Europe, but it could also lead to increased damage from pests and diseases across all regions. Additionally, the risk of uncontrolled fires and storm damage may rise.

As cooling and heating demands change, it is likely that the energy, energy-intensive sectors, and construction sectors will be affected. Heating demand may decrease while cooling needs increase. Implementing more energy-efficient buildings and cooling systems, along with demand-side management, will help reduce future energy demand. However, water scarcity could lead to a decline in hydroelectric supply in some parts of Europe. Additionally, thermal energy production might drop during the summer, and overheating in buildings could become more common.

In the transportation sector, climate change might reduce winter traffic accidents in high latitudes, but it could also negatively affect inland water transport on some rivers. For instance, low water levels in the Rhine River are already impacting river transportation in the region. Railway infrastructure may experience more damage due to high temperatures. Extreme weather conditions in transportation could cause economic damage equivalent to 0.5% to 1% of global GDP by mid-century, although there may be some benefits, such as reduced winter maintenance costs.

The health sector could face negative impacts, and social welfare costs might rise due to increased health and mortality risks from extreme events. Specifically, exposure to heat and cold, along with infectious, cardiovascular, and respiratory diseases, may become more prevalent in Southern Europe. According to the World Health Organization (WHO) assessment in 2018, climate change is expected to cause approximately 250,000 additional deaths per year globally between 2030 and 2050 due to malnutrition, malaria, diarrhea, and heat stress. Health care costs may also rise due to high levels of local air pollution (e.g., in the form of particulates and nitrogen dioxide) resulting from the burning of fossil fuels. Lung diseases and premature deaths related to air pollution are already a problem in many major cities worldwide. It is estimated that air pollution from burning fossil fuels results in 3.7 million premature deaths annually worldwide.

6 THE EFFECTS OF ENVIRONMENTAL CHANGES ON INFLATION

This section discusses three interrelated concepts put forward by Schnabel[2]. These are fossilflation, climateflation, and greenflation. The first two refer to the persistent cost of dependency on fossil fuels, which has not been adequately addressed over the years, known as fossil inflation, and the increasing impact of natural disasters and severe weather conditions on economic activity and prices, known as climate inflation. Traditionally, inflation is seen as a contextual or descriptive aspect of environmental issues, but the economic impacts of climate change contradict this traditional understanding (Jackson 2024).

Schnabel (2022) introduces the concept of energy inflation with terms like climateflation, fossilflation, and greenflation. He also explains 'green inflation,' which refers to inflationary pressures arising from the scarcity of essential metals and minerals for renewable energy infrastructure. Carbon taxes and other climate policies can also lead to price stability effects known as 'green inflation' (Mckibbin et al., 2021). It is recognized that transition scenarios will bring their own inflationary pressures. This article does not

2 Isabel Schnabel, Member of the Executive Board of the European Central Bank.

address the price instability that may result from delayed or unsuccessful transitions.

The relationship between energy prices and price stability is well-known, with fossil fuel price-driven inflation (fossilflation) being a long-standing issue, recently exacerbated by Russia's invasion of Ukraine. The inflationary effects of climate change (climateflation) and environmental degradation are relatively new but increasingly discussed. Climateflation, which is global but disproportionately affects low-income households and countries, mainly results from reduced agricultural activities and crop yield damage. As environmental degradation worsens, it will increasingly contribute to price instability.

The inflation caused by fossil fuel prices (fossilflation) has been a long-standing issue. However, it has become more pronounced with the Ukraine war. The importance of energy for price stability is well known. The effects of climate change (climate inflation) and environmental degradation on inflation are relatively new but increasingly significant. Climate inflation, which affects the whole world but disproportionately impacts low-income households and countries, primarily stems from the reduction in agricultural activities and damage to crop yields. As environmental degradations intensify, they will increasingly contribute to price instability.

The situation where fossil fuels drive inflation, known as fossilflation, is not actually a new phenomenon and has continued from the oil price shocks of the 1970s to the present day. Given the dependence of economies on energy for production and transportation, energy prices affect inflation both directly and indirectly. On the other hand, the strengthening of the US dollar is also leading to increases in global energy prices, which exacerbates the fossil fuel shock for net energy-importing countries.

The burning of fossil fuels is the main cause of climate change, leading to higher temperatures and more frequent and persistent extreme weather events. This trend causes adverse supply shocks and creates inflationary pressures known as climate inflation. These pressures primarily affect the agricultural sector. Current research increasingly shows evidence that extreme weather conditions and rising temperatures have a general inflationary effect. As climate change and environmental degradation intensify in the future, this effect is expected to worsen (Barmes & Bosch, 2024).

Low-income households and countries in the Southern Hemisphere are most adversely affected by rising food prices due to their vulnerability to climate. Therefore, climate inflation further increases inequality both within and between countries. Inflation targeting and the primary policy response of central banks aimed at price levels (interest rate increases) deepen this inequality while failing to address the root cause of inflation. Consequently, financial stability is jeopardized, and green investments necessary for a green and secure transition are hindered in the long term for the sake of price stability.

A recent study indicates that storms and floods can lead to short-term inflation spikes (within one to two quarters) in developing countries, while droughts may have a more lasting upward impact on inflation, persisting for several years. The study also suggests that severe natural disasters in developed countries can influence inflation (Andersson et al., 2020).

In this context, traditional monetary policy negatively impacts price stability and the economic, social, and environmental goals of governments. Raising interest rates does not address the underlying causes of rising energy and food prices and can restrict the government's fiscal capacity while hindering investment in capital-intensive green projects. Instead, central banks should incorporate environmental considerations into monetary policy and enhance coordination with fiscal and industrial authorities. Additionally, new international monetary regulations will be needed to maintain price stability and ensure a fair transition.

Climate change, environmental degradation, and global energy markets together play a role in price instability, significantly affecting inflation forecasts and macroeconomic policy. Central banks need to develop their understanding of these factors influencing inflation and adjust their policies accordingly. It must be acknowledged that achieving environmental goals is vital to prevent the continuation of macroeconomic instability related to the environment. Although fiscal, industrial, and environmental authorities primarily drive the transition to a sustainable economy, innovative monetary policy approaches and improved inflation forecasting should support these efforts (Barmes & Bosch, 2024).

Climate change can also affect the design and implementation of monetary policy. Central banks need to consider the supply and demand shocks caused by climate change, as these factors significantly impact prices and inflation. Using data from 'more developed regions,' a classification by the UN that includes 27 EU countries, four EU candidate countries, the United Kingdom, Canada, the USA, New Zealand, and Australia, Engin and Thakoor (2022) found in their study that climate change shocks increase real interest rates and inflation in these countries. This can also negatively affect developing countries due to the global economic impact of the sampled economies.

Due to energy shocks and the climate crisis, inflation in the disrupted global economy is becoming inherently more ecological and disproportionately affects low-income households and countries. Economic authorities, especially central banks and finance ministries, need to adapt to this new era by incorporating environmental considerations into policy tools and increasing coordination to ensure price stability and a fair transition.

7 INCORPORATING ENVIRONMENTAL FACTORS INTO THE TRADITIONAL IS-LM MODEL

In open economy macroeconomic analyses, similar to the IS-LM-BOP approach, the traditional IS-LM model can be extended to include environmental changes. In Figure 3 below, the traditional IS-LM model is expanded by adding the EE curve, which represents environmental changes.

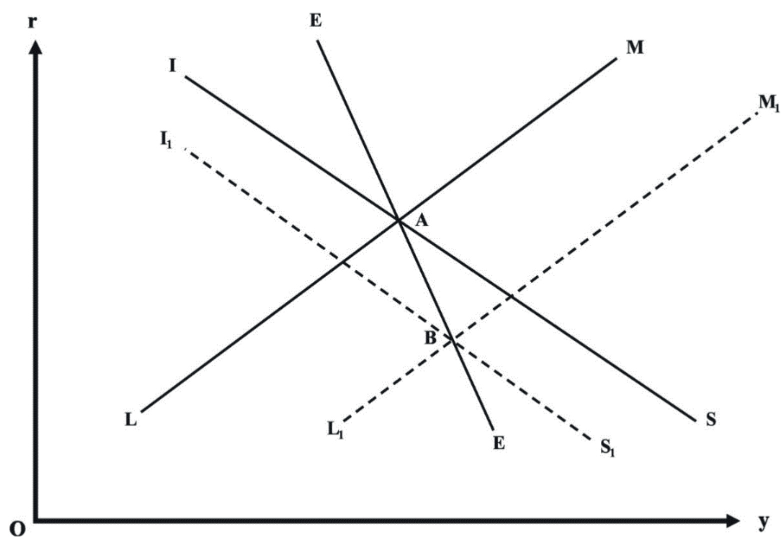

Figure 3 Extending the traditional IS-LM analysis to include the environment

Source: Munasinghe (2004)

In the comparative static analysis of macroeconomic policies, we can also include environmental issues in the IS-LM framework. As is known, IS-LM curves are drawn in the (R, Y) space; where R is the interest rate and Y is the aggregate demand.

$$\frac{dY}{dt} = \varnothing\left[A\left(R,Y,F\right) - Y\right] \equiv \varnothing\left(R,Y,F\right) \quad (1)$$

Here,

Y = real output

A = aggregate demand for goods

R = long-term real interest rate

r = short-term real interest rate

i = short-term nominal interest rate

F= index of fiscal stance

π = rate of inflation

First, let's assume that consumption and investment are affected by R. Here, the demand for goods can be written as $A\left(R,Y,F\right)$, where $A_R < 0$ and $A_Y, A_F > 0$. Here, ∅ has a decreasing relationship with R and Y, and an increasing relationship with F. Equilibrium in the goods market requires ∅ = 0. In this case, the equality A = Y will implicitly give the IS curve. In the {Y, R} space, the slope of the IS curve is $(\frac{-\varnothing_Y}{\varnothing_R})$ and is negative. Increases in F (expansionary fiscal policy) cause rightward shifts.

Monetary market equilibrium is also characterized by traditional portfolio evaluations. Assuming rational expectations (and risk neutrality), arbitrage equates the yield rates of short-run nominal bonds and real consols as follows:

$$R - \frac{\frac{dR}{dt}}{R} = i - \pi^* \quad (2)$$

The balance of the money market requires the equality of money supply and demand.

(M/P)= L(i, Y).

Substituting i into Equation (2) will give the LM curve:

$$\frac{M}{P} = L\left(R - \frac{\frac{dR}{dt}}{R} + \pi^*, Y \right) \tag{3}$$

The LM curve is upward sloping, and monetary expansion will shift it to the right.

To understand the logic behind the EE curve, let's consider a situation where technological progress remains constant. In this scenario, if the amount of materials and energy required to maintain the equilibrium output level exceeds the environment's ability to renew and absorb waste, the output level will become unsustainable. This means that natural capital stocks will deplete, making it impossible to sustain the necessary production in the long term.

Producing output requires a certain amount of natural capital. It is clear that natural capital and physical capital complement each other rather than substitute for one another. Therefore, sustainability requires the preservation of both types of capital.

The necessity of preserving natural capital indicates that a macro-environmental constraint should be added to the standard IS-LM framework. This constraint is represented by the EE curve in the (R, Y) space. To form the EE curve, consider (E) as the technical efficiency of resource use in production.

$$E = \frac{\text{the current energy used for the produced real output}\,(\mathrm{Y})}{\text{available energy in the resource flow}\,(\mathrm{T})}$$

Due to the complementarity between natural and artificial capital, E is always less than one. In equilibrium, E is affected by the production techniques used. More resource-intensive or polluting techniques result in a lower E. It is assumed that E is a function of $R, \beta\, and\, \gamma$, i.e., E = E(R, β, γ).

Cleaner production techniques are more likely to be adopted when R values are low and β values are high. Additionally, an increase in γ provides producers with more advanced techniques that save resources and reduce pollution. By doing so, production at a certain level of technical efficiency will be less costly. Therefore, $E_R < 0$, $E_\beta > 0$ and $E_\gamma > 0$.

Rearranging equation (6) allows us to express the total throughput of matter-energy in the economic process as $T = Y/E$ where $TY > 0$ and $TE < 0$. Therefore, the total matter-energy throughput can be represented as follows:

$$T = \frac{Y}{E(R.\beta,\gamma)} \tag{4}$$

Let *Nt* represent the physical stock of natural capital at time t. Assuming natural capital regenerates at a rate of $s \cdot Nt$ the net rate of natural capital enhancement or depletion can be expressed as follows:

$$-\left(\frac{dN}{dt}\right) = T - s * N \tag{5}$$

$$-\left(\frac{dN}{dt}\right) = \frac{Y}{E(R.\beta,\gamma)} - s * N \tag{6}$$

For environmental equilibrium, natural capital must remain intact. Equation (7) defines the EE curve in the (R, Y) space when $dN/dt = 0$. Differentiating equation (7) indicates that the EE curve has the following slope.

$$\left.\frac{dR}{dY}\right| \mathrm{dN/dt=0} = \frac{E}{Y} \tag{7}$$

Because $ER < 0$, the slope of the EE curve is negative. However, the slope will change over the length of its locus. Indeed, it will be steep whenever the technical efficiency of production is insensitive to changes in *R*.

As shown in Figure 3, this trend will become more pronounced as the maximum allowable output level (Ymax) is approached. When Ymax is achieved and the cleanest available technique is utilized, additional resource savings and pollution reductions cannot be achieved solely by changing production techniques.

In an initially balanced economy, the IS, LM, and EE curves intersect at point A. Expansionary monetary policies will cause the LM curve to shift to L_1M_1. To re-establish the triple equilibrium at point B, assuming the EE curve remains constant, contractionary fiscal policies will be needed to shift the IS curve to I_1S_1.

One of the first studies addressing environmental issues within the IS-LM-EE framework is Lawn (2003). This study suggests the use of tradable resource use permits when production exceeds sustainable levels. Auctioning these permits will raise their prices, increasing production costs and output prices. As prices rise, the real money supply will decrease, creating a contractionary monetary effect that reduces output.

8 SUSTAINABLE ECONOMIC GROWTH

Nowadays, sustainable economic growth and environmental quality have become topics that are evaluated together. As is known, emissions increase as the economy grows. On the other hand, technologies developed to reduce emissions that pollute the atmosphere, especially CO2, can mitigate this environmental impact. For example, a new smokestack filter can reduce emissions while maintaining the same level of production. In the model below, (g_A) represents technological progress that reduces emissions. The emission growth rate (g_E) accompanying balanced growth can be written as follows (Milani, 2023):

$$g_E = g_B + n - g_A \qquad (1)$$

Here,

g_E , growth rate of emissions.

$g_B + n$, scale effect (g_Y).

g_A is the technical effect.

$g_B + n$, the scale effect (g_Y), this suggests that higher output levels lead to increased emissions. In other words, larger GDP values are linked to higher emissions. The term g_A represents the technique effect, indicating that the advancement of clean production techniques will help lower pollution emissions. As can be seen from the equation above, it is subtracted from the first term in the equation because it will reduce the increase in emissions.

Sustainable growth is defined as a balanced growth trajectory that enhances per capita income while improving the environment. To achieve sustainable growth, the following conditions must be satisfied.

$$g_B > 0 \qquad (2)$$

$$G_A > g_B + n \qquad (3)$$

$$g_E < 0 \tag{4}$$

Equation 2 shows that technological progress is necessary for sustainable per capita income growth. Meanwhile, Equation 3 indicates that for emissions to decrease and production to increase, technological progress in reduction must exceed the growth in total production g_Y. Together, these two conditions express the negative emission growth rate given by Equation (4).

9 ECONOMIC GROWTH AND ENVIRONMENTAL POLLUTION: ENVIRONMENTAL KUZNETS CURVE (EKC)

The relationship between the environment and economic growth is complex and often contradictory. Economic growth is vital for social stability and development, making it a top priority for governments. However, as economies grow, environmental constraints related to climate, energy, and land use increasingly limit growth. Uncontrolled growth can lead to irreversible environmental damage. Today, traditional economic models that assume continuous growth are no longer valid.

Currently, there is no comprehensive theory to resolve the conflict between economic growth and environmental sustainability. Although the concept of 'green growth' is appealing, achieving it in practice is difficult. Despite the limited evidence of a significant decoupling between GDP growth and carbon-intensive energy use, it is clear that economic growth and environmental health are opposing concepts (Niu et al., 2022). One approach that attempts to explain the relationship between growth and environmental pollution is the Environmental Kuznets Curve (EKC) model.

The Environmental Kuznets Curve (EKC) shows a relationship between indicators of environmental degradation and per capita income. As economies become wealthier, environmental impacts initially increase but eventually decrease. On the other hand, while some environmental issues decrease in developed countries, other problems persist. However, the statistical evidence for the EKC is not very strong, and the mechanisms behind this approach are still debated (Stern, 2014).

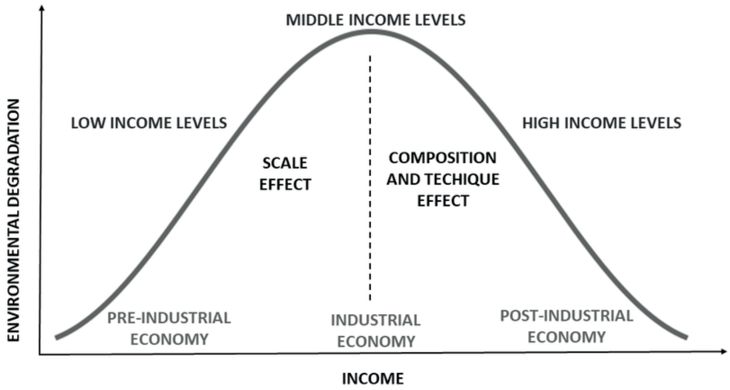

Figure 4 Environmental Kuznets Curve (EKC)

Source: Mitić et al. (2019)

As can be seen from Figure 4, the Environmental Kuznets Curve (EKC) is a hypothesized relationship between environmental degradation indicators and per capita income. According to this, in the early stages of economic growth, pollution and environmental degradation increase. However, after reaching a certain income level (which varies according to different indicators), this trend reverses, leading to environmental improvements at higher income levels. This indicates that the environmental impacts or emissions per capita follow an inverted U-shaped pattern relative to per capita income (Stern, 2014). The EKC is named after Simon Kuznets, who proposed that income inequality initially increases and then decreases as economic development progresses.

10 CONCLUSION

Significant investments aimed at mitigating climate change are already being made by all countries to decarbonize the energy needed for economic growth and to increase energy efficiency. However, much more effort is required to completely decarbonize the economy. Additionally, new climate mitigation measures will be necessary to address rising sea levels and increasingly extreme weather conditions.

Climate change can be seen as a negative shock to the supply potential of the economy. By its nature, climate change appears to be a trend shift accompanied by larger fluctuations rather than being entirely temporary like weather conditions. As a negative supply shock, it will exert downward pressure on production, upward pressure on prices, and reduce future potential growth. Additionally, the uncertainty about the speed and scope of climate change and humanity's ability to adapt is expected to increase uncertainty about future potential growth. This could lead to fluctuations as economic actors adjust their expectations of potential growth based on changing weather conditions and new scientific evidence. As economic units revise their expectations of potential growth in light of changing weather conditions and related emerging scientific evidence, this will likely mean some degree of fluctuation. Changes in the preferences of economic agents can affect product demand and alter behaviors, impacting production and supply.

Climate change can also alter demand conditions. In the short term, infrastructure damage might boost investment, but weaker economic growth and income expectations, along with increased uncertainty, could lead firms to reduce investment and households to save more and spend less in the medium term. Trade may be disrupted by transportation and infrastructure issues due to rising global temperatures. Additionally, the broad impacts of climate change on supply and demand are likely to have indirect effects on inflation. In particular, upward price pressures can arise due to the reduced supply potential of the economy.

A large part of the potential negative macroeconomic impacts comes from climate change's effects on productivity. Some output losses are also due to low productivity. Climate change can negatively affect productivity through various channels. Higher heat and humidity levels can reduce working capacity and cause output losses. Both higher average temperatures and more frequent extreme weather events can adversely impact productivity.

Lower investment can negatively impact capital stock and capital formation. Damage to physical capital, such as infrastructure, buildings, and equipment, may reduce the capital stock, affecting governments, businesses, and households. Although this damage might prompt renewal investments in the short term, it is likely to decrease net wealth at the overall economic level. If firms become more pessimistic about the future impact of climate change on growth, they may reduce investment, leading to a lower capital stock and potential production growth.

Global warming can negatively impact the labor market and household sector. Rising temperatures can affect people's health and working capacity, reducing labor input. With lower labor input and productivity, households might expect decreased future income, leading to reduced spending. Damage to capital stock can also pressure consumer spending by reducing net wealth.

Additionally, climate change can alter migration patterns, causing labor supply to decrease in some regions and increase in others.

In response to the impact of climate change on transportation, trade and production patterns may be affected. While transportation links in colder regions might improve, severe storms, altered precipitation patterns, and extremely high temperatures could cause adverse effects elsewhere. If companies relocate from areas heavily impacted by climate change, it could lead to a reallocation of capital stock, employment, and production across different countries.

Climate change is anticipated to have wider welfare impacts that GDP losses alone do not fully capture. GDP, by design, does not include significant welfare determinants like health risks from changing climates and disruptions from displaced communities. Standard national accounting does not directly account for environmental externalities and the depletion of natural resources (or damage to natural capital). However, activities aimed at addressing these issues, such as healthcare and pollution reduction expenditures, generally have a positive impact on GDP. This measurement issue has led to efforts to supplement GDP with satellite accounts that measure environmental and social variables affecting welfare.

Environmental economics studies are expanding to include macroeconomic analyses due to the undeniable effects of environmental factors on macroeconomic variables. In these studies, the relationships between the environment and economic growth are examined through both growth theory and Kuznets-type approaches. Additionally, the relationships between greenhouse gas emissions and economic development are also being intensively studied. On the other hand, efforts to extend the IS-LM model to include environmental effects are being observed. Therefore, the development of macroeconomic analysis with an environmental dimension inevitably lies ahead of us.

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