# Temperature Shocks and Economic Growth: Evidence from the Last Half Century

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# Introduction

- Effect of temperature & precipitation on aggregate economic outcome
- Test for impact on both level and in growth rates (short run & medium run)
- Identification: country level within variation in year to year temperatures and precipitation
- Explore potential channels like agriculture, industry, investment and political economy

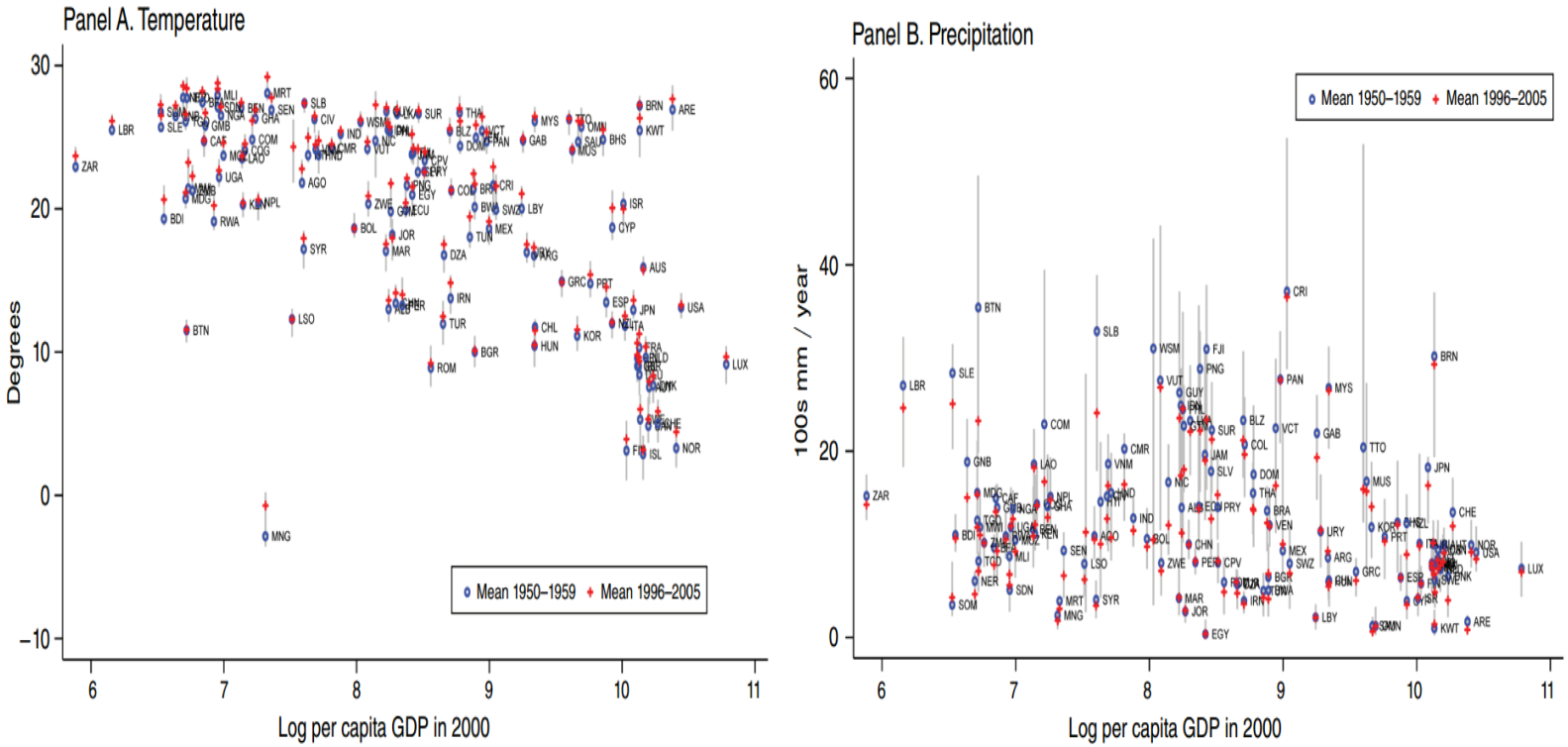
# Main Finding

1. Higher temperatures substantially reduce economic growth in poor countries
2. Higher temperatures may reduce growth rates, not just the level of output
3. Higher temperatures have wide-ranging effects, reducing agricultural output, industrial output, and political stability

# Data

- Panel of 125 countries, sample period: 1950-2003
- Weather: Terrestrial Air Temperature and precipitation: 1900–2006 Gridded Monthly Time Series
- Monthly mean temperature and precipitation data at 0.5 $\times$ 0.5 degree resolution (approximately 56km $\times$ 56km at the equator)
- Population: Global rural-urban Mapping project
- Population-weighted average temperature and precipitation

# Descriptive Statistic I



# Descriptive Statistic II

TABLE 1—OBSERVED TEMPERATURE AND PRECIPITATION VARIATION, 1950–2003

| | Proportion of country-years with temperature […] degrees above/below country mean | | | | | |
|---|---|---|---|---|---|---|
| | 0.25 | 0.50 | 0.75 | 1.00 | 1.25 | 1.50 |
| Raw data | 0.573 | 0.299 | 0.144 | 0.064 | 0.028 | 0.011 |
| After removing worldwide year fixed effects | 0.511 | 0.215 | 0.085 | 0.032 | 0.013 | 0.005 |
| After removing region × year and poor × year fixed effects | 0.448 | 0.153 | 0.051 | 0.018 | 0.008 | 0.002 |

| | Proportion of country-years with precipitation […] 100 mm units above/below country mean | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Raw data | 0.480 | 0.229 | 0.121 | 0.070 | 0.042 | 0.027 |
| After removing worldwide year fixed effects | 0.494 | 0.221 | 0.113 | 0.062 | 0.038 | 0.024 |
| After removing region × year and poor × year fixed effects | 0.462 | 0.213 | 0.106 | 0.058 | 0.032 | 0.021 |

# The Effect of Temperature Fluctuations on Economic Activity

Empirical Framework:

$$Y_{it} = e^{\beta T_{it}} A_{it} L_{it}$$

$$\Delta A_{it}/A_{it} = g_i + \gamma T_{it}$$

Take logs in production function and differencing w.r.t time gives us

$$g_{it} = g_i + (\beta + \gamma) T_{it} - \beta T_{it-1}$$

where $g_{it}$ is the growth rate of per-capita output. The "level effects" of weather shocks on output appear through $\beta$. The "growth effects" of weather shocks appear through $\gamma$.

# The Effect of Temperature Fluctuations on Economic Activity

Panel Regression:

$$g_{it} = \theta_i + \theta_{rt} + \sum_{j=0}^{L} \rho_j T_{it-j} + \varepsilon_{it}$$

where $\theta_i$ are country fixed effects, $\theta_{rt}$ are time fixed effects (interacted separately with region dummies and a poor country dummy in our main specifications), $\epsilon_{it}$ is an error term clustered simultaneously by country and region-year , and $T_{it}$ is a vector of annual average temperature and precipitation with up to L lags included.

# The Effect of Temperature Fluctuations on Economic Activity

Three Null Hypotheses:
Temperature does not affect growth:

$$H_0(L = 0) : \rho_0 = 0$$

Temperature does not affect growth immediately:

$$H_0^1(L > 0) : \rho_0 = 0$$

Temperature does not affect growth cumulatively:

$$H_0^2(L > 0) : \sum_{j=0}^{L} \rho_j = 0$$

# The Effect of Temperature Fluctuations on Economic Activity

TABLE 2—MAIN PANEL RESULTS

| Dependent variable is the annual growth rate | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Temperature | −0.325 | 0.261 | 0.262 | 0.172 | 0.561* |
| | (0.285) | (0.312) | (0.311) | (0.294) | (0.319) |
| *Temperature interacted with…* | | | | | |
| Poor country dummy | | −1.655*** | −1.610*** | −1.645*** | −1.806*** |
| | | (0.485) | (0.485) | (0.483) | (0.456) |
| Hot country dummy | | | | 0.237 | |
| | | | | (0.568) | |
| Agricultural country dummy | | | | | −0.371 |
| | | | | | (0.409) |
| Precipitation | | | −0.083* | −0.228*** | −0.105** |
| | | | (0.050) | (0.074) | (0.053) |
| *Precipitation interacted with…* | | | | | |
| Poor country dummy | | | 0.153* | 0.160** | 0.145* |
| | | | (0.078) | (0.075) | (0.087) |
| Hot country dummy | | | | 0.185** | |
| | | | | (0.078) | |
| Agricultural country dummy | | | | | 0.010 |
| | | | | | (0.085) |
| Observations | 4,924 | 4,924 | 4,924 | 4,924 | 4,577 |
| Within $R^2$ | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 |
| $R^2$ | 0.22 | 0.22 | 0.22 | 0.22 | 0.24 |
| Temperature effect in poor countries | | −1.394*** | −1.347*** | −1.473*** | −1.245*** |
| | | (0.408) | (0.408) | (0.440) | (0.463) |
| Precipitation effect in poor countries | | | 0.069 | −0.0677 | 0.0401 |
| | | | (0.058) | (0.073) | (0.089) |

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# The Effect of Temperature Fluctuations on Economic Activity

TABLE 3—MODELS WITH LAGS

| | No lags (1) | 1 lag (2) | 5 lags (3) | 10 lags (4) | No lags (5) | 1 lag (6) | 5 lags (7) | 10 lags (8) |
|---|---|---|---|---|---|---|---|---|
| Temperature × Poor | −1.394*** | −1.610*** | −1.555*** | −1.597*** | −1.347*** | −1.559*** | −1.514*** | −1.580*** |
| | (0.408) | (0.525) | (0.572) | (0.565) | (0.408) | (0.522) | (0.577) | (0.579) |
| L1: Temperature × Poor | | 0.514 | 0.614 | 0.572 | | 0.576 | 0.666 | 0.627 |
| | | (0.439) | (0.489) | (0.498) | | (0.433) | (0.479) | (0.481) |
| L2: Temperature × Poor | | | −0.334 | −0.368 | | | −0.338 | −0.354 |
| | | | (0.566) | (0.580) | | | (0.570) | (0.586) |
| L3: Temperature × Poor | | | −0.105 | −0.175 | | | −0.064 | −0.152 |
| | | | (0.480) | (0.489) | | | (0.489) | (0.506) |
| Temperature × Rich | 0.261 | 0.206 | 0.227 | 0.219 | 0.262 | 0.215 | 0.235 | 0.234 |
| | (0.312) | (0.323) | (0.330) | (0.348) | (0.311) | (0.322) | (0.338) | (0.356) |
| L1: Temperature × Rich | | 0.135 | 0.143 | 0.166 | | 0.137 | 0.143 | 0.168 |
| | | (0.300) | (0.297) | (0.317) | | (0.298) | (0.299) | (0.323) |
| L2: Temperature × Rich | | | 0.165 | 0.158 | | | 0.181 | 0.172 |
| | | | (0.257) | (0.263) | | | (0.262) | (0.273) |
| L3: Temperature × Rich | | | −0.100 | −0.129 | | | −0.110 | −0.137 |
| | | | (0.271) | (0.277) | | | (0.277) | (0.286) |
| Includes precipitation vars. | No | No | No | No | Yes | Yes | Yes | Yes |
| Observations | 4,924 | 4,924 | 4,916 | 4,906 | 4,924 | 4,924 | 4,916 | 4,906 |
| $R^2$ | 0.22 | 0.22 | 0.22 | 0.23 | 0.22 | 0.22 | 0.23 | 0.23 |
| Within $R^2$ | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 |
| Sum of all temp. coeff. in poor countries | −1.394*** | −1.096*** | −1.235** | −1.171* | −1.347*** | −0.983** | −1.041** | −0.858 |
| | (0.408) | (0.418) | (0.527) | (0.611) | (0.408) | (0.416) | (0.530) | (0.647) |
| Sum of all temp. coeff. in rich countries | 0.261 | 0.341 | −0.180 | −0.152 | 0.262 | 0.352 | −0.191 | −0.189 |
| | (0.312) | (0.400) | (0.566) | (0.786) | (0.311) | (0.396) | (0.546) | (0.758) |

# The Effect of Temperature Fluctuations on Economic Activity

The main results is robust to:
Data sources: the authors try various samples and datasets.
Nonlinear Temperature Effects: Their "non-linear" regression results do not any evidence that this effect is non-linear.

# Channels

TABLE 5—COMPONENTS OF OUTPUT GROWTH

*Panel A. Models with no lags*

| | Dependent variable is | | |
|---|---|---|---|
| | Growth in agriculture value added | Growth in industrial value added | Growth in investment |
| | (1) | (2) | (3) |
| Temperature | No lags | No lags | No lags |
| Immediate effect—poor | −2.666*** (0.948) | −2.036** (0.878) | −0.895 (1.269) |
| Immediate effect—rich | −0.222 (0.650) | 0.514 (0.452) | 0.182 (0.870) |
| Precipitation | | | |
| Immediate effect—poor | 0.182 (0.135) | 0.238 (0.146) | −0.019 (0.223) |
| Immediate effect—rich | 0.16 (0.119) | −0.007 (0.100) | −0.419* (0.217) |
| Observations | 3,835 | 3,835 | 4,419 |

# Channels

*Panel B. Models with lags*

| | Dependent variable is | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Growth in agriculture value added | | | Growth in industrial value added | | | Growth in investment | | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| Temperature | 1 lag | 5 lags | 10 lags | 1 lag | 5 lags | 10 lags | 1 lag | 5 lags | 10 lags |
| Cumulative | −1.26 | −1.051 | −1.337 | −1.835 | −0.958 | −2.242 | 1.170 | 0.128 | −0.219 |
| effect—poor | (0.882) | (1.007) | (1.203) | (1.123) | (1.365) | (1.796) | (1.287) | (1.665) | (1.797) |
| Cumulative | 0.328 | 0.002 | 0.236 | 0.653 | 0.111 | 0.321 | 0.598 | −1.38 | −1.283 |
| effect—rich | (0.678) | (0.754) | (1.203) | (0.572) | (0.734) | (1.096) | (0.894) | (1.333) | (1.356) |
| Immediate | −3.684*** | −3.703*** | −3.797*** | −2.091** | −2.334** | −2.578** | −2.235 | −1.851 | −2.229 |
| effect—poor | (1.389) | (1.385) | (1.416) | (0.987) | (1.112) | (1.172) | (1.946) | (1.972) | (2.025) |
| Immediate | −0.543 | −0.468 | −0.566 | 0.457 | 0.433 | 0.404 | −0.079 | 0.19 | 0.282 |
| effect—rich | (0.792) | (0.793) | (0.815) | (0.486) | (0.498) | (0.500) | (1.185) | (1.199) | (1.172) |
| Precipitation | | | | | | | | | |
| Cumulative | 0.094 | 0.129 | 0.052 | 0.328** | 0.205 | 0.230 | 0.148 | 0.007 | −0.283 |
| effect—poor | (0.120) | (0.159) | (0.185) | (0.158) | (0.237) | (0.322) | (0.268) | (0.289) | (0.349) |
| Cumulative | 0.207* | 0.394*** | 0.476** | −0.071 | −0.083 | −0.113 | −0.317 | −0.017 | −0.519 |
| effect—rich | (0.120) | (0.143) | (0.233) | (0.135) | (0.229) | (0.303) | (0.203) | (0.336) | (0.364) |
| Immediate | 0.220 | 0.235 | 0.252 | 0.188 | 0.108 | 0.078 | −0.106 | −0.174 | −0.190 |
| effect—poor | (0.180) | (0.197) | (0.208) | (0.187) | (0.168) | (0.166) | (0.361) | (0.402) | (0.405) |
| Immediate | 0.154 | 0.153 | 0.169 | 0.012 | 0.001 | 0.002 | −0.434* | −0.468* | −0.457 |
| effect—rich | (0.172) | (0.184) | (0.192) | (0.124) | (0.132) | (0.137) | (0.262) | (0.282) | (0.283) |
| Observations | 3,835 | 3,827 | 3,817 | 3,835 | 3,827 | 3,817 | 4,419 | 4,411 | 4,401 |

# Channels

TABLE 6—POLITICAL ECONOMY EFFECTS

| | Any change in POLITY score (1) | Leader transition (2) | Regular leader transition (3) | Irregular leader transition (4) | Start of conflicts (conditional on conflict = 0 in $t-1$) (5) | End of conflicts (conditional on conflict > 0 in $t-1$) (6) |
|---|---|---|---|---|---|---|
| Temperature | −0.013 | −0.002 | 0.004 | −0.005 | −0.006 | 0.005 |
| | (0.009) | (0.015) | (0.015) | (0.004) | (0.006) | (0.060) |
| Temperature × Poor | 0.040** | 0.033 | −0.017 | 0.050*** | 0.012 | 0.003 |
| | (0.016) | (0.023) | (0.017) | (0.013) | (0.013) | (0.068) |
| Precipitation | 0.001 | 0.003 | 0.003 | 0.000 | 0.000 | 0.023 |
| | (0.003) | (0.002) | (0.003) | (0.001) | (0.001) | (0.019) |
| Precipitation × Poor | 0.008 | −0.008* | −0.008** | 0.000 | 0.000 | −0.031 |
| | (0.005) | (0.004) | (0.004) | (0.002) | (0.002) | (0.020) |
| Observations | 5,388 | 6,624 | 6,624 | 6,624 | 5,702 | 852 |
| $R^2$ | 0.14 | 0.18 | 0.2 | 0.11 | 0.09 | 0.43 |
| Within $R^2$ | 0.003 | 0.001 | 0.001 | 0.004 | 0.000 | 0.004 |
| Temperature effect in poor countries | 0.027* | 0.031* | −0.013 | 0.044*** | 0.007 | 0.008 |
| | (0.015) | (0.017) | (0.010) | (0.013) | (0.011) | (0.037) |
| Precipitation effect in poor countries | −0.009** | −0.005 | −0.005* | 0.000 | 0.000 | −0.009 |
| | (0.004) | (0.004) | (0.003) | (0.002) | (0.002) | (0.007) |

# Medium Run Analysis I

$$\overline{g}_{i2} - \overline{g}_{i1} = \alpha + \theta_r + \gamma(\overline{T}_{i2} - \overline{T}_{i1}) + \varepsilon_i$$

Time: 1970-1985, 1986-2000, $\theta_r$: region FE and dummy for poor

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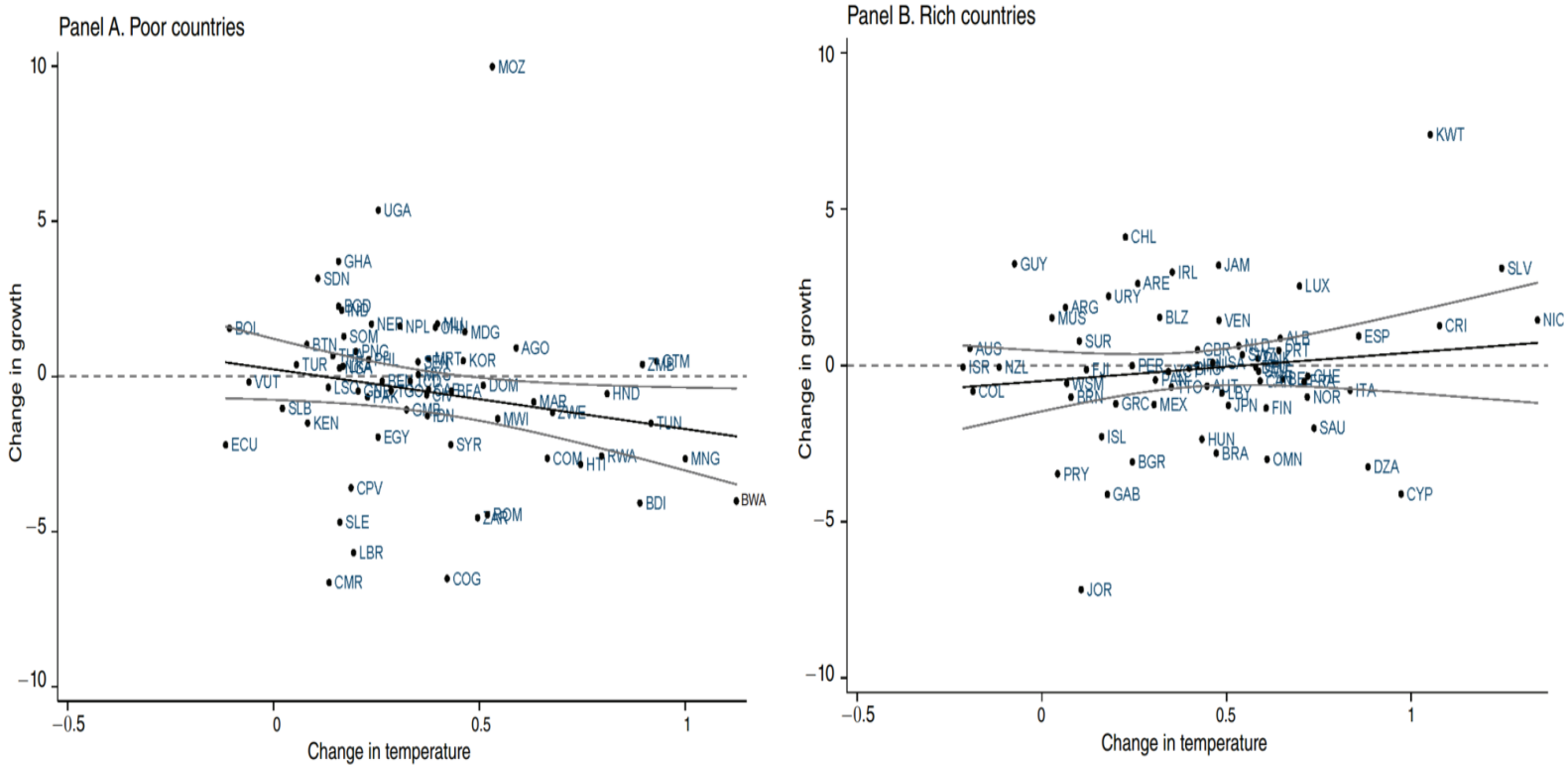

# Medium Run Analysis III

TABLE 7—CHANGES IN GROWTH AND TEMPERATURE IN THE MEDIUM RUN

| | Dependent variable: change in mean growth rate | | | | | | |
|---|---|---|---|---|---|---|---|
| | Baseline sample | | | | Africa only | Excluding Africa | PWT data |
| | OLS | | Median regression | | | | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Change in temperature | 0.952 | 1.325 | 0.004 | 0.440 | −1.654 | 1.318 | 1.576 |
| | (1.021) | (0.980) | (0.584) | (0.747) | (2.250) | (1.004) | (1.135) |
| Change in temp. × poor country | −2.886** | −3.010** | −2.261** | −2.540** | | −2.980** | −3.917** |
| | (1.420) | (1.456) | (0.932) | (1.177) | | (1.435) | (1.532) |
| Change in precipitation | −0.070 | −0.047 | 0.028 | 0.038 | 0.034 | −0.020 | 0.025 |
| | (0.097) | (0.123) | (0.113) | (0.111) | (0.565) | (0.121) | (0.111) |
| Change in precip. × poor country | 0.060 | 0.050 | 0.120 | 0.315 | | 0.009 | 0.010 |
| | (0.191) | (0.214) | (0.182) | (0.208) | | (0.212) | (0.238) |
| Region FE | No | Yes | No | Yes | No | Yes | Yes |
| Poor country dummy | Yes | Yes | Yes | Yes | No | Yes | Yes |
| Early period | 1970–1985 | 1970–1985 | 1970–1985 | 1970–1985 | 1970–1985 | 1970–1985 | 1970–1985 |
| Late period | 1986–2000 | 1986–2000 | 1986–2000 | 1986–2000 | 1986–2000 | 1986–2000 | 1986–2000 |
| Observations | 125 | 125 | 125 | 125 | 35 | 87 | 120 |
| $R^2$ | 0.04 | 0.11 | | | 0.06 | 0.19 | 0.12 |
| Within $R^2$ | 0.03 | 0.04 | | | 0.04 | 0.04 | 0.06 |
| Temp. effect on poor countries | −1.934* | −1.684 | −2.257*** | −2.100** | −1.654 | −1.661 | −2.341** |
| | (0.986) | (1.088) | (0.726) | (0.919) | (2.250) | (1.047) | (1.029) |
| Precip. effect on poor countries | −0.010 | 0.003 | 0.148 | 0.354** | 0.034 | −0.012 | 0.035 |
| | (0.164) | (0.167) | (0.143) | (0.175) | (0.565) | (0.153) | (0.211) |

# Conclusion

- In poor countries, a 1 Celsius rise in temperature $\Longrightarrow$ growth $\downarrow$ by 1.3 pp on average
- Sustained cross-sectional temperature difference for 7 years $\Longrightarrow$ observed corr(per capita income, temp)
- Short-run impacts appear very robust (level and growth)
- Poor countries: $\downarrow$ agriculture, industry output, political stability
- Adaptation can mitigate the medium run effects

# Limitations?

- "Non-linear regression" - still robust?
- Lag structure - deep ocean temperature changes