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The adaptation of economies to climate change: lessons from the economic research

Beyond the issues of energy transition and the development of a sustainable economic model, the process of climate change is already having measurable negative impacts: lower agricultural yields, a fall in the labour supply, weaker productivity growth. It is therefore important to understand to what extent firms and economies in general are liable to adapt and innovate in order to mitigate these adverse effects. An examination of the literature shows that, at this stage, firms have only adapted to a limited extent to the consequences of climate change.

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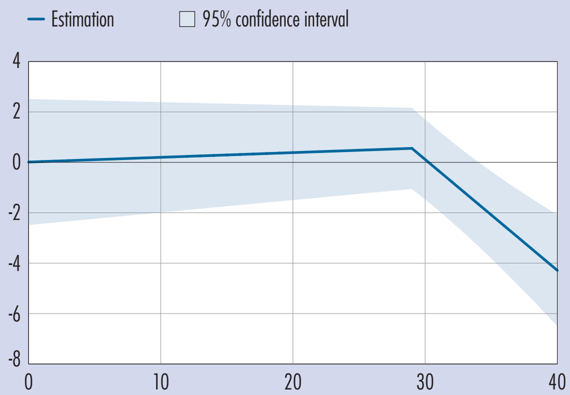
JEL codes
Q50, Q54,
Q55

3.8-5.5%
decline in global production of corn and wheat between 1980 and 2008 compared with a counterfactual without global warming

Up to 1 hour
average reduction in daily working hours on very hot days (temperature above 30°C) in the United States

Non-linear relationship between temperature and corn yields (United States)

(x-axis: temperature in °C; y-axis: % difference in yield)



Source: Burke and Emerick (2016).
Interpretation: One day at 40°C reduces the annual yield by 4.4% compared with a day at 29°C.

1 Physical risks, a major and pressing challenge for certain economic activities

In recent decades, numerous scientific studies have provided unequivocal confirmation of the pace and scale of climate change. The *Sixth Assessment Report* by the Intergovernmental Panel on Climate Change (IPCC, 2021) strongly reasserts in its first volume that human activities have played a major role in driving global warming, and highlights the magnitude and above all the spectacular acceleration of climate change. As well as pointing to the warming of the atmosphere and oceans, the report states that "evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened since the *Fifth Assessment Report*".[1]

What 30 years ago might have seemed like a medium-term risk and challenge is now clearly recognised as a pressing threat that is being brutally felt by all. The imbalances and disruption caused by global warming – especially the increased frequency of "extreme" climate events – are having immediate and escalating effects on human activity (Dell et al., 2014; Lesterquy, 2021), and tackling them poses challenges. The summer of 2021 illustrated this.[2]

In this article, we examine the physical risks[3] that are weighing increasingly on certain economic activities and look at the ways in which those sectors are liable to adapt – or not – in order to mitigate the most damaging consequences. Various forward-looking reports map and describe the climate risks firms need to take into account, and list the initial measures that they have implemented (Ademe, 2019; McKinsey, 2020; CERDD, 2021; CCI, 2021). However, to the best of our knowledge, these institutional reports do not fully exploit the richness of the academic literature on the subject. The aim of this article is therefore to enrich the debate with the main lessons drawn from the literature.

2 Some sectors are already being impacted by the physical risks

In the medium to long term, climate change poses major challenges to our economies: sustainability of certain sectors, transition to sustainable and less polluting energy sources, replacement of industrial components or processes that emit high levels of greenhouse gases (GHGs), stranded assets, etc. The transformations needed to limit global warming – to the extent possible – are huge. Nonetheless, the size of these medium-term challenges should not distract from the fact that climate change is already having an impact on economic activity.

The elasticity of agricultural yields to temperature is not linear

First, the upward trend in average surface temperatures over land and oceans is having quantifiable effects on economic activity (Dell et al., 2012) and especially on agricultural yields. Schlenker and Roberts (2009) estimate the sensitivity of yields of the three main crops grown in the United States (corn, soybeans and cotton) between 1950 and 2005, which corresponds to a period of acceleration in global warming. They find that the elasticity of yields to temperatures is non-linear:[4] yields rise gradually up to 29-32°C, depending on the crop, then fall abruptly.[5] Several studies have confirmed this non-linear elasticity, which is shown in the chart above for corn (Schlenker and Lobell, 2010; Feng et al., 2010; Hsiang, 2010; Burke and Emerick, 2016; Gammans et al., 2018). Lobell et al. (2011) find that between 1980 and 2008 "global maize and wheat production declined by 3.8% and 5.5%, respectively, relative to a counterfactual without climate trends".

1 IPCC (2021), *Headline Statements from the Summary for Policymakers*. See also WEF (2019), *The Global Risks Report* 2019.

2 "*Inondations mortelles en Allemagne et en Belgique, dôme de chaleur au Canada et aux États-Unis, incendies en Grèce et en Turquie: la responsabilité du réchauffement climatique dans la répétition de plus en plus fréquente de ces drames est clairement engagée.*" (*Le Monde*, 9 August 2021).

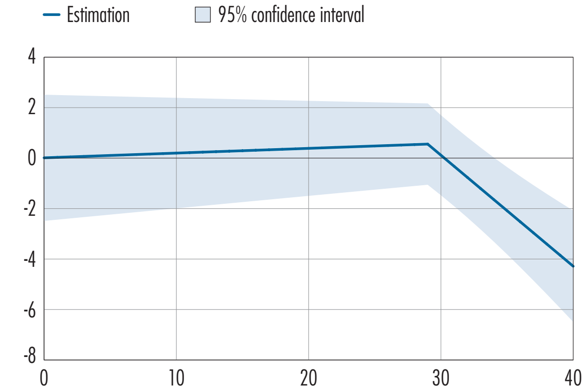
3 Climate change is associated with three types of risk: (i) physical risks resulting from direct damage caused by climate phenomena; (ii) transition risks resulting from the shift towards a low-carbon economy; and (iii) legal and reputational risks (ACPR, 2018). In this article we concentrate on the physical risks, which refer to two main types of event: gradual changes (rising temperatures or sea levels) and natural disasters.

4 This idea of a non-linear process characterises most of the articles cited here. It is one of the most worrying aspects of climate change as it makes it hard to fully grasp the scale of the associated risks.

5 For example, one day (24 hours) at 40°C, and not 29°C, reduces corn yields by an average of 7% according to Schlenker and Roberts (2009).

Non-linear relationship between temperature and corn yields (United States)

(x-axis: temperature in °C; y-axis: % difference in yield)



Source: Burke and Emerick (2016).
Note: The estimates show the difference in yield at the end of the season for one additional day of exposure to a given temperature compared with a day at 0°C (area on the left showing an upward trend) or at 29°C (area on the right showing a downward trend). One day at 40°C reduces the annual yield by 4.4% compared with a day at 29°C. The shaded area shows the confidence interval around the estimates.

Heatwaves, which are becoming more frequent, are impacting labour supply and productivity

The rise in temperatures and increasing frequency of heatwaves are also affecting labour supply and productivity.[6] Using US data, Graff Zivin and Neidell (2014) estimate that, at the aggregate level, the sensitivity of labour supply to temperatures is low. However, this masks considerable heterogeneity between sectors depending on their degree of exposure to climate events: in the most exposed sectors (agriculture, construction, etc.), maximum temperatures in excess of 30°C reduce the time allocated to work by an average of one hour per day (a decline of 14%). Jessoe et al. (2018) confirm this observation using Mexican data: extremely hot days tend to lead to a sharp drop in employment, and especially in wage work and non-farm labour. Zhang et al. (2018) study the elasticity of total factor productivity (TFP) to temperatures using detailed data on Chinese factories over the period 1998-2007. The authors find an "inverted U" relationship between TFP and temperatures, with particularly strong effects in the event of high temperatures. One day of temperatures over 32°C tends to reduce TFP by 0.56% compared with a day with temperatures of between 10°C and 15°C.

These microeconomic studies identify a non-linear relationship between temperatures on the one hand and agricultural yields, labour supply and factor productivity on the other. However, until recently, macroeconomic studies struggled to establish a similar relationship, especially in developed countries (Dell et al. 2012). In an influential article, Burke et al. (2015) reconcile both micro and macro observations: using a panel of 166 countries over the period 1966-2010, they identify a concave and non-linear relationship between aggregate production and productivity on the one hand, and temperatures on the other. Nonetheless, the optimal temperature at the macro level is lower than that highlighted in micro studies. The authors resolve the source of this discrepancy using a model that aggregates micro-level non-linear responses. In particular, the country-level effects of global warming are found to differ for hot and cold countries.

Do natural disasters trigger a process of creative destruction?

While rising temperatures and more frequent heatwaves have a significant impact on agricultural yields, labour supply and productivity, natural disasters, such as floods and cyclones, are liable to affect firms via capital. At the macro level, Hsiang (2010) presents some puzzling results for Caribbean countries: cyclones appear to have no impact on national output. However, a breakdown by sector reveals that they have a negative impact on agriculture and tourism, but a positive impact on construction. These mixed macro-level effects of natural disasters could in part reflect a process of creative destruction. Although natural disasters destroy physical assets indiscriminately (both efficient and non-efficient assets alike), they can also help to rid the economy of excess capacity and trigger a renewal of capital stock,[7] which in turn leads to additional investment and spurs innovation.

Leiter et al. (2009) support this hypothesis and show that, in the European Union, the assets and employment of firms

6 Heal and Park (2016) examine the literature on the economic consequences of heatwaves. Lesterquy (2021) reviews the literature on the relationship between climate change, human health, population and economic growth.

7 As Hornbeck and Keniston (2017) show using the example of the Great Boston Fire of 1872.

in regions affected by floods tend to rise more in the short run than those of comparable firms in regions unaffected by floods. However, their productivity appears to decline after a flood. Similarly, Noth and Rehbein (2019) show that firms' turnover increases after a flood, which they attribute to a learning effect. However, another study of granular Japanese data (Tanaka, 2015) finds more nuanced results: factories that survived the Kobe earthquake[8] reported lower growth in value added and employment than comparable factories not affected by the disaster. Although their physical capital grew at a comparably higher rate, the results do not "support the creative disaster hypothesis, which posits that natural disasters enhance firms' productivity by encouraging firms to replace their existing capital with new capital and adopt new technology. However, the results from the plant-level data suggest that plants in Kobe suffered from over-investment in physical capital and a failure to enhance productivity". In other words, the reconstruction and adaptation of capital following a natural disaster can divert resources from more productive investments and hence have a negative impact on technical progress.

These studies show that climate change is already having significant and non-linear impacts on certain economic activities. This in turn raises the question of whether those sectors are capable of adapting to the increasingly pressing physical risks. Here again the academic literature offers various insights.

3 Adaptation to climate change is fairly limited

Firms' adaptation to the consequences of global warming is difficult to measure *directly*. It can be measured *indirectly*, however, via a comparative analysis (longitudinal and temporal) of how individual firms are affected by climate change. The United States is a useful case study for this due to its geographical – and hence meteorological – heterogeneity, and the availability of statistics over a long time period.

The experience of US agriculture in the 20th century shows a low ability to adapt

Hornbeck (2012) examines the consequences of an episode of permanent soil erosion in the 1930s: the American Dust Bowl. This event, which is very similar to the threat currently weighing on other agricultural regions, provides several answers to the question of adaptation. Hornbeck shows first that a reduction in land's potential for agricultural production leads to an immediate drop in its value and to a persistent decline in agricultural revenues. Then, by comparing the falls in revenues and land values, the author estimates that long-run adjustments recovered only 25% of the difference in initial agricultural costs between high-erosion and low-erosion areas.[9] The author shows in particular that the main adjustment took the form of migration and population decline: labour market equilibrium was re-established through further relative declines in population rather than through changes in crops and techniques or through capital inflows and an increase in local industry. In an analysis of US firm-level data, Jin et al. (2020) come to a similar conclusion. They estimate that firms adapt to climate change "by reducing employment and shutting down establishments in counties experiencing abnormally high temperatures".

This pessimistic observation coincides with the findings of Burke and Emerick (2016) in the study cited previously. By exploiting long-run variations in temperature and precipitation in the United States to identify short and long-run adjustments in the agricultural sector, the authors first confirm that the main crop yields are highly sensitive to long-run changes in weather conditions (see chart above). They then quantify the extent of climate adaptation by comparing long-run and short-run responses to the weather, and find that long-run adaptations appear to have mitigated less than 50% of the measured short-run impacts, with some estimates even indicating a complete lack of adaptation.

8 Although no link has been found between earthquakes and global warming, the study is nonetheless interesting because of the similarity between the effects of earthquakes and those of other disasters that are influenced by climate change.

9 The idea behind this calculation is as follows: the fall in land values may reflect the economic loss (including the expectation of future adjustments) and the immediate drop in revenues may reflect the short-term economic loss (excluding adjustments), so comparing the two indicates the degree of adaptation.

The relative cost of storms is higher in the United States, which may reflect a lower degree of adaptation

At the macro level, Hsiang and Narita (2012) show that countries with tropical cyclone climates suffer lower losses in percentage terms from actual cyclone events, providing strong evidence of a learning effect. However, these adaptations only mitigate 3% of the long-run damage. Similarly, Bakkensen and Mendelsohn (2016) estimate the elasticity of hurricane damage to per capita income in the United States and the rest of the world. The elasticity is less than 1, except in the United States where it lies between 1 and 1.6. The authors interpret this as indirect evidence of a lack of adaptation in the United States: a cyclone in the United States caused the same amount of damage (as a percentage of income per capita) in 1970 as in 2010. The authors estimate that if the United States had the same income elasticity of damage as the rest of the world, the economic costs would be 20 times lower.

Firms' adaptation to global warming is also closely linked to their ability to innovate. Several studies have examined this issue. Hsu et al. (2018) use patent data to show that the most technologically diversified firms are far less affected by natural disasters. Miao and Popp (2014) ask the opposite question: to what extent can natural disasters foster innovation? Using a panel of up to 30 countries over a period of 25 years, they establish a link between the occurrence of a natural disaster and the number of patents for technologies that help adapt to physical risks. However, this observation is not confirmed by Li et al. (2021).

4 Designing appropriate insurance against climate risks

By way of conclusion, it is important to look at the possible contradictory role of insurance. Several of the articles cited above address this issue indirectly: Bakkensen and Mendelsohn (2016) attribute the lower adaptation to hurricanes observed in the United States to the fact that "households, firms, and local governments are compensated for economic damage from tropical cyclones by a combination of subsidised national flood insurance, state regulations on coastal property insurance rates, and generous post disaster relief programs." Annan and Schlenker (2015) take a closer interest in the subject and show that the US government's subsidised crop insurance programme tends to reduce efforts to adapt: the sensitivity of crop yields to extreme heat is between 43% and 67% higher in insured areas than in uninsured areas.

Climate change thus creates a contradiction that is well-known to insurers: higher temperatures and escalating physical risks are imposing increased costs on many economic agents who are not directly responsible for climate change. It is legitimate that these agents should be able to insure themselves against climate-related events, and governments may be tempted to support them with premium subsidies. However, by protecting firms from the impacts of climate change and lowering the costs they incur so that they no longer reflect the real risk, these subsidised insurance schemes reduce firms' incentive to adapt to physical risks. Public insurance schemes must therefore take account of this contradiction in their design, and should be supplemented with ambitious incentive policies to encourage firms to adapt to climate change.

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