The European Central Bank's Climate Change stress test

Serious research or magical realism?

tailrisk economics

te maha hoki o nga pihikete

About Tailrisk economics

Tailrisk economics is a Wellington economics consultancy. It specialises in the economics of low probability, high impact events including financial crises and natural disasters.

Tailrisk economics also provides consulting services on:

- The economics of financial regulation
- Advanced capital adequacy modelling
- Stress testing for large and small financial institutions
- Regulatory compliance for financial institutions
- General economics.

Tailrisk is prepared to undertake economics analyses of public policy proposals on a discounted or pro bono basis. Principal Ian Harrison (B.C.A. Hons. V.U.W., Master of Public Policy SAIS Johns Hopkins) has worked with the Reserve Bank of New Zealand, the World Bank, the International Monetary Fund and the Bank for International Settlements.

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Part one: Introduction and overview

In September 2021 the European Central Bank (ECB) released a climate change stress test in an occasional paper 'ECB economy-wide climate stress test Methodology and results.' (Alogoskoufis, Dunz, et al., 2021)

The modeling was an enormous and complex effort. It works its way from four million individual bank business loan exposures though 1,600 banks to calculate the impact of climate change over the next thirty years on the robustness of banks in Euro area countries.

It runs three of the Network for the Greening of the Financial System (NGFS)[1] standard scenarios: an 'orderly' transition, a 'disorderly transition', where the transition is delayed to 2030 which requires much higher carbon prices; and 'a hothouse world' where no further climate change mitigation is undertaken.

The ECB came to some strong conclusions.

The results show that there are clear benefits to acting early: the short-term costs of the transition pale in comparison to the costs of unfettered climate change in the medium to long term.

Finally, the results suggest that for corporates and banks most exposed to climate risks, the impact would potentially be very significant, particularly in the absence of further climate mitigating actions. Climate change thus represents a major source of systemic risk, particularly for banks with portfolios concentrated in certain economic sectors and specific geographical areas.[2]

While this is a staff paper that comes with the standard disclaimer that it represents the views of the authors and not the ECB, it carries the authority of the institution, has been widely promoted, and has been picked up by the media and the industry as an authoritative ECB position on climate change risk. For example, ING's Think's headline on the paper was:

'The ECB's clear warning to banks on climate risk'[3]

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[1] The NGFS is a Central Bank and Supervisor Climate Change, which is strongly committed to the systemic risk paradigm and is taking an increasing role in developing frameworks and models for climate change stress testing.

[2] See abstract of Alogoskoufis et al., 2021.

[3] See Schuller & Platerink Kosonen, 2021.

And the snap takeout:

The warning from the European Central Bank couldn't be clearer: climate change will be a major source of systemic risk to banks if no action is taken.

No doubt this paper will be taken up by other Central Banks to support their claims that climate change presents a systemic risk. We are not exaggerating or making stuff up they will say. The ECB modeling shows that there is a real threat.

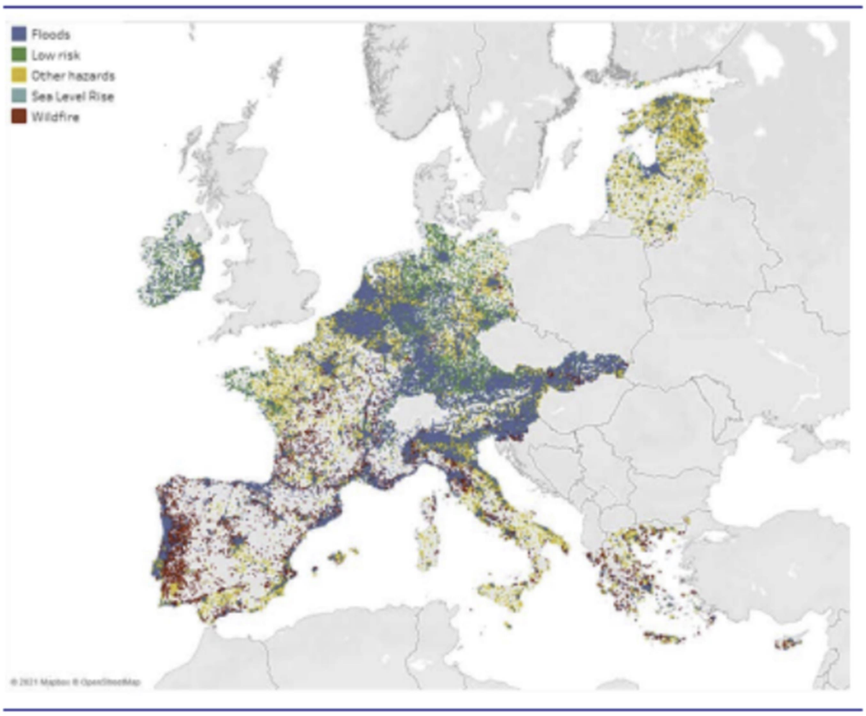
But amongst industry professionals, who understand the evidence and analytics there is a very different understanding. There is nothing, or next to nothing, there. Climate events do not pose a material risk to banks. This empirical literature is clear on this. A recent New York Federal Reserve paper, the showed that weather disasters did not negatively impact on banks in the United States, confirming the findings in other empirical work (Blickle et al., 2021).

A Tailrisk Economics review of the recent literature on climate change and financial stability found almost no evidence that climate change presented a material risk, let alone a systemic risk (Harrison, 2021).

Given the importance of the ECB results we have reviewed the ECB report in detail.

We were immediately struck by serious problems with critical data inputs. For Northern Europe flooding is identified as the major physical risk and the probability that individual business will suffer flooding damage is a major risk driver in the model. The only information we are given on these risks is presented in figure one. Blue dots show businesses with a flood risk of 1:100 or worse.

Figure one: Intensity and sources of physical risks

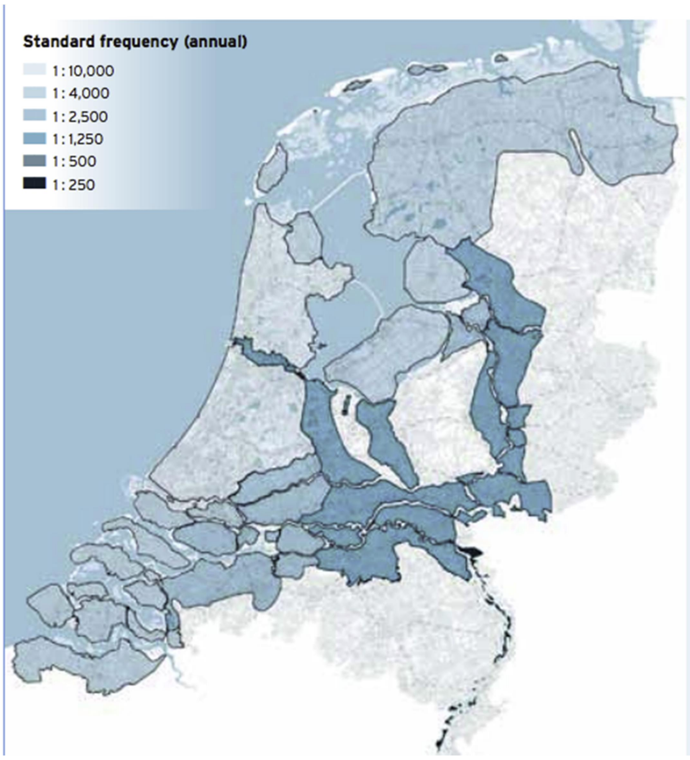


Source: ECB calculations based on Four Twenty Seven data (2018).

It is a little hard to distinguish the blue from the 'safe' green dots, but the central core of the Netherland appears to be wholly blue.

However, flood level protection in the Netherlands is set by law at much higher levels than 1:100, as figure two clearly shows. The most populous parts of the Netherland are protected at the 1:4000 level and the highest risk is 1:200 in isolated pockets.[4]

Figure two: Netherlands flood protection standards



On this error alone the ECB overstated flooding risk, and so the cost of physical climate change damage, by a factor of up to 40 in the Netherlands.

This is all obvious. The Netherland's flood protection regime is widely understood; the NGFS's 'rules of the game' are that official statements on levels of flood protection should be respected in the analysis; and of course, the Netherlands is just down the road from Frankfurt.

And this was just the beginning. The flooding error was almost certainly repeated in other locations and there are several other obvious and significant flaws and holes in the analysis.

[4] The National Flood risk analysis for the Netherland (Ministry of Infrastructure and the Environment) stated: *The Water Act of 2009 currently defines standards for protection from flooding for each levee system. The legislation sets a frequency (the exceedance probability) for each levee, denoting the water level that the flood defences must be able to withstand. The protection level depends on the nature of the threat (river, sea, lake), the size of the protected area and the economic value in the area. The map shows the levee systems in the Netherlands and the formal flood protection standards defined in 1996 in the Flood Defences Act, which has now been superseded by the Water Act of 2009.* (See link here).

An important risk the modelling identifies for Southern Europe is wildfires. But there is no evidence at all in the entire document of how this risk was generated. All we have is the set of red dots which turns out to be seriously consequential for Greece. Its banking system is identified as being at a heightened risk from wildfires with more than 95 percent of loan exposures affected.

The other key issues were:

- The disorderly and hothouse world scenarios are compared with an orderly transition scenario that is void of reality: The entire world immediately adopts policies that will generate net zero by 2050; problems with the uneven application of mitigation policies simply disappear. Similarly, it is assumed that all the problems with the cost and intermittency of renewable energy are solved in short order and firms can borrow to fund green investments at no cost.

- The assumed high cost of physical damage from climate change is based on a model that actually demonstrated that temperature increases do not impact on economic output over the medium and longer term. This result was ignored. Instead, the paper preferred to show the irrelevant result that temperature increase can have a short run impact on output in developing countries.

- Despite these assumptions the modelling does not demonstrate that climate change has a material impact on the overall soundness of banks' portfolios. Banks' lending portfolio default rates increase by only a few percent. The apparently more significant result for the 10 percent of most affected banks are almost certainly an artifact of a series of implausible assumptions in the model.

If this was just another staff paper where the researchers got carried away with their model and were oblivious to the obvious, then it wouldn't matter too much. It could be pulled apart in a more academic setting. But it is not. It is the ECB's jewel in the crown designed to push a political agenda and influence public opinion. It was presumably read and scrutinized by senior staff. But it looks like they have neglected the evidence and the analytics, and instead focused on the message.

Part two: The ECB model and its main results

The occasional paper presents a top-down modelling exercise that relies on data, assumptions and models developed by ECB staff. It analyses banks' credit and market portfolios at the exposure level, accounting for heterogeneous and firm-specific vulnerabilities to climate risks. It encompasses 4 million corporates worldwide, as well as 1,600 consolidated banking groups. In the Euro area 2.3 million European firms were matched with full financial and climate risk information.

Three climate change risks: flooding, wildfires and sea level rise are modelled over 2020-50 and the results of three NGFS mitigation strategies: orderly, disorderly, and hothouse house world are compared.

In the orderly strategy optimal policy actions to reduced emissions consistent with a 1.5-degree target (over pre-industrial levels or an increase of 0.5 C° over current levels); in the 'disorderly case' the response is delayed to 2030 and the response has to be more severe to limit temperature increase to 2 degrees. In the hothouse world there is no further mitigation actions and temperatures increase by 3 degrees by 2100.

Carbon price interventions

Policy responses are modelled by increased carbon prices, which are intended to capture both price and non-price interventions. It is implied that all non-price interventions will be optimal. That is, they will only be applied if they are less costly than the carbon price. This is an obviously optimistic assumption. The track record in many countries is that very costly non-price interventions have often been preferred to higher carbon prices (even when there is a price).

A glaring omission from the paper is the lack of any information on the carbon pricing paths in the different scenarios. This makes it difficult to assess the plausibility of the carbon price assumptions and to understand what is driving some of the outcomes.

While this is not spelt out, it is assumed that the policy responses are worldwide.

The possibly most likely, and worst case, scenario was not tested. Europe executes on its net zero target. The rest of the world doesn't. Europe incurs the transition costs but gets little benefit from reduced climate effects because Europe's emission reductions can have only a minor impact on the world's climate.

The physical effects of climate changes and policy changes on firms' incomes and balance sheets generate a probability of default (PD), a loss given default (LGD) and an expected loss, which is the combination of the two. The individual exposures are then aggregated for each bank. This is intended to allow an assessment of the impact of climate change on the banking system.

Outcomes

Overall

The overall results according to the ECB are as follows:

*The results also show that for corporates and banks most exposed to climate risks, the impact is potentially **very significant**, especially in the absence of further mitigating policies. If climate risks are not reduced, the costs to companies arising from extreme weather events would rise substantially, and significantly and negatively affect their creditworthiness.*

*Climate change thus represents **a major source of systemic risk**, particularly for banks with portfolios concentrated in certain economic sectors and, more importantly, in specific geographical areas. Finally, the anticipated impact on banks in terms of losses would mostly be driven by physical risk and **would potentially be severe over the next 30 years (**our emphases).*

Impact on GDP

Figure three shows that the European economy grows out to 2100, but there is not much difference between the scenarios over the forecast horizon. The differences past 2050 are driven by a simple GDP/ temperature function that is discussed in part four.

Figure four presents the data in terms of differences from the reference, orderly scenario. There is a small relative reduction (a positive difference) as the accelerated transition kicks in over 2020-25 but there after it is all positive. This is basis for the claim that the short run costs 'pale' in comparison to the long run benefits.

Figure three

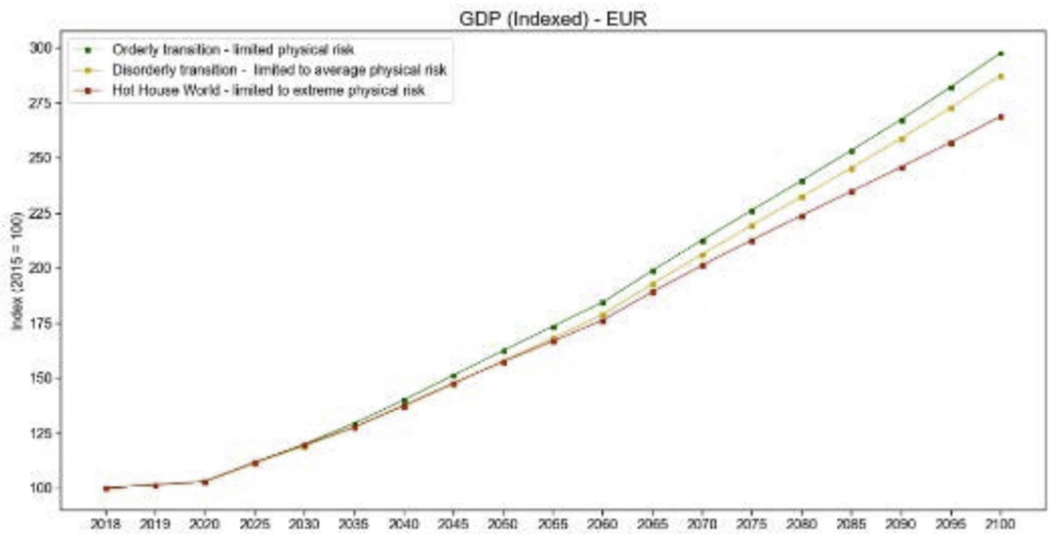
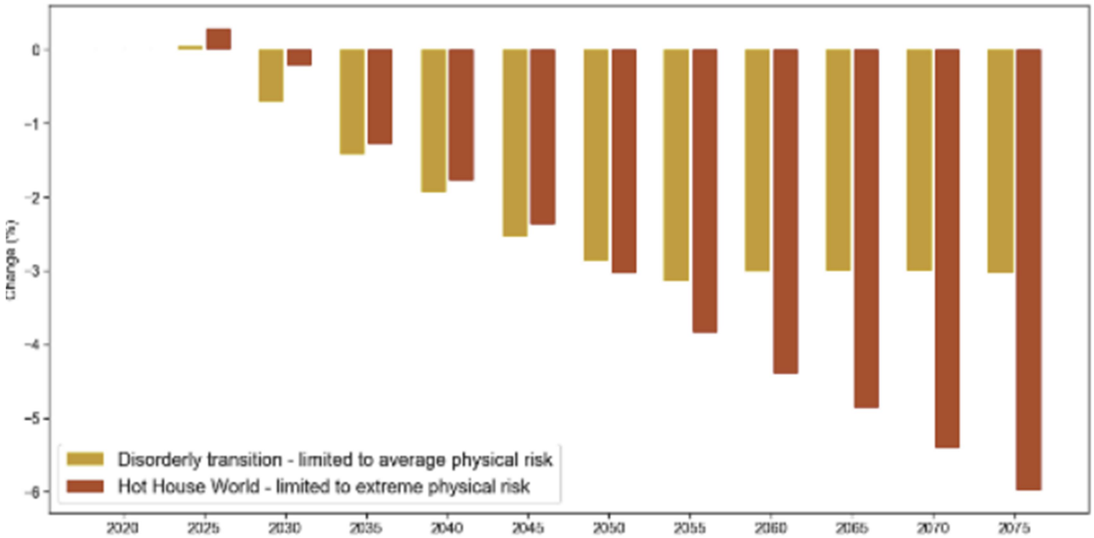


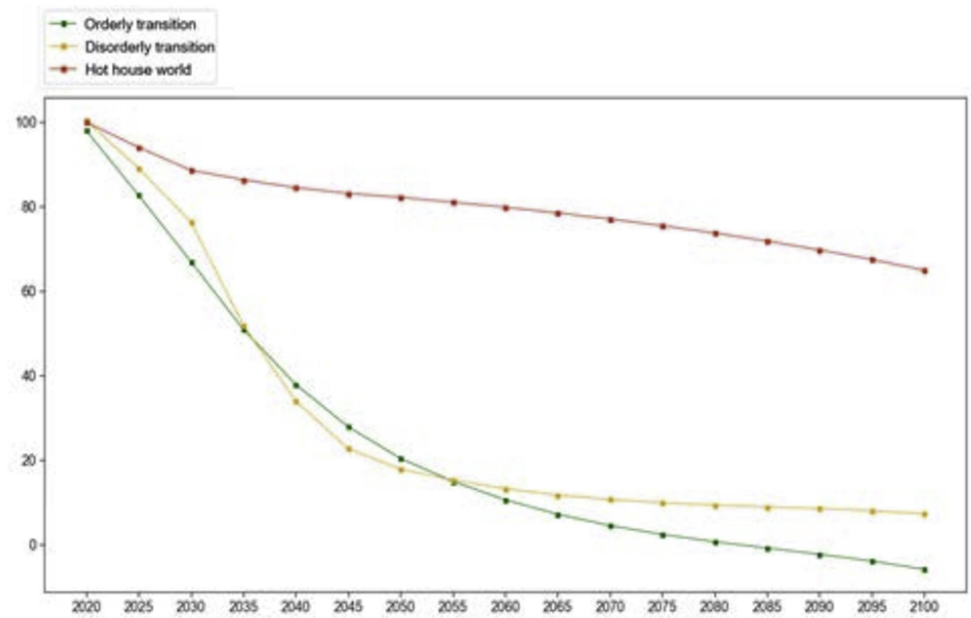
Figure four: GDP impact relative to the reference scenario



Greenhouse gas emissions

Figure five shows emission levels by scenario out to 2100. It shows that the paths of the orderly and disorderly scenarios are not markedly different out to 2050. It is not explained why there is a more significant divergence over 2050-2100.

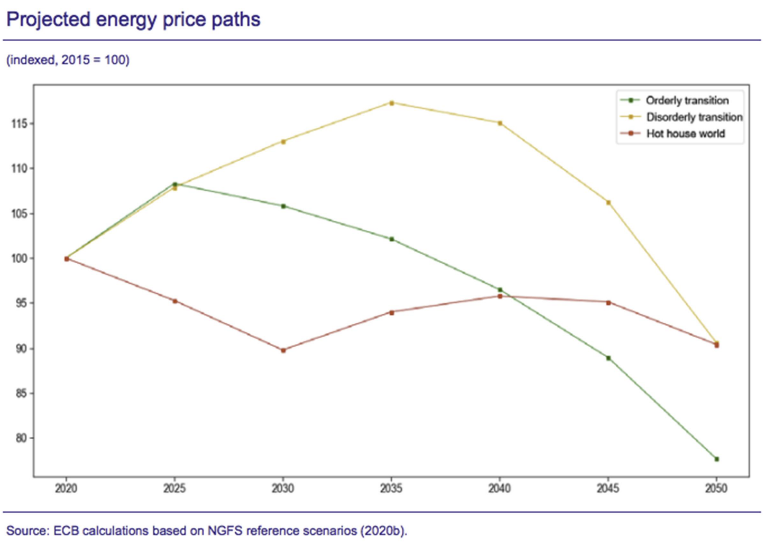
Figure five: Emissions by scenarios



Energy prices

It is assumed that in the orderly transition scenario research into green energy will be effective, economic, and widely deployed. Energy prices will initially increase by about 7 percent and then fall to 20 percent below current prices by 2050. Under a 'disorderly' transition the initial increase is much larger and the later fall is less pronounced. None of the drivers of these changes are explained, in particular the early divergence between the disorderly and hothouse world scenario energy prices in the disorderly scenarios and hothouse world scenarios. If the disorderly scenario delays policy changes to 2030 then the scenarios should be the same up to that point**.**

Figure six: Energy price paths by scenario



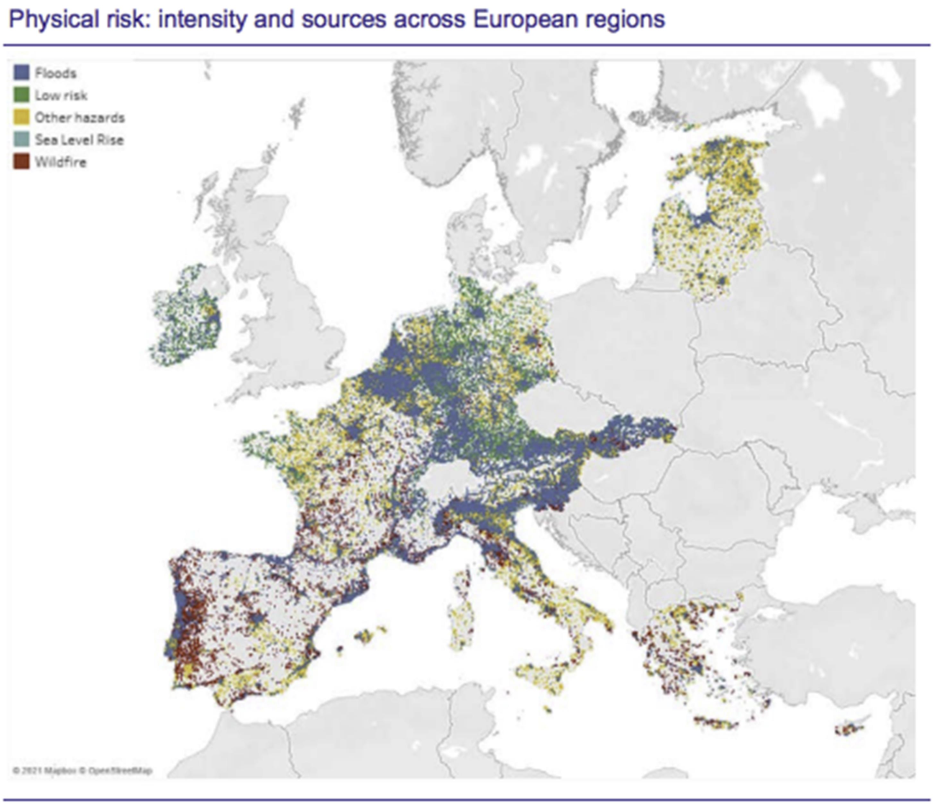
Climate hazards map

Firms 'at risk' are shown in figure seven which is a reproduction of the figure in the introduction. Each dot represents a firm that is subject to high physical risk, which is defined as follows**:**

Firms are subject to high physical risk if their probability of suffering from a wildfire or a river or coastal flood in a given year is over 1%. (Alogoskoufis, Dunz, et al., 2021, Page 32)

'Suffering' is not defined. But it is critical to the exercise. If 'suffering' can include a one percent chance that a firm will suffer a mere annoyance that might cost a few thousand dollars, then the net would be very wide. But if the definition of suffering was a substantial, business threatening damage to physical assets and operations, then most of the dots could well disappear. From the information presented in the ECB's paper we simply don't know what the dots represent. Without a clear definition of the damage threshold the exercise is meaningless.

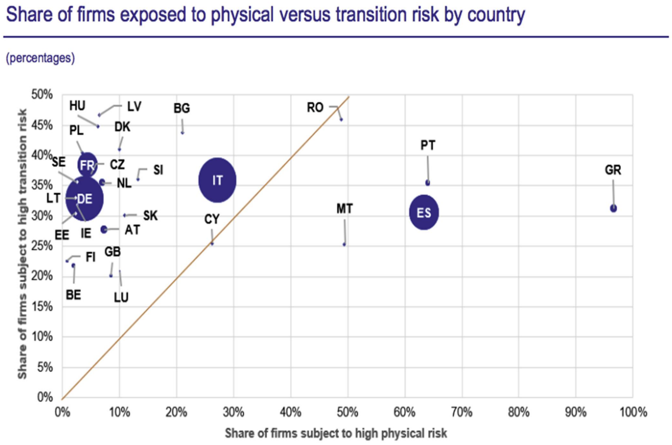
Figure one: (re-presented)



Firms exposed to risk by country

Figure seven shows the proportion of firms exposed to both physical and transition risk by country. The most extreme physical risks are to Greece (about 96 percent of firms), Spain and Portugal (about 65 percent). About 22 percent of exposures is to physical risks, half of which are to wildfire risk. On the transitional risks side there is no explanation of the divergences by country. What drives, for example the difference between Hungary with 45 percent of firms 'at risk' and Belgium with 22 percent at risk is not clear.

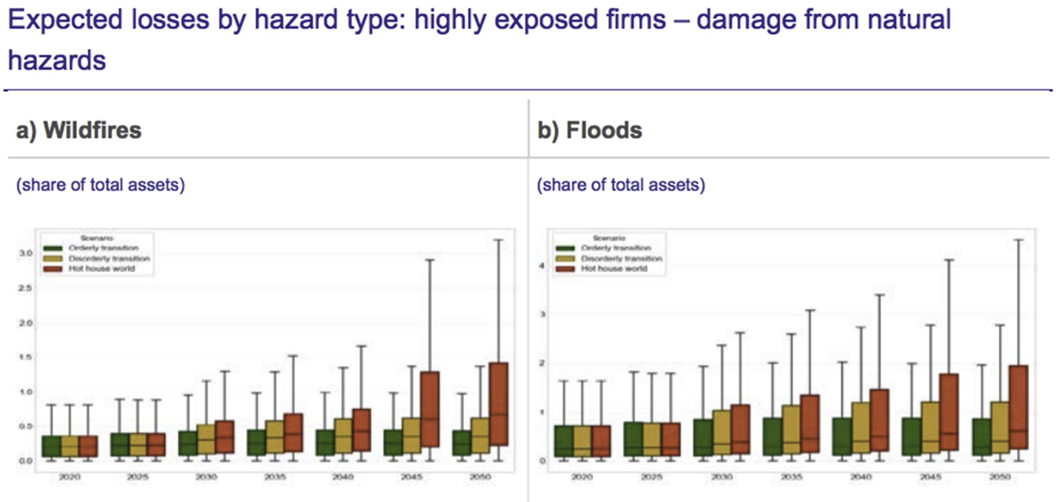
Figure seven: Proportion of firms at risk

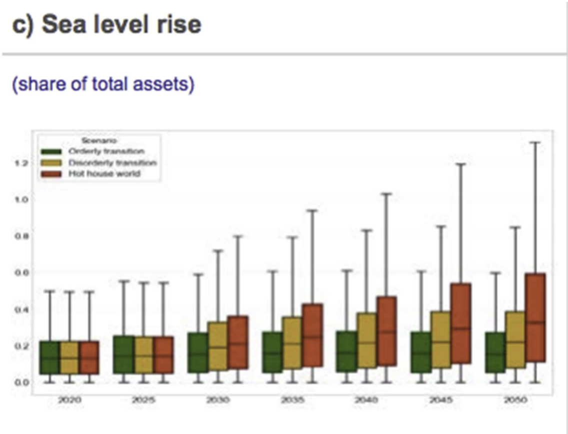


Expected losses by hazard type

Figure eight shows expected loses by hazard type, but only for 'highly exposed' firms. Highly exposed appears to be defined as the most exposed 10 percent of firms. No information is given for the full sample of firms, which is most relevant for an assessment of systemic risk. The loss rates were difficult to read in the original, but wildfire losses increase by 0.4 to 1.4 percent of assets in the 'hothouse world' by 2050. Flood damage increases from about 0.7 to 2 percent. Sea level rise costs increase from 0.2 percent to 0.6 percent. The total cost is 4 percent in 2050**.**

Figure eight: Expected losses by hazard type for highly exposed firms



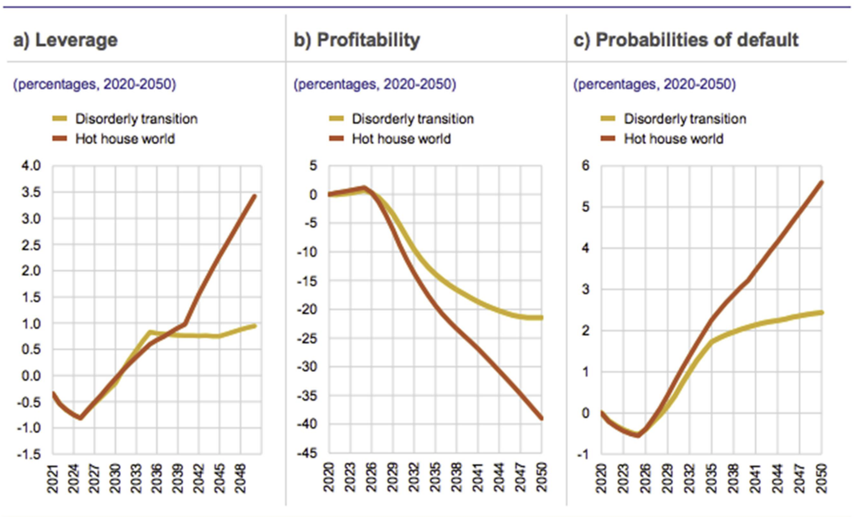


Impacts on median firm risk

Figure nine show the impact on leverage, profitability, and the probability of default for the median European firm. The outcomes are expressed in terms of the percentage differences from the orderly transition base case, which makes them difficult to interpret. As the absolute levels of the variables are not disclosed it is difficult to get a sense of the significance of the differences from the orderly scenarios.

In terms of the risk to banks' portfolios the most important outcome is the probability of default. But here the percentage differences are tiny at 2.5 and 5.5 percent respectively for the disorderly and hothouse world scenarios. These are tiny differences which are inconsequential from a financial risk perspective.

Figure nine: Impacts on firms leverage, profitability and PD



Source: ECB calculations based on NGFS scenarios (2020b), Orbis, iBACH, Urgentem and Four Twenty Seven data (2018).
Note: All charts display median percentage changes under the disorderly transition and hot house world scenarios relative to baseline (orderly transition).

The most pronounced impact is on firm profitability, particularly in the greenhouse world where profits fall by 40 percent compared to the base case. It is driven by increasing physical losses due to weather events and importantly an assumption on the shifting of carbon taxes to consumers. It is assumed that for the lowest emitting firms all of the carbon tax is shifted. The shifting of the tax falls as the emission intensity of the firms increases until the top ten percent of firm bear 100 percent of the tax (up to a limit of 5 percentage points). There is no justification for this assumption, which is a divergence from the conventional starting assumption that carbon taxes will be borne by consumers. A 5 percent turnover tax can have a substantial impact on the profitability of businesses that operate on relatively fine margins.

Similarly with physical damage costs. Expected climate damage costs are economically equivalent to depreciation and we would expect firms would generally be able to shift those costs to consumers over time.

Impact on 10 percent of firms most highly exposed to physical risk

The ECB puts considerable store on the impact on the most highly exposed firms. They had to do so to push their systemic risk narrative because their modelling shows that business risk does not increase materially across the board.

Figure ten repeats figure nine for the 10 percent of the most highly exposed businesses. It shows that these firms become unprofitable in the hot house world scenario with a 160 percent fall in profitability. However, this does not impact materially on default rates, which increases by only 25 percent to about 250 basis points. Nor does leverage increase much. A 3.5 percent increase in leverage increases a 50 percent ratio to 51.75 percent. None of this makes sense. Unprofitable businesses will fail, not become marginally riskier.

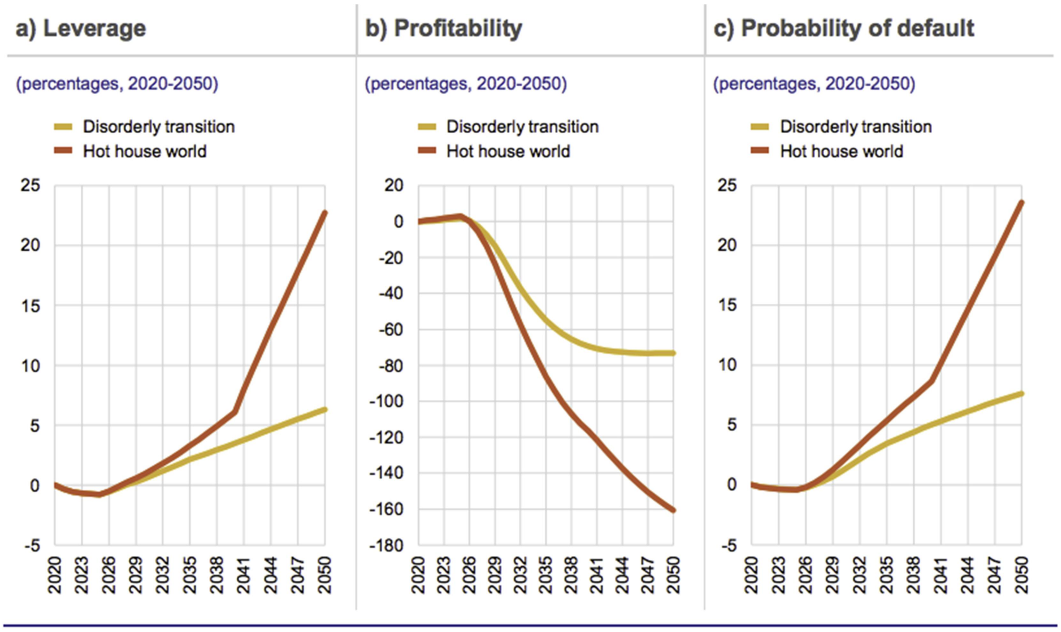
But it is from these results that the ECB concludes that their modelling shows climate change:

may pose serious financial stability concerns[5]

when it is really pointing to serious issues with their modelling and data.

[5] See page 49.

Figure ten: Key indicators for 10 per cent of firms most exposed to physical risk



Source: ECB calculations based on NGFS scenarios (2020), Orbis, iBACH, Urgentem and Four Twenty Seven data (2018).
Notes: In defining the high-physical-risk firms, we took the 10% of the firms with the highest expected damage over the course of the entire period. Here, we show the median of that sample.

Banks' portfolio PDs

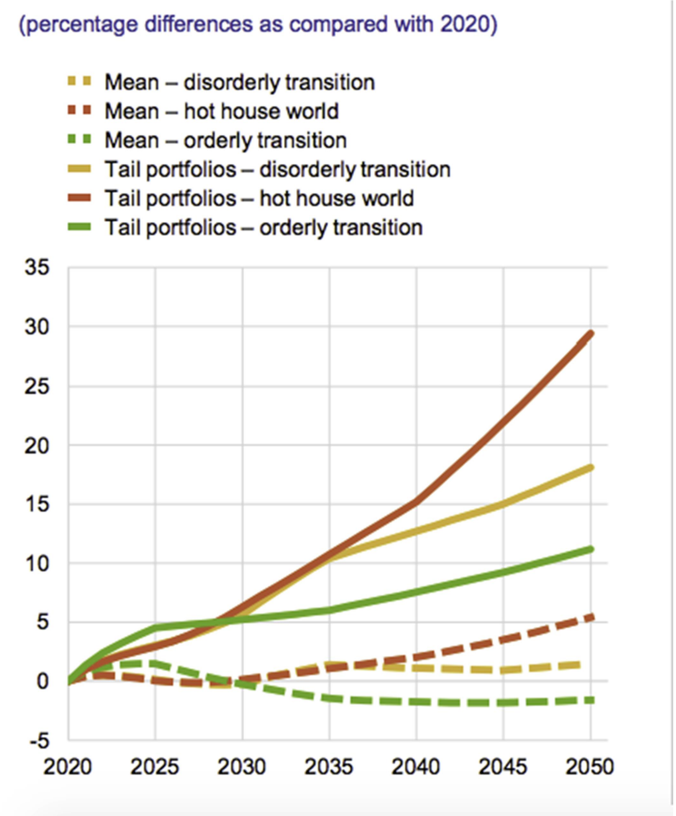
Figure eleven shows the impact on banks' portfolio PDs, on average (dotted lines) and for the ten percent of banks most impacted (solid lines).

But as noted above, these results will be driven by the assumptions on the shifting of physical losses and caron taxes and on assumed climate impacts that appear to be obviously wrong or not supported by evidence. More plausible assumptions would probably see most of the impacts disappear.

But even if there was some impact this does not necessarily mean that there will be an impact on bank profitability and risk. The higher expected losses would translate into higher interest rates and provisions with no impact on banks' profits. There is ample evidence that banks do take weather risk into account and given the high profile of climate change physical risk it is inconceivable that banks would not take actions to preserve their positions.

Banks do not fail because expected losses are realised. They fail because unexpected loses overwhelm their capital defences. As this is an expected loss model, with no unexpected losses, it has almost nothing to say about systemic risk.

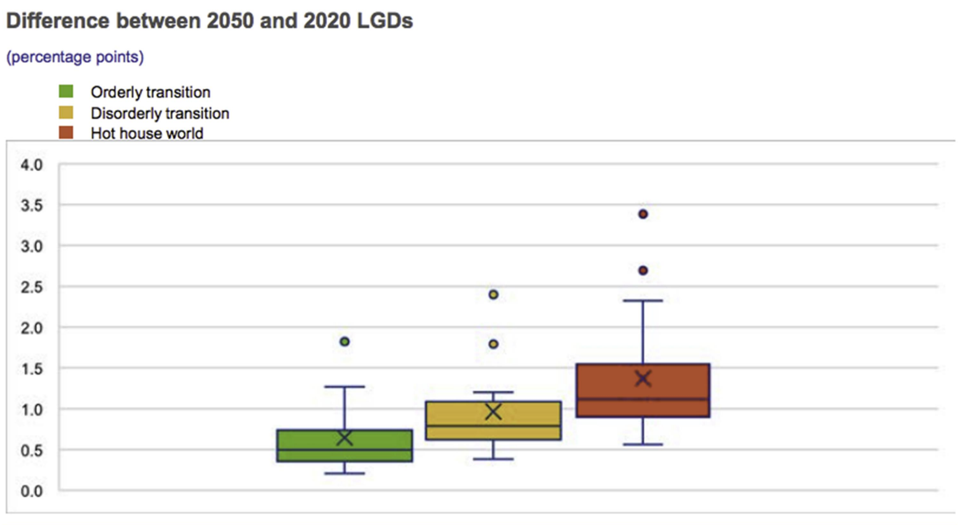
Figure eleven: Banks' portfolio default rates



Impact on banks; portfolio LGDs

The impact on portfolio LGDs is shown in figure twelve. They are tiny. We are not told what the 2050 average orderly scenario LGD is, but assuming a 50 percent rate the median would become just over 51 percent in the worst-case scenario.

Figure twelve: Impact on LGDs



Source: ECB calculations based on NGFS scenarios (2020), AnaCredit, Orbis, Urgentem and Four Twenty Seven data (2018).
Notes: Portfolio LGDs are the average of loan-level LGDs weighted by their exposure amount.

Part three: More issues with the modelling

Static balance sheet assumption

It is assumed that the composition of banks' exposures remains constant over the 30-year modelling horizon (a static balance sheet assumption). As the whole point of mitigation policy is to shift assets to less exposed sectors this assumption is unrealistic and will bias default rates upwards.

Scenario choices are unrealistic

While this is not stated clearly, the implied orderly scenario is that all countries, not just Europe, pursue the net zero 2050 target. If Europe were to reach net zero by 2050 by itself then the longer terms benefits from lower climate damage would not emerge. Europe's current emissions are a small fraction of world emissions.

The required path to net zero for developing countries is not consistent with the Paris Agreement and there is almost no chance of it happening. As countries will proceed along different papers this will inevitably be a disorderly process.

Second, all the policy elements of the orderly process are not transparent, but it seems that a completely optimal and very optimistic process is assumed. This accounts for low cost of the orderly transition.

- The increase in carbon tax revenues is given back to taxpayers through lower income tax rates. This has a positive impact on growth in the ECB model. It appears that this revenue recycling does not occur in the disorderly scenario, slowing growth. But rebalancing the tax system is always open to governments regardless of climate policy, so this benefit should not really be ascribed to an accelerated climate mitigation policy.
- The assumption of a global model takes many stresses out of the transition that could increase risk premia, which are assumed to be lower in the orderly scenario. Uncertainties around policy are assumed to generate risk premia in the 'disorderly' scenario, widening the gap between the scenarios.
- Premature and unbalanced pursuit of some policies are not assessed in this perfectly optimal model. Any adjustment problems are just assumed away. For example, the coal industry fails by 2025 but seamlessly continues to operate.
- Technological innovation policies are perfectly targeted and are successful. Hence energy prices fall earlier and more steeply in the orderly world. In the 'hothouse world' innovation slows down to nothing even though there may be privately profitable opportunities.

Climate change damage functions

The critical elements in the ECB model are the damage functions that link the evolution of weather events to company asset losses and hence to the risk of banks' portfolios in the 2020-50 scenarios. Put bluntly there is nothing that passes for credible asset damage functions in the ECB modelling.

Three climate damage classes were covered.

- Wildfires
- Sea level rise
- Flooding

Of these, sea level rise is relatively localised, and the effects are minor, so the model results are driven by flooding in the north and wildfires in the south.

This is what we are told about this modelling:

FourTwentySeven data was used to calculate forward-looking physical-risk scores for firms, also distinguishing between different types of extreme weather events (physical hazards) Risk scores capture the frequency and severity of future extreme weather events and are derived at address level. (Alogoskoufis, Dunz, et al., 2021, Page 24)

FourTwentySeven describes the exposure of firms to physical hazards at five different levels: "highly exposed to historical and/or projected risks" ("high present/projected exposure"), "exposed today and exposure level is increasing" ("increasing exposure"), "exposed to some historical and/or projected risks" ("some present/projected exposure"), "not significantly exposed to historical or projected risks", and "no exposure" (Alogoskoufis, Carbone, et al., 2021)

These assessments are made:

using satellite data as well as information on weather patterns (Alogoskoufis, Dunz, et al., 2021, Page 77)

This explains, as we demonstrated in the case of the Netherlands, why FourTwentySeven is not a robust information source: Satellites do not provide information on the level of flood protection. Nor, probably, do they provide reliable information on the wildfire mitigation measures that can substantially reduce risk from this source.

FourTwentySeven was a small private consultancy now affiliated with Moodys ESG. The only public information on their modelling is little more than a marketing exercise that does not explain how their model works.

The formal modelling

The main impact of climate change on firms is represented in the following equation:

$$L_{t,c} = \frac{Damages_{t,c}}{GDP_{t,c}}$$

$$Intensity = (L_{t,c} * \left(1 + \left(\frac{Score^{i}_{2050} - Score^{mean(j,a)}_{2050}}{Score^{mean(j,a)}_{2050}}\right)\right) * Phys.capital^{i}_{t}$$

$$Expected\ relative\ damage\ size\ (E) = E[frequency_j] * \ (L_{t,c} * (1 + (\frac{Score^{i}_{2050} - Score^{mean(j,a)}_{2050}}{Score^{mean(j,a)}_{2050}})) * Phys.capital^{i}_{t})$$

The critical term is $L_{t,c}$ = Damages $_{t,c}$/GDP $_{t,c}$. The term with score variables are relative risks for each firm generated from the FourTwentySeven data. The role of this term is to allocate the total risk to firms. However *Damages* $_{t,c}$*/ GDP* $_{t,c}$ is just a ratio of damage to income, which does not directly tell us anything about the relevant ratio, which is damages to assets.

All we are told about the damage ratio is the following:

Leveraging on the estimation of physical damages from the NGFS scenario we calibrate a damage function that predicts the total damage from physical risk at country level (Alogoskoufis, Dunz, et al., 2021, Page 80).

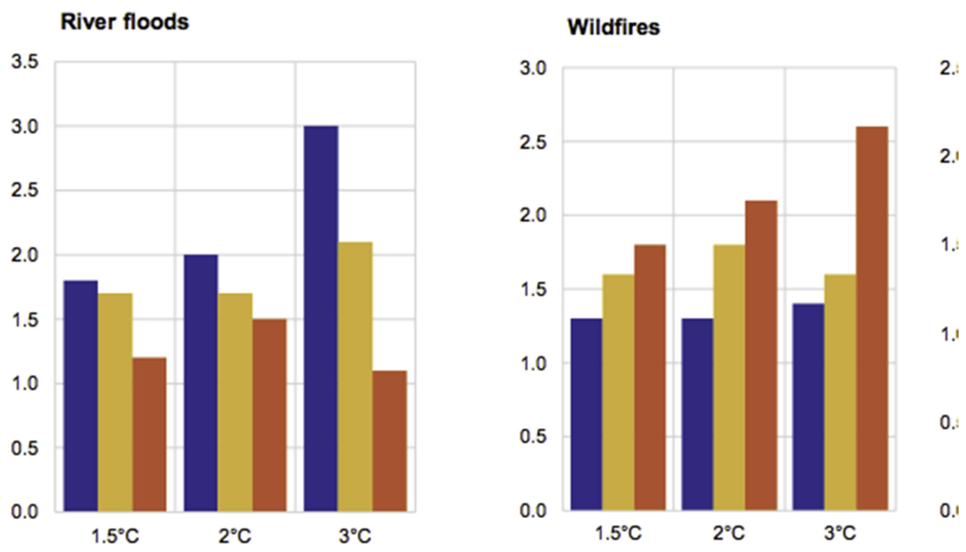
This tells us that there is just one damage function when there are three classes of climate damage. Each should have its own damage function. What appears to be going on is that the damage ratio is the GDP/temperature impact described in the NGFS stress testing documents. This assumes a strong sensitivity of GDP to temperature (a 13 percent impact globally by 2100), so even over the 2020 -50 period there would be a significant cost impact for Europe.

What the ECB knew about climate damages

The ECB did not come to the stress test cold. They had some information about the impact of climate events on physical assets that they could have used in their modelling. They had contributed to the recent ECB-ESRB cross agency report 'Climate-related risk and financial stability' (ECB-ESRB, 2021).

This report presented the following information on the proportion of the population exposed to flooding and wildfire physical risks, see figure below, the orange bar is Europe. What is apparent here is that the proportion of the population (and presumably the proportion of businesses) exposed to these risks is quite low. Further it does not support the narrative that these risks are increasing markedly. Flooding risk actually decreases overall (which does not preclude increases in particular areas) and wildfire risk increases by less than 50 percent.

Figure fourteen: Exposure to flooding and wildfire risk



The ECB-ESRB also did a 'Deep dive' into flood risk in Europe that provided the following relevant information:

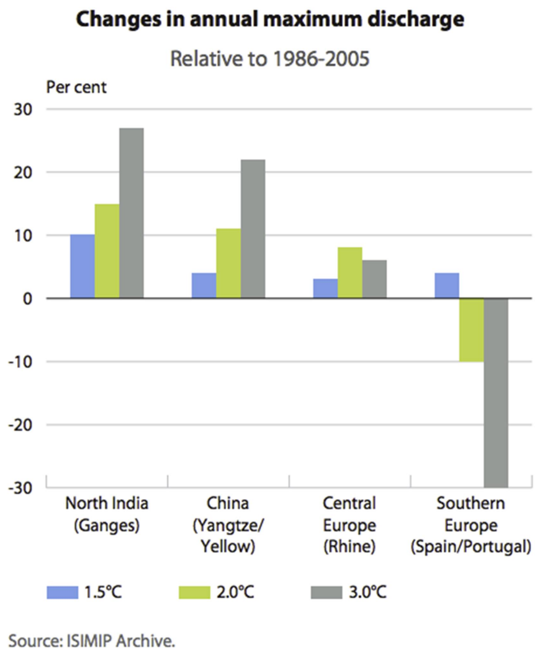
At present, riverine floods cause €7.8 billion worth of damages in the EU and UK (around 0.06% of current GDP) and affect more than 170,000 people annually (JRC (2020b)) (ECB-ESRB, 2021, Page 13)

These were total losses. Business losses were probably a moderate fraction of this. The relevant metric for the stress testing exercise is the ratio to business assets (they have the numbers on asset levels) but this ratio was not mentioned let alone investigated.

Another cited source was a Risk Management Solutions white paper 'Modelling Future European Flood Risk 2021' (RMS, 2021). Relative to the base period 1981–2010 RCP 4.5 emissions scenario losses are estimated to increase by 50 percent from the baseline (centred on 1995) by 2050. The increase in losses would be less from 2021. In North-western Europe the increase in expected losses is 52 per cent and in the south east it is 40 percent. The increases in large event losses (200-year return period) were 51 and 31 percent respectively.

The ECB also had access to the analysis in the 'NGFS Climate Scenarios for central banks and supervisors June 2021' (NGFS, 2021). Figure fifteen presents the estimates for the annual maximum discharge, a measure of river flood risk, for 2100. It shows that the increased risk for Central Europe is quite low. Flooding risk declines sharply in southern Europe.

Figure fifteen: Flood risk indicator 2100



Overall, the evidence on flooding risk is reasonably clear. Only a moderate increase in flood losses can be expected by 2050.

Wildfire Risk

On the magnitude of wildfire risk there is nothing other than the figure presented above that suggested a limited risk exposure.

Risk metric calculations

Leverage

On leverage the ECB occasional paper tells us:

leverage increases gradually as physical damage accumulates, thus adding pressure to firms' debt levels. This effect is more pronounced under the hot house world scenario and becomes significant in the second half of the projection horizon. (Alogoskoufis, Dunz, et al., 2021, Page 43)

A more plausible assumption is that banks would seek to maintain a constant leverage ratio. While there may be some forebearance in the short run, we would expect banks not to treat past weather event losses as a permanent excuse to reduce credit quality.

Profitability

The modelling is quite complex, so it is difficult to understand from the description in the paper what drives the profitability metric. However, it seems clear that the assumptions on how carbon taxes are shifted are a significant driver of profit impacts. As noted above there was no analysis or discussion to support these assumptions.

Firms have to borrow to replace assets and to switch to greener technologies. But the cost of this borrowing is ignored. The profitability metric is operating profit that does not take account of interest expenses. This will bias the profitability results to the orderly scenario.

The replacement costs of green assets are also assumed to differ according to whether the transition is orderly or disorderly, but we are not told how and how this affects the results.

There is also a risk that firm accounting data does not accurately represent the economic position of the firm and this might generate perverse results in some cases.

Default probabilities

The key output for the assessment of systemic risk are the default probabilities that are estimated by the following equation.

$$PD_s^{i,t} = \alpha + \beta_1 leverage_s^{i,t} + \beta_2 \text{Profitability}_s^{i,t} + \beta_3 log(GDP_s^t) + \beta_4 log(GDP_s^t)^2 + \beta_5 age^{i,t} + \epsilon_s^{i,t}$$

It has poor explanatory power with a R^2 of 0.118, which means that there is a lot of noise in the ECB's estimates. The assumption that physical climate damage will generate higher leverage over time will generate an upward trend in the the PD metric.

Loss given default

The technical appendix has just this to say about the LGD:

Loss given default Loss given defaults (LGDs) are not reported in AnaCredit. Hence, loan-level LGDs are approximated by looking at the collateral value relative to the notional value of the loan. This is predicated on the assumption that in the event of a default a bank can only recover the collateral assigned to the loan and that it will be paid the full collateral value. (Alogoskoufis, Dunz, et al., 2021, Page 78)

This assumption will exaggerate bank wide LGDs because it presumes that the recovery rate on unsecured loans will be zero. This is wrong. Unsecured loans are often a bank's best credits (which is why the lending is unsecured) and there is an expectation that there will be some recovery on default. This assumption scales banks loses possibly by a factor of two (assuming an unsecured LGD of 50 percent and 50 percent of loans are unsecured).

Part four: Modelling the relationship between GDP and temperature

At heart the ECB model and conclusions are driven by a model of the relationship between GDP and temperature change. This is based on a single model by Kalkuhl & Wenz (2020) that the NGFS has adopted as their preferred GDP/temperature explanation. This modelling was described as 'state of the art' in the NGFS technical paper[6] although the basic flaw in the analysis was identified.

The empirical analysis finds strong evidence for immediate productivity effects, but not significant evidence for permanent long-run growth reductions.

Obviously, the long run results, which suggest no relationship, was the relevant result for long run scenario analysis. But the NGFS ignored this problem. Kalkuhl and Wenz delivered a big bottom-line number (a thirteen percent impact on world GDP by 2100) and that was all that mattered.

The following is our review of the Kalkuhl and Wenz paper.

Review of Kalkuhl & Wenz, 2020

The Kalkunl paper uses a data set of subnational economic output, Gross Regional Product (GRP), for more than 1,500 regions in 77 countries to empirically estimate historical climate impacts at different time scales. Three estimates are produced using: annual panel models; long-difference regressions; and cross-sectional regressions.

There are two major technical issues with the paper.

- Income is measured in terms of nominal US dollars converted at the current exchange rate. This would account for part of the extremely high income volatility. The average nominal annual growth is 7 percent, but the standard deviation of this rate is 15 percent. Converting to US dollars introduces a large amount of variability into measured non-US income. As the variable of interest is the impact on climate on real variables, it would have been better to use a real income measure for each country.
- The regional data are not weighted by aggregate income. This can, and almost certainly has, generated results that are biased to small and poor regions' temperature/output relationships. To illustrate, consider a country that has 10 regions. Nine are rural and poor and are heavily impacted by increased temperatures. Assume the data shows a 20 percent impact over the estimation period for these regions. Together these regions account for 10 percent of national income. The other region is modern and rich, with a large population and an economy based on IT. Because work is done in airconditioned offices temperature increases have no impact on output. On a national basis the temperature increase has reduced output by 2 percent. But if the regional impacts are aggregated on an unweighted basis national income falls by 18 percent, which is clearly wrong. But this is how the Kalkuhl

[6] Bertram et al., 2021.

model works, though in a less pronounced manner. High income regions account for only about 18 percent of the number of regions, but more than 60 percent of world income.

The annual panel model

This model generated the largest relationship between temperature and per capita output and was used by the NGFS to generate the 13 percent GDP impact by 2100. However, all this analysis is showing is that in poor countries with large agricultural sectors, temperature changes contribute to the year-to-year volatility of output. This this does not necessarily mean that there is the same relationship between slow and anticipated temperature change and trend GDP particularly in advanced countries.

It is widely understood that over the longer time horizons relevant to an analysis of climate change impacts, adaptation will reduce temperature impacts. For example, air conditioning will become more common and more heat resistant crops will be introduced.

The relationship was not tested for high- and low-income countries. Other studies have found a short-term relationship between weather and output for poor countries with large agricultural sectors, but not for high income countries.

The long difference model

This model tested the temperature/output relationship over longer time horizons. Earlier 10-year periods were compared with 2005-2014. They found no relationship between temperature and output. This was put down to adaptation and the fact that the temperature changes might have been 'too small' to uncover an impact.

This was the key result from a climate change impact perspective, but it was simply ignored in the damage curve modelling that the NGFS used for its GDP impact assessments. The contribution from this paper was that temperature increases do not have a sustained effect on output. But this is not what was reported.

Cross sectional regression model

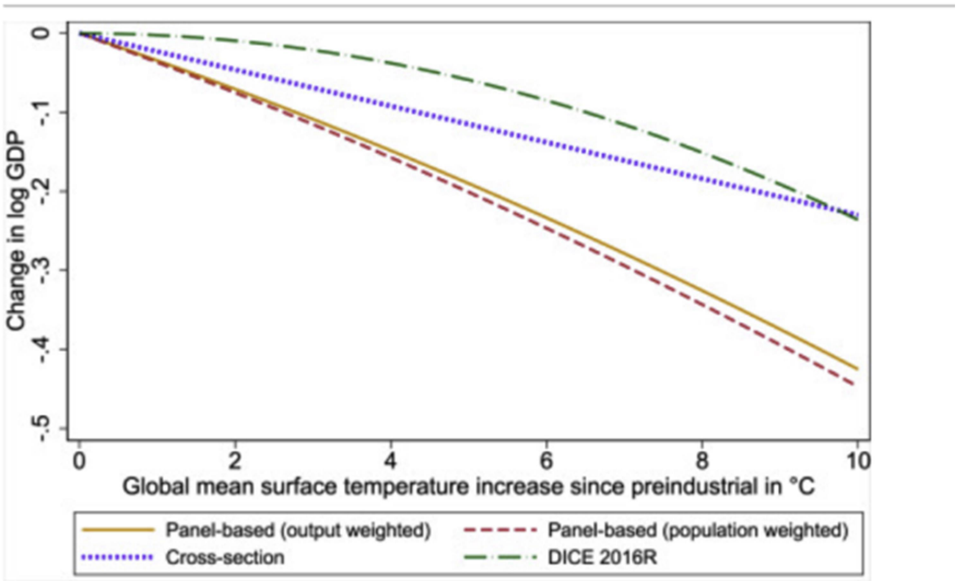
Regional income was modelled as a function of temperature, cumulative oil extraction, distance to coast, distance to rivers, altitude, over 10-year intervals from 1955 to 2014. It was found that temperature was significant in explaining income differences. A one-degree temperature increase was associated with income reduction of 2 – 4 percent. The positive current relationship is not a surprise. Poor countries are currently disproportionately hot. But correlation does not prove causation.

Simple climate driven explanations of income levels have a long pedigree. For example, Montesquieu argued in 'The Spirit of Laws' (1748) that an "excess of heat" made men "slothful and dispirited." But now most economists are sceptical of simple climate driven models of economic performance and look at a complex combination of history, institutions, culture, unequal allocations of natural resources and so on, to explain differences in income levels between countries.

Obviously, climate does have an impact on economic performance in some circumstances. But it is quite another thing to argue as Kalkuhl and Wenz and the NGFS do, that rich countries will be strongly affected by slow and anticipated temperature increases.

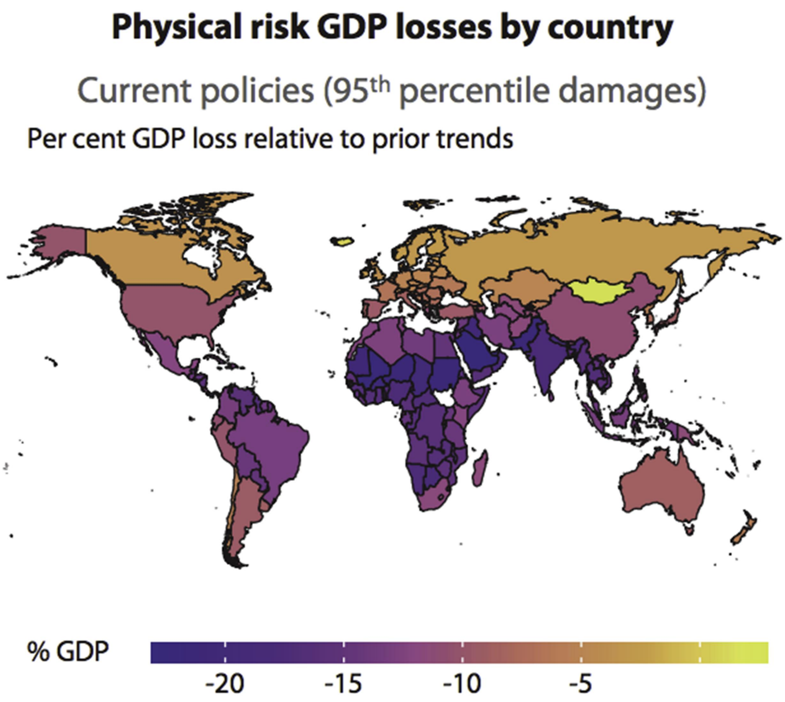
The temperature damage curve Figure eight shows the temperature damage curves derived from the panel based and cross-sectional models. The DICE model curve which is also represented is based on more robust bottom-up modelling and analysis by Nordhaus and others.

Figure sixteen: Temperature Damage curve



The NGFS presents GDP impacts on a country basis based on the Kakuhl modelling. We believe that these were used in the ECB modelling. Note that the numbers are based on the 95th percentile, which provides a boost to the estimates. This sets up a perverse outcome. The weaker the estimate the wider the confidence bounds and the more ‘compelling’ the estimate.

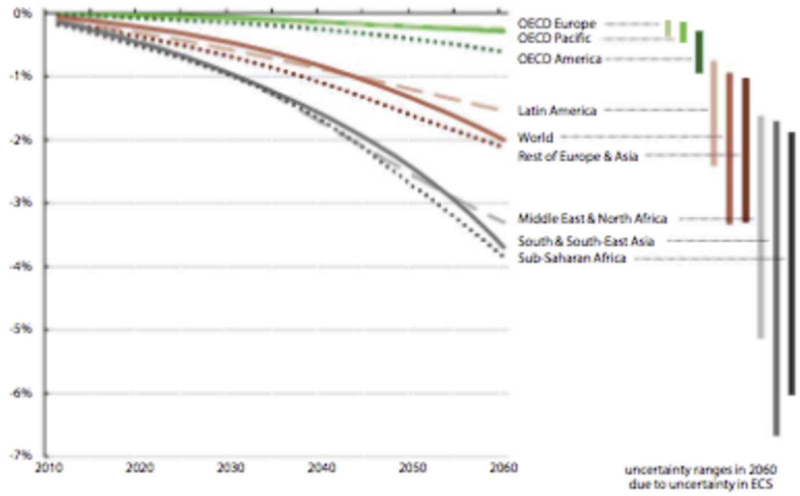
Figure seventeen: Impact on GDP by country 2100



The OECD analysis

If the ECB insists on using the climate impact on GDP to proxy the impact on assets values, then an obvious option would have been the OECD's 2015 paper (OECD, 2015). The impact for European OECD countries for 2050 was a GDP reduction of 0.2 percent. It is not possible to assess the ECB model assessment of the 2050 because the damage function is not disclosed but it is almost certainly a large multiple of 0.2 percent.

Figure eighteen: OECD climate change impact on GDP



Source: ENV-Linkages model.

Part five: Discussion

The ECB paper makes two main points. The first is that the costs of the transition to a zero-carbon economy are relatively small and are soon outweighed by much larger benefits from abated costs of global warming.

The second is that if the rapid transition does not occur there could be significant impacts on the European financial system under both the disorderly and hothouse scenarios.

On the first point the ECB does not really make a new contribution. They have simply picked up on the flawed Kalkuhl and Wenz modelling results used by the NGFS to push its systemic risk narrative.

On the second point then they might well be right on the relative costs of transition. But this would require amongst other things that: the whole world could be persuaded to pursue the ECB's zero carbon plan tomorrow; lower cost green energy solutions are just waiting to be discovered; all governments would pursue optimal climate policies; and the cost of borrowing to fund the transition was zero.

But this is more magical realism than serious analysis.

Even if we were to accept the ECB's PD results as robust, they do not point to a systemic risk problem. The average bank portfolio default rate increases by 5 percent in the 'hothouse world' and by 2 percent in the disorderly scenario. These changes are inconsequential.

The ECB appears then to rescue their argument by focussing just on the top ten percent of banks. Here the PD increases are 15 and 29 percent. But these figures do not necessarily present a problem for that 10 percent of banks. They can simply increase their interest rates and add to their provisions to cover the higher expected cost. The probability that the bank would fail would not change.

However, the ECB's results are not robust and almost certainly overstate the expected physical costs of climate change by a wide margin.

- A loss assessment should depend on damage functions that link the climate changes (floods and wildfires) to asset losses. These functions simply don't exist in the ECB modelling. Instead, they have made some sort of linkage between an (overstated) NGFS estimate of the relationship between GDP and temperature change and asset damage. This key linkage is not disclosed. However, there is no necessary close relationship between temperature impacts on GDP and the damage to structures. Greece might well be affected because higher temperatures lowers labour productivity (impacting more on the returns to labour than businesses) , but this does not mean that structures are necessarily damaged by wildfires.

- Wildfires are identified as a key risk for Southern Europe but there is no evidence on the costs they will generate in the ECB paper and associated documents. It is likely that many of the 10 percent of the ECBs most 'risky' banks are subject to wildfire risk that is grossly exaggerated.

- The ECB relies heavily on proprietary information on the evolution of physical risk from a private consultancy FourTwentySeven. We are told little about their methodology and its robustness, but as we demonstrated in the case of the Netherlands it is suspect.

- The modelling of the impact of carbon taxes on profitability is driven by the assumption that high emitting firms do not shift at least part of that tax to other firms and consumers. This assumption generates exaggerated negative profitability impacts for some firms.

- Similarly, It is assumed that firms do not at least partially shift expected costs from higher insurance premiums and physical damage to other parties

- Interest costs do not impact on profitability. Firms can invest in low emission assets or replace existing damaged assets without consequences for their profitability.

- The equation that generates the key risk metric, the probability of default, has very little explanatory power with an R^2 of 0.119.

In short, the paper is something of a mess and a muddle. It leaves the strong impression that the conclusion that climate change presents a systemic risk was predetermined, and that the role of the modelling was to somehow generate the supporting evidence. When that was not forthcoming the ECB pressed on regardless, biasing the results in some subtle and not so subtle ways, to produce something that could be represented as supporting their systemic risk narrative.

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