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Beyond GDP: Quantifying Heterogeneous Impact of Climate Change on Social Progress

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Abstract

This study examines the relationship between well-being and temperature across 167 countries from 1990 to 2019, employing the Social Progress Index (SPI) as a measure of well-being and social progress. Using a fixed-effects panel data framework, I study temperature impacts on social progress by modelling local and global weather anomalies simultaneously, capturing both within-country temporal and global climate variation. First, a statistically significant negative relationship exists between annual temperature anomalies and well-being, with a 1°C global (local) mean temperature deviation leading to a 0.8068 (0.0929) point decline, respectively. Second, annual precipitation anomalies have no statistically significant effect on the SPI. Third, an increase in temperature anomaly has a more adverse impact in winter and spring than in other seasons. Fourth, poorer regions, hotter climates,global south, and countries with weak institutions are disproportionately affected by temperature deviations. Fifth, the impact of temperature on well-being persists over the medium term, most clearly through the global temperature anomalies.

JEL Codes: Q13,Q54, Q56

Keywords: Temperature Anomalies, Social Progress Index

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1 Introduction

Traditionally, research on human well-being has predominantly focused on socioeconomic factors such as income, health, and employment conditions, which have long been recognised as pivotal in shaping individuals' quality of life (Kahneman & Deaton, 2010). However, climate variables, particularly temperature, are increasingly recognised as key determinants of happiness in a relatively new but developing strand of economic literature (Rehdanz & Maddison, 2005; Maddison & Rehdanz, 2011; Malpede & Percoco, 2024; Frijters et al., 2020). While a substantial body of research has examined the economic impact of global warming, particularly its effects on output growth and other economic indicators (Dell et al., 2014), far less attention has been paid to its impact on broader dimensions of human well-being. Initially, a nation's welfare was primarily assessed through economic indicators such as its national income per capita; however, nations worldwide are now increasingly focused on improving the quality of life for their citizens (UNDP, 2024; Stiglitz et al., 2009; Haq, 1995). Economic well-being was primarily measured by national income per capita, but this has evolved to incorporate broader indicators, including health, education, and overall quality of life (UNDP, 2024; Haq, 1995). The Social Progress Index (SPI) has emerged as a key metric, integrating only non-economic factors to reflect societal progress beyond mere economic output (O'Sullivan, 2014; Peiró-Palomino et al., 2026). Temperature has heterogeneous impacts on income across regions contingent on income, temperature, and geography (Desbordes & Eberhardt, 2024; Berg et al., 2024). Richer countries, with strong economies and advanced technology, can adapt more effectively (Kahn et al., 2021). Existing research has not yet investigated the heterogeneous effects of temperature on well-being[1] , nor has it identified the potential mechanisms through which these impacts occur. Additionally, there is a limited understanding of how these effects vary across different income levels, geographic regions, and institutional capacity. Using a global dataset of 167 countries with substantial spatial variation (167 countries) and temporal variability (30 years), this study employs panel data fixed effects to estimate the heterogeneous impact of temperature on well-being.

Historically, economic indicators such as GDP have been used to understand the impacts of climate change. Shifting from GDP to the Social Progress Index as a measure of well-being is essential for several reasons, especially when addressing the impact of temperature. GDP per capita, although a popular metric for assessing economic size and production capacities, does not capture other dimensions of human well-being, such as social inequality, health, and

[1]In this paper, I use the terms well-being and social progress interchangeably.

education (Fleurbaey & Blanchet, 2013; Peiró-Palomino et al., 2023; Haq, 1995; Stiglitz et al., 2009). This shortfall means that GDP can often reflect a misleading picture of a country's true development and the quality of life of its citizens. The SPI, in contrast to traditional metrics like GDP, offers a multidimensional approach that evaluates social and environmental outcomes, providing a comprehensive measure of societal well-being (O'Sullivan, 2014; Peiró-Palomino et al., 2026; Krylova et al., 2026). The SPI is calculated by aggregating three key dimensions: Basic Human Needs (BHN), Foundations of Wellbeing (FOW), and Opportunity (OPP). BHN includes nutrition, water, shelter, and safety; FOW includes access to knowledge, health, and environmental quality; and Opportunity covers personal rights, freedom, and inclusiveness (Porter et al., 2014) [2]. Each dimension is measured using a set of indicators, normalised, and combined to produce the SPI score (Krylova et al., 2026; Peiró-Palomino et al., 2023). This focus on social progress aligns closely with the objectives of sustainable development, which prioritise social equity and environmental sustainability, often overshadowed by an exclusive emphasis on GDP growth (Peiró-Palomino et al., 2023, 2026). Adopting the SPI over GDP reorients economic policies toward the broader goal of social progress, making it a superior metric for guiding global efforts toward sustainable and equitable development in the context of climate change (Social Progress Imperative, 2025; Peiró-Palomino et al., 2023, 2026). This study aligns with the United Nations Sustainable Development Goals, particularly Goal 3 (Good Health and Well-Being) and Goal 13 (Climate Action), by shifting the focus of climate policy evaluation from GDP growth to a broader consideration of societal well-being (Stiglitz et al., 2009; Haq, 1995).

Against this backdrop, I examine the relationship between well-being & social progress and temperature across 167 countries from 1990 to 2019. I utilise annual data on temperature, precipitation, and relative humidity from the European Centre for Medium-Range Weather Forecasts (ECMWF) sourced from World Bank (2025a) and the social progress index as a measure of well-being sourced from the Social Progress Imperative (2025). This paper's methodology involves a fixed-effects panel data framework to study the heterogeneous impact of time-varying historical temperature anomalies (both local and global) on well-being & social progress, with additional climate controls for precipitation and humidity anomalies. Furthermore, I address several key questions in this paper: First, how does temperature adversely affect the social progress index? Second, does the impact of temperature anomalies extend over medium-term time horizons? Third, what are the economic mechanisms/channels of these impacts? Fourth,

[2]See Online supplementary material Figure A1 for detailed indicator list. Data is sourced from the Social Progress Imperative. Krylova et al. (2026) provides a detailed discussion of the methodology and robustness checks underlying the data.

how do these effects vary across different income levels and geographic regions, particularly in poorer and warmer areas? Fifth, in what ways do variations in seasonal temperature anomalies impact well-being?

This study distinguishes itself from and contributes to the existing literature on the relationship between climate and social progress in several key respects. First, it employs a comprehensive and detailed country-level well-being & social progress panel dataset from the Social Progress Imperative (2025); Krylova et al. (2026), covering 167 countries from 1990 to 2019, unlike Maddison & Rehdanz (2011) and Rehdanz & Maddison (2005), which use the World Values Survey with limited national and temporal coverage, or Malpede & Percoco (2024) with a shorter timeframe. Second, while prior work has largely examined the temperature–well-being nexus within individual countries such as the United States (Frijters et al., 2020; Connolly, 2013), Ecuador (Zapata, 2022), Russia (Frijters & van Praag, 1998), and China (Li et al., 2024), this study provides a comprehensive cross-country analysis spanning 167 nations over three decades. Third, conventional econometric models assume a country's economic growth depends only on its own climate shocks, ignoring global interconnections through trade, investment, and financial markets (Neal et al., 2025; Bilal & Känzig, 2026; Berg et al., 2024). Existing Climate - Wellbeing studies overlook spatial dependencies and fail to distinguish local from global temperature changes. Unlike most studies except Neal et al. (2025); Bilal & Känzig (2026); Berg et al. (2024), which focus on within-country climate variations, my framework integrates both local and global temperature anomalies. By explicitly modelling both local and global anomalies, I can leverage the aggregate variation in global temperature time-series data[3], instead of depending exclusively on within-country variation (Bilal & Känzig, 2026). Fourth, this study contributes by examining underlying channels and mechanisms that remain underexplored in the existing literature (Rehdanz & Maddison, 2005; Maddison & Rehdanz, 2011; Malpede & Percoco, 2024). Fifth, I also investigate the persistence of climate change on well-being using a Jordà (2005)- style local projections approach, something that existing studies have not looked at.

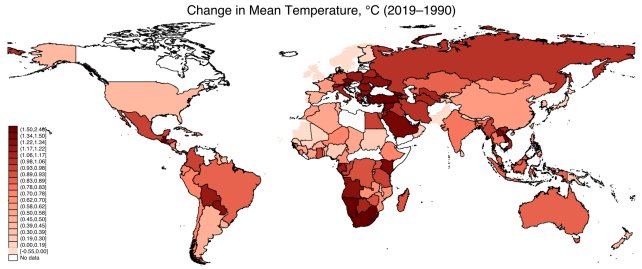
This study presents several findings. First, a statistically significant negative correlation is observed between annual temperature anomalies and well-being. Specifically, a 1°C deviation from rolling 30-year historical temperature norms is associated with a reduction of approximately 0.0929 points in the SPI. Similarly, a 1°C increase in global mean temperature anomalies results in an adverse and significant decline of 0.8068 points in the SPI. In contrast, neither global

[3]The global anomaly is common to all countries, so its coefficient is identified from about 30 annual observations; with Driscoll–Kraay standard errors it is significant only at the 5–10 per cent level. I therefore read the global estimate as suggestive evidence consistent with an adverse effect of global warming.

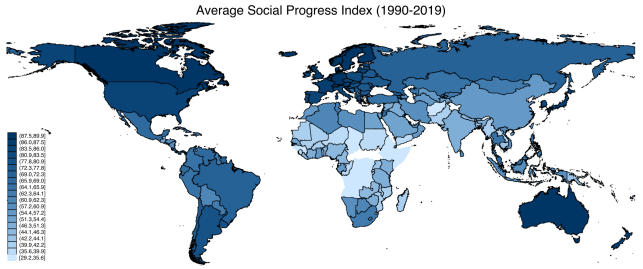
nor local precipitation anomalies exhibit a statistically significant effect on the SPI. Second, this paper also finds evidence of heterogeneous seasonal temperature effects: deviations from 30-year rolling temperature norms have larger effects on well-being during winter and spring, with seasons defined separately for the Northern and Southern Hemispheres. Third, poorer regions, hotter regions, the global south, and countries with poor institutional quality are disproportionately impacted by annual temperature deviations from their 30 year historical norms, which negatively affect their well-being. Fourth, the subcomponent analysis provides suggestive evidence of three transmission channels, consistent with the conceptual framework in Online Appendix Section A: temperature adversely affects Basic Human Needs, Foundations of Wellbeing through health and education, and Opportunity through personal rights and personal freedom. Fifth, using Jordà (2005) local projections, this study suggests that the impact of temperature anomalies is found to broadly persist over medium-term horizons. These results are robust across multiple robustness checks, including subsample estimates and sensitivity tests incorporating different model parameters and control variables.

The remainder of this paper is organised as follows: Section 2 outlines the Data and Empirical Strategy, and Section 3 discusses the Results, Section 4 suggests potential mechanisms, and Section 5 offers the Conclusion and Policy Implications.

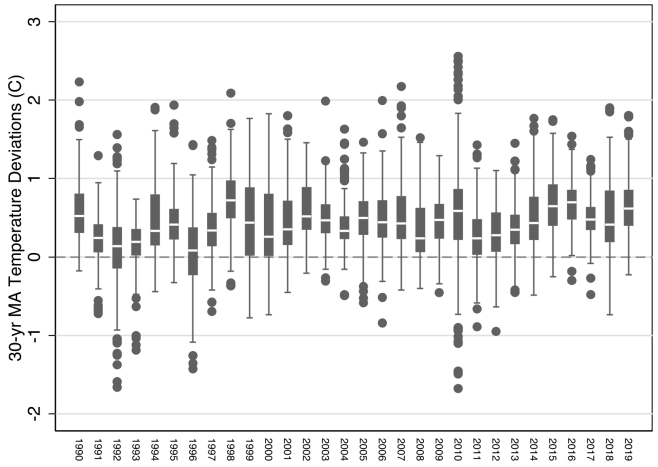
Figure (1) Cross-Country Distribution of Climate Anomalies and Social Progress: Maps and Boxplots (1990–2019)



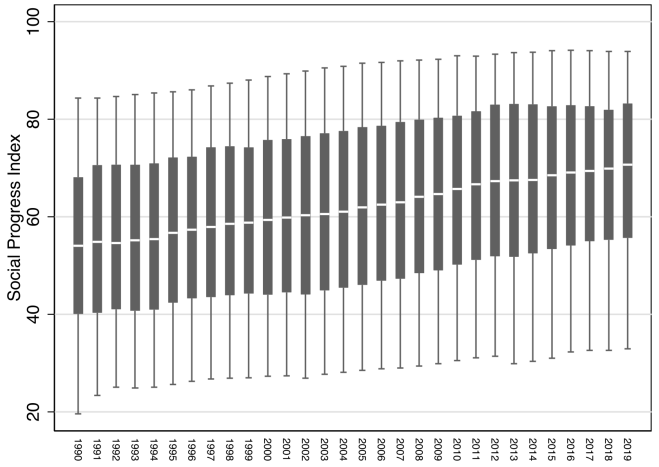
(a) Changes in Mean Temperature (1990-2019)



(b) Average Social Progress Index (1990-2019)



(c) Trends in 30-year Temperature Anomalies over 1990-2019



(d) Trends In Social Progress Index over 1990-2019

Notes: Panel (a) maps the change in mean temperature, that is, the 2019 value minus the 1990 value, for the 140 countries observed in both years; panel (b) maps the 1990–2019 average SPI for all 167 countries in the estimation sample (4,814 country-year observations). Country boundaries follow the World Bank shapefiles. Panel (c) presents annual boxplots of 30-year moving- Average temperature anomalies (°C) for each year from 1990 to 2019. Anomalies are calculated using ERA5 reanalysis data (0.25° × 0.25° grid) (World Bank, 2025a). Panel (d) shows annual boxplots of country-level SPI scores over the same period, based on the Social Progress Imperative database (Social Progress Imperative, 2025).

2 Methods

2.1 Data and Variables

2.1.1 Climate Data

I utilised area-weighted country-level ERA5 reanalysis datasets from the European Centre for Medium-Range Weather Forecasts (ECMWF), sourced from the World Bank Climate Change Knowledge Portal (World Bank, 2025a). ERA (Hersbach et al., 2023) datasets integrate satellite and ground observations with modelling to provide high-quality atmospheric variables at a spatial resolution of $0.25° \times 0.25°$. To evaluate global and local warming, the primary independent variables are annual global and local weather anomalies, measured as deviations from historical norms following Kahn et al. (2021); Natoli (2023). Specifically, these deviations are defined as the difference between the temperature in country i in year t and the time-varying historical temperature norm computed over the preceding m years. The annual temperature anomaly for country i in year t is $\tilde{T}_{it}(m) = [T_{it} - T^*_{i,t-1}(m)]$, where T_{it} is the average temperature and $T^*_{i,t-1}(m) = \frac{1}{m}\sum_{k=1}^{m} T_{i,t-k}$represents the historical norm over the preceding m years, with $m = 20, 30, 40$. Similarly, I compute the precipitation anomalies $\tilde{P}_{it}(m) = [P_{it} - P^*_{i,t-1}(m)]$ and relative humidity anomalies $\tilde{H}_{it}(m) = [H_{it} - H^*_{i,t-1}(m)]$.

To account for seasonal variations, I extend this methodology to meteorological quarters as per (World Bank, 2025a): DJF (December–February), MAM (March–May), JJA (June–August), and SON (September–November). For each season s, temperature anomalies are defined as $\tilde{T}_{it,s}(m) = [T_{it,s} - T^*_{i,t-1,s}(m)]$, precipitation anomalies as $\tilde{P}_{it,s}(m) = [P_{it,s} - P^*_{i,t-1,s}(m)]$, and humidity anomalies as $\tilde{H}_{it,s}(m) = [H_{it,s} - H^*_{i,t-1,s}(m)]$, where the corresponding historical norms are $T^*_{i,t-1,s}(m)$, $P^*_{i,t-1,s}(m)$, and $H^*_{i,t-1,s}(m)$.In the Robustness section, I utilised climate data from the Climate Research Unit, sourced from the World Bank's Climate Change Knowledge Portal (World Bank, 2025a).

2.1.2 Well-being measures

Well-being & Social progress are measured by the SPI, as defined and sourced from Krylova et al. (2026); Social Progress Imperative (2025). The SPI focuses solely on non-economic factors, clearly separating social development from economic growth as discussed in (Peiró-Palomino et al., 2023, 2026), addressing a limitation of previous indices (Krylova et al., 2026; Social Progress

Imperative, 2025). Indicators are standardised to a scale from 0 (worst) to 100 (best).[4] The SPI's subcomponents capture key social progress areas. Basic Human Needs include Nutrition and Basic Medical Care, Water and Sanitation, Shelter, and Personal Safety. FOW includes Access to Basic Knowledge, Information and Communications, Health and Wellness, and Environmental Quality. Opportunity covers Personal Rights, Personal Freedom, and Choice, Inclusiveness, and Access to Advanced Education. The SPI source covers 1990 to 2020 and spans 169 countries; I use the 1990–2019 window, which gives 30 years of coverage [5].

For robustness analysis, I also incorporate additional economic indicators from World Bank (2025b); Akyapi et al. (2025), including log GDP per capita,[6] inflation rate, official exchange rate, and commodity terms of trade. This paper's final dataset comprises an unbalanced panel covering 167 countries from 1990 to 2019, yielding 4,814 [7] country-year observations (See Table A5 in the Appendix for the list of countries and Table A6 for sample composition)

Table (1) Summary Statistics for Key Variables, 167 Countries (1990–2019)

Panel A: SPI indicators					
Indicator	Mean	SD	Min	Max	*N*
Social Progress Index	62.22	17.52	19.61	94.12	4 814
Panel B: Climate variables					
Annual precipitation (100 mm)	11.58	8.45	0.06	48.97	4 814
Annual mean temperature (°C)	18.72	8.00	-4.85	29.79	4 814
Annual mean humidity (%)	68.02	14.76	23.82	88.46	4 814
30-yr precipitation anomaly (100 mm)	-0.07	1.77	-9.39	16.36	4 814
30-yr mean-temperature anomaly (°C)	0.45	0.46	-1.68	2.56	4 814

Notes: The sample is an unbalanced panel of 167 countries over 1990–2019, giving 4,814 country-year observations. Means and standard deviations are rounded to two decimal places.

2.2 Methodology and Data Descriptive

2.2.1 Empirical Model Specification

To investigate the effects of historical climate anomalies on societal well-being, as quantified by the SPI, I employ a fixed-effects panel data model (Dell et al., 2014; Kahn et al., 2021; Akyapı et al., 2025). Moving-average historical anomalies are preferred over absolute temperature levels

[4] For a detailed discussion of the construction of the SPI, see Krylova et al. (2026) and Peiró-Palomino et al. (2023, 2026). A brief discussion is also provided in Online Supplementary Material, Section C.

[5] See Figure A1 for complete indicator list

[6] Log GDP per capita is deposited on a $100 \times \ln$ scale. A one-unit increase in the regressor therefore corresponds to a one per cent rise in GDP per capita, and the reported coefficient should be read on that basis.

[7] After merging the SPI data (Krylova et al., 2026; Social Progress Imperative, 2025) with climate indicators (World Bank, 2025a) and economic controls (World Bank, 2025b; Akyapi et al., 2025), the final unbalanced panel covers 167 countries and 4,814 country-year observations. I retain all country-years for which the required variables are jointly available.

because they normalise regional and temporal climate variability, filter out short-term noise, and align with the adaptive expectations of agents as emphasised in the work of (Kahn et al., 2021; Natoli, 2023). All climate variables (anomalies) enter in levels; the dependent variable, $\text{SPI}_{i,t}$, is also in levels. Online supplementary material Table A3 summarises the main variables, their definitions, units, and data sources; the remaining controls are documented in the notes to the tables in which they appear.

This paper's baseline specification, focusing on local climate effects, is

$$\text{SPI}_{i,t} = \alpha_i + \beta_1 \widetilde{T}_{i,t}(m) + \beta_2 \widetilde{P}_{i,t}(m) + \gamma_i t + \lambda_t + \varepsilon_{i,t}, \tag{1}$$

where $\text{SPI}_{i,t}$ is the Social Progress Index of country i in year t; α_i captures country fixed effects absorbing time-invariant heterogeneity (e.g. geography, institutions); $\gamma_i t$ denotes country-specific linear trends (Dell et al., 2014); λ_t represents year fixed effects controlling for common global shocks; and $\varepsilon_{i,t}$ is the error term, with standard errors clustered at the country level.

The anomaly variables are defined as $\widetilde{T}_{i,t}(m) = T_{i,t} - T^*_{i,t-1}(m)$ and $\widetilde{P}_{i,t}(m) = P_{i,t} - P^*_{i,t-1}(m)$, where $T_{i,t}$ and $P_{i,t}$ are the annual mean temperature (°C) and precipitation (100 mm) of country i in year t, and $T^*_{i,t-1}(m) = \frac{1}{m}\sum_{l=1}^{m} T_{i,t-l}$ and $P^*_{i,t-1}(m) = \frac{1}{m}\sum_{l=1}^{m} P_{i,t-l}$ are the time-varying historical norms computed over the preceding m years, following Kahn et al. (2021); Neal et al. (2025). Humidity anomalies $\widetilde{H}_{i,t}(m)$ are defined analogously. Climate norms are conventionally based on 30-year moving averages (Arguez et al., 2012); but to check robustness, I also consider historical norms computed using a moving average with $m = 20$ and $m = 40$.

Other variant specification extends Equation (1) by adding humidity anomalies, reflecting their documented role in climate–well-being linkages (Connolly, 2013; Rehdanz & Maddison, 2005; Malpede & Percoco, 2024; Zapata, 2023; Maddison & Rehdanz, 2011). A further variant replaces humidity with macroeconomic controls (log GDP per capita, CPI inflation, the exchange rate, and commodity terms of trade) to test whether climate effects operate independently of economic channels.

To address global interconnectedness through trade, supply chains, and financial markets, which may bias local-only estimates due to spatially correlated shocks (Dell et al., 2014; Kahn et al., 2021; Frijters et al., 2020), my preferred specification replaces year fixed effects with cross-sectional averages of climate anomalies [8] following the recent developments by Berg et al. (2024); Desbordes & Eberhardt (2024); Neal et al. (2025); Kumar & Maiti (2025b) as proxies for

[8] Global weather anomalies refer to the annual cross-sectional averages of country-level weather anomalies in the estimation sample.

unobserved common factors, as in the correlated common effects (CCE)[9] approach of Pesaran & Tosetti (2011):

$$\text{SPI}_{i,t} = \alpha_i + \beta_1 \widetilde{T}_{i,t}(m) + \beta_2 \widetilde{P}_{i,t}(m) + \beta_3 \widetilde{H}_{i,t}(m) + \gamma_i t + \theta_1 \overline{\widetilde{T}}_t(m) + \theta_2 \overline{\widetilde{P}}_t(m) + \theta_3 \overline{\widetilde{H}}_t(m) + \varepsilon_{i,t}, \quad (2)$$

where the global anomalies are the cross-sectional averages

$$\overline{\widetilde{T}}_t(m) = \frac{1}{N}\sum_{i=1}^{N} \widetilde{T}_{i,t}(m), \qquad \overline{\widetilde{P}}_t(m) = \frac{1}{N}\sum_{i=1}^{N} \widetilde{P}_{i,t}(m), \qquad \overline{\widetilde{H}}_t(m) = \frac{1}{N}\sum_{i=1}^{N} \widetilde{H}_{i,t}(m),$$

computed across all N countries in year t. These can also be interpreted as foreign weather shocks. The full estimation is repeated for $m \in \{20, 30, 40\}$.

I estimate both local and global temperature anomaly models following recent literature (Bilal & Känzig, 2026; Neal et al., 2025; Berg et al., 2024) to show the distinct roles of spatial heterogeneity and global systemic risk on economic well-being. Unlike standard econometric models that implicitly assume economies are unaffected by weather shocks in other countries, thereby mischaracterising global weather impacts, this paper's approach explicitly integrates global temperature anomalies alongside local variations (Bilal & Känzig, 2026; Neal et al., 2025; Berg et al., 2024). This inclusion is motivated by the interconnectedness of the global economy, particularly through international trade and supply chains, which implies that a country's economic growth prospects depend not only on its weather conditions but also on global weather patterns (Neal et al., 2025). Global weather impacts economic outcomes separately from local conditions through spillover effects (general equilibrium effects), global correlations with extreme weather events not captured by local averages, and disruptions in global commodity supply chains (Bilal & Känzig, 2026; Neal et al., 2025; Berg et al., 2024). Global temperature variation is also less dominated by idiosyncratic local risk and is more strongly associated with widespread climatic extremes (Bilal & Känzig, 2026; Berg et al., 2024).

2.2.2 Persistence Using Local Projections

The preferred fixed-effects panel model presented in the equation (2) estimates average effects but may not adequately capture the dynamic persistence of climate anomalies on societal well-being. To investigate these temporal dynamics, similar to the work by Akyapı et al. (2025), I adopt the local projection method proposed by Jordà (2005), which facilitates the estimation

[9] This is a CCE-style common-factor augmentation as in (Neal et al., 2025), not the canonical CCE estimator (Pesaran, 2006; Pesaran & Tosetti, 2011).

of impulse response functions (IRFs) by regressing the forward leads of the outcome variable on the climate shocks across successive horizons.

I estimate the following local-projection specification for each horizon $h = 0, 1, \ldots, H$ (with $H = 4$ in my primary analysis):

$$\text{SPI}_{i,t+h} = \alpha_i + \beta_h \widetilde{T}_{i,t}(m) + \delta_h \widetilde{P}_{i,t}(m) + \phi_h \widetilde{H}_{i,t}(m) + \gamma_i t + \theta_h \overline{\widetilde{T}}_t(m) + \psi_h \overline{\widetilde{P}}_t(m) + \omega_h \overline{\widetilde{H}}_t(m) + \varepsilon_{i,t+h}, \tag{3}$$

where $\text{SPI}_{i,t+h}$ is the Social Progress Index for country i at time $t + h$. The local climate anomalies is temperature $\widetilde{T}_{i,t}(m)$, precipitation $\widetilde{P}_{i,t}(m)$, and humidity $\widetilde{H}_{i,t}(m)$,are computed as m-year moving-average deviations from historical norms ($m = 30$). The corresponding global climate anomalies $\overline{\widetilde{T}}_t(m)$, $\overline{\widetilde{P}}_t(m)$, and $\overline{\widetilde{H}}_t(m)$. The specification includes country fixed effects α_i and country-specific linear time trends $\gamma_i t$; Standard errors are clustered at the country level. For the *local* IRF, the coefficient $\{\beta_h\}_{h=0}^{H}$ delineates dynamic response of local temperature anomaly; for the *global temperature anomalies* IRF it is $\{\theta_h\}_{h=0}^{H}$. Confidence bands at the 90% and 68% levels are constructed with critical values $z_{0.90} = 1.645$ and $z_{0.68} \approx 0.994$. This methodology is further extended to seasonal anomalies for the December- January - February (DJF) period.

2.2.3 Discussion on Identification

Exogeneity of weather anomalies- Climate anomalies are typically exogenous in well-being studies, external to individual control, and minimally affected by short-run human actions (Meierrieks & Stadelmann, 2024; Zapata, 2023). This exogeneity allows us to estimate the effect of temperature on SPI, consistent with the notion of "experienced utility" reflecting actual living conditions (Zapata, 2023). My econometric specification uses this identification strategy through the country fixed effects (α_i), which absorb all time-invariant confounders; country-specific linear trends ($\gamma_i t$), which control for differential development trajectories, and cross-sectional averages of climate anomalies, which absorb the common global economic cycle.

Reverse causality - Climatic variables are predominantly driven by global anthropogenic and non-anthropogenic factors rather than local economic activities, substantially mitigating concerns about reverse causality between climate anomalies and the SPI (Dell et al., 2014; Malpede & Percoco, 2024). Nonetheless, following the recent literature (Neal et al., 2025; Kahn et al., 2021; Malpede & Percoco, 2024; Bilal & Känzig, 2026), I mitigate potential reverse causality by controlling for lagged annual CO_2 emissions. The temperature response to emissions

unfolds over long horizons, often spanning decades, while annual emission fluctuations explain little short-run temperature variation (Bilal & Känzig, 2026; Neal et al., 2025). Granger-causality tests also show no evidence that SPI or Environmental Quality predicts subsequent weather variation in my sample.

Over-controlling vs Bad controls-Including time-varying variables which are themselves affected by temperature risks "bad controls" bias, distorting estimates (Dell et al., 2014; Malpede & Percoco, 2024). To control for economic confounders, I augment specifications (2) with macroeconomic variables (log GDP per capita, inflation, official exchange rate, commodity terms of trade). Low intra-region mobility and exogenous climate patterns further reduce endogeneity (Zapata, 2023). Under these maintained identifying assumptions, I interpret the estimated temperature effects as causal.

2.3 Descriptive Statistics

Figure 1 presents the spatial and temporal distribution of climate anomalies and social progress across 167 countries over 1990–2019. Panel (a) shows widespread but spatially heterogeneous increases in mean temperature, with the magnitude of warming varying substantially across countries. Panel (b) documents marked cross-country differences in average SPI: scores are generally highest in North America, Europe, and Oceania, while substantially lower values are concentrated in Sub-Saharan Africa and parts of South Asia. Panel (c) shows that the 30-year temperature anomaly is consistently positive: the median is above zero in every year and the lower quartile is also positive in 28 of the 30 years. The annual distributions fluctuate over time, with the interquartile range lying broadly between 0.1°C and 0.9°C, alongside several positive and negative outliers. Panel (d) shows a clear upward shift in social progress, with the median SPI increasing from approximately 54 in 1990 to around 70 by 2019.

Table 1 reports summary statistics for the key variables across 4,814 country-year observations. The overall SPI has a mean of 62.22 with a standard deviation of 17.52, and ranges from 19.61 to 94.12. There is considerable variation across its sub-indicators as well. Among the climate variables, the annual mean temperature averages 18.72°C (SD 8.00), with values ranging from negative 4.85°C to 29.79°C. Annual precipitation varies widely, from 0.06 to 48.97 in units of 100 mm. The 30-year mean temperature anomaly is relatively small on average (0.45°C, SD 0.46), consistent with a pattern of gradual warming. However, precipitation anomalies show much greater fluctuation, with a standard deviation of 1.77 (about 177 mm).

3 Key Findings

Table (2) Climate Change and Social Progress Index: 30-Year Moving-Average Weather Anomalies

	Main Results: 30-Year Moving Average					
	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
Local weather anomalies						
Mean-temp anomaly	−0.0862*	−0.0962**	−0.1090**	−0.0820	−0.0929*	−0.1123**
	(0.0497)	(0.0477)	(0.0475)	(0.0522)	(0.0496)	(0.0481)
Precipitation anomaly	−0.0004	0.0037	−0.0059	−0.0005	0.0039	−0.0053
	(0.0129)	(0.0169)	(0.0129)	(0.0133)	(0.0170)	(0.0130)
Humidity anomaly		−0.0089			−0.0096	
		(0.0219)			(0.0223)	
Global weather anomalies						
Global mean-temp anomaly				−0.8324***	−0.8068***	−0.6056***
				(0.1234)	(0.1257)	(0.1227)
Global precipitation anomaly				0.0427	0.0304	0.0112
				(0.0405)	(0.0506)	(0.0442)
Global humidity anomaly					0.0358	
					(0.0862)	
Economic indicators	✗	✗	✓	✗	✗	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✗	✗	✗
Observations	4814	4814	4098	4814	4814	4098
Countries (N)	167	167	159	167	167	159
Years (T)	30	30	29	30	30	29
Within R^2	0.0009	0.0010	0.0352	0.0148	0.0149	0.0552
F-statistic	1.5061	1.3581	6.7446	24.1801	16.3585	15.0364
F p-value	0.2248	0.2575	0.0000	0.0000	0.0000	0.0000
Root MSE	1.1294	1.1295	1.0080	1.1735	1.1737	1.0380

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Table 2 (continued)

Notes: Robust standard errors clustered at the country level are reported in parentheses. The dependent variable is the Social Progress Index (Social Progress Imperative, 2025; Krylova et al., 2026). Annual temperature and precipitation anomalies are calculated from country-aggregated ERA5 reanalysis data accessed via the World Bank Climate Change Knowledge Portal (World Bank, 2025a). Specifications (1)–(3) include country and year fixed effects and a country-specific linear time trend; Specifications (2) and (5) additionally include a humidity anomaly. Specifications (4)–(6) retain country fixed effects and country-specific trends but omit year fixed effects, replacing them with cross-sectional (global) weather averages. Specifications (3) and (6) further incorporate macroeconomic controls, including the annual inflation rate, official exchange rate, commodity terms of trade, and log GDP per capita; these columns cover 1990–2018. The official exchange rate is the nominal period-average rate in local currency units per US dollar, and the commodity terms of trade is a GDP-weighted index with 2012 = 100. Significance levels: *, $p < 0.10$; **, $p < 0.05$; ***, $p < 0.01$.

3.1 Main Results

3.1.1 Effect size

Table 2 reports the estimation results from six specifications outlined in Equations (1)–(2), examining the effects of climate anomalies on the Social Progress Index (SPI). The baseline specification defines climate anomalies relative to time-varying historical norms calculated using a 30-year moving average. Robustness results based on alternative 20- and 40-year moving averages are reported in Table A18 of the Online Supplementary Material. The baseline specifications (column 1 estimated using equation (1)) incorporate only temperature and precipitation anomalies, whereas the preferred specifications (column 5 estimated using equation (2)) augment these with humidity anomalies, drawing on prior literature on the nexus between climate and happiness (Connolly, 2013). Local temperature anomalies exhibit a statistically significant negative association with SPI, indicating that deviations from historical norms reduce social progress. The coefficient for local mean-temperature anomalies is -0.0929 in the preferred specification (column 5), with estimates ranging from -0.082 to -0.112 across columns. This indicates that a 1°C temperature deviation from its 30-year historical norms reduces SPI by approximately 0.1 points. Similar negative and significant patterns hold in other columns. Local precipitation anomalies, however, are consistently insignificant.

The inclusion of global weather anomalies[10] (columns 4-6) reveals adverse effects from global temperature anomalies, reflecting global economic interdependence. Column 5 suggests a 1°C deviation in global mean-temperature anomalies reduces SPI by 0.8068 points, with global

[10]Global weather anomalies are constructed as cross-sectional averages of available country-level climate variables within the analytical sample.

precipitation anomalies showing no effect.[11] Robustness holds across $m = 20, 30, 40$: in the preferred specification, the local temperature coefficient is -0.1242 for the 20-year window (Online supplementary material Table A18, Panel A) and -0.1195 for the 40-year window (Panel B), both significant at the 5 per cent level, against -0.0929 for $m = 30$, while precipitation effects remain null.

3.1.2 Post Estimation Diagnostics

Fixed-effects estimation does not require the dependent variable to exhibit high-frequency variation (Dell et al., 2014; Kahn et al., 2021); rather, identification relies on sufficient, non-collinear within-unit variation in the explanatory variables after partialling out the included fixed effects (Dell et al., 2014; Letta & Tol, 2019). Table A4, Online supplementary material, shows that this condition is satisfied in my data. For the aggregate SPI, the within-country standard deviation over the period 1990–2019 is approximately 5 points on a 0–100 scale. Given the long time dimension of the panel ($T \approx 30$), this degree of within-unit variation is sufficient to support fixed-effects identification. Identification in my empirical specification is driven by annual within-country weather variation. Climate anomalies vary year-to-year within countries and are orthogonal to time-invariant country characteristics and global common shocks, which are absorbed by country fixed effects and time fixed effects. In addition, country-specific linear trends absorb deterministic convergence paths and other slow-moving structural factors. As a result, estimated coefficients are identified from deviations around each country's own long-run trajectory. The Social Progress Index and all climate variables are stationary in levels(see Table A7, Online supplementary material).

Residual diagnostics indicate approximately symmetric errors with somewhat heavier tails than the normal (see Figure A3); inference therefore rests on large-sample cluster-robust asymptotics. Residual-based Fisher-ADF tests reject the null that all panels contain a unit root (see Table A12), which is not what a spurious regression would produce. Variance inflation factors are uniformly low (mean VIF = 1.36; maximum = 1.58), implying no multicollinearity-induced instability. Within R-squared ranges from about 0.0002 to 0.0820 across Table 2 to

[11] To contextualise the magnitudes, I use a simple back-of-the-envelope calculation based on the average historical improvement in social progress. SPI increased by approximately 0.5407 points per year over 1990–2019. At this rate, a 1°C local temperature anomaly offsets roughly 2.06 months of typical social progress, while a 1°C global temperature anomaly offsets approximately 17.91 months. The substantially larger global effect may reflect the broader transmission of correlated climate shocks through trade, supply chains, macroeconomic linkages, and shared ecological systems (Desbordes & Eberhardt, 2024; Neal et al., 2025; Bilal & Känzig, 2026; Kumar & Maiti, 2025b). These calculations are illustrative and translate the estimated coefficients into units of average historical SPI improvement.

Table A19 [12]. Collectively, these diagnostics support a causal interpretation of the estimates as being identified from plausibly exogenous climate variation, consistent with the broader climate-economics literature (Kahn et al., 2021; Burke et al., 2015b; Dell et al., 2014; Desbordes & Eberhardt, 2024).

[12]The within-R^2 values reported in this paper are comparable to and consistent with other studies' reported R^2 in different tables of the paper, such as Akyapı et al. (2025); Malpede & Percoco (2024); Mastropietro et al. (2025); Emmerling et al. (2021)

Table (3) 30-Year Weather Anomalies and Social Progress Index: Robustness

Panel A – Reverse Causality (Annual CO_2 Emissions)						
	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
30-yr mean-temp anomaly (local)	−0.0871*	−0.0977**	−0.1063**	−0.0830	−0.0942*	−0.1081**
	(0.0511)	(0.0481)	(0.0489)	(0.0527)	(0.0486)	(0.0493)
30-yr precipitation anomaly (local)	−0.0073	−0.0029	−0.0095	−0.0073	−0.0026	−0.0087
	(0.0123)	(0.0162)	(0.0123)	(0.0130)	(0.0167)	(0.0125)
Global 30-yr temperature anomaly (cross-sectional mean)				−1.1005***	−1.0891***	−0.7240***
				(0.1488)	(0.1383)	(0.1516)
Global 30-yr precipitation anomaly (cross-sectional mean)				0.0311	0.0264	0.0049
				(0.0419)	(0.0531)	(0.0446)
Economic indicators	✗	✗	✓	✗	✗	✓
Lagged CO_2 emissions control	✓	✓	✓	✓	✓	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✗	✗	✗
Observations	4644	4644	3983	4644	4644	3983
Countries (N)	167	167	159	167	167	159
Years (T)	29	29	28	29	29	28
Within R^2	0.0031	0.0033	0.0374	0.0276	0.0277	0.0608
F-statistic	1.7691	1.6594	6.2948	20.7082	16.6806	14.4269
F p-value	0.1550	0.1618	0.0000	0.0000	0.0000	0.0000
Root MSE	1.0996	1.0996	0.9912	1.1397	1.1399	1.0214
Panel B – Driscoll–Kraay Standard Errors						
	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
30-yr mean-temp anomaly (local)	−0.0862	−0.0962	−0.1090*	−0.0820	−0.0929	−0.1123*
	(0.0624)	(0.0665)	(0.0563)	(0.0620)	(0.0664)	(0.0566)

Continued on next page

Table 3 (continued)

30-yr precipitation anomaly (local)	−0.0004	0.0037	−0.0059	−0.0005	0.0039	−0.0053
	(0.0131)	(0.0102)	(0.0124)	(0.0130)	(0.0103)	(0.0122)
Global 30-yr temperature anomaly (cross-sectional mean)				−0.8324*	−0.8068**	−0.6056*
				(0.4102)	(0.3934)	(0.3022)
Global 30-yr precipitation anomaly (cross-sectional mean)				0.0427	0.0304	0.0112
				(0.2327)	(0.2220)	(0.1930)
Economic indicators	✗	✗	✓	✗	✗	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✗	✗	✗
Observations	4814	4814	4098	4814	4814	4098

Panel C – Heterogeneous Mean-Group (MG)

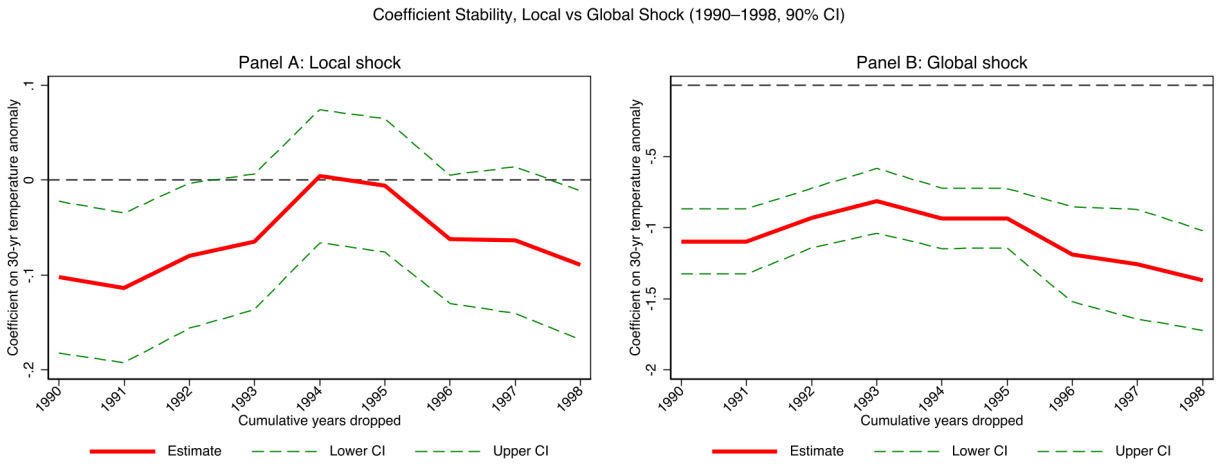
	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
30-yr mean-temp anomaly (local)	−0.2154***	−0.1859***	−0.1134*	−0.0376	−0.0358	−0.0621
	(0.0569)	(0.0609)	(0.0643)	(0.1014)	(0.1032)	(0.0730)
30-yr precipitation anomaly (local)	−0.0834	−0.0852*	0.0043	−0.0331	−0.1325	0.0437
	(0.0766)	(0.0468)	(0.0344)	(0.0874)	(0.1086)	(0.0574)
Global 30-yr temperature anomaly (cross-sectional mean)				−0.9169***	−0.7926***	−0.1714
				(0.1552)	(0.1646)	(0.1306)
Global 30-yr precipitation anomaly (cross-sectional mean)				0.0605	0.0521	0.0033
				(0.0474)	(0.0556)	(0.0458)
Economic indicators	✗	✗	✓	✗	✗	✓
Observations	4 814	4 814	4 080	4 814	4 800	4 070

Continued on next page

Table 3 (continued)

Notes: **Panel A** augments the baseline specification with one lag of territorial CO_2 emissions,following Neal et al. (2025),to address potential reverse causality. **Panel B** reports Driscoll–Kraay (heteroskedasticity- and autocorrelation-consistent) Driscoll & Kraay (1998) standard errors to account for cross-sectional dependence. **Panel C** implements the heterogeneous mean-group estimator, running separate country-level regressions and averaging the resulting slopes Desbordes & Eberhardt (2024). Panel A reports robust standard errors clustered by country. Panel B reports Driscoll–Kraay standard errors. Panel C reports standard errors from the mean-group estimator. The dependent variable is the SPI (Social Progress Imperative, 2025; Krylova et al., 2026). Annual temperature and precipitation anomalies are calculated from country-aggregated ERA5 reanalysis data accessed via the World Bank Climate Change Knowledge Portal (World Bank, 2025a). In Panels A and B, Specifications (1)–(3) include country and year fixed effects and country-specific linear trends; Specifications (4)–(6) omit year fixed effects and include cross-sectional weather averages. Columns 2 and 5 include humidity anomalies as climate controls in all panels. Panel C estimates analogous specifications using the mean-group estimator with country-specific linear trends and no year fixed effects. Specifications (3) and (6) further incorporate macroeconomic controls, including the annual inflation rate, official exchange rate, commodity terms of trade, and log GDP per capita; these columns cover 1990–2018. The official exchange rate is the nominal period-average rate in local currency units per US dollar, and the commodity terms of trade is a GDP-weighted index with 2012 = 100. Annual country-level CO_2 emissions are obtained from the Global Carbon Project's *Global Carbon Budget*, as processed and distributed by Our World in Data (Global Carbon Budget, 2025).Significance levels: *, $p < 0.10$; **, $p < 0.05$; ***, $p < 0.01$.CO_2 refers to territorial annual emissions, measured in million tonnes. The maximum lag for the Driscoll–Kraay standard errors is three (Driscoll & Kraay, 1998).

Figure (2) Coefficient Stability for the 30-Year Temperature Anomaly



Notes: The horizontal axis shows each calendar year (1990–1998) sequentially dropped from the panel, so the leftmost point estimates on 1991–2019 and the rightmost on 1999–2019. Panel A plots the coefficient on the local 30-year temperature anomaly and Panel B the coefficient on its cross-sectional (global) average. In both panels the solid red line is the estimated coefficient and the green dashed lines are its 90% confidence interval. All regressions include contemporaneous precipitation and humidity anomalies (and their cross-sectional means), country fixed effects, a country-specific linear trend, and cluster-robust standard errors at the country level.

I check whether the temporal stability of the estimated coefficients in my preferred specifications has weakened over time, similar to Kahn et al. (2021); Colacito et al. (2019). Specifically, I re-estimate (estimated using equation (2)) repeatedly, each time shifting the starting year of the sample forward by one year, from 1991 through 1998, beyond which the sample becomes too small. Figure 2 shows the resulting estimated coefficients on the 30-year local and global temperature anomaly, coefficient impact estimates in red, with their 90% confidence bands in green. The estimated effects remain broadly stable across subsamples. For the global temperature anomaly, coefficients are consistently negative and statistically significant at the 10% level in all nine subsamples. The local temperature anomaly estimates are also generally stable and negative, with significance at the 10% level in four subsamples. If new technologies or policies had largely offset the harm from temperature anomalies, these coefficients should drift steadily toward zero in later subsamples; their persistent negative coefficient instead suggests only limited evidence of broad adaptation.

3.2 Robustness

I conducted thorough robustness checks to validate the reliability of my findings. First, Specifications (3) and (6) were augmented with a set of macroeconomic control variables, including the annual inflation rate, official exchange rate, commodity terms of trade, and the natural

logarithm of GDP per capita, following the papers by Akyapı et al. (2025); Schötz et al. (2026) and Rehdanz & Maddison (2005). The results demonstrate that the estimated effect of temperature on the Social Progress Index remains quantitatively consistent across these specifications, thereby partially mitigating concerns regarding the influence of macroeconomic factors. Second, one potential concern in climate regressions is the reverse causation between the outcome and the climate indicator. Following the recommendations of Akyapı et al. (2025); Neal et al. (2025), I added one lag of annual carbon dioxide emissions in all specifications and found results hold in both sign and significance. Additionally, regressions of climate anomalies on contemporaneous and lagged SPI yield statistically insignificant coefficients both individually and jointly, with negligible explanatory power, indicating no evidence of reverse causality from social progress to climate (Table A15, Online supplementary material). Third, Panel B of Table 3 re-estimates all six specifications using Driscoll–Kraay standard errors (Driscoll & Kraay, 1998). The coefficients remain negative, although some lose statistical significance, providing broadly suggestive evidence of an adverse effect. Fourth, motivated by recent studies that estimate temperature effects by running separate regressions for each cross-sectional unit (Berg et al., 2024; Desbordes & Eberhardt, 2024), I implement the heterogeneous mean group estimator as in Desbordes & Eberhardt (2024); as reported in Panel C of Table 3, the magnitude of the estimated temperature effect is somewhat larger, while its sign and statistical significance remain consistent with my baseline findings.

The remaining checks are reported in the Online supplementary material. Fifth, in line with recent empirical practice (Schötz et al., 2026), the robustness of this paper's results to potential outliers has been thoroughly examined. I follow the approach of Gilli et al. (2024) and Schötz et al. (2026) by excluding observations in the top 5 percentiles of both the Social Progress Index and temperature anomalies; as shown in (Table A8 Online supplementary material), this paper temperature coefficients remain consistent in sign and significance, with a somewhat larger point estimate. To mitigate the influence of historical extremes, I then restrict the sample to the post-1998 period, where the estimates remain negative throughout (Table A9). Next, following Akyapı et al. (2025), I directly include three additional climate indicators from Akyapi et al. (2025) identified there through a LASSO procedure: the share of grid-days with mean temperature in the 9–12 °C range, the share of grid-days with maximum temperature above 35 °C, and harsh drought prevalence. My principal temperature- SPI estimates are unchanged, harsh drought prevalence enters negatively, and the two temperature-exposure indicators provide only suggestive evidence (Table A10, Online supplementary material). I further re-estimate all specifications using an alternative climate series from the Climatic Research Unit at the

University of East Anglia, sourced from World Bank (2025a), which validates the stability of my results across climate datasets (Table A11, Online supplementary material). Post-estimation diagnostics confirm that the residuals from the preferred specification are stationary and that multicollinearity is not a concern, with all variance inflation factors well below conventional thresholds (Table A12, Online supplementary material).

I next probe the climate–social progress nexus beyond the headline SPI. Panel A of Table A13 Online supplementary material regresses the GDP-net log(SPI) residual, defined as the component of the log Social Progress Index unexplained by income, on 30-year weather anomalies; the temperature coefficient remains negative and statistically significant across all specifications, confirming that the climate effect operates independently of the income channel. Panel B uses the first difference of the Human Development Index (ΔHDI): precipitation anomalies exert a statistically significant negative effect, while temperature coefficients are small and insignificant. Table A14 (Online supplementary material) replaces the rolling 30-year norm with a fixed, country-standardised baseline, expressing each weather variable as the deviation of its level from that country's own 1990 to 2019 mean, divided by its own standard deviation. The temperature coefficient stays negative in all six specifications and is significant in five. Granger-style tests in which climate anomalies are regressed on the contemporaneous SPI and its first five lags yield coefficients that are insignificant both individually and jointly, with negligible explanatory power, indicating no reverse causality running from social progress to climate (Table A15, Online supplementary material); the same conclusion holds when the environmental quality component of the SPI is used in place of the composite index (Table A17, Online supplementary material). Finally, replacing mean with maximum temperature anomalies leaves the findings quantitatively similar (Table A16), as does varying the anomaly window to 20- and 40-year moving averages (Table A18 Online supplementary material).

3.3 Seasonal impact

Using quarterly data, instead of annual averages, may provide a clearer understanding of how temperature changes affect socio-economic outcomes by capturing intra-annual variability. While extensive research has demonstrated the significant effects of seasonal temperature variations on economic indicators, such as higher average summer temperatures reducing employment growth in U.S. counties (Nguyen, 2024) and seasonal economic cycles through intra-annual fluctuations (Linsenmeier, 2024), these studies predominantly focus on aggregate output metrics that overlook broader societal dimensions of well-being.

In this study, a one-degree Celsius deviation from the 30-year moving average historical norms shows a negative effect on the SPI in most quarters (see Table 4 and Online supplementary material Table A19). In the preferred specification, the pooled point estimates are −0.0283 for DJF, −0.0409 for MAM and −0.0438 for JJA, of which only DJF is significant, at the 10 per cent level, while SON is essentially zero[13]. These calendar labels mix seasons across the equator; however, DJF is the cold quarter north of it and the warm quarter south of it. Splitting the panel at the equator (Online supplementary material Table A19) resolves the pattern by local season: the effect falls in winter and spring and is statistically insignificant in summer and autumn. The split also shows that the burden falls disproportionately on the Southern Hemisphere, where the seasonal effects are substantially larger in magnitude in every quarter, and the winter response is the strongest and most significant. In the Northern Hemisphere, the seasonal effects are small and largely insignificant, and the pooled model attributes the effect to December–February only because Northern Hemisphere countries dominate the sample. This concentration, in the colder seasons and in the smaller and poorer Southern sample, is consistent with weather disruptions such as lower farm output and reduced agricultural productivity.[14].

Table (4) Seasonal 30-Year Weather Anomalies and Social Progress Index

	Dependent variable: Social Progress Index					
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: December–February (DJF)						
Local weather anomalies						
DJF temp anomaly	−0.0300*	−0.0291*	−0.0434***	−0.0292*	−0.0283*	−0.0427***
	(0.0153)	(0.0155)	(0.0140)	(0.0158)	(0.0164)	(0.0145)
DJF precip anomaly	0.0091	0.0026	−0.0072	0.0098	0.0028	−0.0061
	(0.0227)	(0.0267)	(0.0222)	(0.0229)	(0.0256)	(0.0220)
DJF humidity anomaly		0.0036			0.0038	
		(0.0096)			(0.0101)	
Global weather anomalies						
Global DJF temp anomaly				−0.2626***	−0.2723***	−0.2348***
				(0.0455)	(0.0455)	(0.0442)
Global DJF precip anomaly				0.3234**	−0.0637	0.0987
				(0.1483)	(0.1845)	(0.1546)
Global DJF humidity anomaly					0.1749***	
					(0.0307)	
Economic indicators	✗	✗	✓	✗	✗	✓

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[13]Seasonal precipitation anomalies yield a different result: anomalies during the June–August (JJA) meteorological quarter have a positive effect on the SPI, whereas annual precipitation anomalies show no statistically significant association.

[14]Hemisphere is assigned from the sign of each country's polygon centroid latitude. The classification is necessarily coarse close to the equator, where 17 of the 167 countries lie within five degrees and no quarter constitutes a meteorological winter, so the local-season interpretation applies less naturally to them.

Table 4 (continued)

	Dependent variable: Social Progress Index					
	(1)	(2)	(3)	(4)	(5)	(6)
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✗	✗	✗
Observations	4814	4814	4098	4814	4814	4098
Countries (N)	167	167	159	167	167	159
Years (T)	30	30	29	30	30	29
Within R^2	0.0007	0.0008	0.0352	0.0090	0.0142	0.0525
F-statistic	1.9598	1.3407	7.0793	15.3000	19.7263	14.8999
F p-value	0.1441	0.2630	0.0000	0.0000	0.0000	0.0000
Root MSE	1.1295	1.1296	1.0079	1.1769	1.1741	1.0395
Panel B: March–May (MAM)						
Local weather anomalies						
MAM temp anomaly	−0.0332	−0.0400	−0.0335	−0.0328	−0.0409	−0.0380
	(0.0324)	(0.0325)	(0.0254)	(0.0334)	(0.0330)	(0.0262)
MAM precip anomaly	−0.0364	−0.0267	−0.0111	−0.0366	−0.0249	−0.0096
	(0.0297)	(0.0351)	(0.0294)	(0.0299)	(0.0360)	(0.0293)
MAM humidity anomaly		−0.0052			−0.0063	
		(0.0116)			(0.0117)	
Global weather anomalies						
Global MAM temp anomaly				−0.2304**	−0.1536*	−0.1927**
				(0.0897)	(0.0779)	(0.0767)
Global MAM precip anomaly				0.4924*	0.0908	0.0354
				(0.2896)	(0.2131)	(0.2857)
Global MAM humidity anomaly					0.1005***	
					(0.0362)	
Economic indicators	✗	✗	✓	✗	✗	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✗	✗	✗
Observations	4814	4814	4098	4814	4814	4098
Countries (N)	167	167	159	167	167	159
Years (T)	30	30	29	30	30	29
Within R^2	0.0007	0.0008	0.0339	0.0039	0.0050	0.0461
F-statistic	1.0359	0.7894	6.1399	3.8413	4.0222	9.0005
F p-value	0.3572	0.5014	0.0000	0.0052	0.0009	0.0000
Root MSE	1.1296	1.1296	1.0086	1.1800	1.1796	1.0430
Panel C: June–August (JJA)						
Local weather anomalies						
JJA temp anomaly	−0.0224	−0.0508	−0.0467	−0.0158	−0.0438	−0.0449
	(0.0373)	(0.0449)	(0.0378)	(0.0387)	(0.0458)	(0.0393)
JJA precip anomaly	0.0694**	0.0863***	0.0369	0.0695**	0.0861***	0.0350
	(0.0277)	(0.0322)	(0.0268)	(0.0278)	(0.0322)	(0.0267)
JJA humidity anomaly		−0.0145			−0.0142	

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Table 4 (continued)

	Dependent variable: Social Progress Index					
	(1)	(2)	(3)	(4)	(5)	(6)
		(0.0128)			(0.0131)	
Global weather anomalies						
Global JJA temp anomaly				−0.8465***	−0.8725***	−0.4873***
				(0.1077)	(0.1206)	(0.1110)
Global JJA precip anomaly				0.1813	0.3521	0.0844
				(0.1323)	(0.2278)	(0.1154)
Global JJA humidity anomaly					−0.0853	
					(0.0593)	
Economic indicators	✗	✗	✓	✗	✗	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✗	✗	✗
Observations	4814	4814	4098	4814	4814	4098
Countries (N)	167	167	159	167	167	159
Years (T)	30	30	29	30	30	29
Within R^2	0.0024	0.0029	0.0352	0.0164	0.0178	0.0512
F-statistic	4.5146	3.2867	6.7345	25.6948	17.4027	12.2551
F p-value	0.0123	0.0222	0.0000	0.0000	0.0000	0.0000
Root MSE	1.1286	1.1284	1.0080	1.1725	1.1720	1.0402
Panel D: September–November (SON)						
Local weather anomalies						
SON temp anomaly	0.0040	0.0047	0.0125	0.0036	0.0042	0.0084
	(0.0314)	(0.0320)	(0.0284)	(0.0307)	(0.0313)	(0.0287)
SON precip anomaly	−0.0307	−0.0328	−0.0419	−0.0308	−0.0326	−0.0390
	(0.0321)	(0.0393)	(0.0307)	(0.0317)	(0.0389)	(0.0303)
SON humidity anomaly		0.0013			0.0011	
		(0.0101)			(0.0104)	
Global weather anomalies						
Global SON temp anomaly				−0.4978***	−0.4693***	−0.2736*
				(0.1239)	(0.1302)	(0.1432)
Global SON precip anomaly				−0.2525*	−0.2078	−0.0429
				(0.1329)	(0.1281)	(0.1604)
Global SON humidity anomaly					−0.0637	
					(0.0450)	
Economic indicators	✗	✗	✓	✗	✗	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✗	✗	✗
Observations	4814	4814	4098	4814	4814	4098
Countries (N)	167	167	159	167	167	159
Years (T)	30	30	29	30	30	29
Within R^2	0.0004	0.0004	0.0344	0.0057	0.0061	0.0458
F-statistic	0.4792	0.3239	5.7084	4.8502	5.1484	5.8434

Continued on next page

Table 4 (continued)

	Dependent variable: Social Progress Index					
	(1)	(2)	(3)	(4)	(5)	(6)
F p-value	0.6201	0.8081	0.0000	0.0010	0.0001	0.0000
Root MSE	1.1297	1.1298	1.0084	1.1789	1.1789	1.0431

Notes: Robust standard errors clustered at the country level are reported in parentheses. The dependent variable is the Social Progress Index (SPI) (Social Progress Imperative, 2025; Krylova et al., 2026). Panels A–D report 30-year moving-average weather anomalies for winter (DJF), spring (MAM), summer (JJA), and autumn (SON), respectively. Temperature, precipitation, and humidity anomalies are calculated from country-aggregated ERA5 reanalysis data accessed via the World Bank Climate Change Knowledge Portal (World Bank, 2025a). Specifications (1)–(3) include country and year fixed effects and country-specific linear time trends. Specification (2) additionally includes the local humidity anomaly. Specifications (4)–(6) retain country fixed effects and country-specific linear trends but omit year fixed effects and instead include annual cross-sectional averages of the corresponding weather anomalies. Specification (5) additionally includes both the local humidity anomaly and its cross-sectional average. Specifications (3) and (6) further include macroeconomic controls: the annual inflation rate, official exchange rate, commodity terms of trade, and log GDP per capita. The official exchange rate is the nominal period-average rate in local currency units per US dollar, and the commodity terms of trade is a GDP-weighted index with 2012 = 100. Significance levels: *, $p < 0.10$; **, $p < 0.05$; ***, $p < 0.01$.

3.4 Persistence

The persistence of climate impacts on the SPI is crucial for understanding the medium-term consequences of climate shocks (Berg et al., 2024). Existing studies often identify persistence by including lagged climate variables (Nguyen, 2024). In this paper, I establish the medium-term persistence of climate impacts on the SPI using two complementary approaches. First, I estimate my main specifications with up to three lags of 30 yr moving average temperature anomalies to examine whether delayed effects are statistically significant or exhibit sign reversals. Second, I implement Jordà (2005) local projection method to trace the dynamic response of SPI to a climate shock over future horizons, providing a flexible assessment of temporal impact patterns.

In my primary specifications, I incorporate three lags of temperature to evaluate the delayed effects of 30-year weather anomalies on the SPI, with results presented in Table 5. For local weather anomalies, the contemporaneous mean temperature anomaly exhibits negative and statistically significant coefficients. The lagged mean temperature terms (Lag 1, Lag 2, and Lag 3) also show negative coefficients, many of which are statistically significant, such as -0.111** in Column 2 and -0.166*** in Column 4 of Table 5, suggesting persistent delayed impacts. In contrast, local precipitation and humidity anomalies are generally non-significant. For global weather anomalies, the mean temperature anomaly shows strongly negative and statistically significant coefficients, while global precipitation and humidity anomalies exhibit smaller, less consistent effects. These findings show that lagged temperature effects are significant, suggesting persistence in climate impacts on SPI.

Employing the Jordà (2005) Local Projections approach, I explore the persistence of SPI responses to climate shocks, estimating impulse responses to a one-degree Celsius shock across multiple horizons, as detailed in Section 2.2.2. Results, depicted in Figure 3, suggest the impact of 30-year temperature anomalies on SPI across four panels: (a) annual local, (b) annual global, (c) DJF local, and (d) DJF global temperature anomalies. Each panel plots horizons ($h = 0$ to 4) against SPI impulse responses, with point estimates (solid line), 68% (dark-blue band) and 90% (light-blue band) confidence intervals. Annual local temperature anomalies show suggestive evidence of persistent declines in SPI, while global temperature anomalies produce larger and statistically significant negative effects over the four-year horizon. DJF results follow a similar pattern, with local shocks indicating adverse effects and global shocks showing a more gradual but statistically significant decline in SPI. These findings confirm that climate shocks exert broadly significant, persistent effects on SPI over the 4-year horizon.

Taken together, the lagged temperature approach, similar to Nguyen (2024), and the local-projection approach, similar to Akyapı et al. (2025), my results suggest that temperature deviations from long-run norms indicate a persistent negative impact that cannot be fully offset within a four-year window. This finding aligns with the macro-climate literature, where lagged temperature effects on GDP are typically weak but level effects remain persistent (Dell et al., 2014). More recent evidence from Kahn et al. (2021) similarly reports persistence in output losses.

3.5 Heterogeneity

The effects of climate change are anticipated to be heterogeneous across nations, owing to differences in geography and climatic vulnerabilities (Letta & Tol, 2019). I investigate whether findings from the complete panel dataset of countries differ from those emerging from examinations of homogeneous national subgroups (Equation (2) estimated for each subgroup). This exercise serves dual purposes: it acts as a robustness measure and also a means to explore pathways through which climate-related shocks heterogeneously impact the Social Progress Index. To assess heterogeneity in the temperature-Social Progress Index relationship, I partition the sample following a seminal paper Akyapı et al. (2025) by income (World Bank high- vs. low-income), climate regime (mean annual temperature $\geq 22.1°C$ vs. $< 22.1°C$), economic structure (above- vs. below-median agricultural share of GDP), and institutional quality (above- vs. below-median V-Dem democracy scores), further distinguishing "agricultural-hot" and "agricultural-cold" groups to capture the joint effects of climate and agrarian dependence. I also

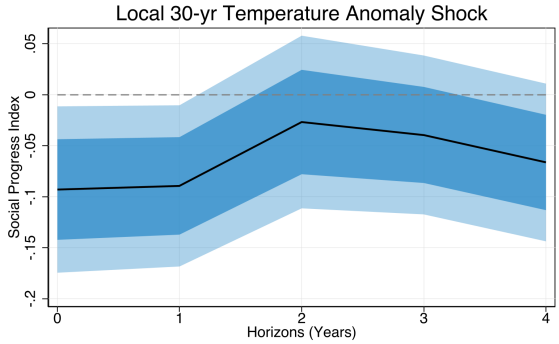
Table (5) 30-Year Weather Anomalies and Social Progress Index: Distributed Lag (Three Lags)

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
Local weather anomalies						
Mean-temp anomaly (t)	−0.0716	−0.0913*	−0.0737*	−0.0815*	−0.1027**	−0.0857*
	(0.0459)	(0.0494)	(0.0434)	(0.0472)	(0.0495)	(0.0436)
Mean-temp anomaly ($t-1$)	−0.0719	−0.1114**	−0.0731	−0.1660***	−0.2035***	−0.1438***
	(0.0470)	(0.0457)	(0.0451)	(0.0444)	(0.0438)	(0.0435)
Mean-temp anomaly ($t-2$)	0.0196	−0.0287	−0.0547	−0.1059**	−0.1597***	−0.1493***
	(0.0497)	(0.0498)	(0.0445)	(0.0473)	(0.0481)	(0.0439)
Mean-temp anomaly ($t-3$)	0.0162	−0.0441	−0.0362	−0.0238	−0.1042**	−0.0506
	(0.0484)	(0.0487)	(0.0429)	(0.0432)	(0.0446)	(0.0416)
Precipitation anomaly	−0.0130	−0.0076	−0.0128	−0.0098	−0.0037	−0.0089
	(0.0120)	(0.0143)	(0.0122)	(0.0125)	(0.0150)	(0.0123)
Humidity anomaly		−0.0141			−0.0162	
		(0.0160)			(0.0163)	
Global weather anomalies						
Global mean-temp anomaly				−0.9856***	−1.0208***	−0.7322***
				(0.1238)	(0.1349)	(0.1216)
Global precipitation anomaly				0.1588***	0.1807***	0.0615
				(0.0457)	(0.0428)	(0.0477)
Global humidity anomaly					−0.0920	
					(0.0805)	
Economic indicators	✗	✗	✓	✗	✗	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✗	✗	✗
Observations	4313	4313	3736	4313	4313	3736
Countries (N)	167	167	159	167	167	159
Years (T)	27	27	26	27	27	26
Within R^2	0.0027	0.0118	0.0365	0.0306	0.0446	0.0646
F-statistic	1.6153	2.3495	3.3644	13.4406	10.6417	11.7694
F p-value	0.1238	0.0082	0.0002	0.0000	0.0000	0.0000
Root MSE	1.0310	1.0268	0.9388	1.0658	1.0588	0.9666

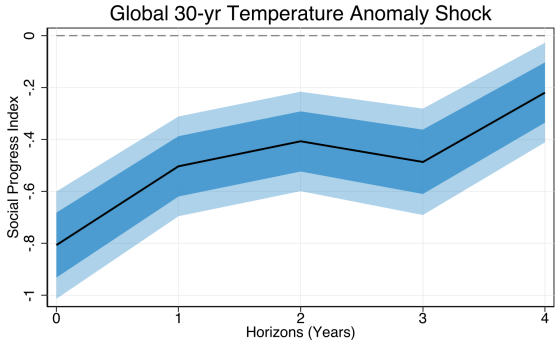
Notes: Robust standard errors clustered at the country level are in parentheses. The dependent variable is the SPI (Social Progress Imperative, 2025; Krylova et al., 2026). Specifications (1)–(3) include country and year fixed effects and a country-specific linear time trend. Specifications (4)–(6) retain country fixed effects and country-specific linear trends but omit year fixed effects, replacing them with contemporaneous cross-sectional (global) weather averages. Each specification includes the contemporaneous local temperature anomaly and its first three annual lags to capture dynamic responses. All specifications also include the contemporaneous precipitation anomaly and its first three annual lags. Specifications (2) and (5) additionally include the contemporaneous humidity anomaly and its first three annual lags; Specification (5) also includes the contemporaneous cross-sectional humidity average. Coefficients on precipitation and humidity anomaly lags are suppressed for clarity. Specifications (3) and (6) further include macroeconomic controls, including the annual inflation rate, official exchange rate, commodity terms of trade, and log GDP per capita. The official exchange rate is the nominal period-average rate in local currency units per US dollar, and the commodity terms of trade is a GDP-weighted index with 2012 = 100. Significance levels: $^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$.

Figure (3) Persistence of 30-Year Temperature Anomaly Shocks on Social Progress Index

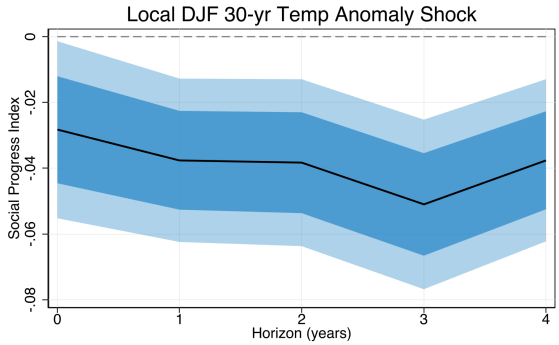
(a) Annual Local Temperature Anomaly



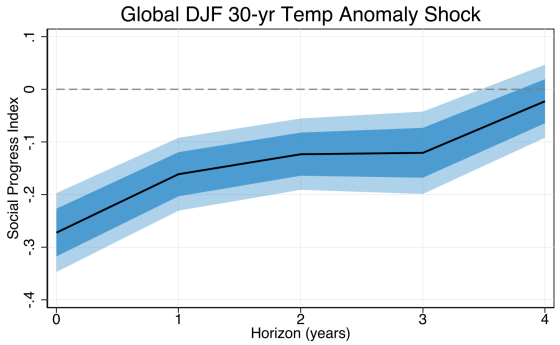
(b) Annual Global Temperature Anomaly



(c) DJF Local Temperature Anomaly



(d) DJF Global Temperature Anomaly

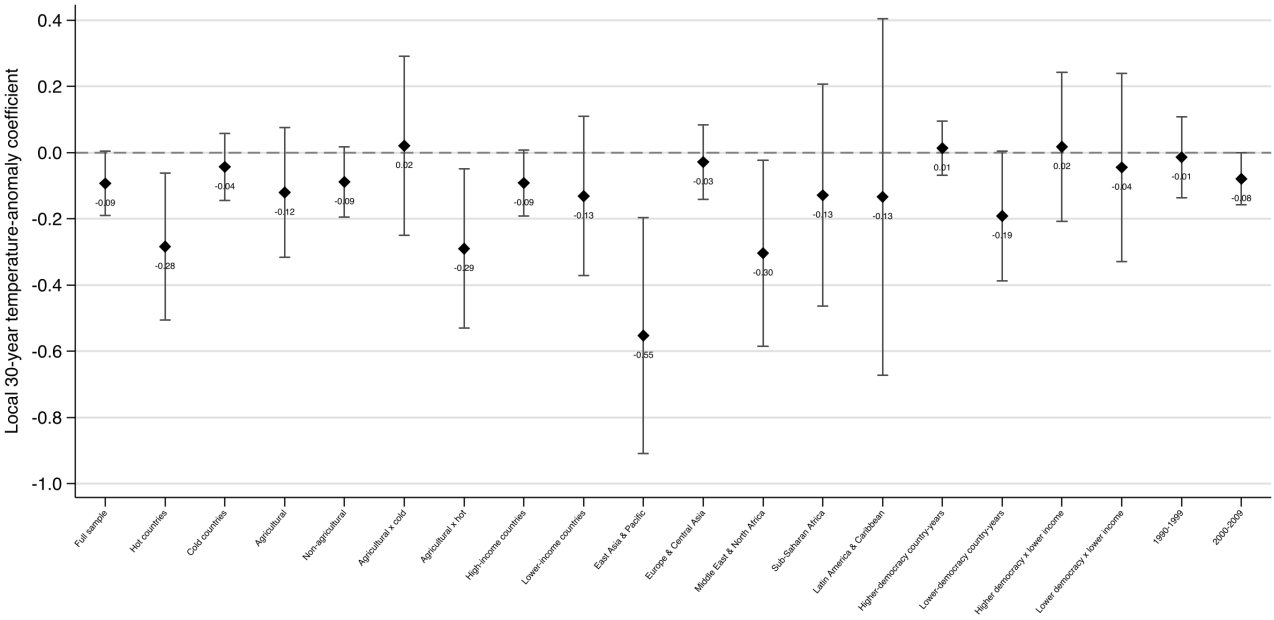


Notes: Each figure shows horizons $h = 0, \ldots, 4$ on the x-axis and the estimated impulse response of temperature anomalies on the Social Progress Index on the y-axis. The solid black line plots the point estimates; the dark-blue inner band is the 68% confidence interval and the light-blue outer band the 90% confidence interval. All panels use local linear projections for both annual and DJF temperature anomalies and include controls for contemporaneous precipitation and humidity anomalies (and their global cross-sectional means), country fixed effects, and a country-specific linear time trend. Standard errors are clustered at the country level. The sample is 167 countries over 1990–2019. Each horizon drops one year, so the estimation sample falls from 4,814 country-year observations at $h = 0$ to 4,647, 4,480, 4,313 and 4,146 at $h = 1$ through $h = 4$; the number of countries is 167 throughout.

assign each country to a World Bank macro-region, reporting the five with sufficient coverage, and split the data into two decades (1990–1999 vs. 2000–2009). For every subgroup, I re-estimate my baseline fixed-effects specification (estimated using equation (2)). Detailed definitions and sample sizes for each subgroup appear in the notes to Figure 4.

Figure 4 shows substantial heterogeneity in the estimated effect of the 30-year local temperature anomaly on SPI. A 1°C increase in local temperature anomaly is associated with a statistically significant decline of about 0.28 SPI points in hot countries. A similar pattern appears across economic structures. Agricultural economies have a more negative point estimate than non-agricultural economies. The "agricultural-hot" subgroup, where both high dependence on agriculture and high temperature are present, shows the decline in SPI numbers, as local

Figure (4) Impact of the 30-Year Local Temperature Anomaly Across Groups



Notes: The figure reports the estimated coefficient for the 30-year local temperature anomaly. All subgroup regressions use the same preferred specification; only the sample restriction changes. All models regress the SPI on temperature, precipitation, and humidity anomalies and their cross-sectional averages(see 2). Each specification incorporates country fixed effects and country-specific linear trends. Standard errors are robust and clustered at the country level, and the bars are 95% confidence intervals. The full analytical sample includes 4,814 country-year observations covering 167 countries from 1990 to 2019. Subgroup definitions and respective sample sizes are as follows: High-temperature (n = 2,395; mean annual temperature $\geq 22.1°C$), Low-temperature (n = 2,419; mean annual temperature $< 22.1°C$); Agricultural (n = 2,423; agriculture share above median in 2002), Non-agricultural (n = 2,262; agriculture share below median; the remaining 129 country-years have no agricultural-share classification and enter neither group); Interaction of Agricultural and Temperature subgroups: Agricultural×Cold (n = 938), Agricultural×Hot (n = 1,485); High-income (n = 2,697; World Bank classification as upper middle" or high" income), Low-income (n = 2,117; classified as lower middle" or low" income); Regional subgroups: East Asia & Pacific (n = 587), Europe & Central Asia (n = 1,363), Middle East & North Africa (n = 547), Sub-Saharan Africa (n = 1,296), Latin America & Caribbean (n = 745); Democracy subgroups classified by V-Dem index: High democracy (n = 2,404; above median), Low democracy (n = 2,398; below median); Combined democracy-income subgroups: High democracy & Low-income (n = 564), Low democracy & Low-income (n = 1,549); Temporal splits: 1990–1999 (n = 1,516), 2000–2009 (n = 1,647).

warming decreases yields(productivity) and global warming increases input costs and market volatility. Non-agricultural economies have smaller impacts from local temperature anomalies. The estimated coefficient for poorer economies is more negative, suggesting that higher income and adaptive capacity may moderate the social consequences of persistent warming.

The institutional split points in a similar direction: high-democracy countries have an estimate close to zero, whereas low-democracy countries record a considerably more negative coefficient (around -0.19). This provides suggestive evidence that institutional capacity may influence countries' ability to absorb long-run climatic stress. At the regional level, the effects are heterogeneous in both magnitude and statistical significance. East Asia & Pacific records the largest negative coefficient (approximately -0.55), which is statistically significant. Middle East & North Africa also exhibits a relatively large negative coefficient (approximately -0.30) that is statistically significant. In contrast, the estimated coefficients for Sub-Saharan Africa and Latin America & Caribbean are negative (around -0.13) but statistically insignificant. Europe & Central Asia also record a small negative and statistically insignificant coefficient. Thus, the regional estimates indicate that the adverse effects of persistent warming are not uniformly statistically significant across the Global South; rather, statistically significant effects are concentrated in particular regions, most notably East Asia & Pacific and Middle East & North Africa.

Overall, I find that a one-degree Celsius deviation in local temperature anomalies has a greater impact in countries with hotter climates, lower income levels, those in the Global South, weaker institutional frameworks, and higher dependence on agriculture.

4 Potential Mechanism: Sub-component Analysis

In this section, I test the propositions derived from the conceptual framework developed in Sections A and B of the Online Supplementary Material by estimating separate regressions for each subcomponent, following Malpede & Percoco (2024); Mastropietro et al. (2025). In that framework, local and global temperature anomalies lower agricultural productivity, which reduces output, private consumption, and the public resources available for services. These resource losses can then affect Basic Human Needs, Foundations of Wellbeing, and Opportunity. The framework therefore predicts adverse responses across the three SPI pillars.

Broadly, the SPI subcomponents decline with both local and global temperature anomalies, driven by falling agricultural productivity, though the global channel is the more consistent of

the two[15]. Figure 5 presents impulse response functions estimated using the local projection method of Jordà (2005) from equation (3). Local temperature shocks produce small and largely statistically insignificant responses across Basic Human Needs and its subcomponents, whereas global temperature anomalies generate a clear and significant short-run decline. The BHN aggregate falls by roughly -0.34 on impact and largely recovers to about -0.03 by $h = 2$, with the adverse response concentrated mainly in Nutrition and Basic Medical Care.

Panel (b) shows that Foundations of Well-being experiences the most persistent damage among the three SPI pillars. Local temperature anomalies generate a modest adverse response, reaching about -0.11 at $h = 1$ and significant only at the 68 per cent confidence level, before fading by $h = 2$. Global temperature anomalies produce a much larger and persistent decline of about -1.30 on impact, remaining statistically significant through $h = 2$. The global effect is driven particularly by Access to Information and Communications and short-run losses in Health and Wellness, while Environmental Quality shows weaker and imprecise responses[16].

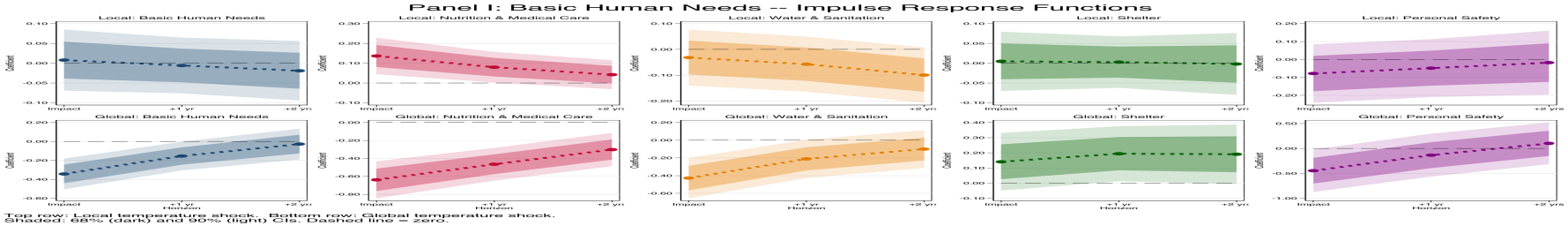
Panel (c) shows that Opportunity exhibits a negative short-run response to temperature anomalies. Local temperature anomalies reduce the aggregate by about -0.23 on impact and remain statistically significant at $h = 1$, before attenuating by $h = 2$; this pattern is driven mainly by Personal Rights and Inclusiveness. Global temperature anomalies generate a larger impact decline of about -0.78, but the aggregate response becomes statistically insignificant thereafter. Personal Rights records the largest global impact among the subcomponents at about -1.36, while Personal Freedom and Choice and Access to Advanced Education also show sizeable short-run declines[17].

[15]Taking the agricultural-productivity channel (Pal, 2026) established in the literature as given, I focus on how temperature-induced resource losses affect individual SPI subcomponents.

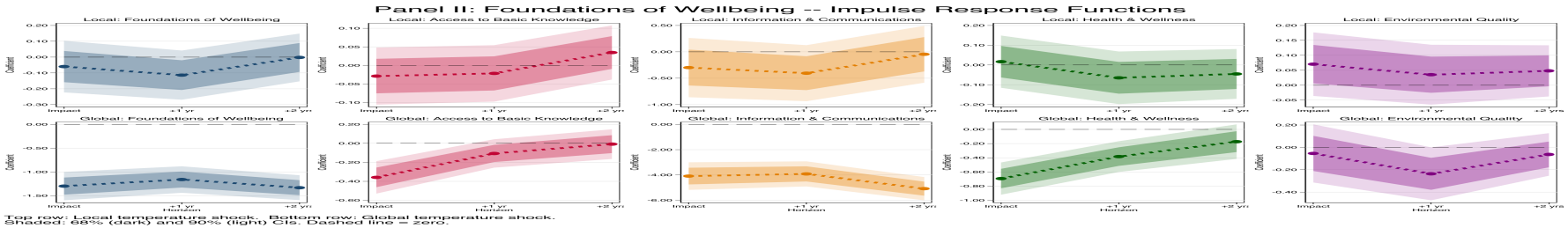
[16]The indicators comprising the Environmental Quality sub-component are more plausibly outcomes of temperature shocks than determinants of those shocks. See Table A17 for details.

[17]A large body of evidence links climate variation to conflict and institutional disruption. Hsiang et al. (2013) find that a one-standard-deviation rise in temperature increases interpersonal conflict by 4% and intergroup conflict by 14%. Using a larger sample, Burke et al. (2015a) report smaller but consistent effects. Climate-driven economic stress can also raise grievances, weaken trust in institutions (Kumar & Maiti, 2025a), and increase the risk of democratic backsliding. (Burke et al., 2015a)

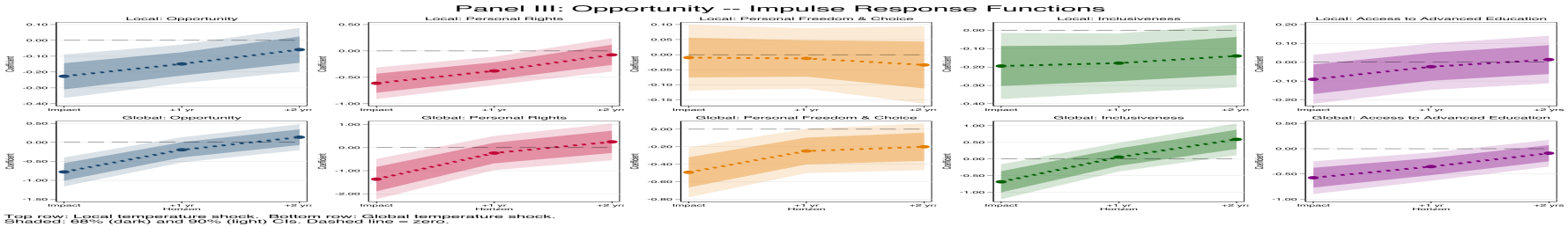
Figure (5) 30-Year Temperature Anomalies and Social Progress Sub-Indices (1990–2019)



(a) Basic Human Needs



(b) Foundations of Well-being



(c) Opportunity

Notes: This figure reports impulse response functions (IRFs) from local projections at horizons $h = 0, 1, 2$ years for each sub-component of the SPI. Panel (a) covers Basic Human Needs and its sub-indicators: *Nutrition and Basic Medical Care* (NBMC), *Water and Sanitation* (WS), *Shelter* (SH), and *Personal Safety* (PS). Panel (b) covers Foundations of Well-being: *Access to Basic Knowledge* (ABK), *Access to Information and Communications* (AIC), *Health and Wellness* (HW), and *Environmental Quality* (EQ). Panel (c) covers Opportunity: *Personal Rights* (PR), *Personal Freedom and Choice* (PFC), *Inclusiveness* (INC), and *Access to Advanced Education* (AAE). Within each panel, the top row plots the coefficient on the *local* 30-year temperature anomaly, and the bottom row plots the coefficient on the *global-mean* (cross-sectional average) temperature anomaly; both are estimated jointly in the same regression. All specifications include local precipitation and humidity anomalies and their global-mean counterparts as controls, along with country fixed effects and country-specific linear time trends. Robust standard errors are clustered at the country level. Shaded bands denote 68% (dark) and 90% (light) confidence intervals. The dashed line marks zero. The sample covers 1990–2019 and comprises 167 countries: 4,814 country-year observations at $h = 0$, 4,647 at $h = 1$ and 4,480 at $h = 2$, the panel losing one year at each horizon. Weather variables are constructed from ERA5 reanalysis data (World Bank CCKP) (World Bank, 2025a).

5 Conclusion and Policy Implications

Using the SPI from Social Progress Imperative (2025) across 167 countries from 1990 to 2019, this study identifies a significant negative impact of temperature on well-being and reveals that a 1°C deviation from historical temperature norms reduces the SPI by approximately 0.1 points, while a 1°C increase in global mean temperature anomalies leads to a more substantial decline of 0.8068 points. Precipitation anomalies, both local and global, show no statistically significant effect on well-being. Colder seasons have larger adverse effects on well-being than anomalies in other seasons. Poorer regions, hotter climates, the Global South, and countries with weaker institutional quality experience disproportionate adverse effects from local temperature deviations, worsening challenges to social progress. I provide suggestive evidence of three primary transmission channels: negative impacts on basic human needs, foundations of well-being, and opportunities. Employing Jordà (2005)local projections, the study demonstrates that the effects of temperature anomalies broadly persist over medium-term horizons. By integrating both local and global temperature anomalies, the study captures aggregate time-series variation in global temperatures similar to Neal et al. (2025); Bilal & Känzig (2026); Desbordes & Eberhardt (2024).

To mitigate the adverse effects of temperature on societal well-being, policymakers must implement measures that recognise global interconnectedness via trade, investment, and financial markets. First, the markedly larger effect of global mean temperature anomalies on the SPI compared to local deviations indicates that domestic adaptation efforts alone are insufficient to safeguard societal well-being; effective climate policy must prioritise ambitious multilateral mitigation commitments alongside national adaptation. The COP29 agreement to triple climate finance to developing countries, reaching USD 300 billion annually by 2035, represents progress in this direction, yet my results suggest that even these commitments may understate what is needed, given the magnitude of global-channel effects on non-economic dimensions of well-being. Strengthen social protection systems, including healthcare and income support, to shield marginalised groups from disproportionate impacts. Second, the heterogeneous impacts I document whereby poorer countries, hotter climates, and nations with weaker institutional quality suffer disproportionately larger SPI declines imply that governance reform and institutional capacity-building are not separate from the climate adaptation agenda but are essential preconditions for it (Kumar & Maiti, 2025a). Persistent temperature effects in my local projection estimates imply that climate shocks generate cumulative medium-term welfare losses (Bilal & Känzig, 2026; Neal et al., 2025; Berg et al., 2024). Delayed mitigation, therefore,

represents not postponed action but escalating harm to societal well-being, increasingly difficult to offset through adaptation, and strengthens the case for viewing climate finance as a long-term investment in sustained human progress rather than short-term relief (Stiglitz et al., 2009; IPCC, 2023; Emmerling et al., 2021; Fleurbaey & Blanchet, 2013).

This paper's findings highlight several limitations and future research directions. First, while this paper focused on temperature effects, future studies should examine natural disasters' impacts on well-being (Yang et al., 2018). Second, subnational data, if available, could reveal localised heterogeneity, potentially using remote sensing to identify climate-social progress intersections similar to Malpede & Percoco (2024); Mastropietro et al. (2025). Third, future research may use dynamic panel models, such as panel ARDL similar to Kahn et al. (2021), which could capture short- and long-term climate effects. A common concern is the correlation between beyond-GDP indicators and income (Fehder et al., 2018, 2019). To address this, I regress SPI on GDP and use the residual, social progress orthogonal to income, as the dependent variable. The results persist, showing that temperature anomalies undermine non-income dimensions of well-being.

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ONLINE SUPPLEMENTARY MATERIAL: Beyond GDP: Quantifying Heterogeneous Impact of Climate Change on Social Progress

A Related Literature

A.1 Climate Change and Social Progress

A.1.1 Beyond GDP Metrics and the Construction of the Social Progress Index

While GDP is a common metric for economic impact, it inadequately captures the true effects of climate change (van den Bergh & Botzen, 2018; Barrington-Leigh & Galbraith, 2019; Emmerling et al., 2021). GDP focuses on the market value of goods and services. High GDP does not guarantee shared prosperity, as many countries still struggle with the effects of climate change (Haq, 1995; UNDP, 2024; Malpede & Percoco, 2024). Focusing on economic indicators(GDP per capita)as in HDI overlooks critical non-economic drivers of well-being, potentially delineating policymakers from broader aspects of quality of life (Stiglitz et al., 2009; Rojas & García-Vega, 2017; Peiró-Palomino et al., 2023) [1].In contrast, the SPI, developed by the non-profit Social Progress Imperative (2025), offers an alternative by measuring development through three pillars: basic human needs, foundations of well-being, and opportunities, all of which are independent of economic factors

As defined by Peiró-Palomino et al. (2023); Pörtner et al. (2022); Social Progress Imperative (2025); Annoni & Bolsi (2020)

[1]Multiple measures of well-being exist as beyond GDP, including the Genuine Progress Indicator (GPI), which adjusts consumption for inequality and environmental costs; the Ecological Footprint, which tracks resource demand against biocapacity; the Human Development Index (HDI), combining income, health, and education; Gross National Happiness (GNH); and the Happy Planet Index (HPI) (Kubiszewski et al., 2013; Gundimeda & Atkinson, 2024). However, a principal component analysis by Wang & Chen (2022) of the twelve such indicators suggests that they most strongly correlate with GDP per capita. The SPI is preferred here because it *exclusively* uses social and environmental outcome indicators, deliberately excluding income (Krylova et al., 2026).

> Social progress is the capacity of a society to meet the basic human needs of its citizens, establish the building blocks that allow people and communities to enhance and sustain the quality of their lives, and create the conditions for all individuals to reach their full potential.

The SPI employs a systematic ten-step methodology to transform raw indicators into a composite measure of societal well-being scaled from 0 to 100 (Krylova et al., 2026; Annoni & Bolsi, 2020; Fehder et al., 2018; O'Sullivan, 2014; UNDP, 2024; Porter et al., 2014). Missing data are addressed through a tiered imputation strategy utilising carry-forward/backward techniques (maximum 5 years), linear interpolation (maximum 14 years) (Krylova et al., 2026; Annoni & Bolsi, 2020; Fehder et al., 2018; O'Sullivan, 2014; Porter et al., 2014). Outliers and skewed distributions are treated through statistical testing, applying square root transformations when skewness coefficients exceed 2.0 or capping at the 99th/1st percentile when coefficients range between 1.5-2.0, alongside theoretical boundary caps for specific indicators based on measurement units or international standards (Krylova et al., 2026; Annoni & Bolsi, 2020; Fehder et al., 2018; O'Sullivan, 2014; UNDP, 2024; Porter et al., 2014). Best and worst-case scenarios are established using pre-defined scales for bounded indicators (Peiró-Palomino et al., 2023; Stiglitz et al., 2009; Porter et al., 2014). Following indicator inversion to ensure directional consistency (higher values indicating superior outcomes), all indicators undergo z-score standardisation to enable cross-metric comparability before aggregation. Component scores are calculated using Principal Component Factor analysis, which generates data-driven weights accounting for inter-indicator correlations and unique variance contributions [2], then scaled to 0-100 through min-max normalisation (Krylova et al., 2026; Annoni & Bolsi, 2020; Fehder et al., 2018; O'Sullivan, 2014; UNDP, 2024; Porter et al., 2014). These 12 components are arithmetically averaged into 3 dimensions (Basic Human Needs, Foundations of Wellbeing, Opportunity), which are subsequently averaged to produce the final index score (Peiró-Palomino et al., 2023; Porter et al., 2014).

[2] Krylova et al. (2026); Social Progress Imperative (2025) validate the SPI 1990–2020 through multiple statistical tests, including Cronbach's Alpha (above 0.7), Kaiser-Meyer-Olkin adequacy (above 0.5), and single-factor dominance for all components. They recalculate the Index using three alternative aggregation methods and report Spearman rank correlations of at least 0.96 with the baseline. Similarly, Peiró-Palomino et al. (2023) test their SPI using alternative weighting and aggregation approaches, finding rank correlations between 0.953 and 0.998 across methods. Both studies address missing data through systematic imputation procedures and confirm that the Index results are not sensitive.

A.2 Heterogeneous impact

Temperature affects well-being unevenly across regions contingent on income, temperature, institutions and geography. Poorer countries, especially those in hot, resource-poor areas, face greater climate risks. Developing economies often rely on agriculture, which is directly impacted by rising temperatures and extreme weather (Letta & Tol, 2019; Desbordes & Eberhardt, 2024). I contribute to the second strand of the literature by examining whether poorer and hotter regions, predominantly in the Global South, experience more severe adverse impacts of temperature than wealthier regions.

A.3 Potential Mechanism

This section presents a conceptual framework showing that temperature anomalies reduce social progress and well-being through a decline in agricultural productivity (Colmer, 2021a; Alem & Colmer, 2022; Pal, 2026)(for the detailed derivation see Sections A and B of this supplement). Lower agricultural productivity adversely affects education (Graff Zivin et al., 2018), health (Zhang et al., 2024; Deschenes, 2014), nutrition (Fanzo et al., 2025), basic medical care, personal rights (Burke et al., 2015), and personal freedom (Burke et al., 2024; Hsiang et al., 2013), ultimately reducing the overall well-being and social progress of a country (Colmer, 2021b). Local and global temperature anomalies enter the simple conceptual framework only through the agricultural productivity channel (Colmer, 2021a; Alem & Colmer, 2022; Pal, 2026), represented by the damage function $A_{it} = \bar{A}_i \exp(-\delta_\tau \tau_{it} - \delta_g g_t)$, while all other equations remain climate neutral (Colmer, 2021b). Output $Y_{it} = A_{it} L_i$ is divided into private consumption $C_{it} = (1 - \theta_i) Y_{it}$ and public revenue $T_{it} = \theta_i Y_{it}$. The government allocates public revenue across the three SPI pillars (Kumar & Maiti, 2025), namely Basic Human Needs, Foundations of Wellbeing, and Opportunity, using fixed shares s_B, s_F, s_O. Each pillar is modelled as a Cobb–Douglas function of private consumption and public expenditure, while the overall SPI is the geometric mean of the three pillars, and well-being increases with SPI. The closed form solution gives $\ln J_{it} = c_J + \kappa_J \ln A_{it}$ for all aggregates $J \in B, F, O, \text{SPI}, \text{WB}$, where $\kappa_J > 0$. The framework yields two implications. The first is testable and is taken to the data in Section 4 of the main text: all SPI sub-components decline with higher local and global temperature anomalies. The second, that these effects operate through a decline in agricultural productivity, is maintained as an assumption rather than tested here, since the framework takes the agricultural-productivity channel as given.

Table (A1) Climate and Well-Being: Cross-Country and Regional Studies

Study	Sample	Outcome	Climate variables	Estimator	Key findings
Rehdanz & Maddison (2005)	67 countries, 1972–2000 (185 obs.)	Average happiness, 1–4 scale	Mean/extreme temperature and precipitation; hot, cold, wet and dry months	Panel-corrected least squares	Warmer coldest months and cooler hottest months are associated with greater happiness; more dry months reduce happiness. Limited warming benefits higher-latitude countries but harms already-hot countries.
Maddison & Rehdanz (2011)	79 countries, WVS, 1981–2008 (158 obs.)	Average life satisfaction, 1–10 scale	Heating and cooling degree-months (base 18.3 °C)	OLS with regional dummies	More degree-months are associated with lower life satisfaction; the IPCC A2 scenario implies large losses in Africa and modest gains in Northern Europe.
Malpede & Percoco (2024)	1,564 regions, 135 countries, 1990–2015	Sub-national HDI and components	Temperature, precipitation and potential evapotranspiration (PET)	OLS: region/year FE and country trends; long-run cross-section with country FE	Long-run temperature and precipitation effects on HDI are insignificant; higher PET lowers HDI and is negatively associated with life expectancy and completed schooling.
Mastropietro et al. (2025) (preprint)	1,773 regions, 1990–2020; projections to 2100	HDI components: income, schooling and life expectancy	Mean temperature, rainfall, rainfall extremes, wet days, temperature variability and heatwaves	Region/year FE, country quadratic trends and distributed lags	Climate shocks have predominantly adverse effects across all three HDI components; projected global HDI loss reaches 3.9% under SSP5–8.5 by 2100.
Al-Maadid et al. (2025)	6 GCC countries, 2005–2024	HDI	Climate Risk Index; surface-temperature change	Time-varying interactive FE	Climate-risk effects are insignificant in 2005–2010 and intensify sharply after 2020; ICT is positively associated with HDI.

Table (A2) Climate and Well-Being: Individual-Level Studies

Study	Sample	Outcome	Climate variables	Estimator	Key findings
Connolly (2013)	US, Princeton Affect and Time Survey, May–Aug. 2006 (3,982 respondents)	Life, home, health and job satisfaction; episode affect	Daily temperature and precipitation	OLS regressions	Rain lowers life satisfaction; cooler summer days raise happiness and net affect. Weather responses are substantially stronger for women.
Frijters et al. (2020)	US, Gallup Daily Poll, about 2 million respondents from 2008	Self-reported health, life satisfaction and emotions	Daily temperature and precipitation	Cross-sectional regressions	Estimated weather effects are non-robust and small; a 2 °C warming implies an equivalent income variation of at most 0.3% of income.
Li et al. (2024)	China, CHARLS panel, adults aged 50+	Life satisfaction	Monthly exposure to high and extremely high temperatures	Individual FE and city×interview-year-month FE	Extreme heat lowers life satisfaction; one additional extremely hot day per summer month is equivalent to about 672 yuan lower monthly household expenditure. Early-life resources improve adaptation.

Table (A3) Variable Definitions, Units and Data Sources (167 countries, 1990–2019)

Variable	Definition (unit)	Primary data source
A. Social Progress Index (SPI) indicators (0–100 scale)		
Aggregate scores		
Social Progress Index	Arithmetic mean of three dimensions (Basic Human Needs, Foundations of Wellbeing, Opportunity)	Krylova et al. (2026); Social Progress Imperative (2025)
B. Climate variables		
Annual levels		
Annual precipitation	Calendar-year total precipitation (100 mm; one unit = 100 mm).	ERA5 via World Bank Climate Change Knowledge Portal World Bank (2025)
Annual mean temperature	Mean daily 2 m air temperature (°C).	ERA5 via World Bank Climate Change Knowledge Portal World Bank (2025)
Annual mean relative humidity	Mean daily 2 m relative humidity (%).	ERA5 via World Bank Climate Change Knowledge Portal World Bank (2025)
Moving-average climate anomalies (annual)		
k-year precipitation anomaly	$\tilde{P}_{k,t} = \left[P_t - \bar{P}^*_{k,t-1}\right]$ (100 mm), $k \in \{20, 30, 40\}$	Author calc. from ERA5 World Bank (2025)

Continued on next page

Variable	Definition (unit)	Primary data source
k-year mean-temperature anomaly	$\tilde{T}_{k,t} = \left[T_t - \bar{T}^*_{k,t-1}\right]$ (°C)	Author calc. from ERA5 World Bank (2025)
k-year humidity anomaly	$\tilde{H}_{k,t} = \left[H_t - \bar{H}^*_{k,t-1}\right]$ (%)	Author calc. from ERA5 World Bank (2025)

Table (A4) Panel descriptive statistics, 1990–2019 (167 countries)

Variable	Component	Mean	SD	Min	Max	Notes
Social Progress Index	overall	62.2245	17.5160	19.6100	94.1200	$N = 4\,814$
	between	–	16.9591	29.1867	89.9117	$n = 167$
	within	–	4.9961	46.1895	79.4602	$\bar{T} = 28.83$
`Annual precipitation (100 mm)`	overall	11.5802	8.4503	0.0611	48.9740	$N = 4\,814$
	between	–	8.2936	0.1152	39.2257	$n = 167$
	within	–	1.6513	-0.8811	27.0313	$\bar{T} = 28.83$
`Annual mean temperature (°C)`	overall	18.7199	8.0025	-4.8500	29.7900	$N = 4\,814$
	between	–	8.0637	-3.5226	28.7720	$n = 167$
	within	–	0.5067	16.3119	20.7985	$\bar{T} = 28.83$
`Annual mean humidity (%)`	overall	68.0211	14.7559	23.8200	88.4600	$N = 4\,814$
	between	–	14.7367	25.5843	87.5593	$n = 167$
	within	–	1.6580	57.2454	77.1718	$\bar{T} = 28.83$
`30--yr precipitation anomaly (100 mm)`	overall	-0.0736	1.7681	-9.3939	16.3641	$N = 4\,814$
	between	–	0.5535	-1.9495	2.8615	$n = 167$
	within	–	1.6772	-11.9480	15.8462	$\bar{T} = 28.83$
`30--yr mean-temperature anomaly (°C)`	overall	0.4499	0.4622	-1.6773	2.5590	$N = 4\,814$
	between	–	0.1785	0.1342	0.8970	$n = 167$
	within	–	0.4275	-1.8407	2.4564	$\bar{T} = 28.83$

Figure (A1) Social Progress Index: Dimensions, Components, and Underlying Indicators

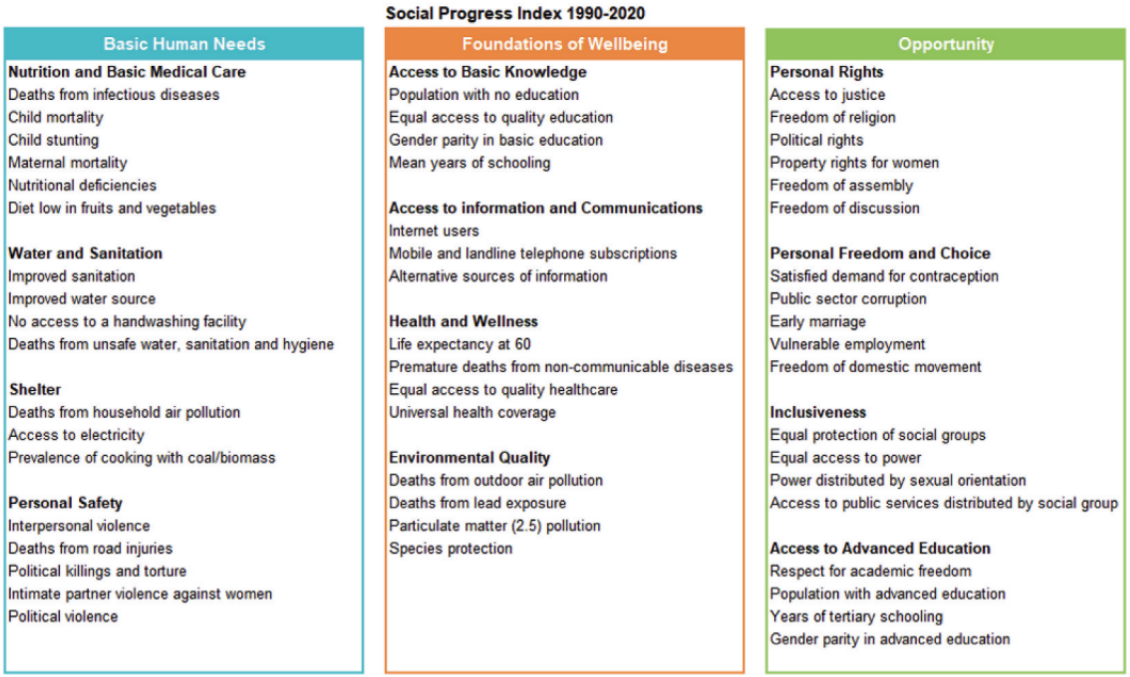


Figure 1. Social Progress Index 1990–2020, indicators framework. Source: Authors Note: We provide full definitions of indicators (Annex A) and full citations of data sources (Annex C) in the online supplementary file.

Notes: The Social Progress Index (SPI) comprises three equally weighted dimensions, Basic Human Needs, Foundations of Wellbeing, and Opportunity, each built from four components. The index is designed to measure social progress independently of economic indicators. Source: Social Progress Imperative (Social Progress Imperative, 2025; Krylova et al., 2026).

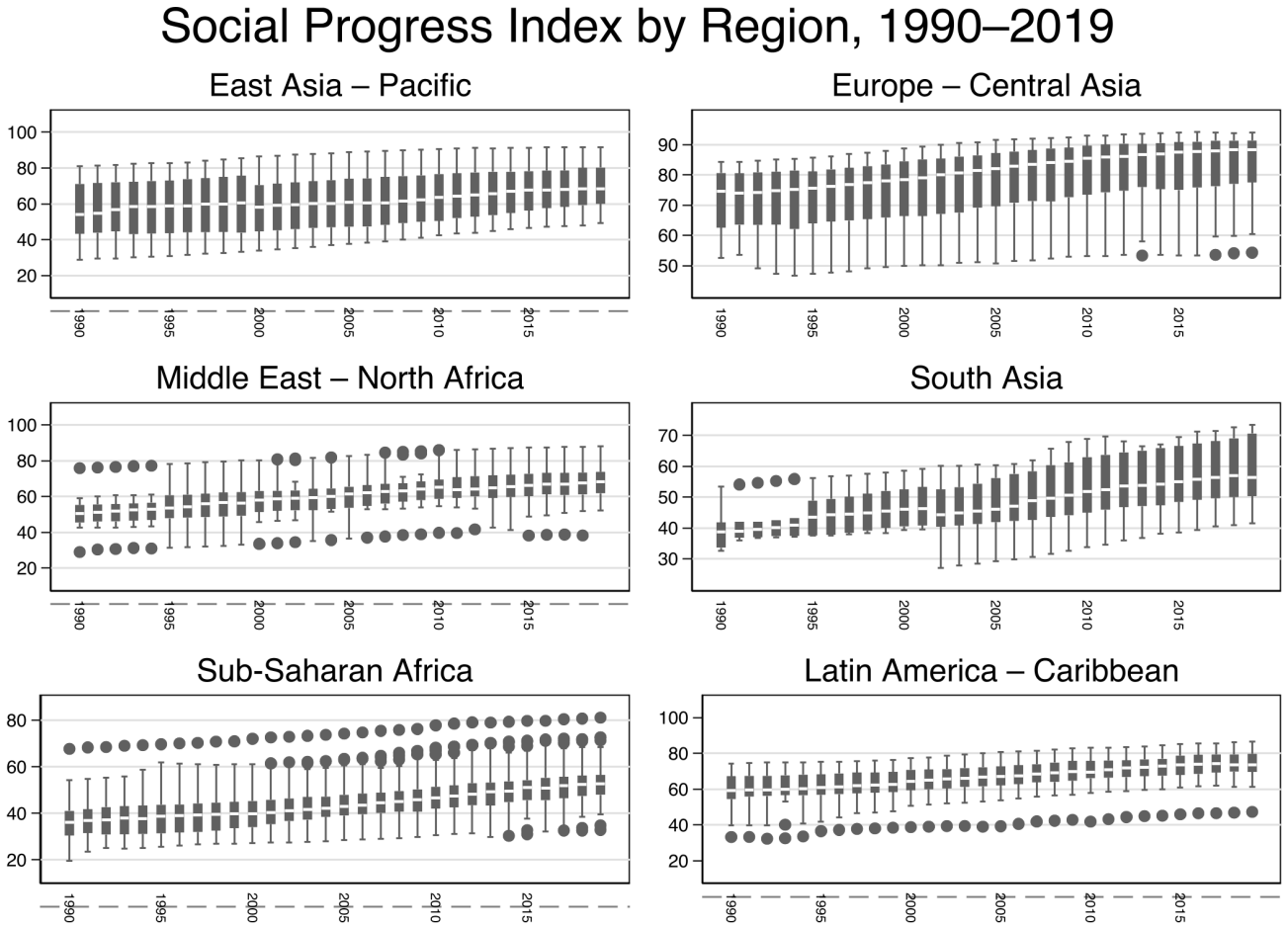


Figure (A2) Regional Trends in Social Progress Index (1990–2019)

Notes: Social Progress Index (SPI) reflects multi-dimensional development outcomes. Each region's panel shows the annual distribution across the countries in that region, on the published 0–100 SPI scale. Vertical axes are free, so levels are comparable within a panel but not across panels.

Table (A5) Panel coverage by country (1990–2019)

#	Country (ISO)	Start	End	N	#	Country (ISO)	Start	End	N	#	Country (ISO)	Start	End	N
1	Afghanistan (AFG)	2002	2019	18	2	Angola (AGO)	1990	2019	30	3	Albania (ALB)	1990	2019	30
4	United Arab Emirates (ARE)	1990	2019	30	5	Argentina (ARG)	1990	2019	30	6	Armenia (ARM)	1990	2019	30
7	Australia (AUS)	1990	2019	30	8	Austria (AUT)	1990	2019	30	9	Azerbaijan (AZE)	1990	2019	30
10	Burundi (BDI)	1990	2019	30	11	Belgium (BEL)	1990	2019	30	12	Benin (BEN)	1990	2019	30
13	Burkina Faso (BFA)	1990	2019	30	14	Bangladesh (BGD)	1990	2019	30	15	Bulgaria (BGR)	1990	2019	30
16	Bahrain (BHR)	1990	2019	30	17	Bosnia Herzegovina (BIH)	1994	2019	26	18	Belarus (BLR)	1990	2019	30
19	Bolivia (BOL)	1990	2019	30	20	Brazil (BRA)	1990	2019	30	21	Barbados (BRB)	1990	2019	30
22	Bhutan (BTN)	1990	2019	30	23	Botswana (BWA)	1990	2019	30	24	Canada (CAN)	1997	2019	23
25	Switzerland (CHE)	1990	2019	30	26	Chile (CHL)	1990	2019	30	27	China (CHN)	1990	2019	30
28	Côte d'Ivoire (CIV)	1990	2019	30	29	Cameroon (CMR)	1990	2019	30	30	Congo, Dem.Rep.(COD)	1990	2019	30
31	Congo (COG)	1990	2019	30	32	Colombia (COL)	1990	2019	30	33	Comoros (COM)	1990	2019	30
34	Cabo Verde (CPV)	1990	2019	30	35	Costa Rica (CRI)	1990	2019	30	36	Cuba (CUB)	1990	2019	30
37	Cyprus (CYP)	1990	2019	30	38	Czechia (CZE)	1990	2019	30	39	Germany (DEU)	1990	2019	30
40	Djibouti (DJI)	2013	2019	7	41	Denmark (DNK)	1990	2019	30	42	Dominican Republic (DOM)	1990	2019	30
43	Algeria (DZA)	1990	2019	30	44	Ecuador (ECU)	1990	2019	30	45	Egypt (EGY)	1990	2019	30
46	Eritrea (ERI)	1992	2011	20	47	Spain (ESP)	1990	2019	30	48	Estonia (EST)	1995	2019	25
49	Ethiopia (ETH)	1990	2019	30	50	Finland (FIN)	1990	2019	30	51	Fiji (FJI)	1990	2019	30
52	France (FRA)	1990	2019	30	53	Gabon (GAB)	1990	2019	30	54	United Kingdom (GBR)	1990	2019	30
55	Georgia (GEO)	1990	2019	30	56	Ghana (GHA)	1990	2019	30	57	Guinea (GIN)	1990	2019	30
58	Gambia (GMB)	1990	2019	30	59	Guinea-Bissau (GNB)	1990	2019	30	60	Equatorial Guinea (GNQ)	1990	2019	30
61	Greece (GRC)	1990	2019	30	62	Guatemala (GTM)	1990	2019	30	63	Guyana (GUY)	1990	2019	30
64	Honduras (HND)	1990	2019	30	65	Croatia (HRV)	1995	2019	25	66	Haiti (HTI)	1990	2019	30
67	Hungary (HUN)	1991	2019	29	68	Indonesia (IDN)	1990	2019	30	69	India (IND)	1990	2019	30
70	Ireland (IRL)	1990	2019	30	71	Iran (IRN)	1990	2019	30	72	Iraq (IRQ)	1990	2019	30
73	Iceland (ISL)	1995	2019	25	74	Israel (ISR)	1995	2019	25	75	Italy (ITA)	1990	2019	30
76	Jamaica (JAM)	1990	2019	30	77	Jordan (JOR)	1990	2019	30	78	Japan (JPN)	1990	2019	30
79	Kazakhstan (KAZ)	1990	2019	30	80	Kenya (KEN)	1990	2019	30	81	Kyrgyzstan (KGZ)	1990	2019	30
82	Cambodia (KHM)	1993	2019	27	83	Korea Rep. (KOR)	1990	2019	30	84	Kuwait (KWT)	1995	2019	25
85	Lao PDR (LAO)	1990	2019	30	86	Lebanon (LBN)	1990	2019	30	87	Liberia (LBR)	2000	2019	20
88	Libya (LBY)	1999	2019	21	89	Sri Lanka (LKA)	1990	2019	30	90	Lesotho (LSO)	1990	2019	30
91	Lithuania (LTU)	1995	2019	25	92	Luxembourg (LUX)	1990	2019	30	93	Latvia (LVA)	1995	2019	25
94	Morocco (MAR)	1990	2019	30	95	Moldova (MDA)	1995	2019	25	96	Madagascar (MDG)	1990	2019	30
97	Maldives (MDV)	1995	2019	25	98	Mexico (MEX)	1990	2019	30	99	North Macedonia (MKD)	1990	2019	30
100	Mali (MLI)	1990	2019	30	101	Malta (MLT)	1990	2019	30	102	Myanmar (MMR)	1990	2019	30
103	Mongolia (MNG)	1990	2019	30	104	Mozambique (MOZ)	1990	2019	30	105	Mauritania (MRT)	1990	2019	30
106	Mauritius (MUS)	1990	2019	30	107	Malawi (MWI)	1990	2019	30	108	Malaysia (MYS)	1990	2019	30
109	Namibia (NAM)	1990	2019	30	110	Niger (NER)	1990	2019	30	111	Nigeria (NGA)	1990	2019	30
112	Nicaragua (NIC)	1990	2019	30	113	Netherlands (NLD)	1990	2019	30	114	Norway (NOR)	1990	2019	30
115	Nepal (NPL)	1990	2019	30	116	New Zealand (NZL)	1990	2019	30	117	Oman (OMN)	1990	2019	30
118	Pakistan (PAK)	1990	2019	30	119	Panama (PAN)	1990	2019	30	120	Peru (PER)	1990	2019	30
121	Philippines (PHL)	1990	2019	30	122	Papua New Guinea (PNG)	1990	2019	30	123	Poland (POL)	1990	2019	30
124	Portugal (PRT)	1990	2019	30	125	Paraguay (PRY)	1990	2019	30	126	Qatar (QAT)	2000	2019	20
127	Romania (ROU)	1990	2019	30	128	Russian Federation (RUS)	1990	2019	30	129	Rwanda (RWA)	1990	2019	30
130	Saudi Arabia (SAU)	1990	2019	30	131	Sudan (SDN)	1990	2019	30	132	Senegal (SEN)	1990	2019	30
133	Singapore (SGP)	1990	2019	30	134	Solomon Islands (SLB)	1990	2019	30	135	Sierra Leone (SLE)	1990	2019	30
136	El Salvador (SLV)	1990	2019	30	137	Somalia (SOM)	2013	2019	7	138	Serbia (SRB)	1995	2019	25
139	São Tomé and Príncipe (STP)	2001	2019	19	140	Suriname (SUR)	1990	2019	30	141	Slovakia (SVK)	1992	2019	28
142	Slovenia (SVN)	1995	2019	25	143	Sweden (SWE)	1990	2019	30	144	Eswatini (SWZ)	1990	2019	30
145	Syria (SYR)	1990	2019	30	146	Chad (TCD)	1990	2019	30	147	Togo (TGO)	1990	2019	30
148	Thailand (THA)	1990	2019	30	149	Tajikistan (TJK)	1990	2019	30	150	Turkmenistan (TKM)	1990	2019	30
151	Timor-Leste (TLS)	2000	2019	20	152	Trinidad and Tobago (TTO)	1990	2019	30	153	Tunisia (TUN)	1990	2019	30
154	Türkiye (TUR)	1990	2019	30	155	Tanzania (TZA)	1990	2019	30	156	Uganda (UGA)	1990	2019	30
157	Ukraine (UKR)	1990	2019	30	158	Uruguay (URY)	1990	2019	30	159	United States (USA)	1990	2019	30
160	Uzbekistan (UZB)	1990	2019	30	161	Venezuela (VEN)	1990	2014	25	162	Viet Nam (VNM)	1990	2019	30
163	Vanuatu (VUT)	1990	2019	30	164	Yemen (YEM)	1990	2018	29	165	South Africa (ZAF)	1990	2019	30
166	Zambia (ZMB)	1990	2019	30	167	Zimbabwe (ZWE)	1990	2019	30					

Table (A6) Country coverage by region

Region	**Countries**	*N*
East Asia & Pacific (EAP)	Australia, China, Fiji, Indonesia, Japan, Lao People's Democratic Republic, Malaysia, Mongolia, Myanmar, New Zealand, Papua New Guinea, Philippines, Republic of Korea, Singapore, Solomon Islands, Thailand, Vanuatu, Vietnam, Cambodia, Timor-Leste	20
Europe & Central Asia (ECA)	Albania, Armenia, Austria, Azerbaijan, Belarus, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Finland, France, Georgia, Germany, Greece, Ireland, Italy, Kazakhstan, Kyrgyz Republic, Luxembourg, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Russian Federation, Spain, Sweden, Switzerland, Tajikistan, Turkmenistan, Türkiye, Ukraine, United Kingdom, Uzbekistan, Hungary, Slovak Republic, Bosnia and Herzegovina, Croatia, Estonia, Iceland, Latvia, Lithuania, Moldova, Serbia, Slovenia	47
Middle East & North Africa (MENA)	Algeria, Arab Republic of Egypt, Bahrain, Iraq, Islamic Republic of Iran, Jordan, Lebanon, Malta, Morocco, Oman, Saudi Arabia, Syrian Arab Republic, Tunisia, United Arab Emirates, Republic of Yemen, Israel, Kuwait, Libya, Qatar, Djibouti	20
North America (NA)	United States of America, Canada	2
South Asia (SA)	Bangladesh, Bhutan, India, Nepal, Pakistan, Sri Lanka, Maldives, Afghanistan	8
Sub-Saharan Africa (SSA)	Angola, Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Chad, Comoros, Congo, Côte d'Ivoire, Democratic Republic of Congo, Equatorial Guinea, Eswatini, Ethiopia, Gabon, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, South Africa, Sudan, Tanzania, The Gambia, Togo, Uganda, Zambia, Zimbabwe, Eritrea, Liberia, São Tomé and Príncipe, Somalia	45
Latin America & Caribbean (LAC)	Argentina, Barbados, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Suriname, Trinidad and Tobago, Uruguay, Venezuela (R. B.)	25
	Total	**167**

Table (A7) Fisher-type Panel Unit-Root Tests, 1990–2019

Variable	P	$p(P)$	P_m	$p(P_m)$
Panel A: Social Progress Index				
SocialProgressIndex	378.677	0.0462	1.729	0.0419
Panel B: Climate Variables (Levels)				
Annual precipitation (100 mm)	1115.669	0.0000	30.244	0.0000
Annual mean temperature (°C)	1070.222	0.0000	28.485	0.0000
Annual mean humidity (%)	855.979	0.0000	20.196	0.0000
Panel C: 30–Year Climate Anomalies				
30–yr precipitation anomaly (100 mm)	1055.362	0.0000	27.910	0.0000
30–yr mean-temperature anomaly (°C)	1103.958	0.0000	29.791	0.0000
Panel D: Seasonal Anomalies (30–Year)				
30–yr DJF temperature anomaly (°C)	1188.410	0.0000	33.058	0.0000
30–yr DJF humidity anomaly(%)	1019.087	0.0000	26.507	0.0000
30–yr MAM precipitation anomaly (100 mm)	1227.254	0.0000	34.561	0.0000
30–yr MAM temperature anomaly (°C)	1251.016	0.0000	35.480	0.0000
30–yr MAM humidity anomaly (%)	1047.014	0.0000	27.587	0.0000
30–yr JJA precipitation anomaly (100 mm)	1029.448	0.0000	26.908	0.0000
30–yr JJA temperature anomaly (°C)	1086.951	0.0000	29.133	0.0000
30–yr JJA humidity anomaly(%)	1013.636	0.0000	26.296	0.0000
30–yr SON precipitation anomaly (100 mm)	981.856	0.0000	25.066	0.0000
30–yr SON temperature anomaly (°C)	1123.168	0.0000	30.534	0.0000
30–yr SON humidity anomaly (%)	947.632	0.0000	23.742	0.0000
Panel E: Macroeconomic Controls				
log GDP per capita (constant 2015 USD)	363.035	0.1318	1.123	0.1306
Inflation rate, consumer prices (annual %)	1156.814	0.0000	32.716	0.0000
Commodity terms of trade (index, 2012 = 100)	205.311	1.0000	-4.727	1.0000

Notes: Null hypothesis H_0: all panels contain a unit root. P is Maddala–Wu's inverse χ^2 statistic with $2N$ degrees of freedom; P_m is Choi's modified inverse χ^2 statistic (standard normal). Tests employ augmented Dickey-Fuller regressions with two lags on demeaned data. Exact p-values are reported to four decimal places. Panel E reports the same tests for the macroeconomic controls that enter Specifications (3) and (6); the commodity terms-of-trade series does not reject the null, which is why it is carried in levels alongside country fixed effects and country-specific trends.

Table (A8) Impact of Local and Global Weather Anomalies on Social Progress Index
(Robustness: Dropping Top 5% of Anomalies)

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
Panel A: 20-Year Weather Anomalies						
20-year mean-temp anomaly	-0.1344*	-0.1669**	-0.1696**	-0.1331	-0.1640**	-0.1745**
	(0.0794)	(0.0720)	(0.0729)	(0.0840)	(0.0762)	(0.0724)
20-year precipitation anomaly	0.0015	0.0118	-0.0056	0.0016	0.0115	-0.0046
	(0.0135)	(0.0177)	(0.0136)	(0.0145)	(0.0187)	(0.0143)
20-year humidity anomaly		-0.0243			-0.0234	
		(0.0250)			(0.0253)	
log GDP per capita			0.0181***			0.0200***
			(0.0035)			(0.0041)
Inflation rate (annual %)			0.0001			0.0001
			(0.0001)			(0.0001)
Official exchange rate			0.0001			0.0001
			(0.0001)			(0.0001)
Commodity terms of trade (index, 2012 = 100)			0.0067			0.0093
			(0.0075)			(0.0073)
Global (CS) 20-yr temp anomaly				-0.5443***	-0.5576***	-0.4248***
				(0.1474)	(0.1558)	(0.1390)
Global (CS) 20-yr precip anomaly				-0.1015**	-0.0843	-0.0641
				(0.0475)	(0.0583)	(0.0490)
Global (CS) 20-yr humidity anomaly					-0.0740	
					(0.0715)	
Observations	4312	4312	3667	4312	4312	3667
Countries (N)	167	167	159	167	167	159

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	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
Years (T)	30	30	29	30	30	29
Within R^2	0.0015	0.0023	0.0360	0.0086	0.0097	0.0493
F-statistic	1.4564	2.1043	8.0173	15.1945	10.7918	15.5256
F p-value	0.2360	0.1016	0.0000	0.0000	0.0000	0.0000
Root MSE	1.1222	1.1219	1.0096	1.1715	1.1711	1.0410
Panel B: 30-Year Weather Anomalies						
30-year mean-temp anomaly	-0.1094	-0.1407**	-0.1295*	-0.1095	-0.1402*	-0.1358*
	(0.0725)	(0.0704)	(0.0707)	(0.0770)	(0.0746)	(0.0714)
30-year precipitation anomaly	-0.0023	0.0081	-0.0088	-0.0022	0.0077	-0.0081
	(0.0128)	(0.0165)	(0.0129)	(0.0138)	(0.0172)	(0.0134)
30-year humidity anomaly		-0.0242			-0.0231	
		(0.0233)			(0.0235)	
log GDP per capita			0.0182***			0.0200***
			(0.0035)			(0.0041)
Inflation rate (annual %)			0.0001			0.0001
			(0.0001)			(0.0001)
Official exchange rate			0.0001			0.0001
			(0.0001)			(0.0001)
Commodity terms of trade (index, 2012 = 100)			0.0066			0.0089
			(0.0075)			(0.0073)
Global (CS) 30-yr temp anomaly				-0.7313***	-0.6548***	-0.5744***
				(0.1491)	(0.1580)	(0.1453)
Global (CS) 30-yr precip anomaly				-0.0137	-0.0501	-0.0153
				(0.0419)	(0.0533)	(0.0438)

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	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
Global (CS) 30-yr humidity anomaly					0.1147	
					(0.1057)	
Observations	4312	4312	3667	4312	4312	3667
Countries (N)	167	167	159	167	167	159
Years (T)	30	30	29	30	30	29
Within R^2	0.0010	0.0017	0.0349	0.0107	0.0117	0.0503
F-statistic	1.1471	1.5313	7.8135	16.5787	11.3501	15.4402
F p-value	0.3201	0.2083	0.0000	0.0000	0.0000	0.0000
Root MSE	1.1225	1.1223	1.0102	1.1702	1.1699	1.0405
Panel C: 40-Year Weather Anomalies						
40-year mean-temp anomaly	-0.1331*	-0.1683**	-0.1434**	-0.1326*	-0.1669**	-0.1455**
	(0.0744)	(0.0704)	(0.0715)	(0.0788)	(0.0746)	(0.0731)
40-year precipitation anomaly	-0.0050	0.0067	-0.0089	-0.0049	0.0067	-0.0078
	(0.0122)	(0.0158)	(0.0122)	(0.0133)	(0.0168)	(0.0129)
40-year humidity anomaly		-0.0273			-0.0272	
		(0.0224)			(0.0228)	
log GDP per capita			0.0188***			0.0202***
			(0.0036)			(0.0040)
Inflation rate (annual %)			0.0000			0.0001
			(0.0000)			(0.0001)
Official exchange rate			0.0001			0.0001
			(0.0001)			(0.0001)
Commodity terms of trade (index, 2012 = 100)			0.0061			0.0083
			(0.0074)			(0.0073)

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	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
Global (CS) 40-yr temp anomaly				-1.0251***	-1.0180***	-0.7104***
				(0.1764)	(0.1667)	(0.1765)
Global (CS) 40-yr precip anomaly				-0.0625	-0.0585	-0.0540
				(0.0450)	(0.0512)	(0.0466)
Global (CS) 40-yr humidity anomaly					-0.0216	
					(0.0991)	
Observations	4181	4181	3575	4181	4181	3575
Countries (N)	167	167	159	167	167	159
Years (T)	29	29	28	29	29	28
Within R^2	0.0015	0.0024	0.0372	0.0189	0.0199	0.0547
F-statistic	1.6471	2.3443	8.4476	19.1018	16.0714	15.7269
F p-value	0.1957	0.0749	0.0000	0.0000	0.0000	0.0000

Root MSE	1.0968	1.0964	0.9927	1.1398	1.1395	1.0226

Notes: Robust standard errors clustered at the country level are reported in parentheses. The dependent variable is the Social Progress Index (SPI) (Social Progress Imperative, 2025; Krylova et al., 2026). Annual temperature and precipitation anomalies are calculated from country-aggregated ERA5 reanalysis data accessed via the World Bank Climate Change Knowledge Portal (World Bank, 2025). The estimation sample drops observations above the 95th percentile of the Social Progress Index and above the 95th percentile of the 20-, 30- and 40-year mean-temperature anomalies. Specifications (1)–(3) include country and year fixed effects and a country-specific linear time trend; Specifications (2) and (5) additionally include a humidity anomaly. Specifications (4)–(6) retain country fixed effects and country-specific trends but omit year fixed effects, replacing them with cross-sectional (global) weather averages. Specifications (3) and (6) further incorporate macroeconomic controls, including the annual inflation rate, official exchange rate, commodity terms of trade, and log GDP per capita; these columns cover 1990–2018, because the commodity terms-of-trade series ends in 2018. The official exchange rate is the nominal period-average rate in local currency units per US dollar, and the commodity terms of trade is a GDP-weighted index with 2012 = 100. Significance levels: *, $p < 0.10$; **, $p < 0.05$; ***, $p < 0.01$.

Table (A9) Impact of Local and Global Weather Anomalies on Social Progress Index
(Robustness: Year Starting from 1998)

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
Panel A: 20-Year Weather Anomalies						
20-year mean-temp anomaly	-0.0974**	-0.1087**	-0.1117***	-0.0979**	-0.1087**	-0.1165***
	(0.0414)	(0.0432)	(0.0419)	(0.0448)	(0.0460)	(0.0447)
20-year precipitation anomaly	-0.0185	-0.0136	-0.0232*	-0.0186	-0.0139	-0.0219
	(0.0129)	(0.0152)	(0.0133)	(0.0135)	(0.0158)	(0.0136)
20-year humidity anomaly		-0.0106			-0.0101	
		(0.0133)			(0.0129)	

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	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
log GDP per capita (log, 2015 USD)			0.0139**			0.0196***
			(0.0067)			(0.0063)
Inflation rate (annual %)			-0.0004			-0.0013
			(0.0018)			(0.0020)
Official exchange rate			0.0001***			0.0001**
			(0.0000)			(0.0000)
Commodity terms of trade (index, 2012 = 100)			0.0042			0.0036
			(0.0070)			(0.0073)
Global (CS) 20-yr temp anomaly				-1.1822***	-1.1622***	-0.9302***
				(0.2351)	(0.2381)	(0.2119)
Global (CS) 20-yr precip anomaly				0.1879***	0.1686***	0.0942*
				(0.0486)	(0.0487)	(0.0512)
Global (CS) 20-yr humidity anomaly					0.0644*	
					(0.0372)	
Observations	3616	3616	3168	3616	3616	3168
Countries (N)	167	167	159	167	167	159
Years (T)	22	22	21	22	22	21
Within R^2	0.0025	0.0027	0.0244	0.0373	0.0377	0.0586
F-statistic	3.1474	2.4397	4.1852	14.9407	15.6593	8.9019
F p-value	0.0455	0.0663	0.0006	0.0000	0.0000	0.0000
Root MSE	0.8910	0.8910	0.8238	0.9314	0.9315	0.8594
Panel B: 30-Year Weather Anomalies						
30-year mean-temp anomaly	-0.0534	-0.0635	-0.0669	-0.0536	-0.0632	-0.0710
	(0.0424)	(0.0453)	(0.0437)	(0.0445)	(0.0468)	(0.0455)

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	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
30-year precipitation anomaly	-0.0212*	-0.0168	-0.0256*	-0.0213	-0.0172	-0.0242*
	(0.0126)	(0.0150)	(0.0130)	(0.0134)	(0.0157)	(0.0134)
30-year humidity anomaly		-0.0093			-0.0089	
		(0.0143)			(0.0137)	
log GDP per capita (log, 2015 USD)			0.0139**			0.0197***
			(0.0067)			(0.0063)
Inflation rate (annual %)			-0.0004			-0.0013
			(0.0018)			(0.0020)
Official exchange rate			0.0001***			0.0001**
			(0.0000)			(0.0000)
Commodity terms of trade (index, 2012 = 100)			0.0043			0.0037
			(0.0071)			(0.0073)
Global (CS) 30-yr temp anomaly				-1.2733***	-1.2567***	-1.0202***
				(0.2306)	(0.2326)	(0.2055)
Global (CS) 30-yr precip anomaly				0.1773***	0.1523***	0.0822
				(0.0505)	(0.0491)	(0.0529)
Global (CS) 30-yr humidity anomaly					0.0791	
					(0.0480)	
Observations	3616	3616	3168	3616	3616	3168
Countries (N)	167	167	159	167	167	159
Years (T)	22	22	21	22	22	21
Within R^2	0.0017	0.0019	0.0233	0.0373	0.0378	0.0587
F-statistic	1.7786	1.4109	3.8200	15.4364	15.6898	9.3407
F p-value	0.1721	0.2415	0.0014	0.0000	0.0000	0.0000
Root MSE	0.8913	0.8914	0.8243	0.9314	0.9314	0.8593

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	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
Panel C: 40-Year Weather Anomalies						
40-year mean-temp anomaly	-0.0720*	-0.0849*	-0.0825*	-0.0729	-0.0853*	-0.0882*
	(0.0419)	(0.0441)	(0.0426)	(0.0456)	(0.0474)	(0.0455)
40-year precipitation anomaly	-0.0182	-0.0125	-0.0226*	-0.0184	-0.0129	-0.0212
	(0.0125)	(0.0149)	(0.0128)	(0.0131)	(0.0156)	(0.0131)
40-year humidity anomaly		-0.0122			-0.0118	
		(0.0143)			(0.0138)	
log GDP per capita (log, 2015 USD)			0.0139**			0.0202***
			(0.0067)			(0.0063)
Inflation rate (annual %)			-0.0004			-0.0013
			(0.0018)			(0.0020)
Official exchange rate			0.0001***			0.0001**
			(0.0000)			(0.0000)
Commodity terms of trade (index, 2012 = 100)			0.0044			0.0038
			(0.0071)			(0.0073)
Global (CS) 40-yr temp anomaly				-1.2493***	-1.2389***	-0.9806***
				(0.2205)	(0.2220)	(0.1947)
Global (CS) 40-yr precip anomaly				0.1323**	0.1376***	0.0401
				(0.0544)	(0.0507)	(0.0563)
Global (CS) 40-yr humidity anomaly					-0.0236	
					(0.0521)	
Observations	3616	3616	3168	3616	3616	3168
Countries (N)	167	167	159	167	167	159
Years (T)	22	22	21	22	22	21

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	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
Within R^2	0.0017	0.0020	0.0232	0.0324	0.0327	0.0560
F-statistic	2.0744	1.7441	3.8778	16.6387	14.7125	9.8426
F p-value	0.1289	0.1600	0.0012	0.0000	0.0000	0.0000
Root MSE	0.8913	0.8913	0.8243	0.9337	0.9339	0.8605

Notes: Robust standard errors clustered at the country level are reported in parentheses. The dependent variable is the Social Progress Index (SPI) (Social Progress Imperative, 2025; Krylova et al., 2026). Annual temperature and precipitation anomalies are calculated from country-aggregated ERA5 reanalysis data accessed via the World Bank Climate Change Knowledge Portal (World Bank, 2025). Specifications (1)–(3) include country and year fixed effects and a country-specific linear time trend; Specifications (2) and (5) additionally include a humidity anomaly. Specifications (4)–(6) retain country fixed effects and country-specific trends but omit year fixed effects, replacing them with cross-sectional (global) weather averages. Specifications (3) and (6) further incorporate macroeconomic controls, including the annual inflation rate, official exchange rate (LCU per USD, period average), commodity terms of trade, and log GDP per capita. The official exchange rate is the nominal period-average rate in local currency units per US dollar, and the commodity terms of trade is a GDP-weighted index with 2012 = 100. Significance levels: *, $p < 0.10$; **, $p < 0.05$; ***, $p < 0.01$. The sample is restricted to years 1998 onward.

Table (A10) Robustness: 30-Year Weather Anomalies with Additional Climate Indicators following Akyapı et al. (2025)

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
30-yr mean-temp anomaly	-0.0814	-0.0916*	-0.1090**	-0.0883	-0.0966*	-0.1261**
	(0.0515)	(0.0487)	(0.0492)	(0.0537)	(0.0507)	(0.0499)
30-yr precipitation anomaly	-0.0051	-0.0008	-0.0080	-0.0029	0.0006	-0.0037

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Table A10 (continued)

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
	(0.0139)	(0.0168)	(0.0139)	(0.0142)	(0.0171)	(0.0141)
Mean T [9,12)°C	-0.0043	-0.0032	0.0108	-0.0103	-0.0093	0.0148**
	(0.0065)	(0.0065)	(0.0066)	(0.0066)	(0.0069)	(0.0072)
Harsh Drought Prevalence	-0.0213*	-0.0237**	-0.0178	-0.0159	-0.0176	-0.0035
	(0.0111)	(0.0120)	(0.0110)	(0.0107)	(0.0117)	(0.0105)
Max T >35°C	-0.0007	-0.0023	0.0053	0.0105	0.0095	0.0229**
	(0.0096)	(0.0106)	(0.0088)	(0.0094)	(0.0102)	(0.0093)
30-yr humidity anomaly		-0.0105			-0.0084	
		(0.0229)			(0.0234)	
log GDP per capita			0.0186***			0.0213***
			(0.0040)			(0.0045)
Inflation rate (%)			0.0001			0.0001
			(0.0001)			(0.0001)
Official exchange rate			0.0001			0.0000
			(0.0001)			(0.0001)
Commodity ToT (index, 2012 = 100)			0.0060			0.0082
			(0.0080)			(0.0079)
Global (CS) 30-yr temp anomaly				-0.8623***	-0.8439***	-0.6084***
				(0.1251)	(0.1267)	(0.1228)
Global (CS) 30-yr precip anomaly				0.0430	0.0345	0.0059
				(0.0407)	(0.0515)	(0.0441)

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Table A10 (continued)

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
Global (CS) 30-yr humidity anomaly					0.0236	
					(0.0880)	
Observations	4780	4780	4081	4780	4780	4081
Countries (N)	167	167	159	167	167	159
Years (T)	30	30	29	30	30	29
Within R^2	0.0013	0.0015	0.0351	0.0162	0.0163	0.0553
F-statistic	1.7591	1.6710	4.9259	17.2886	13.6064	11.9364
F p-value	0.1240	0.1311	0.0000	0.0000	0.0000	0.0000

Root MSE	1.1237	1.1237	1.0069	1.1683	1.1685	1.0376

Notes: Robust standard errors clustered at the country level are in parentheses. The dependent variable is the Social Progress Index (SPI) (Social Progress Imperative, 2025; Krylova et al., 2026). Annual temperature and precipitation anomalies are from country-aggregated ERA5 reanalysis data accessed via the World Bank Climate Change Knowledge Portal (World Bank, 2025). Specifications (1)–(3) include country and year fixed effects and a country-specific linear time trend; Specifications (2) and (5) include a humidity anomaly. Specifications (4)–(6) retain country fixed effects and trends but replace year fixed effects with cross-sectional (global) weather averages. Specifications (3) and (6) include macroeconomic controls: annual inflation rate, official exchange rate, commodity terms of trade, and log GDP per capita. The official exchange rate is the nominal period-average rate in local currency units per US dollar, and the commodity terms of trade is a GDP-weighted index with 2012 = 100. The three additional climate indicators follow Akyapı et al. (2025) and are measured as shares, not levels: Mean T in [9,12)°C is the share of grid-days with mean daily temperature in that interval; Max T >35°C is the share of grid-days with maximum daily temperature above 35°C; Harsh Drought Prevalence is the share of grid-months with a Palmer Drought Severity Index below −4. Requiring these three indicators reduces the sample from 4,814 to 4,780 country-years. Global (CS) anomaly: annual cross-sectional mean. Significance levels: *, $p < 0.10$; **, $p < 0.05$; ***, $p < 0.01$.

Table (A11) Robustness: Weather Anomalies and Social Progress Index using CRU Weather Data

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
Panel A: 20-Year Weather Anomalies (CRU)						
20-yr mean temperature anomaly (CRU)	-0.2111***	-0.1767***	-0.1901***	-0.2116***	-0.1783***	-0.1939***

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Table A11 – continued from previous page

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
	(0.0560)	(0.0594)	(0.0540)	(0.0570)	(0.0603)	(0.0532)
20-yr precipitation anomaly (CRU)	-0.0099	-0.0170	-0.0148	-0.0102	-0.0170	-0.0138
	(0.0122)	(0.0130)	(0.0106)	(0.0128)	(0.0135)	(0.0112)
20-yr humidity anomaly (CRU)		0.0429			0.0413	
		(0.0262)			(0.0261)	
log GDP per capita			0.0187***			0.0215***
			(0.0041)			(0.0044)
Inflation rate (%)			0.0001			0.0001
			(0.0001)			(0.0001)
Official exchange rate			0.0001			0.0001
			(0.0001)			(0.0001)
Commodity ToT (index, 2012 = 100)			0.0054			0.0073
			(0.0079)			(0.0078)
Global (CS) 20-yr temp anomaly (CRU)				-0.8319***	-0.8275***	-0.6363***
				(0.1400)	(0.1353)	(0.1404)
Global (CS) 20-yr precip anomaly (CRU)				-0.2069*	-0.2180*	-0.0968
				(0.1134)	(0.1142)	(0.1021)
Global (CS) 20-yr humidity anomaly (CRU)					0.2086***	
					(0.0729)	
Observations	4814	4814	4098	4814	4814	4098
Countries (N)	167	167	159	167	167	159
Years (T)	30	30	29	30	30	29
Within R^2	0.0047	0.0064	0.0383	0.0256	0.0285	0.0616
F-statistic	7.5517	5.7866	7.8926	27.3442	19.7866	16.2728

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Table A11 – continued from previous page

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
F p-value	0.0007	0.0009	0.0000	0.0000	0.0000	0.0000
Root MSE	1.1273	1.1264	1.0064	1.1670	1.1656	1.0344
Panel B: 30-Year Weather Anomalies (CRU)						
30-yr mean temperature anomaly (CRU)	-0.1687***	-0.1501**	-0.1527***	-0.1693***	-0.1525**	-0.1570***
	(0.0553)	(0.0584)	(0.0532)	(0.0570)	(0.0604)	(0.0531)
30-yr precipitation anomaly (CRU)	-0.0104	-0.0142	-0.0177	-0.0105	-0.0140	-0.0168
	(0.0130)	(0.0140)	(0.0111)	(0.0134)	(0.0143)	(0.0116)
30-yr humidity anomaly (CRU)		0.0233			0.0209	
		(0.0266)			(0.0264)	
log GDP per capita			0.0188***			0.0215***
			(0.0041)			(0.0044)
Inflation rate (%)			0.0001			0.0001
			(0.0001)			(0.0001)
Official exchange rate			0.0001			0.0001
			(0.0001)			(0.0001)
Commodity ToT (index, 2012 = 100)			0.0055			0.0072
			(0.0080)			(0.0079)
Global (CS) 30-yr temp anomaly (CRU)				-0.9192***	-0.9156***	-0.6943***
				(0.1432)	(0.1389)	(0.1430)
Global (CS) 30-yr precip anomaly (CRU)				-0.1507	-0.1589	-0.0575
				(0.1133)	(0.1151)	(0.1011)
Global (CS) 30-yr humidity anomaly (CRU)					0.1223*	
					(0.0691)	
Observations	4814	4814	4098	4814	4814	4098

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Table A11 – continued from previous page

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
Countries (N)	167	167	159	167	167	159
Years (T)	30	30	29	30	30	29
Within R^2	0.0030	0.0035	0.0369	0.0245	0.0253	0.0609
F-statistic	4.9234	3.4553	7.4244	24.6344	17.0214	15.5293
F p-value	0.0084	0.0179	0.0000	0.0000	0.0000	0.0000
Root MSE	1.1282	1.1281	1.0071	1.1677	1.1674	1.0348
Panel C: 40-Year Weather Anomalies (CRU)						
40-yr mean temperature anomaly (CRU)	-0.1837***	-0.1703***	-0.1660***	-0.1848***	-0.1737***	-0.1723***
	(0.0561)	(0.0597)	(0.0537)	(0.0573)	(0.0610)	(0.0530)
40-yr precipitation anomaly (CRU)	-0.0047	-0.0076	-0.0115	-0.0048	-0.0071	-0.0104
	(0.0128)	(0.0138)	(0.0110)	(0.0133)	(0.0142)	(0.0115)
40-yr humidity anomaly (CRU)		0.0170			0.0139	
		(0.0268)			(0.0266)	
log GDP per capita			0.0188***			0.0217***
			(0.0041)			(0.0045)
Inflation rate (%)			0.0001			0.0001
			(0.0001)			(0.0001)
Official exchange rate			0.0001			0.0001
			(0.0001)			(0.0001)
Commodity ToT (index, 2012 = 100)			0.0056			0.0073
			(0.0080)			(0.0079)
Global (CS) 40-yr temp anomaly (CRU)				-0.8271***	-0.8092***	-0.6184***
				(0.1499)	(0.1467)	(0.1497)
Global (CS) 40-yr precip anomaly (CRU)				-0.1500	-0.1705	-0.0674

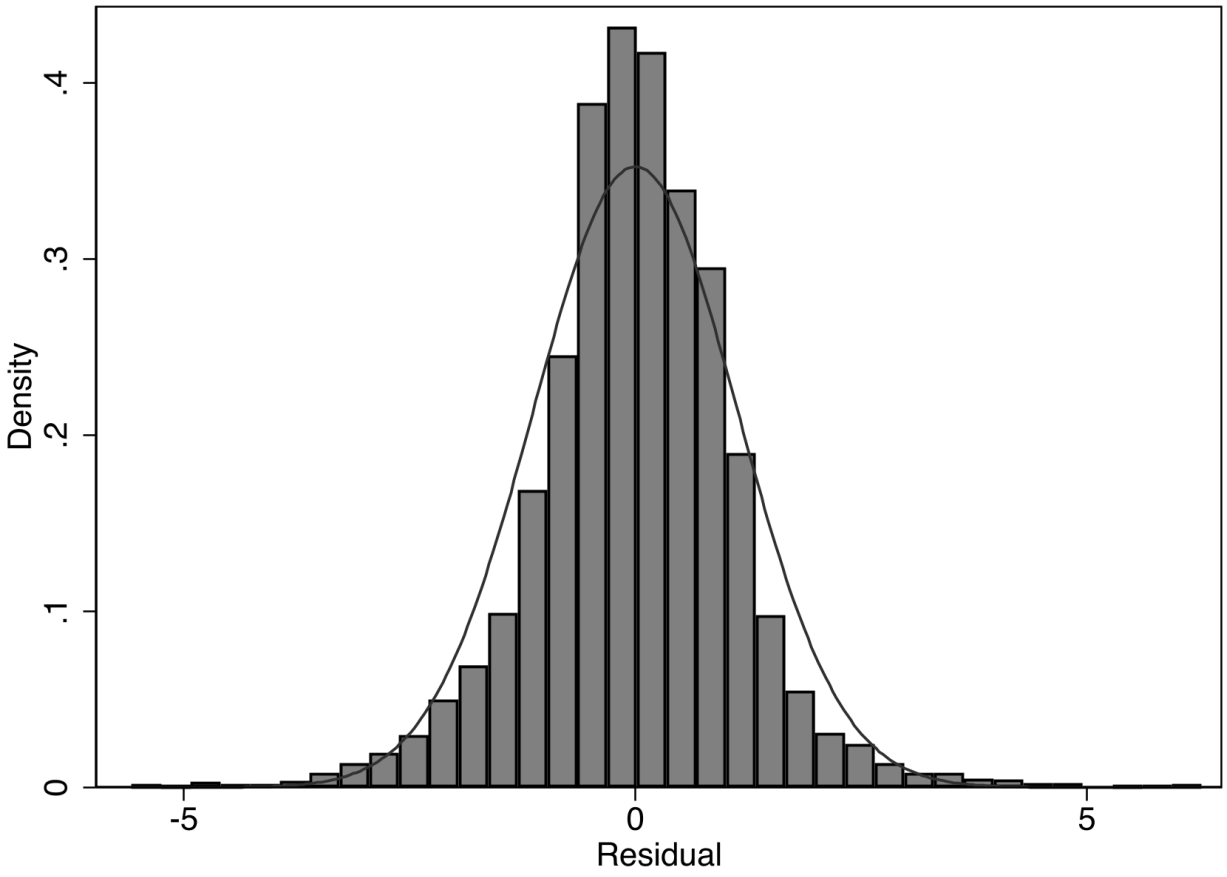
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Table A11 – continued from previous page

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
				(0.1093)	(0.1098)	(0.0976)
Global (CS) 40-yr humidity anomaly (CRU)					0.1831**	
					(0.0709)	
Observations	4814	4814	4098	4814	4814	4098
Countries (N)	167	167	159	167	167	159
Years (T)	30	30	29	30	30	29
Within R^2	0.0034	0.0037	0.0370	0.0219	0.0229	0.0592
F-statistic	5.3995	3.7234	7.5127	20.6079	14.9797	14.1607
F p-value	0.0053	0.0126	0.0000	0.0000	0.0000	0.0000
Root MSE	1.1280	1.1280	1.0070	1.1692	1.1689	1.0358

Notes: Robust standard errors clustered at the country level are in parentheses. The dependent variable is the Social Progress Index (SPI) (Social Progress Imperative, 2025; Krylova et al., 2026). Annual temperature and precipitation anomalies are from country-aggregated Climatic Research Unit (CRU) data accessed via the World Bank Climate Change Knowledge Portal (World Bank, 2025), in place of the ERA5 reanalysis used in the main tables. Specifications (1)–(3) include country and year fixed effects and a country-specific linear time trend; Specifications (2) and (5) include a humidity anomaly. Specifications (4)–(6) retain country fixed effects and trends but replace year fixed effects with cross-sectional (global) weather averages. Specifications (3) and (6) include macroeconomic controls: annual inflation rate, official exchange rate, commodity terms of trade, and log GDP per capita. The official exchange rate is the nominal period-average rate in local currency units per US dollar, and the commodity terms of trade is a GDP-weighted index with 2012 = 100. Significance levels: *, $p < 0.10$; **, $p < 0.05$; ***, $p < 0.01$.

Figure (A3) Residual Diagnostics for the Baseline Fixed-Effects Model



Notes: Residuals are obtained from the preferred fixed-effects specification with country fixed effects and country-specific linear trends.

Table (A12) Post-Estimation Diagnostics for the Preferred Fixed-Effects Model

Panel A: Residual Stationarity Tests			
	Statistic	p-value	Decision
Fisher-type ADF test (H_0: all panels contain a unit root; H_a: at least one panel is stationary; 1 lag)			
Inverse χ^2, P (df = 334)	555.6412	0.0000	Reject H_0
Inverse normal, Z	−5.5894	0.0000	Reject H_0
Inverse logit, L^* (df = 839)	−6.7091	0.0000	Reject H_0
Modified inv. χ^2, P_m	8.5756	0.0000	Reject H_0
Panels (N) / average periods ($\bar{T}$)	167 / 28.83		
Panel B: Uncentred Variance Inflation Factors (Multicollinearity)			
Variable	VIF	1/VIF	Assessment
Humidity anomaly (local)	1.58	0.6328	Low
Precipitation anomaly (local)	1.43	0.6995	Low
Humidity anomaly (cross-sectional)	1.32	0.7582	Low
Mean temperature anomaly (local)	1.31	0.7635	Low
Mean temperature anomaly (cross-sectional)	1.28	0.7821	Low
Precipitation anomaly (cross-sectional)	1.22	0.8179	Low
Mean VIF	1.36		
Observations	4,814		

Notes: **Panel A** reports unit-root tests on the residuals of the preferred 30-year global-average specification (column 5 of the main table), which regresses the Social Progress Index on the local temperature, precipitation and humidity anomalies together with their annual cross-sectional averages, absorbing country fixed effects and country-specific linear trends. The Fisher-type ADF test allows heterogeneous autoregressive parameters across panels and includes panel means but no time trend or drift. All four statistics reject the null at any conventional level, implying that *at least one* panel is stationary; the test does not establish stationarity in every panel.

Panel B reports uncentred variance inflation factors from an auxiliary OLS regression, without an intercept, of the within-transformed dependent variable on the within-transformed regressors, where the within transformation absorbs country fixed effects and country-specific linear trends. Consistent with the Frisch–Waugh–Lovell theorem, this auxiliary regression reproduces the column 5 point estimates exactly. All values are well below the conventional threshold of 5, indicating no multicollinearity concern.

Table (A13) 30-Year Weather Anomalies: Alternative Dependent Variables

	Panel A: GDP-Net log(SPI) Residuals					
	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: GDP-net log(SPI) residuals					
Local weather anomalies						
Mean-temp anomaly	−0.0028***	−0.0035***	−0.0022**	−0.0028***	−0.0035***	−0.0022**
	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0009)
Precipitation anomaly	−0.0002	0.0001	−0.0001	−0.0002	0.0000	−0.0001
	(0.0002)	(0.0003)	(0.0002)	(0.0002)	(0.0003)	(0.0002)
Humidity anomaly		−0.0006			−0.0006	
		(0.0004)			(0.0004)	
Economic controls						
Log GDP per capita			−0.0006***			−0.0005***
			(0.0001)			(0.0001)
Inflation rate			0.0000			0.0000
			(0.0000)			(0.0000)
Official exchange rate			0.0000			0.0000
			(0.0000)			(0.0000)
Commodity terms of trade			0.0003			0.0003
			(0.0002)			(0.0002)
Global weather anomalies						
Global mean-temp anomaly				−0.0112***	−0.0110***	−0.0097***
				(0.0026)	(0.0026)	(0.0027)
Global precipitation anomaly				0.0005	0.0005	0.0002
				(0.0008)	(0.0009)	(0.0008)
Global humidity anomaly					−0.0003	
					(0.0015)	
Economic indicators	✗	✗	✓	✗	✗	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✗	✗	✗
Observations	4814	4814	4098	4814	4814	4098
Within R^2	0.0027	0.0040	0.0820	0.0121	0.0134	0.0759
F-statistic	5.1795	5.6449	4.9723	15.5928	11.2172	7.2878
F p-value	0.0066	0.0010	0.0001	0.0000	0.0000	0.0000
Root MSE	0.0214	0.0214	0.0190	0.0218	0.0218	0.0194
	Panel B: First Difference of HDI (ΔHDI)					
	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Δ Human Development Index					
Local weather anomalies						
Mean-temp anomaly	0.0001	0.0000	−0.0001	0.0000	−0.0000	−0.0001
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Precipitation anomaly	−0.0001**	−0.0001	−0.0001*	−0.0001**	−0.0001	−0.0001*
	(0.0000)	(0.0001)	(0.0000)	(0.0000)	(0.0001)	(0.0000)

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Table A13 (continued)

Humidity anomaly		−0.0001			−0.0001	
		(0.0001)			(0.0001)	
Economic controls						
Log GDP per capita			0.0001**			0.0001***
			(0.0000)			(0.0000)
Inflation rate			−0.0000			−0.0000
			(0.0000)			(0.0000)
Official exchange rate			−0.0000***			−0.0000**
			(0.0000)			(0.0000)
Commodity terms of trade			−0.0000			−0.0000
			(0.0000)			(0.0000)
Global weather anomalies						
Global mean-temp anomaly				0.0005	0.0001	0.0005
				(0.0007)	(0.0007)	(0.0007)
Global precipitation anomaly				0.0006**	0.0008***	0.0001
				(0.0002)	(0.0003)	(0.0003)
Global humidity anomaly					−0.0008***	
					(0.0003)	
Economic indicators	✗	✗	✓	✗	✗	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✗	✗	✗
Observations	4351	4351	3786	4351	4351	3786
Within R^2	0.0010	0.0013	0.0112	0.0024	0.0044	0.0137
F-statistic	2.4973	1.8996	3.4586	2.9670	3.7377	3.0593
F p-value	0.0854	0.1317	0.0031	0.0212	0.0016	0.0031
Root MSE	0.0051	0.0051	0.0047	0.0051	0.0051	0.0048

Notes: Robust standard errors clustered at the country level are in parentheses. **Panel A**: the dependent variable is the GDP-net log Social Progress Index, defined as the residual from a pooled OLS regression of log(SPI) on log GDP per capita (no fixed effects; $R^2 = 0.407$, $N = 4{,}814$), capturing the component of social progress unexplained by income. Log GDP per capita re-enters as a control in Specifications (3) and (6); it is orthogonal to the residual by construction only in the pooled sample, not after absorbing country fixed effects and trends. **Panel B**: the dependent variable is the first difference of the Human Development Index (ΔHDI); the sample reflects the merge with the HDI file on country code and year (166 countries, falling to 159 once the macroeconomic controls are required). Annual temperature and precipitation anomalies are calculated from country-aggregated ERA5 reanalysis data accessed via the World Bank Climate Change Knowledge Portal (World Bank, 2025). Specifications (1)–(3) include country and year fixed effects and a country-specific linear time trend; Specifications (2) and (5) additionally include a humidity anomaly. Specifications (4)–(6) retain country fixed effects and country-specific trends but omit year fixed effects, replacing them with cross-sectional (global) weather averages. Specifications (3) and (6) further incorporate macroeconomic controls, including the annual inflation rate, official exchange rate, commodity terms of trade, and log GDP per capita; these columns cover 1990–2018, because the commodity terms-of-trade series ends in 2018. The official exchange rate is the nominal period-average rate in local currency units per US dollar, and the commodity terms of trade is a GDP-weighted index with 2012 = 100.Annual country-level Human Development Index (HDI) data are obtained from the United Nations Development Programme (UNDP) Human Development Report, as processed and distributed by Our World in Data (United Nations Development Programme, 2025). Coefficients smaller than 5×10^{-5} in absolute value display as 0.0000 at four decimal places; their signs and significance are still shown. Significance levels: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

Table (A14) Country-Standardised Weather Variation and the Social Progress Index

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
Local weather variation (country-standardised)						
Temp anomaly	−0.0461	−0.0567*	−0.0650**	−0.0498*	−0.0601**	−0.0713***
	(0.0282)	(0.0288)	(0.0263)	(0.0289)	(0.0293)	(0.0258)
Precip anomaly	0.0132	0.0435	0.0046	0.0116	0.0409	0.0059
	(0.0195)	(0.0298)	(0.0187)	(0.0201)	(0.0299)	(0.0190)
Humidity anomaly		−0.0499			−0.0482	
		(0.0383)			(0.0395)	
Economic controls						
Log GDP per capita			0.0188***			0.0216***
			(0.0041)			(0.0047)
Inflation rate			0.0001			0.0001
			(0.0001)			(0.0001)
Official exchange rate			0.0001			0.0000
			(0.0001)			(0.0001)
Commodity terms of trade			0.0060			0.0087
			(0.0080)			(0.0079)
Global weather variation (cross-sectional mean, standardised)						
Global temp anomaly				−0.2400***	−0.2382***	−0.1759***
				(0.0556)	(0.0606)	(0.0482)
Global precip anomaly				−0.0732	−0.0781	−0.0729
				(0.1577)	(0.1670)	(0.1440)
Global humidity anomaly					−0.0037	
					(0.0856)	
Economic indicators	✗	✗	✓	✗	✗	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✗	✗	✗
Observations	4814	4814	4098	4814	4814	4098
Countries (N)	167	167	159	167	167	159
Years (T)	30	30	29	30	30	29
Within R^2	0.0011	0.0020	0.0356	0.0080	0.0087	0.0517
F-statistic	1.6976	1.8215	7.1079	11.7811	8.8639	13.5057
F p-value	0.1863	0.1452	0.0000	0.0000	0.0000	0.0000
Root MSE	1.1293	1.1289	1.0077	1.1775	1.1773	1.0399

Notes: Robust standard errors clustered at the country level are in parentheses. The dependent variable is the Social Progress Index (SPI) (Social Progress Imperative, 2025; Krylova et al., 2026). Each weather variable is standardised within country over 1990–2019 by subtracting the country's own sample mean and dividing by the country's own sample standard deviation of the annual *level*, so that coefficients are expressed per within-country standard-deviation change. Countries with naturally variable weather therefore do not dominate identification. Temperature, precipitation and humidity are country-aggregated ERA5 reanalysis series accessed via the World Bank Climate Change Knowledge Portal (World Bank, 2025). Specifications (1)–(3) include country and year fixed effects and a country-specific linear time trend; Specifications (2) and (5) additionally include a humidity anomaly. Specifications (4)–(6) retain country fixed effects and country-specific trends but omit year fixed effects, replacing them with cross-sectional (global) means of each standardised variable. Specifications (3) and (6) further incorporate macroeconomic controls, including the annual inflation rate, official exchange rate, commodity terms of trade, and log GDP per capita; requiring these controls reduces the sample to 159 countries over 29 years. The models in columns (1) and (2) are not jointly significant at conventional levels. Significance levels: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

Table (A15) Reverse Causality Test: Climate Anomalies Regressed on Social Progress Index

	(1) Mean Temperature (ERA5)	(2) Max Temperature (CRU)	(3) Precipitation (ERA5)
SPI_t	−0.0064	−0.0025	−0.0129
	(0.0126)	(0.0131)	(0.0533)
SPI_{t-1}	−0.0004	−0.0068	0.0277
	(0.0191)	(0.0199)	(0.0809)
SPI_{t-2}	−0.0004	−0.0019	−0.0279
	(0.0189)	(0.0197)	(0.0799)
SPI_{t-3}	0.0130	0.0056	0.0175
	(0.0189)	(0.0196)	(0.0798)
SPI_{t-4}	−0.0179	−0.0202	−0.0328
	(0.0182)	(0.0190)	(0.0771)
SPI_{t-5}	0.0029	0.0147	0.0008
	(0.0114)	(0.0119)	(0.0483)
Joint F-statistic	0.9362	1.6154	0.4876
Joint p-value	0.4675	0.1385	0.8181
Within R^2	0.0015	0.0026	0.0008
Observations	3979	3979	3979
Countries	167	167	167
Years	25	25	25
Country FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes

Notes: This table reports Granger-style reverse causality tests in which 30-year climate anomalies are regressed on the contemporaneous Social Progress Index and its first five lags. The dependent variable in column (1) is the mean temperature anomaly constructed from ERA5 reanalysis data, in column (2) the maximum temperature anomaly constructed from CRU TS gridded observations, and in column (3) the precipitation anomaly constructed from ERA5 reanalysis data. All specifications include country and year fixed effects. Requiring five lags restricts the estimation window to 1995–2019, so 25 year effects are estimated for 167 countries. The joint F-statistic tests the null hypothesis that all six SPI coefficients are jointly equal to zero, on (6, 3782) degrees of freedom. None of the joint tests rejects at conventional significance levels, and the within R^2 values are negligible, indicating that social progress does not predict subsequent climate anomalies. Standard errors are reported in parentheses; they are not clustered, and clustering at the country level would widen them, so the failure to reject is conservative. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table (A16) Robustness: Max Temperature Anomalies and Social Progress Index (CRU Data)

	Baseline			Global weather averages		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: 20-Year Weather Anomalies						
Max temperature anomaly	−0.1922***	−0.1547**	−0.1572***	−0.1931***	−0.1572**	−0.1639***
	(0.0526)	(0.0618)	(0.0541)	(0.0540)	(0.0629)	(0.0538)
Precipitation anomaly	−0.0145	−0.0195	−0.0178*	−0.0148	−0.0196	−0.0170
	(0.0121)	(0.0129)	(0.0105)	(0.0127)	(0.0134)	(0.0111)

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Table A16 – continued from previous page

	Baseline			Global weather averages		
	(1)	(2)	(3)	(4)	(5)	(6)
Humidity anomaly		0.0376			0.0359	
		(0.0284)			(0.0282)	
Global max temperature anomaly				−0.7979***	−0.7884***	−0.6043***
				(0.1352)	(0.1328)	(0.1387)
Global precipitation anomaly				−0.1978*	−0.2071*	−0.0884
				(0.1135)	(0.1143)	(0.1023)
Global humidity anomaly					0.1489**	
					(0.0723)	
Macroeconomic controls	No	No	Yes	No	No	Yes
Observations	4,814	4,814	4,098	4,814	4,814	4,098
Countries	167	167	159	167	167	159
Years	30	30	29	30	30	29
Within R^2	0.0048	0.0061	0.0375	0.0257	0.0275	0.0602
F-statistic	7.1750	5.6282	7.4892	26.6078	19.1389	15.0455
F p-value	0.0010	0.0011	0.0000	0.0000	0.0000	0.0000
RMSE	1.1272	1.1266	1.0067	1.1670	1.1662	1.0352
Panel B: 30-Year Weather Anomalies						
Max temperature anomaly	−0.1587***	−0.1413**	−0.1305**	−0.1588***	−0.1439**	−0.1364**
	(0.0526)	(0.0616)	(0.0529)	(0.0547)	(0.0634)	(0.0533)
Precipitation anomaly	−0.0141	−0.0166	−0.0203*	−0.0143	−0.0164	−0.0195*
	(0.0130)	(0.0138)	(0.0111)	(0.0134)	(0.0142)	(0.0115)
Humidity anomaly		0.0176			0.0151	
		(0.0287)			(0.0283)	
Global max temperature anomaly				−0.8640***	−0.8619***	−0.6426***
				(0.1418)	(0.1397)	(0.1450)
Global precipitation anomaly				−0.1412	−0.1457	−0.0494
				(0.1128)	(0.1145)	(0.1007)
Global humidity anomaly					0.0584	
					(0.0677)	
Macroeconomic controls	No	No	Yes	No	No	Yes
Observations	4,814	4,814	4,098	4,814	4,814	4,098
Countries	167	167	159	167	167	159
Years	30	30	29	30	30	29
Within R^2	0.0033	0.0035	0.0365	0.0244	0.0247	0.0596
F-statistic	4.8502	3.4495	7.1596	23.6086	16.3547	14.4067
F p-value	0.0090	0.0180	0.0000	0.0000	0.0000	0.0000
RMSE	1.1281	1.1281	1.0073	1.1677	1.1678	1.0356

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Table A16 – continued from previous page

	Baseline			Global weather averages		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel B: 40-Year Weather Anomalies						
Max temperature anomaly	−0.1649***	−0.1539**	−0.1341**	−0.1649***	−0.1569**	−0.1408***
	(0.0520)	(0.0613)	(0.0521)	(0.0536)	(0.0629)	(0.0519)
Precipitation anomaly	−0.0084	−0.0100	−0.0140	−0.0085	−0.0096	−0.0130
	(0.0129)	(0.0137)	(0.0110)	(0.0133)	(0.0140)	(0.0115)
Humidity anomaly		0.0112			0.0080	
		(0.0287)			(0.0285)	
Global max temperature anomaly				−0.7762***	−0.7520***	−0.5767***
				(0.1452)	(0.1453)	(0.1486)
Global precipitation anomaly				−0.1484	−0.1640	−0.0651
				(0.1096)	(0.1096)	(0.0979)
Global humidity anomaly					0.1293*	
					(0.0714)	
Macroeconomic controls	No	No	Yes	No	No	Yes
Observations	4,814	4,814	4,098	4,814	4,814	4,098
Countries	167	167	159	167	167	159
Years	30	30	29	30	30	29
Within R^2	0.0034	0.0035	0.0363	0.0213	0.0217	0.0574
F-statistic	5.0705	3.5281	7.2313	19.6284	14.1745	13.1277
F p-value	0.0073	0.0162	0.0000	0.0000	0.0000	0.0000
RMSE	1.1280	1.1281	1.0074	1.1696	1.1696	1.0368

Notes: The dependent variable in all columns is the Social Progress Index (SPI). All climate variables are constructed from CRU TS gridded observations aggregated to the country level via the World Bank Climate Change Knowledge Portal (CCKP). Columns (1)–(3) include country fixed effects, year fixed effects, and country-specific linear time trends. Columns (4)–(6) replace year fixed effects with cross-sectional (global) averages of the climate regressors; note that the cross-sectional average of the dependent variable is not included, so this is a partial rather than a full common correlated effects specification. Columns (2) and (5) additionally control for humidity anomalies. Columns (3) and (6) additionally control for log GDP per capita (constant 2015 US$), inflation, the official exchange rate, and the commodity terms of trade; requiring these controls reduces the sample to 159 countries over 29 years. Robust standard errors clustered at the country level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table (A18) Climate Change and Social Progress Index: 20- and 40-Year Moving Averages

Panel A: 20-Year Moving Average					
(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable: Social Progress Index					

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Table A18 (continued)

Local weather anomalies						
Mean-temp anomaly	−0.1152**	−0.1280***	−0.1442***	−0.1109*	−0.1242**	−0.1491***
	(0.0546)	(0.0480)	(0.0482)	(0.0571)	(0.0492)	(0.0480)
Precipitation anomaly	0.0026	0.0076	−0.0031	0.0026	0.0079	−0.0022
	(0.0135)	(0.0180)	(0.0136)	(0.0140)	(0.0183)	(0.0138)
Humidity anomaly		−0.0110			−0.0114	
		(0.0237)			(0.0243)	
Global weather anomalies						
Global mean-temp anomaly				−0.7243***	−0.7612***	−0.5180***
				(0.1228)	(0.1268)	(0.1178)
Global precipitation anomaly				−0.0340	−0.0094	−0.0234
				(0.0495)	(0.0574)	(0.0492)
Global humidity anomaly					−0.0873*	
					(0.0496)	
Economic indicators	✗	✗	✓	✗	✗	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✗	✗	✗
Observations	4814	4814	4098	4814	4814	4098
Countries (N)	167	167	159	167	167	159
Years (T)	30	30	29	30	30	29
Within R^2	0.0017	0.0019	0.0365	0.0129	0.0135	0.0550
F-statistic	2.2543	2.4270	7.2555	24.9200	17.3550	16.3325
F p-value	0.1081	0.0674	0.0000	0.0000	0.0000	0.0000
Root MSE	1.1290	1.1290	1.0073	1.1746	1.1745	1.0381
	Panel B: 40-Year Moving Average					
	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Social Progress Index					
Local weather anomalies						
Mean-temp anomaly	−0.1023**	−0.1215**	−0.1156**	−0.0994*	−0.1195**	−0.1198**
	(0.0513)	(0.0483)	(0.0485)	(0.0527)	(0.0483)	(0.0486)

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Table A18 (continued)

Precipitation anomaly	−0.0028	0.0053	−0.0055	−0.0029	0.0055	−0.0046
	(0.0123)	(0.0160)	(0.0123)	(0.0129)	(0.0164)	(0.0125)
Humidity anomaly		−0.0173			−0.0182	
		(0.0212)			(0.0219)	
Global weather anomalies						
Global mean-temp anomaly				−1.0704***	−1.0997***	−0.6887***
				(0.1528)	(0.1414)	(0.1526)
Global precipitation anomaly				−0.0272	−0.0056	−0.0440
				(0.0434)	(0.0487)	(0.0482)
Global humidity anomaly					−0.0731	
					(0.0840)	
Economic indicators	✗	✗	✓	✗	✗	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✓	✓	✗	✗	✗
Observations	4672	4672	3999	4672	4672	3999
Countries (N)	167	167	159	167	167	159
Years (T)	29	29	28	29	29	28
Within R^2	0.0013	0.0017	0.0370	0.0222	0.0230	0.0589
F-statistic	1.9934	2.2000	7.0754	24.0366	19.9711	15.1783
F p-value	0.1395	0.0900	0.0000	0.0000	0.0000	0.0000
Root MSE	1.1059	1.1058	0.9930	1.1464	1.1462	1.0233

Notes: Robust standard errors clustered at the country level are reported in parentheses. The dependent variable is the Social Progress Index (SPI) (Social Progress Imperative, 2025; Krylova et al., 2026). Annual temperature and precipitation anomalies are calculated from country-aggregated ERA5 reanalysis data accessed via the World Bank Climate Change Knowledge Portal (World Bank, 2025). Panels A and B use a 20-year and a 40-year historical norm respectively. Specifications (1)–(3) include country and year fixed effects and a country-specific linear time trend; Specifications (2) and (5) additionally include a humidity anomaly. Specifications (4)–(6) retain country fixed effects and country-specific trends but omit year fixed effects, replacing them with cross-sectional (global) weather averages. Specifications (3) and (6) further incorporate macroeconomic controls, including the annual inflation rate, official exchange rate, commodity terms of trade, and log GDP per capita; requiring these controls reduces the sample to 159 countries. The 40-year anomaly is undefined in the first sample year, which is why Panel B loses one year and 142 observations relative to Panel A. Significance levels: *, $p < 0.10$; **, $p < 0.05$; ***, $p < 0.01$.

Table (A17) Reverse Causality Test: Environmental Quality and Climate Anomalies

	(1) Mean Temperature (ERA5)	(2) Precipitation (ERA5)
EQ_t	0.0073	−0.0414
	(0.0099)	(0.0417)
EQ_{t-1}	0.0095	0.0118
	(0.0137)	(0.0578)
EQ_{t-2}	−0.0146	0.0674
	(0.0135)	(0.0572)
EQ_{t-3}	0.0075	−0.0365
	(0.0134)	(0.0565)
EQ_{t-4}	−0.0077	−0.0594
	(0.0135)	(0.0568)
EQ_{t-5}	0.0025	0.0433
	(0.0096)	(0.0405)
Joint F-statistic	0.7921	0.8293
Joint p-value	0.5760	0.5470
Within R^2	0.0013	0.0013
Observations	3979	3979
Countries	167	167
Years	25	25
Country FE	Yes	Yes
Year FE	Yes	Yes

Notes: Granger-style reverse causality tests in which 30-year climate anomalies are regressed on contemporaneous Environmental Quality and its first five lags. Both dependent variables are constructed from ERA5 reanalysis data. All specifications include country and year fixed effects. Requiring five lags restricts the estimation window to 1995–2019, so 25 year effects are estimated for 167 countries. The joint F-statistic tests the null that all six Environmental Quality coefficients are zero, on (6, 3782) degrees of freedom. Neither joint test rejects and no individual coefficient is significant at the 10 per cent level, indicating that environmental quality does not predict subsequent climate anomalies. Standard errors are reported in parentheses; they are not clustered, and clustering at the country level would widen them, so the failure to reject is conservative. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table (A19) Seasonal 30-Year Weather Anomalies and Social Progress Index, by Hemisphere

	Dependent variable: Social Progress Index					
	Full sample		Northern hemisphere		Southern hemisphere	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: DJF						
Local weather anomalies						
DJF temp anomaly	−0.0291*	−0.0283*	−0.0260	−0.0262	−0.1582	−0.1548
	(0.0155)	(0.0164)	(0.0160)	(0.0171)	(0.1173)	(0.1404)
DJF precip anomaly	0.0026	0.0028	−0.0174	−0.0172	0.0411	0.0417
	(0.0267)	(0.0256)	(0.0342)	(0.0308)	(0.0535)	(0.0535)
DJF humidity anomaly	0.0036	0.0038	0.0131	0.0133	−0.0291	−0.0290
	(0.0096)	(0.0101)	(0.0087)	(0.0094)	(0.0348)	(0.0358)
Global weather anomalies						
Global DJF temp anomaly		−0.2723***		−0.2654***		−0.0938
		(0.0455)		(0.0383)		(0.1731)
Global DJF precip anomaly		−0.0637		0.4819**		0.5871
		(0.1845)		(0.2002)		(0.3890)
Global DJF humidity anomaly		0.1749***		0.1413***		−0.2766*
		(0.0307)		(0.0322)		(0.1434)
Global averages	✗	✓	✗	✓	✗	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✗	✓	✗	✓	✗
Observations	4814	4814	3774	3774	1040	1040
Countries (N)	167	167	132	132	35	35
Years (T)	30	30	30	30	30	30
Within R^2	0.0008	0.0142	0.0016	0.0239	0.0017	0.0138
F-statistic	1.3407	19.7263	2.0558	29.4518	0.7021	1.7567
F p-value	0.2630	0.0000	0.1092	0.0000	0.5574	0.1379
Root MSE	1.1296	1.1741	1.0670	1.1215	1.2999	1.3345
Panel B: MAM						
Local weather anomalies						
MAM temp anomaly	−0.0400	−0.0409	−0.0560*	−0.0574*	−0.1427	−0.1430
	(0.0325)	(0.0330)	(0.0307)	(0.0313)	(0.1095)	(0.1197)
MAM precip anomaly	−0.0267	−0.0249	−0.0447	−0.0441	−0.0459	−0.0432
	(0.0351)	(0.0360)	(0.0492)	(0.0496)	(0.0448)	(0.0456)
MAM humidity anomaly	−0.0052	−0.0063	−0.0026	−0.0034	−0.0139	−0.0143
	(0.0116)	(0.0117)	(0.0140)	(0.0143)	(0.0268)	(0.0253)
Global weather anomalies						
Global MAM temp anomaly		−0.1536*		−0.0177		0.3686
		(0.0779)		(0.0636)		(0.2353)
Global MAM precip anomaly		0.0908		−0.0204		1.2285*
		(0.2131)		(0.1173)		(0.6157)
Global MAM humidity anomaly		0.1005***		0.1074*		−0.0803

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Table A19 (continued)

	Dependent variable: Social Progress Index					
	Full sample		Northern hemisphere		Southern hemisphere	
	(1)	(2)	(3)	(4)	(5)	(6)
		(0.0362)		(0.0583)		(0.0573)
Global averages	✗	✓	✗	✓	✗	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✗	✓	✗	✓	✗
Observations	4814	4814	3774	3774	1040	1040
Countries (N)	167	167	132	132	35	35
Years (T)	30	30	30	30	30	30
Within R^2	0.0008	0.0050	0.0016	0.0055	0.0028	0.0251
F-statistic	0.7894	4.0222	1.4150	1.1313	1.3551	1.8290
F p-value	0.5014	0.0009	0.2413	0.3477	0.2730	0.1227
Root MSE	1.1296	1.1796	1.0670	1.1321	1.2992	1.3268
Panel C: JJA						
Local weather anomalies						
JJA temp anomaly	−0.0508	−0.0438	−0.0135	−0.0056	−0.2760***	−0.2813***
	(0.0449)	(0.0458)	(0.0526)	(0.0546)	(0.0949)	(0.0998)
JJA precip anomaly	0.0863***	0.0861***	0.1029***	0.1024***	−0.0218	−0.0226
	(0.0322)	(0.0322)	(0.0351)	(0.0360)	(0.0718)	(0.0737)
JJA humidity anomaly	−0.0145	−0.0142	−0.0124	−0.0119	−0.0156	−0.0160
	(0.0128)	(0.0131)	(0.0159)	(0.0162)	(0.0247)	(0.0285)
Global weather anomalies						
Global JJA temp anomaly		−0.8725***		−0.8867***		0.3016
		(0.1206)		(0.0945)		(0.2678)
Global JJA precip anomaly		0.3521		0.5091**		0.5668
		(0.2278)		(0.2112)		(0.3450)
Global JJA humidity anomaly		−0.0853		−0.1324***		0.0720
		(0.0593)		(0.0484)		(0.0924)
Global averages	✗	✓	✗	✓	✗	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✗	✓	✗	✓	✗
Observations	4814	4814	3774	3774	1040	1040
Countries (N)	167	167	132	132	35	35
Years (T)	30	30	30	30	30	30
Within R^2	0.0029	0.0178	0.0042	0.0219	0.0095	0.0112
F-statistic	3.2867	17.4027	3.2254	21.8642	4.5549	3.3130
F p-value	0.0222	0.0000	0.0247	0.0000	0.0087	0.0112
Root MSE	1.1284	1.1720	1.0656	1.1227	1.2948	1.3362
Panel D: SON						
Local weather anomalies						
SON temp anomaly	0.0047	0.0042	0.0160	0.0151	−0.2025*	−0.1994*
	(0.0320)	(0.0313)	(0.0331)	(0.0316)	(0.0997)	(0.1124)

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Table A19 (continued)

	Dependent variable: Social Progress Index					
	Full sample		Northern hemisphere		Southern hemisphere	
	(1)	(2)	(3)	(4)	(5)	(6)
SON precip anomaly	−0.0328	−0.0326	−0.0112	−0.0118	−0.0326	−0.0340
	(0.0393)	(0.0389)	(0.0417)	(0.0429)	(0.0810)	(0.0863)
SON humidity anomaly	0.0013	0.0011	0.0043	0.0044	−0.0234	−0.0223
	(0.0101)	(0.0104)	(0.0100)	(0.0103)	(0.0284)	(0.0316)
Global weather anomalies						
Global SON temp anomaly		−0.4693***		−0.3276***		0.1360
		(0.1302)		(0.1180)		(0.4328)
Global SON precip anomaly		−0.2078		−0.2090*		−0.4285
		(0.1281)		(0.1109)		(0.3159)
Global SON humidity anomaly		−0.0637		−0.0552		−0.0086
		(0.0450)		(0.0391)		(0.0720)
Global averages	✗	✓	✗	✓	✗	✓
Country fixed effect	✓	✓	✓	✓	✓	✓
Country-specific linear trend	✓	✓	✓	✓	✓	✓
Year fixed effect	✓	✗	✓	✗	✓	✗
Observations	4814	4814	3774	3774	1040	1040
Countries (N)	167	167	132	132	35	35
Years (T)	30	30	30	30	30	30
Within R^2	0.0004	0.0061	0.0002	0.0051	0.0054	0.0093
F-statistic	0.3239	5.1484	0.1068	4.5371	2.4763	2.0875
F p-value	0.8081	0.0001	0.9560	0.0003	0.0780	0.0806
Root MSE	1.1298	1.1789	1.0677	1.1323	1.2975	1.3375

Notes: Robust standard errors clustered at the country level are in parentheses. The dependent variable is the SPI (Social Progress Imperative, 2025; Krylova et al., 2026). Panels A–D present 30-year moving average anomalies for DJF, MAM, JJA, and SON, respectively. Temperature, precipitation and humidity anomalies are calculated from country-aggregated ERA5 reanalysis data accessed via the World Bank Climate Change Knowledge Portal. This table re-estimates Specifications (2) and (5) of Table 4 in the main text separately by hemisphere. Columns (1)–(2) use the full sample of 167 countries, columns (3)–(4) the 132 Northern hemisphere countries, and columns (5)–(6) the 35 Southern hemisphere countries. Hemisphere is assigned from the sign of each country's land centroid latitude, taken from the World Bank ADM0 boundary file used elsewhere in the paper; the full country-by-country assignment is reported in the replication files. Specifications (1), (3) and (5) correspond to Model 2 and include country fixed effects, country-specific linear time trends and year fixed effects, together with a humidity anomaly. Specifications (2), (4) and (6) correspond to Model 5: they retain country fixed effects and country-specific trends but omit year fixed effects, replacing them with cross-sectional (global) weather averages of temperature, precipitation and humidity. In columns (1)–(2) these cross-sectional averages are taken over all 167 countries; in columns (3)–(6) they are taken within the estimated hemisphere, since the common factors the estimator is intended to absorb are those shared by the countries actually entering the regression. Note that the panels are defined on fixed meteorological quarters following the World Bank convention, so a given calendar quarter falls at opposite points of the annual cycle either side of the equator: DJF is the cold quarter north of the equator and the warm quarter south of it, and conversely for JJA. Significance levels: *, $p < 0.10$; **, $p < 0.05$; ***, $p < 0.01$.

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