FINRES

CVM - Economic analyses

Macroeconomic consequences of climate change: GDP growth, inflation and interest rate

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1. Executive summary bullets

- At all levels of warming analysed, climate change will have detrimental macroeconomic consequences. Overall, the picture depicted in this analysis is dire with lower-than-expected incomes across all nations, higher inflation that together will translate in worsened living conditions. Combined with increased interest rates, governments and households will have a limited ability to invest in sustainable development, mitigation, and adaptation at the required scale:
    - Decreased GDP per capita growth will lead to lower income levels across all countries, with some countries facing up to 30% decrease in their growth potential (e.g., Central Asian economies), particularly in a scenario without climate action.
    - With more frequent precipitation extremes affecting countries, prices are projected to increase. Across all nations, the study finds inflationary trends from limited levels below one percentage point (median) in Americas at 1.5°C of warming to 2.4 points in Asia and Africa in a scenario without further climate action. These figures are continental mean estimates for the periods, country-level annual fluctuations can be far higher.
    - As a response to more variable GDP per capita growth and increasing inflation, interest rates are projected to increase across all regions. Measured in basis points, the study finds that median interest rates could climb above 65 points in Asia and Europe. Such increases in the cost of borrowing across all nations will limit their ability to invest in mitigation and adaptation, accelerating the downward spiral of under-investment in mitigation and adaptation aggravating the levels of consequences observed on incomes and inflation.

- Keeping global mean temperature increase below 1.5°C will have undisputable macroeconomic benefits:
    - On average, across all continents, the additional 0.5°C of warming induced by reaching 2.0°C would lead to more than a doubling in the negative consequences of climate change on incomes compared to those observed at 1.5°C.
    - A similar pattern is observed for inflation, though at a lower scale, with higher inflation up to 66% in a 2.0°C world compared to inflation measured at 1.5°C.
    - Interest rates also respond following a similar trajectory with increases in basis points, between 1.5°C and 2.0°C, up to 50% for European countries.
- Limiting global mean temperature increase below 1.5°C in line with the objective of the Paris Agreement appears as the only viable global economic objective as even though it will lead to higher investments in mitigation, it will also reduce the needs for adaptation and loss and damage while dramatically reducing the negative impacts on income, inflation, and interest rates – making it a more viable macroeconomic trajectory than warming levels close and beyond 2.0°C.

- Hitherto, most of the studies investigating the consequences of climate change on economic development found that developed nations would be among the least affected with even some of them benefiting from increasing temperatures induced by climate change.

- The new methodological approach implemented in this analysis does not find that countries with currently low mean annual temperature will experience an increase in GDP per capita or more favourable price conditions thanks to climate change. Indeed, for Canada, Russia, Scandinavian countries or Mongolia, the projections show significant reductions in GDP per capita.
- More temperate countries in Europe or the USA are also projected to face decreasing GDP per capita growth, at a higher level than projected earlier in econometric studies.
- These estimates are a clear call for action for high-income nations towards faster and more stringent mitigation actions as their economies are also projected to face negative consequences even at low levels of warming.

2. Introduction

Droughts, floods, heat waves or tropical cyclones can have detrimental consequences on economic development.

Countries have experienced steep increase in inflation as a response to droughts, tropical cyclones – especially in small island nations – as they have have the potential to wipe out infrastructure and disrupt economic activities. With climate change further modifying temperature and precipitation patterns, macroeconomic indicators are projected to be increasingly affected with GDP per capita projected to reach lower levels than expected while on the opposite side inflation and interest rates could reach higher degrees.

In this section, the research focuses on estimating the past and future relationships between climate change, especially temperature and precipitation, and macroeconomic indicators – namely GDP per capita growth, inflation, and interest rates. While there exists a growing body of scientific literature on GDP per capita and inflation, very few publications have addressed the question of interest rates, even less so for all countries globally.

The method for this analysis allows for a first-of-its-kind appraisal at the national level for all countries thanks to the use of advanced statistical technics.

3. Indicators

To investigate the macroeconomic consequences of climate change at different levels of warming, three indicators are analysed: GDP per capita growth, inflation, and interest rates. The effects of climate variability and change on GDP per capita growth and inflation are estimated using temperature and precipitation, following an econometric approach developed by Baarsch et al. (2020). The potential effects of climate change on interest rates are simulated using the deviations in GDP per capita growth and inflation induced by climate change as inputs to the Taylor rule (John B Taylor 1993), a rule applied by Central Banks in low- to high-income countries to determine interest rates.

3.1. GDP per capita growth & inflation

3.1.1. Theoretical background, methodology and caveats

With the emergence of a warming signal across all geographies, the macroeconomic analysis starts by taking stock of the extent to which the countries already experience economic losses in response to climate change. This analysis of vulnerability of macroeconomic indicators is performed using a piecewise panel regression, an econometric approach published in World Development (Baarsch et al. (2020). The coefficients resulting from the panel regression and then calibrated at the country-level using Bayesian hierarchical calibration. After estimating countries' macroeconomic vulnerability to temperature and precipitation extremes, the third step of the analysis consists in applying the inferred vulnerability to the projected changes in climate for different global warming levels: 1.5°C (approximated with SSP126 for the 2021-2040 period), 2.0°C (SSP370 for the 2041-2060 period) and about 3.6°C (SSP370 for the 2080-2099 period).

The methodology implemented for inflation and GDP per capita growth in this study is a combination of an approach published in 2015 (Burke, Hsiang, and Miguel 2015) in which country's mean annual temperature drives a multi-country panel regression combined with a more recent approach (Baarsch et al., 2020) in which precipitation are normalized to facilitate comparison of heterogenous precipitation levels across countries. In addition, still building on this last publication, the results of the regression analysis are calibrated thanks to a Bayesian hierarchical calibration at the country level to ensure that the vulnerabilities estimated econometrically are an accurate representation of a country's climatic vulnerability.

Hitherto, most econometric analyses used a quadratic representation of the effect of temperature on economic outputs. Following this approach, which is recognized as a mathematical simplification (see for example Burke, et al. (2015) supplementary information), an "optimal" temperature level above and below which economies perform non-optimally is approximated. Therefore, for countries with temperature below the optimum temperature level, warming temperatures induced by climate change are projected to conduce a major increase in economic performance. For this study and following an extensive literature review, a different approach was implemented. This novel approach consists in estimating a "kink" from which economic performance decreases because of increasing temperature. Before the "kink" or "break point", economic performance is not affected by changing temperature (neither positively nor negatively). Since such an approach is particularly complex to infer in an econometric estimation, it is integrated at the calibration phase. Thanks to the calibration, the temperature break points are estimated at the country-level, reinforcing the robustness and accuracy of the simulated results and therefore projections.

In addition to temperature, the effects of hydrometeorological extremes are also considered in the regression analysis. Monthly local precipitation patterns are normalized using the Standardized Precipitation Index (SPI) and aggregated so that extreme dry and wet events are defined according to the local climatic conditions of a country – as such for a country with significantly different precipitation patterns, different threshold of extreme dryness or wetness are defined. The same applies at the global level. In this way, the model can isolate the specific effects of these extremes on GDP per capita and inflation.

Table 1: *Summary of input variables and methods for modelling GDP per capita and inflation*

Indicators	**GDP & Inflation**
Input variables	• Population-weighted precipitation normalized using the Standardized Precipitation Index (SPI), Population weighted temperature (ISIMIP database for historical and projected climates) • Socioeconomic variables influencing GDP per capita growth and inflation, as control variables (World Bank – World Development Indicators) • GDP per capita (World Bank – World Development Indicators) • Monthly general consumer price index (International Labor Organization)
Methods	• Econometrics (piecewise regression in panel)

- Income-level panel estimation augmented using a Bayesian hierarchical calibration at the country-level

Even though the model can provide a precise country-level perspective on the economic consequences of climate variability and change, there are three main limitations induced by an econometric-based approach and the data used in the analysis.

1. econometrics works by analogy (Hallegatte, Hourcade, and Ambrosi 2007) by inferring the effects of past weather extremes and pattern on economic outputs. Because of this approach the effects of sea-level rise on macroeconomic indicators that were not observable in the recent decades, they cannot be integrated in the modelling. Also, major and unprecedented hazards that could form into the future cannot be integrated.
2. the model does not account for the direct and indirect consequences of [high] windspeed on macroeconomic indicators and therefore limit the integration of the potential consequences of tropical cyclones – however, as the model already includes the consequences of extreme wet events induced by tropical cyclones, these are not absent from the modelling results – they suffer from a partial assessment of the whole consequences induced by high windspeed destructiveness and disruption.
3. the relatively large size of the grid cell from climate models (0.5°, or about 50km at the Equator) limits the ability of the model to replicate satisfactorily the climate of small islands and / or countries with diverse topography, as most of the cells covering these countries are oceans that warm at a slower rate (for islands) and cannot adequately distinguish the areas exposed to extreme precipitation events especially mountainous ones. In follow-up analyses on small island states, climate data with a higher resolution could be used to improve the inference and assessment of past and future impacts on these countries.

3.1.2. Key findings: GDP per capita growth

At all levels of warmings, the global region that is projected to be the most affected by the consequences of climate change is Central Asia with a mean change in GDP growth of -3% at 1.5°C, -6.1% at 2.0°C and down to -16.3% if no stringent climate action is implemented. The second most affected is projected to be North America, due to the large impacts observed in Canada at all levels of warming (see **Box 1**). On the African continent, Southern African countries could face the largest consequences with -9.9% at in the absence of adequate mitigation policies, followed by Central and Eastern Africa and finally Western Africa at -8.6%, -7.7% and -6.6%, respectively.

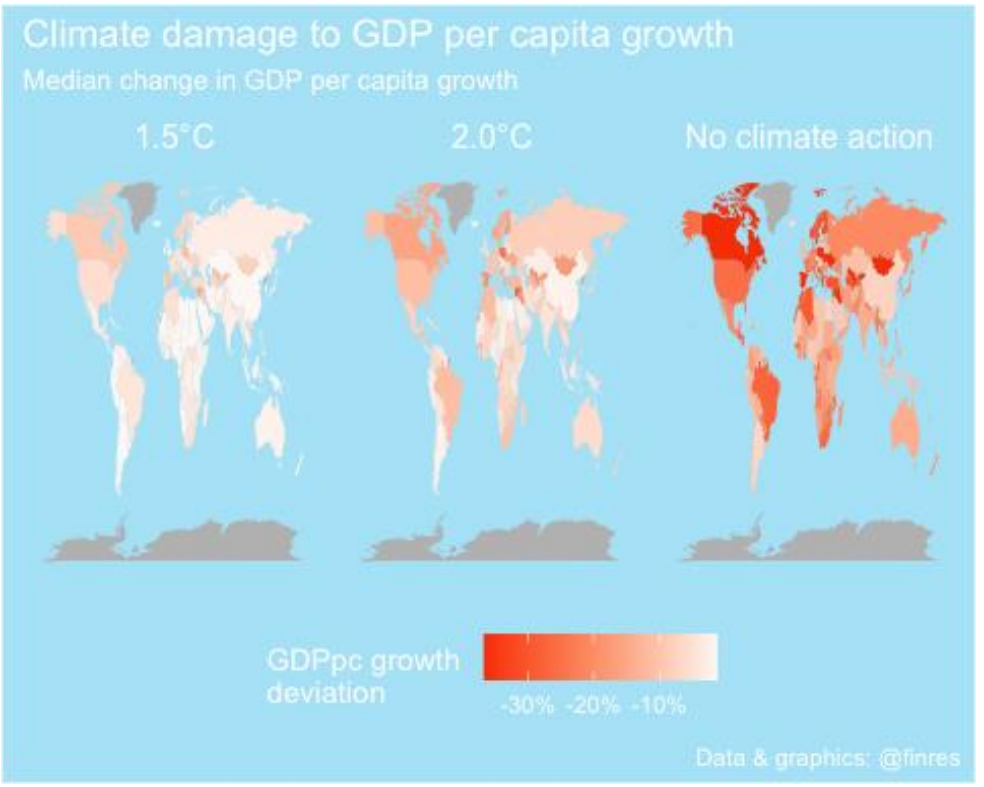

Figure 1: *Effects of climate change on GDP per capita growth at three levels of warming: 1.5°C, 2.0°C and without climate action (~3.6°C). The results are expressed in percentage of GDP growth. Source: Authors' calculations based on World Bank - World Development Indicators (WDI) for socioeconomic data and ISIMIP for the past and projected climate data.*

As explained in the methodology (section above), the projections for the Pacific and Caribbean island states largely underestimate the macroeconomic consequences of climate change as it suffers from three fundamental limitations: 1- the consequences of sea-level rise on macroeconomic indicators are not considered; 2- the model does not take into account the consequences of high windspeed; and finally, 3- the resolution of the climate models is too scarce to adequately capture the actual climate of these islands. These limitations lead to low macroeconomic consequences of climate change on these regions: -0.6%, -1.5% and from -4.6 to -5.4% for the Pacific and Caribbean countries, respectively at the same levels of warming as described above.

Box 1: Canada and Northern economies results

The results of the modelling on GDP per capita growth available in this study depict a different pattern from past and recent publications of the projected impacts of climate change on economic growth. In most studies, authors traditionally find that Northern economies would benefit from the consequences of climate change. This benefit is driven by an econometric hypothesis that assumes that economies grow until they reach an optimal temperature. Past this level any further increase in temperature lead to negative macroeconomic consequences. For example, Burke, et al. (2015) found that the global optimal temperature was about 13°C for all countries – therefore any economy with a mean annual temperature below this level would largely benefit from increasing temperature until

it reaches the optimum level. Consequently, numerous studies have projected major increases in GDP for Russia, Scandinavian countries, or Canada.

However, in this study a very different pattern is observed with for example Canada suffering major losses to its GDP growth as temperature increases with no benefit in a short- to mid-term resulting from global heating.

Specifically for Canada, a recently published study (Sawyer et al. 2022), based on bottom-up microeconomic evidence, found similar results to this analysis. The authors find that GDP growth could be reduced by 5% in the near-term (around 2025), 6% by mid-century and between 11 and 27% by the end of the 21st century. With similar timeframes and scenario characteristics, the present analysis projects the following decrease in GDP growth: 4% in the 2021-2040 period, 7% by mid-century and finally a median 19% by the end of the century. The results provided by both studies - despite the use of different modelling approaches - converge in the direction of a decrease in GDP growth for Canada.

In the bottom-up analysis of the macroeconomic consequences of climate change in Canada, the authors point out that the possible benefit for the agricultural sector and hydropower are insufficient to compensate the negative consequences in the rest of the economy for example on heat labour productivity, weather-related disasters, flooding or change in electricity demand.

If confirmed in more studies for high-income and Northern economies, the implications of such results could be wide-ranging.

The most staggering implication of these results is the effect of 0.5°C of warming from 1.5°C of global mean temperature increase to 2.0°C (**Table 2**). For all continents and regions, the negative macroeconomic consequences are projected to more than double with increases ranging from 110% in Asia to 160% in Oceania between these two levels of warming. With further warming resulting from limited climate action at the global level, the macroeconomic effects could be multiplied up to seven times compared to losses at 1.5°C of warming with increases ranging from 480% in Asian countries to 711% in Americas.

Table 2: *Mean continental deviation in GDP per capita growth. The percentages into brackets indicate the change compared to 1.5°C.*

Continent	GWL 1.5°C	GWL 2.0°C	No climate action
Africa	-1.1%	-2.8% (+150%)	-7.9% (+611%)
Americas	-0.9%	-2.3% (+153%)	-7.5% (+711%)
Asia	-1.7%	-3.6% (+110%)	-10.0% (+484%)
Europe	-1.9%	-4.4% (+131%)	-11.8% (+515%)
Oceania	-0.6%	-1.7% (+160%)	-5.1% (+683%)

These results on the macroeconomic consequences of climate change are another reminder of the importance of stringent mitigation action in line with the objective of the Paris Agreement to ensure that global mean temperature increase is maintained below 1.5°C above pre-industrial levels. Higher levels of warming could lead to drastic economic consequences,

limiting countries' ability to invest in their own adaptation, further aggravating the projected consequences.

3.1.3. Key findings: inflation

At all levels of warmings, similarly as for GDP per capita growth, the global region that is projected to be the most affected by the consequences of climate change is Central Asia with a mean change in inflation of 1.5 percentage points at 1.5°C, 1.9 points at 2.0°C and up to -4.1 points without further climate action. The second most affected is projected to be Eastern Europe. Eastern Europe is followed by Northern Africa and other African regions with climate-induced inflation from 0.9 point at 1.5°C of warming up to 3.0 points without further mitigation. On the African continent, West African countries could face the largest consequences with -2.7 points increase in the absence of adequate mitigation policies, followed by East Africa, Central Africa and Southern Africa at 2.1 points, 2.2 points and 2.1 points respectively.

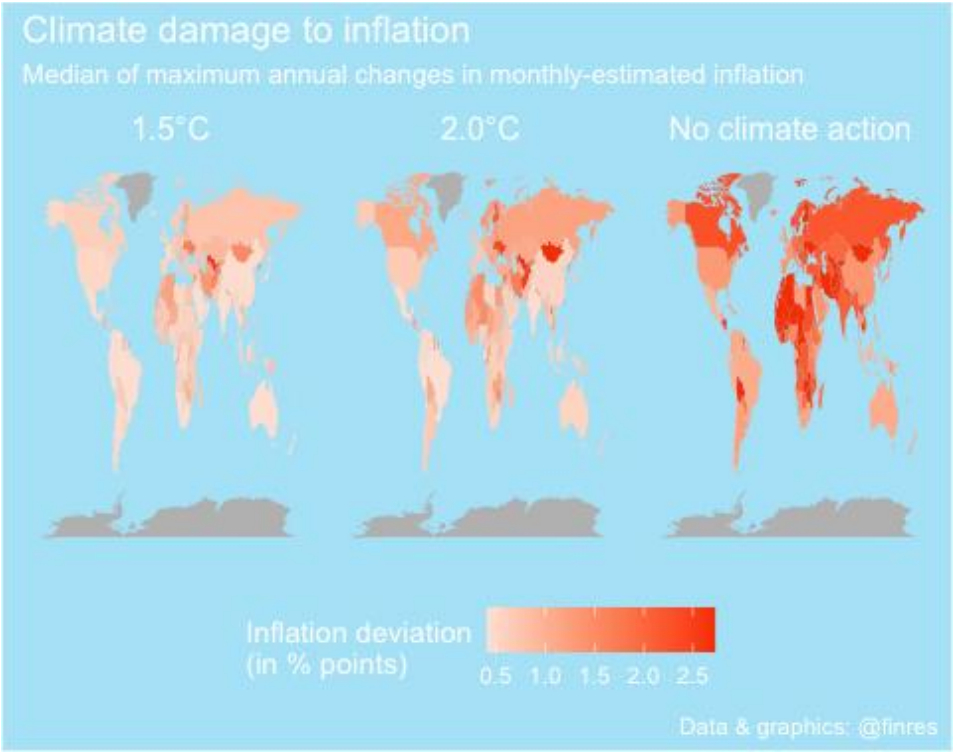

Figure 2: *Effects of climate change on general inflation at three levels of warming: 1.5°C, 2.0°C and without climate action (~3.6°C). The results are expressed in percentage points of inflation. Source: Authors calculations based on World Bank - World Development Indicators (WDI) for socioeconomic data and ISIMIP for the past and projected climate data.*

On the African continent, two regions are particularly affected by the negative consequences of climate change on interest rates: the countries ranging from Algeria in the North to Guinea in the West and Chad in the East and in the Southern part of Africa: Zambia, Zimbabwe, and Malawi. In South America, Bolivia stands out – possibly induced by currently lower temperatures that are projected to increase faster than the rest of the countries in the region and rapid modifications in precipitation patterns, especially in winter months.

At the difference of GDP per capita, for which the largest share of the negative consequences on GDP results from the effect of temperature, the damage to inflation is driven by hydrometeorological extremes. This change in driver of consequences explains the difference in regions facing the largest impact (at the exception of Central Asia) and the lower effect of warming from 1.5 to 2.0°C as observed for GDP per capita. Even though the effect of 0.5°C of warming is significant with values ranging from 10% (Caribbean) to 66% (Northern Europe) they are less than half of those measured for GDP per capita.

Table 3: *Mean continental level deviation in inflation. The percentages into brackets indicate the change compared to 1.5°C.*

Continent	GWL 1.5°C	GWL 2.0°C	No climate action
Africa	0.73	0.93 (+27%)	2.38 (+226%)
Americas	0.57	0.7 (+23%)	1.41 (+147%)
Asia	0.81	1.07 (+32%)	2.39 (+195%)
Europe	0.77	1.12 (+45%)	2.08 (+170%)
Oceania	0.75	0.82 (+9%)	1.24 (+65%)

An additional implication of this analysis at different levels of warming is to shed light on the benefit of limiting global mean temperature increase at 1.5°C instead of 2.0°C (**Table 3**). For all continents and regions, keeping global mean temperature below 1.5°C would decrease climate-induced inflationary risks from 10% (Oceania) to 45% (Europe) at an average level of about 30%. With further warming resulting from limited climate action, the inflation effects could almost triple compared to inflation at 1.5°C of warming with increases ranging from 65% in Oceanian countries to 195% in Asia.

3.2. Interest rates

3.2.1. Theoretical background

To estimate the future impacts of climate change on interest rates, this study is built on the Taylor rule (John B. Taylor 1993). The Taylor rule allows for an estimation of interest rates based on four main parameters derived from inflation and GDP growth: the gap between actual inflation and desired inflation and actual economic output growth against the desired output growth. According to Taylor, the two parameters of inflation and GDP should have an equal weight. To account for different decision-makers' preferences, two additional sets of parameters with unequal weight were used to convey the possibility that decision-makers favor GDP growth against inflation or the opposite (additional results available upon request).

The previous sections introduced the results of the effects of climate change and climate-related disasters on inflation and economic outputs. To estimate their impacts on countries' interest rates, these results are integrated in the Taylor rule (as described above) to appraise the evolution of interest rates as a response to the same changes in climate. The influence of climate-related disasters on interest rates through the Taylor rule can be two-fold, in the case of drought leading to an increase in inflation the rule would prescribe an increase in interest rates as central banks are expected to tighten monetary policy to keep inflation at reasonable

levels. On the other side, the same drought could also lead to lower-than-expected economic output – conducting the central bank towards an easing in monetary policies by lowering interest rates. The objective of this analysis is to indicate a potential trend in interest rates because of climate-related disasters.

Table 4: *Summary of input variables and methods for modelling interest rates.*

Indicators	Interest rates
Input variables	Results for preceding section: • Climate change-induced deviation in GDP per capita growth (deviation to 10-year average) • Climate change-induced deviation in inflation (deviation to 10-year average)
Methods	• Taylor rule (Taylor, 1993) to estimate interest rates based on actual and expected inflation and GDP growth
Data sources	Inflation & GDP growth: own estimates described above

In addition to the limitations affecting the projections of GDP per capita and inflation, the main caveats of this analysis are the following:

1. Even though the rule is well recognized, the decision to adjust interest rates respond to more indicators than those integrated in the Taylor rule. Therefore, the climate-induced change in interest rates through this rule represents only a partial perspective.
2. Interest rates derived from this rule are third-order impacts in the sense that they are computed based on second-order estimates of GDP per capita growth and inflation deviations. Consequently, the level of uncertainty associated with these estimates rises due to the multiplication of uncertainties from climate projections, into GDP per capita growth and inflation projections to their effect on interest rates.

The results for interest rates are measured in basis points, with 100 basis points being equal to one percentage point.

3.2.2. Key findings: interest rates

The pattern provided by the results on interest rates mirror the those observed for GDP per capita growth and inflation due to the nature of their calculation. Therefore, the most affected areas for either GDP per capita and / or inflation also display similar magnitude when it comes to interest rates.

At all levels of warmings, the global region that is projected to be the most affected by the consequences of climate change is Central Asia with a mean change in interest rates of 37 basis points (bps) at 1.5°C, 47 bps at 2.0°C and up to 119 bps without further climate action. The second most affected is projected to be Eastern Europe (91 bps without climate action). Eastern Europe is followed by Russia / North Asia region with climate-induced deviation in interest rates from 26 basis points at 1.5°C of warming up to 67 bps without further mitigation. On the African continent, North African countries could face the largest consequences with -

82 basis points increase in the absence of adequate mitigation policies, followed by West Africa, Southern Africa, East Africa, and Central Africa at 70 bps, 60 bps, 53 bps, 49 bps, respectively. In between Southern and Eastern Africa, a pocket of major impacts is observed with countries such as Zimbabwe, Zambia, and Malawi – in line with the strong drying and warming signal projected for this region of Africa that could lead, as modelled here, to drastic macroeconomic consequences.

Middle Eastern countries could face up to 60 bps increase in the scenario without further climate action. While East Asian countries are exposed to an average to an increase of 72 bps.

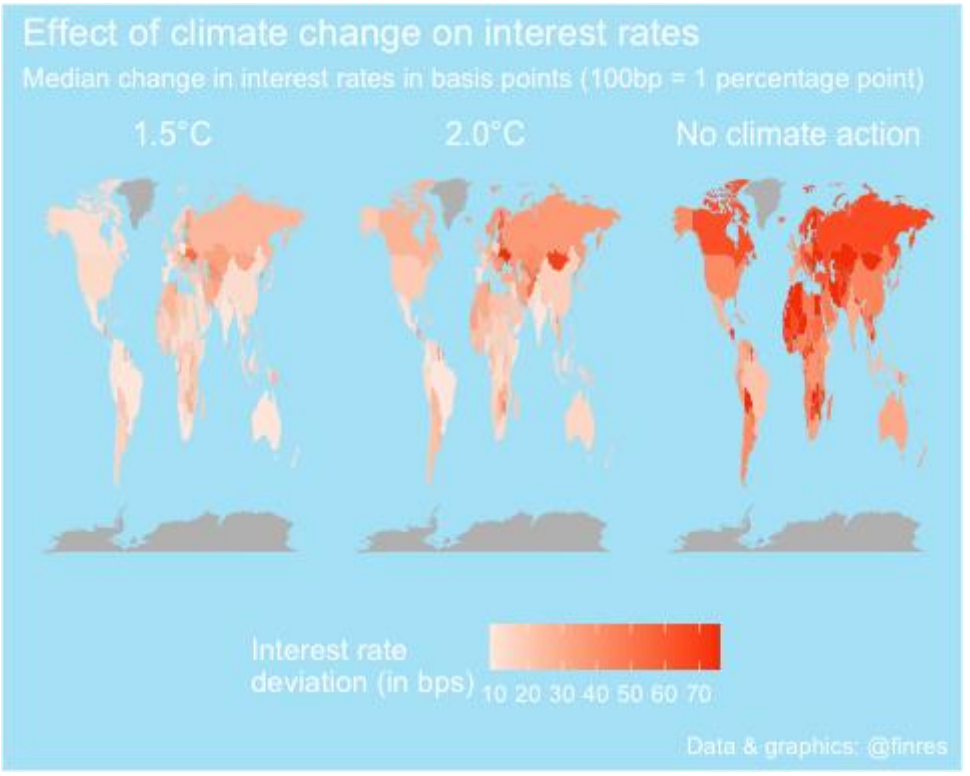

Figure 3: *Effects of climate change on interest rates at three levels of warming: 1.5°C, 2.0°C and without climate action (~3.6°C). The results are expressed in basis points. Source: Authors calculations based on World Bank - World Development Indicators (WDI) for socioeconomic data and ISIMIP for the past and projected climate data.*

Box 2: The macroeconomic and financial consequences of Ghana 2015 floods

In June 2015, heavy rains in Ghana lead to catastrophic consequences in Accra, the capital city. A gas station, where affected people found shelter, exploded causing more than 150 casualties. In addition to the social and human consequences induced by the floods, the event also deteriorated Ghana's macroeconomic indicators. First, right in the aftermath of the floods, the cedi, the local currency, dropped by 1.4% against the dollar - at the lowest level ever observed for the currency since 1994. This drop further aggravated the already weak position of the currency that had observed a 22-percent drop against the dollar since the beginning of 2015. Second, Ghana debt yield increased by 8 basis points at 8.89 percent compared to 8.25 percent less than a year earlier. At a time when the government needed several hundreds of millions of dollars for reconstruction in the aftermath of the floods, its ability to

borrow funds from the international market was several constrained by both lowered local currency value combined increased debt yield. Source: (Moses Mozart Dzawu and Paul Wallace 2015; Neo Khanyile and Paul Wallace 2015)

With interest rates being computed as a function of both deviations in GDP per capita and inflation, the effects across warming levels by continent reflect those observed for these two indicators.

The continent that would gain the most at keeping global mean temperature at 1.5°C in line with the objective of the Paris Agreement is Europe, with a 49% increase induced by 0.5°C increase in temperature. Europe would be followed by Asia and America, with 33% and 26% increase in interest rates because of temperature increasing from 1.5°C to 2.0°C above pre-industrial levels. At a higher level of warming induced by insufficient climate action, the continent that would be exposed to the most drastic increase in interest rates is projected to be Asia followed by Africa both facing a potential multiplication by three in interest rates.

Table 5 *Mean continental level deviation in interest rates. The percentages into brackets indicate the change compared to 1.5°C.*

Continent	GWL 1.5°C	GWL 2.0°C	No climate action
Africa	20bp	23bp (+16%)	61bp (+214%)
Americas	15bp	19bp (+26%)	41bp (+171%)
Asia	20bp	26bp (+33%)	66bp (+235%)
Europe	23bp	34bp (+49%)	68bp (+194%)
Oceania	21bp	23bp (+5%)	35bp (+63%)

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