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# INTRODUCTION TO WEATHER EXTREMES AND MONETARY POLICY

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**Résumé Non Technique.** Alors que le changement climatique ravage notre planète, les banques centrales cherchent la réponse la plus appropriée, dans le cadre de leurs mandats, à des catastrophes naturelles plus fréquentes et plus intenses.

Ce papier commence par une revue de la littérature sur les effets économiques que les chocs climatiques ont pu avoir dans le passé. Les résultats permettent de dégager un message clair : les chocs climatiques dégradent l'activité économique, surtout dans les pays en développement. Bien que la plupart des études se soient concentrées sur les effets sur la production, des recherches récentes révèlent que les chocs climatiques peuvent également avoir un impact sur l'inflation.

Ensuite, nous analysons les risques supplémentaires pour la stabilité des prix représentés par des chocs climatiques plus fréquents et plus graves. Divers mécanismes pourraient entrer en jeu. Les futurs chocs climatiques sont susceptibles d'accroître la volatilité économique et avoir une incidence sur la dynamique de l'inflation. En outre, les chocs climatiques pourraient brouiller les perspectives d'inflation à moyen terme, rendant plus difficile la prise de décision par les banques centrales. En détériorant les bilans des banques, les chocs climatiques pourraient également nuire à la transmission de la politique monétaire à travers le système bancaire jusqu'à l'économie réelle. Enfin, les chocs climatiques pourraient réduire la marge de manœuvre conventionnelle à disposition des banques centrales.

L'interaction exacte de ces différentes forces reste incertaine à ce moment. Toutefois, la combinaison du réchauffement climatique et d'une plus grande fréquence des catastrophes naturelles obligera les banquiers centraux à se préparer à des épisodes d'incertitude accrue et à une plus grande volatilité des agrégats économiques.

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Summer, 2022. E-mail: pablo.garciasanchez@bcl.lu. Banque centrale du Luxembourg, Département Économie et Recherche, 2 boulevard Royal, L-2983 Luxembourg. My thanks to Paolo Guarda and Olivier Pierrard. This paper should not be reported as representing the views of the BCL or the Eurosystem. The views expressed are those of the authors and may not be shared by other research staff or policymakers in the BCL or the Eurosystem.

*Fate holds terrible forfeits for those who gamble on certainties.*

Winston Churchill

## 1. Introductory Remarks

The material standard of living is higher today than it ever was. However, our staggering success in boosting our wealth and numbers has come at a cost - Nature is on the brink of environmental collapse.

Here is the root of the problem: the prices we pay for Nature's goods and services[1] have long differed from their intrinsic values [Dasgupta (2021)]. Hence, our demand for these goods and services have far exceeded Nature's ability to supply them. This market failure has allowed, if not encouraged, our harmful effects on the planet's biosphere, the sum of all its ecosystems.

In terms of climate change, this note's topic, our overconsumption of Nature's goods and services has had a well-known consequence: atmospheric concentrations of carbon dioxide ($CO_2$) have exploded.

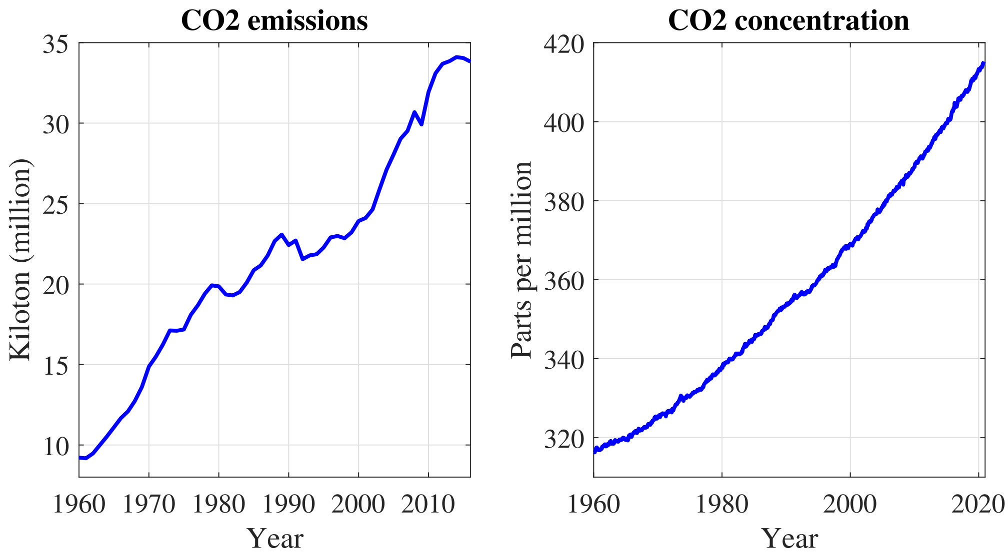
As seen in Figure 1, $CO_2$ concentrations are now around 400 parts per million (ppm), higher than anything seen in the last 3 million years. If we do not reduce the pace of $CO_2$ emissions, concentration levels will be around 750ppm by 2100. The last time that happened was in the Eocene Epoch, 35 million years ago. Ice-free, hot and with small differences in temperature from the equator to the poles, the earth at that time would not have been a suitable place for modern *homo sapiens*. Our species has only been around about 250,000 years, which helps to put these time frames into perspective.

We cannot accurately predict how much global temperatures will rise as a result of exploding $CO_2$ concentration levels [Pindyck (2021)]. Nor can we predict other aspects of climate change, such as changing patterns in precipitation or the loss of biodiversity [Stern (2013)]. Future climate patterns are mostly unknown, if not unknowable - what King (2016) calls radical uncertainty.

'If we don't know what the future might hold, we don't know, and there is no point pretending otherwise,' said King, former governor of the Bank of England.

[1] Nature provides a myriad of goods and services that are essential for human life: food, water, timber, air purification, soil formation, pollination, $CO_2$ storage...

FIGURE 1. Carbon Dioxide.




*Notes.* The left panel displays emissions stemming from the burning of fossil fuels and the manufacture of cement. The datasource is the World Bank. The right panel displays atmospheric CO2 levels measured at Mauna Loa Observatory, Hawaii. The data comes from Keeling et al. (2005).

We know one thing, however: climate change increases the risks of catastrophic weather events, even if we cannot quantify these risks.

Consider two examples. 25 million Europeans are currently exposed to extreme events each year. That number could reach 240 million by 2070, and 350 million by 2100. In other words, by the end of this century, two-thirds of Europeans could experience extreme weather events every year. Higher fatalities are to be expected. Nowadays heatwaves claim roughly 2,500 European lives each year, but by 2100 this could be around 150,000. Yes, this represents a 5,900% increase [Forzieri et al. (2017)].

This increase in physical risks from climate change -heatwaves, windstorms, floods, droughts and the like- encourages central banks to ask how a more hostile natural environment might affect their ability to meet their mandates.[2]

To help in this endeavour, the first part of this note reviews the economic effect of past weather extremes. I begin by exploring the empirical literature, and then present three case studies: the fall of the Roman Empire, the French revolution of 1848, and Kansas in the 1880s.[3] The second part of this note discusses how more frequent and severe weather extremes could

[2]Please refer to Drudi et al. (2021) for more details.

[3]These three case studies illustrate important links between weather shocks and economic damages, emphasising key channels such as social unrest, debt-fuelled speculation, mass migrations or international competition for a scarce resource. Other relevant episodes not covered here include the Little Ice Age and the Bengal famine of 1943.

risk price stability, and offers some thoughts on the modelling of weather shocks, a crucial step in designing good monetary policy.

Here is my main message. Even in wealthy economies, weather events will affect central banks' ability to achieve their primary goal - keeping prices in check.

## 2. On the economic effects of climate extremes

2.1. **Historical background.** Already in the fourteenth century, Ibn Khaldun, an Arab historian, explained differences in people's customs and institutions by their physical environment and the ways they are compelled to satisfy their needs [Gates (1967)]. Khaldun's emphasis on the influence of heat upon the human body and temperament reappeared four centuries later in Montesquieu's *The Spirit of Laws* (1750), which argued that "*excess of heat*" made men "*slothful and dispirited*".

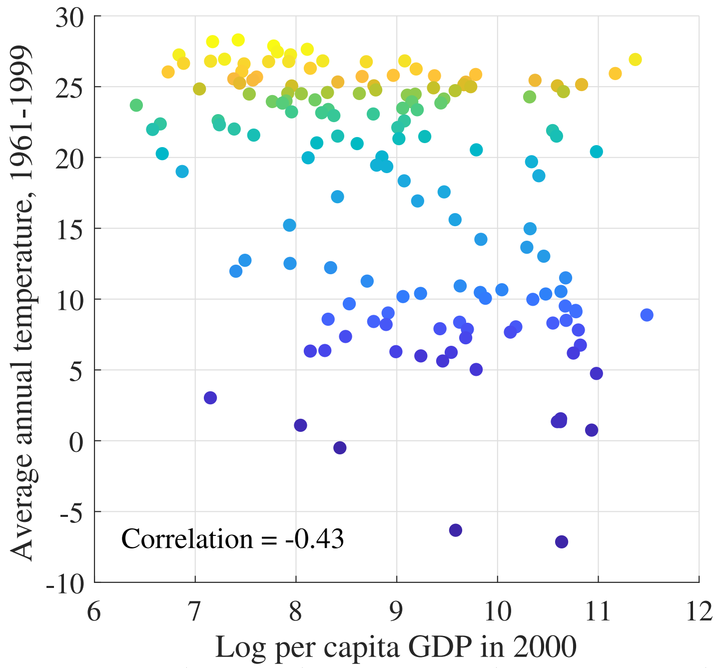
Sir John Chardin provided a link between the North African medieval thinker and the French philosopher of the Enlightenment [Dodds (1929)]. Knighted by Charles II of England after fleeing French persecution of the Huguenots, Chardin published *The Travels of Sir John Chardin*, which was regarded at the time as one of the finest works of scholarship on Persia. This seventeenth century best-seller established the bases for what was to become Montesquieu's theory of climate, by arguing that: "*la température des climats chauds énerve l'esprit comme le corps, dissipe ce feu d'imagination nécessaire pour l'invention ou pour la perfection dans les arts*" [Chardin (1686)].

A century later, the Victorian economist Stanley Jevons went further, arguing that financial crises were generated by sunspots [Landon-Lane et al. (2011)]. Jevons was focused on India. Sunspots distorted rainfall and harvest in India, lowering domestic income and depressing British imports. The resulting disruption in trade caused financial distress in the City of London.[4] Often ridiculed, Jevons was nonetheless supported by John Maynard Keynes: "*Jevons' notion, that meteorological phenomena play a part in harvest fluctuations and that harvest fluctuations play a part in the trade cycle, is not to be lightly dismissed*" [Keynes (1936)].

The link between climate and income kept appearing in seminal works of the first half on the twentieth century, such as Huntington (1916) and Pigou (1927).

[4]The "transit of Venus" hypothesis has some merit too. According to the nineteenth century American economist Henry Moore, every eight years Venus passed directly between the sun and the Earth, generating a regular eight-year rainfall cycle, a regular eight-year crop cycle, and a regular eight-year business cycle [Landon-Lane et al. (2011)]. Venus does not cross the sun every eight years.

FIGURE 2. Relation between temperature and per capita GDP in a sample of 155 countries.




*Notes.* Each dot represents a nation. The vertical axis represent the average annual temperature for the period 1961 to 1999. The horizontal axis represents the log per capita GDP in the year 2000 in 2017 international dollars.

Several more recent studies explored the relation between temperature and income in cross-sections of countries [e.g. Sachs and Warner (1997) and Gallup et al. (1998)]. Figure 2 conveys their key finding: hot countries tend to be poor, and cold countries wealthy. According to a basic linear regression, in the year 2000 a 1°C decline in annual temperature was associated with a 6% increase in per capita GDP.

Though appealing in its simplicity, this negative correlation is driven by the spurious relationships between temperature and other national features such as institution quality [Acemoglu et al. (2002) and Rodrik et al. (2004)].[5]

To overcome this obstacle, researchers have turned to time-series models, exploiting high-frequency variations in climate variables to unveil their economic consequences. I review this new Climate-Economy literature next.

## 2.2. **The new Climate-Economy literature.**

[5]Formally, the linear regression: Income $= \beta_0 + \beta_1$Temperature $+ u$, has a severe endogeneity problem, for the explanatory variable is correlated with the error term. This violates the assumption that the error term is unpredictable, as one can use the independent variable to predict it. As a result, the ordinary least square estimates are biased and no longer BLUE.

2.2.1. *Methodology.* To identify the effects of climate variables on the economy, the new Climate-Economy literature uses variations of the form:

$$y_{i,t} = \beta_0 + \beta_1 d_{i,t} + \beta_2 X_{i,t} + \epsilon_{i,t}, \tag{1}$$

where $i$ indexes geographical areas (e.g., countries, provinces), and $t$ indexes short time periods (e.g. years, months). Variable $d_{i,t}$ denotes climatic hazards (e.g. wind speed for hurricanes, temperatures for heat waves), $y_{i,t}$ is the variable of interest (e.g. per capita GDP, labor productivity), $X_{i,t}$ is a vector of controls, and $\epsilon_{i,t}$ is an identically and independently distributed error term.

As the climate variable, $d_{i,t}$, is exogenously determined and varies randomly over space-time, eq. (1) has strong identification properties [Dell et al. (2012)]. It is therefore not polluted by the spurious relationships described in 2.1.

Coefficient $\beta_1$ is the parameter of interest, as it pins down the marginal effects of weather events, $d_{i,t}$, on the economy, $y_{i,t}$.

In words, this new approach exploits changes over time within a given geographical unit to identify the impact of weather disturbances.

2.2.2. *Findings.* Results using the methodology outlined above convey a clear message: weather shocks degrade economic performance, particularly in developing countries.

Raddatz (2007) was among the first to draw our attention to the negative consequences of weather shocks on short term output dynamics. In subsequent work, the same author argues that smaller and poorer nations are more vulnerable to natural disasters [Raddatz (2009)]. Noy (2009) complements these findings by showing that better scores on development indicators (e.g., high quality institutions, high income per capita or high openness to trade) improve countries' ability to withstand weather shocks.

Looking at particular weather hazards, Dell et al. (2012) study how annual changes in temperature affect growth in per capita income in a sample of countries from 1950 to 2003. In poor countries, a $1°C$ increase in a given year impairs growth in per capita income by 1.4%. In wealthy countries, the results are not statistically significant. In the same vein, Hsiang (2010) claims that a $1°C$ increase in a given year lowers per capita output by 2.5% in a sample of 28 Caribbean nations.

Other studies, like Hsiang and Narita (2012) and Hsiang and Jina (2014), focus on the economic damages caused by cyclones. According to these authors, these tropical storms affect growth rates, not just income levels. Between 1970 and 2008, they estimate that cyclones lowered annual growth rate of world GDP by 1.3%. Likewise, in a sample of 174 countries, Kahn et al. (2019) find that output growth slows when temperatures are persistently above or below their historical norms.

In the United States, Landon-Lane et al. (2011) describes how the 1930s Dust Bowl phenomenon hit the banking system, impairing financial intermediation and economic recovery for a long period. Similarly, Nordhaus (2010) sets the annual cost of hurricanes between 1950 and 2008 to 0.07% of annual GDP. But the distribution has a long right tail: Hurricane Katrina's damages reached 1% of annual GDP. Mendelsohn et al. (2011) also find increased economic losses with increasing storm severity.

Almost all existing research focuses on production and income. Parker (2018) is among the exceptions: he focuses on inflation and finds that most weather shocks have negligible effects in rich countries, but often raise inflation in developing economies. However, the impact from severe weather shocks is large and significant even in wealthy nations. Along the same lines, Heinen et al. (2019) find that on 15 Caribbean islands wind and flood damages have a significant impact on some price indexes. Lastly, Faccia et al. (2021) established that extreme temperatures have a significant effect on a range of price indexes, including consumer and producer prices and the GDP deflator.

2.2.3. *Limitations.* The previous subsection shows that weather shocks damage the economy. Although it may be tempting to forecast the economic impacts of expected weather changes using these estimates, there are three arguments against such extrapolation [Dell et al. (2014)].

First, *adaptation*. Throughout history, humans have adapted to climate variability (with varying degrees of success). Today, there are numerous adaptation options. For instance, sustainable agriculture lowers risks to natural ecosystems, while sustainable water management can protect urban areas. Likewise, new materials and construction techniques can improve the resilience of the housing stock, and coastal defence can mitigate the effects of sea level rises.[6] Adaptation suggests that the estimated coefficient $\beta_1$ in eq. (1) changes over time.

Second, *general equilibrium effects*. Weather shocks affect the economy not just directly via first-round effects, but also indirectly via general equilibrium adjustments [Bowen et al. (2012)]. Eq. (1), as a reduced form model, is not well suited to capture these second-round effects.

[6]Please see IPCC (2018) for more details.

Third, *uncertainty*. More frequent and severe weather extremes will increase the prospect of irreversible damage to people and ecosystems [IPCC (2014)]. For example, if droughts force certain areas to be abandoned, the value of capital, infrastructure and land is lost. To the extent that these phenomena have no historical precedent, estimates from eq. (1) cannot predict future damages.

In sum, the new Climate-Economy literature based on eq. (1) does not capture the underlying structure needed to understand the potential long term impact of climate change.

## 3. CASE STUDIES

The previous section reviewed the evidence on the costs of weather extremes. However, it was silent on the underlying mechanisms. I now present three case studies that provide more qualitative evidence on the links between weather shocks and economic damages that could serve to better understand these underlying mechanisms.

3.1. **The fall of the Roman Empire.** [7] At its peak in the second century A.D., the Roman Empire reached from northern Britain to the edges of the Sahara and from the Atlantic to Mesopotamia. Thanks to the prevailing social and political stability, the economy boomed and the arts flourished.

Thousands of miles of new roads were built, together with new aqueducts, bridges and harbours. Long-distance trade exploded and cities expanded. The wealthy came to appreciate the soft silks and polished gems brought from the Far East. Horace, Virgil, and Ovid wrote their masterpieces. And all across the empire the cultural elites adopted the same hairstyles, wore the same clothes, read the same books, and laughed at the same theatre plays.

By the end of the fifth century, the Roman Empire was reduced to a Byzantine rump-state controlled from Constantinople, its former western territories occupied by various barbaric kingdoms. Plagued by decadence and violence, population declined, cities shrank, trade fell and technological progress came to a halt.

The fall of Rome had many fathers. Most scholars have looked at the persistent political instability, the incompetence of the ruling classes,[8] or the pressures on the frontiers by

[7] Please refer to Harper (2018) for a detailed description of this episode. For detailed data on climate patterns during Roman times, see McCormick et al. (2012).

[8] Emperor Caligula made his horse a senator and invited him to formal state dinners. Emperor Nero had rich men name him as their heir before forcing them to commit suicide.

neighbours leading increasingly effective armies. New evidence, however, reveals the role of climate change in bringing about Rome's demise.

The empire-builders had that one feature Napoleon would later demand in his generals: luck. From roughly 100 B.C. to 200 A.D., weather conditions -wet, warm and predictable- encouraged the development of an agricultural society. The resulting economic growth reinforced the political and social institutions by which Rome controlled its domains.

In the third century A.D., however, the climate became cooler, drier and unpredictable, with more common droughts and crop failures. We do not yet know why these climate changes occurred, but some combination of external factors like solar variability and volcanic eruptions must have played a role.

A less favourable climate did not directly lead to the fall of Rome in any simple manner. Instead, it damaged the Empire's resilience to various threats including pandemics, political turmoil, or economic instability. It also brought the Empire into contact with a new force - the Huns.

A forty-year drought forced the Huns to quit Central Asia, bringing death and devastation to Rome's Northern frontiers. These invasions of Germanic lands contributed to what is known as the 'Wandering of the Peoples': the mass migration of Germanic tribes, such as the Goths and the Vandals, into the Roman Empire.

These migrations disrupted Roman society, and raids and rebellions ultimately led to the fall of the Western Roman Empire. In 476 A.D., the Germanic King Odoacer deposed the last Roman Emperor and became King of Italy.

Of course, climate change alone does not explain Rome's fall. But Rome was heavily dependent on the climate conditions that had persisted for centuries. When these changed, the Empire's structure failed to adapt, which contributed to its end.

3.2. **French Revolution of 1848.** Louis Philippe, King of the French, abdicated on February 24, 1848. Not too eager to follow in his cousin's footsteps to the guillotine, he crossed the Channel. Incognito as the Comte de Neuilly, he settled at Claremont, an estate in Surrey placed at his disposal by Queen Victoria.

The flight of the King resulted from the collapse in basic food supplies that had shaken France and much of the Continent over years [Traugott (1983)]. In mid-1845, the arrival of an unfamiliar fungus, *phytophthera infestans*, reduced potato yields by 20%, causing substantial distress in the northern French provinces.[9] In normal circumstances, failure of the potato alone would not have generated a subsistence crisis. Wheat and rye could be used instead. But, by the autumn of 1846, it was clear that bad weather would wipe out much of the cereal harvest too.[10]

This was a massive shock and a lethal combination. Grains and potatoes were essential in people's diets, with poor households spending roughly two-third of their incomes on them [Berger and Spoerer (2001)]. Crucially, as the daily intake of calories approached subsistence levels, the demand for grains and potatoes became inelastic. Therefore, agricultural distress quickly transformed into a huge economic crisis, as rising food prices depleted households' available resources to buy industrial goods. Faced with falling demand, firms responded by cutting back production and laying off employees. In Paris, half of the industrial labor force would eventually be out of work [Traugott (1983)].

Preventing a famine required importing grain in large quantities. However, all neighbouring countries had the same need for grain. Import prices went sky-high. The French balance of payments turned unfavourable. The bullion reserves of the Banque de France shrank. Money supply declined.

These monetary developments, coupled with deteriorating expectations of future economic conditions and the decline in savings, led to a liquidity crunch. Interest rates rose, credit rationing set in, and a banking panic occurred. Even the Banque de France saw its deposits fall from 320 million francs in 1845 to 57 million francs in 1847.

The economic crisis contributed to political instability and the French Revolution of 1848.

3.3. **1880s Kansas.** [11] In the early 1880s, Kansas' economy boomed. Rising land prices, exceptional crop-yields and abundant credit made this agricultural state look like the shortest path to wealth. People moved into Kansas: from 1880 to 1885 its population went from 900,000 to 1,200,000.

High wheat and corn prices underpinned this surge of economic development. Indeed, the year 1881 marked the peak-prices of these two grains between the Civil War and the end of the century. However, what began as a healthy development rapidly degenerated into a gigantic bubble.

[9] In Ireland, this failure of the potato killed 1 million people [Grada et al. (2006)].

[10] The decline in rye and wheat yields would eventually fall by roughly 25% [Grada et al. (2006)].

[11] Please refer to Miller (1925) for a detailed description of this episode.

Ever-increasing land prices and easy access to credit made speculation and over-borrowing widespread. Mortgages came to be approved without any income verification from the borrower, for payment was guaranteed by the rising value of the underlying collateral. Moreover, loans were bundled into mortgage-backed-securities and sold in the eastern United States and in Europe. With one mortgage for every two adults, Kansas alone could not have supplied all this credit.

Excessive construction of railroads also defined Kansas in the 1880s; the increase in railroad mileage was second only to Texas. Not that this construction responded to actual needs: the goal was to boost land and real estate prices.

In this environment of irrational exuberance, public debt, mostly used to finance business of all sorts, particularly the railroads, almost tripled, leaving the state with one of the largest per capital public debt in the country.

'Do not be afraid of going into debt. Spend money for the city's betterment as freely as water. [...] Let the bugaboo of high taxes be nursed by old women,' commented one local newspaper. [12]

The music stopped when drought struck from 1886 to 1888. Suddenly, farms could not support the families living on them, and highly indebted households defaulted on their mortgages. That many of those households were not so much farmers as speculators speeded up foreclosures, as they promptly quit their lands once the hoped-for-riches were no more.

The international financial distress of the early 90's compounded Kansas's problems, as agricultural prices plummeted. A huge mass migration took place: thousands of wagons, carrying entire families and their possessions, left Kansas by the same roads they had entered it only years earlier. The mottos emblazoned on those wagons bore testimony to the end of the boom: 'Going back to the wife's folks', or still the more common one, 'In God we trusted, in Kansas we busted'.

The drought and the international crisis had a severe impact on the financial system of Kansas. Sure enough, most of the mortgage brokers went bankrupt, as their business activity vanished.

National (federally chartered) banks in Kansas were not immune either. From 1890 to 1900, 30 institutions went bust, whereas only two banks had defaulted in the previous 15 years. Most of these 30 banks had operated for only a few years: they were creatures of the boom.

[12] *Belle Plaine News*, February 27, 1886.

That most of them reported 'depreciation of securities' as the reason for their failure is no surprise. Though the nature of these securities is unknown, they were most likely railroad bonds and mortgage-backed securities issued by land companies [Landon-Lane et al. (2011)].

These three case studies illustrate how natural disasters can lead to economic mayhem. Of course, our economy differs vastly from that of the Roman Empire or XIX century France. Ours is wealthier, healthier, and stronger. And yet, many of the mechanisms highlighted above (e.g. social unrest, debt-fuelled speculation, over-borrowing, mass migrations, international competition for a scarce commodity) continue to play a crucial role in the XXI century.

## 4. Monetary policy

Here is the main message so far: even developed economies are vulnerable to Nature. With climate change raising the frequency and severity of droughts, storms, floods, wildfires and erosion, central banks are rushing to understand how a more hostile natural environment may affect their ability to meet their mandates.

4.1. **Price stability.** Despite remarkable uncertainty and many unknowns, more frequent and more severe weather extremes will pose risks to central banks' primary objective - price stability. Various channels will be at play.

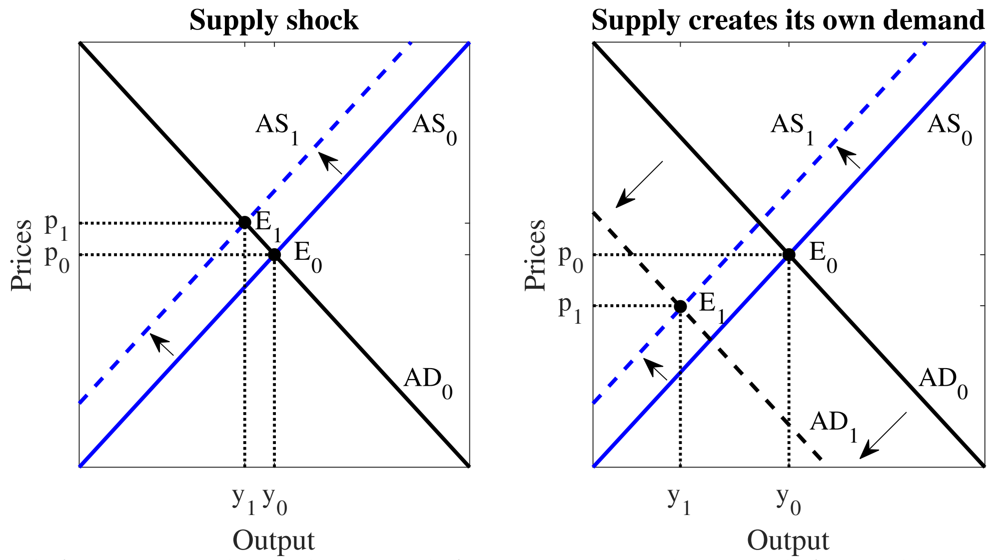
First, future weather extremes will affect the business cycle, potentially increasing economic volatility and distorting inflation dynamics. As mentioned earlier, for example, very hot summers have already led to higher prices, for food in particular [Faccia et al. (2021)].

Second, heatwaves, windstorms, floods, droughts and the like may blur the medium-term inflation outlook, thus hindering central banks' ability to make informed policy choices.

'[Climate change] will cause the signal-to-noise ratio to deteriorate and thereby increase the risk that central banks take action when in fact they shouldn't, or vice-versa,' said Benoît Coeuré, former member of the Executive Board of the European Central Bank.

Third, weather extremes may damage the transmission of monetary policy to the real economy. Losses from weather shocks (e.g. destroyed infrastructure) could impair bank balance sheets, lowering the flow of credit to households and firms. Likewise, changes in the perceived frequency and severity of weather shocks may lead to sudden price changes that ripple through the financial system, before reaching the real economy [Brainard (2020)].

FIGURE 3. Negative supply and demand shocks.




*Note:* AD stands for aggregate demand. AS stands for aggregate supply. E stands for equilibrium. The left panel features a negative supply shock, in which the price level goes up and production goes down. The right panel features both a negative supply shock and a negative demand shock. In this case, both prices and quantities decline.

Lastly, climate extremes might reduce central banks' conventional policy space. Uncertainty about climate-related shocks may boost precautionary savings and reduce incentives to invest, thus lowering the natural rate of interest [Schnabel (2021)]. In addition, as the distribution of weather shocks changes to grow fat tails, central banks might be forced to rely on unconventional tools more often.

Exactly how these forces will play out remains uncertain. Climate change is a cumulative process that keeps transforming the statistical relationships that link economic and climate variables.

4.2. **Supply and demand.** Climate extremes are often viewed as supply side shocks, for they distort the productive capacity of the economy by destroying the capital stock and/or lowering productivity [McKibbin et al. (2017)].

As seen in the left panel of Figure 3, weather extremes could shift the aggregate supply curve upwards, simultaneously reducing output and increasing prices.

Within this framework, weather extremes create a classic monetary challenge: how to tackle the fall in activity while stabilising inflation around its target and ensuring inflation expectations remain anchored [Klomp (2020)]. On the one hand, limiting the downturn calls for expansionary policy that boosts aggregate demand. On the other hand, controlling the upward pressure on prices calls for contractionary policy that lowers aggregate demand and output. This dilemma reveals the lack of a 'divine coincidence' when facing climate disruptions. The optimal monetary response will depend on the relative weights on inflation and the output gap in the central bank's loss function (assuming these accurately reflect the social welfare function).

Unfortunately, this framework is somewhat simplistic, as supply and demand are not so neatly separated and negative supply shocks may create their own lack of demand [Cochrane (2020)].

Imagine that an intense heatwave hits a large share of the population, forcing them to stay at home. Surely, the fall in labor productivity and the loss of intangible capital (e.g. matches between job vacancies and job seekers) will lower output and raise prices. However, there will be demand effects too: consumers hunkered down at home will not go out buy a new bicycle. If the fall in spending is large enough, it may offset the initial upward pressure on prices, eliminating the trade-off described earlier (see the right panel of Figure 3).

From a modelling perspective, including these demand effects will matter when determining the optimal monetary response to disasters. For example, using a standard New Keynesian model, Keen and Pakko (2011) argue in favour of *raising* the nominal interest rate in response to a disaster. Not surprisingly, in their framework climate extremes are pure supply shocks: they destroy a share of the economy's capital stock, and lower total factor productivity. Consequently, the central bank, whose objective is to keep inflation at its target, should increase the policy rate following a disaster. In contrast, Isore and Szczerbowicz (2017) argue in favour of *lowering* the nominal interest rate in response to a natural disaster. In their case, disasters also reduce agents' propensity to consume, weakening aggregate demand. As a result, the optimal monetary response involves lowering the nominal interest rate to boost spending.

The stark difference between these two policy recommendations reveals how important it is to model natural disasters carefully. Future studies should therefore aim to disentangle the supply and demand effects of extreme weather shocks.

## 5. Summary

Even wealthy economies are vulnerable to natural disasters. As climate change increases the risk of extreme weather events, central banks need to prepare for more frequent episodes of heightened uncertainty and heavy losses.

## References


Acemoglu, D., Johnson, S., and Robinson, J. A. (2002). Reversal of fortune: geography and institutions in the making of the modern world income distribution. *The Quarterly Journal of Economics*, 117(4):1231–1294.

Berger, H. and Spoerer, M. (2001). Economic crises and the European revolutions of 1848. *The Journal of Economic History*, 61(2):293–326.

Bowen, A., Cochrane, S., and Fankhauser, S. (2012). Climate change, adaptation and economic growth. *Climatic Change*, 113(2):95–106.

Brainard, L. (2020). Strengthening the financial system to meet the challenge of climate change. Speech given at: The Financial System and Climate Change: A Regulatory Imperative.

Chardin, J. (1686). Journal du voyage du Chevalier Chardin en Perse. Paris: Daniel Horthemels.

Cochrane, J. H. (2020). Coronavirus monetary policy. In *Economics in the Time of COVID-19*, pages 105–109. Centre for Economic Policy Researchs Press.

Dasgupta, P. (2021). The economics of biodiversity: The dasgupta review. Technical report, HM Treasury, London.

Dell, M., Jones, B. F., and Olken, B. A. (2012). Temperature shocks and economic growth: evidence from the last half century. *American Economic Journal: Macroeconomics*, 4(3):66–95.

Dell, M., Jones, B. F., and Olken, B. A. (2014). What do we learn from the weather? The new climate-economy literature. *Journal of Economic Literature*, 52(3):740–798.

Dodds, M. (1929). Les recits de voyages: sources de l'esprit des Lois de Montesquieu. Paris: H. Champion.

Drudi, F., Moench, E., Holthausen, C., Weber, P.-F., Ferrucci, G., Setzer, R., Adao, B., Dees, S., Alogoskoufis, S., and Tellez, M. D. (2021). Climate change and monetary policy in the euro area. Occasional Paper Series 271, European Central Bank.

Faccia, D., Parker, M., and Stracca, L. (2021). Feeling the heat: extreme temperatures and price stability. Working Paper Series 2626, European Central Bank.

Forzieri, G., Cescatti, A., e Silva, F. B., and Feyen, L. (2017). Increasing risk over time of weather-related hazards to the european population: a data-driven prognostic study. *The Lancet Planetary Health*, 1(5):200–208.

Gallup, J. L., Sachs, J. D., and Mellinger, A. D. (1998). Geography and economic development. Working Paper 6849, National Bureau of Economic Research.

Gates, W. E. (1967). The spread of Ibn Khaldun's ideas on climate and culture. *Journal of the History of Ideas*, 28(3):415–422.

Grada, C. O., Vanhaute, E., and Paping, R. (2006). The European subsistence crisis of 1845-1850 : a comparative perspective. Working Papers 200609, School of Economics, University College Dublin.

Harper, K. (2018). *The fate of Rome: climate, disease, and the end of an Empire*. Princeton University Press.

Heinen, A., Khadan, J., and Strobl, E. (2019). The price impact of extreme weather in developing countries. *Economic Journal*, 129(619):1327–1342.

Hsiang, S. M. (2010). Temperatures and cyclones strongly associated with economic production in the caribbean and central america. *Proceedings of the National Academy of Sciences*, 107(35):15367–15372.

Hsiang, S. M. and Jina, A. S. (2014). The Causal effect of environmental catastrophe on long-run economic growth: evidence from 6,700 cyclones. NBER Working Papers 20352, National Bureau of Economic Research, Inc.

Hsiang, S. M. and Narita, D. (2012). Adaptation To cyclone risk: evidence from the global cross-section. *Climate Change Economics (CCE)*, 3(02):1–28.

Huntington, E. (1916). Civilisation and climate. *Nature*, 97:358–359.

IPCC (2014). Climate change 2014 synthesis report. Technical report, Intergovernmental Panel on Climate Change, Switzerland.

IPCC (2018). Global warming of 1.5c. Technical report, Intergovernmental Panel on Climate Change, Switzerland.

Isore, M. and Szczerbowicz, U. (2017). Disaster risk and preference shifts in a New Keynesian model. *Journal of Economic Dynamics and Control*, 79(C):97–125.

Kahn, M. E., Mohaddes, K., Ng, R. N., Pesaran, M. H., Raissi, M., and Yang, J.-C. (2019). Long-term macroeconomic effects of climate change: A cross-country analysis. NBER Working Papers 26167, National Bureau of Economic Research, Inc.

Keeling, C., Piper, S., Bacastow, R., Wahlen, M., Whorf, T., Heimann, M., and Meijer, H. (2005). Atmospheric co2 and co2 exchange with the terrestrial biosphere and oceans from 1978 to 2000: Observations and carbon cycle implications. In *A History of Atmospheric CO2 and its*

*Effects on Plants, Animals and Ecosystems*. Springer, New York.

Keen, B. D. and Pakko, M. R. (2011). Monetary policy and natural disasters in a dsge model. *Southern Economic Journal*, 77(4):973–990.

Keynes, J. M. (1936). William Stanley Jevons 1835-1882: A centenary allocation on his life and work as economist and statistician. *Journal of the Royal Statistical Society*, 99(3):516–555.

King, M. (2016). *The end of alchemy: money, banking, and the future of the global economy*. W. W. Norton, New York.

Klomp, J. (2020). Do natural disasters affect monetary policy? A quasi-experiment of earthquakes. *Journal of Macroeconomics*, 64(C).

Landon-Lane, J., Rockoff, H., and Steckel, R. H. (2011). Droughts, floods and financial distress in the United States. In *The Economics of Climate Change: Adaptations Past and Present*, NBER Chapters, pages 73–98. National Bureau of Economic Research, Inc.

McCormick, M., Buntgen, U., Cane, M. A., Cook, E. R., Harper, K., Huybers, P., Litt, T., Manning, S. W., Mayewski, P. A., More, A. F. M., Nicolussi, K., and Tegel, W. (2012). Climate change during and after the roman empire: Reconstructing the past from scientific and historical evidence. *The Journal of Interdisciplinary History*, 43(2):169–220.

McKibbin, W., Morris, A., Panton, A. J., and Wilcoxen, P. J. (2017). Climate change and monetary policy: dealing with disruption. CAMA Working Papers 2017-77, Centre for Applied Macroeconomic Analysis, Crawford School of Public Policy, The Australian National University.

Mendelsohn, R., Emanuel, K., and Chonabayashi, S. (2011). The impact of climate change on hurricane damages in the United States. Policy Research Working Paper Series 5561, The World Bank.

Miller, R. (1925). The background of populism in Kansas. *The Mississippi Valley Historical Review*, 11(4):469–489.

Nordhaus, W. (2010). The economics of hurricanes and implications of global warming. *Climate change economics*, 1(1):1–20.

Noy, I. (2009). The macroeconomic consequences of disasters. *Journal of Development Economics*, 88(2):221–231.

Parker, M. (2018). The Impact of Disasters on Inflation. *Economics of disasters and climate change*, 2(1):21–48.

Pigou, A. (1927). Industrial fluctuations. London: Macmillan.

Pindyck, R. S. (2021). What we know and dont know about climate change, and implications for policy. *Environmental and Energy Policy and the Economy*, 2(1):4–43.

Raddatz, C. (2007). Are external shocks responsible for the instability of output in low-income countries? *Journal of Development Economics*, 84(1):155–187.

Raddatz, C. (2009). The wrath of God : macroeconomic costs of natural disasters. Policy Research Working Paper Series 5039, The World Bank.

Rodrik, D., Subramanian, A., and Trebbi, F. (2004). Institutions rule: the primacy of institutions over geography and integration in economic development. *Journal of Economic Growth*, 9(2):131–165.

Sachs, J. D. and Warner, A. M. (1997). Sources of slow growth in African economies. *Journal of African Economies*, 6(3):335–376.

Schnabel, I. (2021). Climate change and monetary policy. Finance and Development, International Monetary Fund.

Stern, N. (2013). The structure of economic modeling of the potential impacts of climate change: grafting gross underestimation of risk onto already narrow science models. *Journal of Economic Literature*, 51(3):838–859.

Traugott, M. (1983). The mid-nineteenth-century crisis in France and England. *Theory and Society*, 12(4):455–468.

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