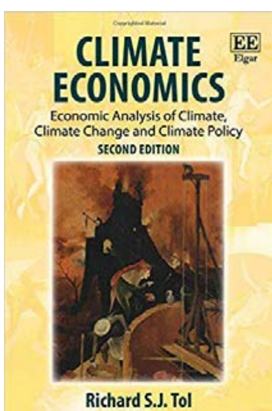
Weather, climate and the economy

Richard S.J. Tol
University of Sussex
Vrije Universiteit, Amsterdam
Tinbergen Institute
CESifo
Payne Institute



Climate matters

- Climate matters to the economy
- If not, climate change would not matter
- This is not the same as climate determinism
  - 管仲 (Guan Zhong), Hippocrates, Aristotle, Ibn Khaldun, Huntington, Diamond all argue that geography is destiny, that the character of a people, and hence its success is determined solely by the prevailing environmental conditions

Climate matters

- Mainstream economists are institutional determinists
  - The only thing that matters to humans are other humans (Easterly & Levine *JME* 2003; Rodrik , Subramanian & Trebbi *JEG* 2004)
  - Climate mattered in shaping institutions, but is no longer relevant now (Acemoglu , Johnson & Robinson *AER* 2001; Alsan *AER* 2015)
- If true, climate change is irrelevant in the long run, perhaps matters in transition

Climate matters

- Climate matters for agriculture, for energy demand, for tourism, for health, for labour productivity
- Climate explains, in part, the income distribution within countries (Nordhaus *PNAS* 2006; Henderson , Squires, Storeygard & Weil *QJE* 2018)

- Identification is problematic
  - Climate varies slowly over time, many confounders
  - Climate varies strongly over space, many confounders

Weather and economic output

- Effect of weather on economy is well-documented (Barrios, Bertinelli & Strobl *JUE* 2006, *REStat* 2010; Strobl *REStat* 2011; Dell, Jones & Olken *AER* 2009, *AEJ Macro* 2012, *JEL* 2014; Hsiang & Jina *AER* 2015; Burke, Hsiang & Miguel *Nature* 2015; Hornbeck *AER* 2012; Carleton & Hsiang *Science* 2016; Burke, Davis & Diffenbaugh, *Nature*, 2018)
- Weather is random from an economic perspective, and claims of causality are readily made
- Weather affects many economic activities that in turn affect one another

Weather and economic growth

- Weather shocks affect growth
  - More so in poor countries (Dell, Jones & Olken *AER* 2009, *AEJ Macro* 2012; Letta & Tol *ERE* 2018)
  - More so in hot countries (Burke, Hsiang & Miguel *Nature* 2015; Burke, Davis & Diffenbaugh *Nature* 2018)
- Cross-validation somewhat favours specifications in which weather affects the level of economic activity rather than its growth rate (Newell, Prest & Sexton *RFF* 2018)

Weather and economic output

- Problematic extrapolation from weather to climate (Dell et al. *JEL* 2014)
  - Climate is what you expect, weather is what you get
  - Response to weather shocks is limited: Put up an umbrella, close the flood gates
  - Adaptation to climate is extensive: Buy an umbrella, build flood gates
- Conditions for weather impacts to inform climate impacts are strict (Deryugina & Hsiang *NBER* 2017) or very strict (Lemoine *NBER* 2018)

- There are also papers that apply climate change impact functions to weather shocks (Cai & Lontzek *JPE* 2019; Caleb, Chapman, Stainforth & Watkins *Nat Comm* 2020)

Contribution

- Simultaneously model impacts of *climate* and *weather* on economic activity
- Climate impacts production potential
  - Denmark is good for Holsteiners, bad for rice
  - Thailand is good for rice, bad for Holsteiners
- Weather shocks are lost potential
  - Crop failure
  - Disruptions of production and transport
- Climate in production frontier, weather as a source of inefficiency
- Stochastic Frontier Analysis

Data

- DepVar: Output per worker (Penn World Tables 9.0)
- 1950-2014, 160 countries
- Frontier: Capital per worker (PWT 9.0), 30-year average temperature and rainfall, gridded data (University of Delaware 2014), aggregated using population weights
- Inefficiency: temperature and rainfall anomalies (absolute values of level differences from long-run averages, normalized by dividing by the long-run standard deviation)

Stochastic frontier analysis

- Production efficiency, a frontier that cannot be exceeded but is imperfectly observed
- Deviations from this extreme represent inefficiencies, inframarginal producers that would up their game or go bankrupt later
- Composite error term: two-sided idiosyncratic error plus a one-sided error that represents inefficiency
- Originally developed for cross-sectional data (Aigner, Lovell and Schmidt, 1977; Meeusen & Van den Broeck, 1977)
  - Panel data (Pitt & Lee, 1981; Battese & Coelli, 1988)
  - Time-varying inefficiency (Kumbhakar, 1990; Battese & Coelli, 1992; Greene, 2005)
  - Explanatory variables for inefficiency (Kumbhakar et al. 1991; Wang, 2002; Wang & Schmidt, 2002; Greene, 2005)

US

Econometrics

- True fixed-effects (TFE) model (Greene 2005): a SF approach for panel data with fixed effects – allows to disentangle time-varying inefficiency from individual unobserved heterogeneity
- Frontier

$$\ln(y_{it}) = \beta_1 ln(k_{it}) + \beta_2 \bar{T}_{it} + \beta_3 \bar{T}_{it}^2 + \beta_3 \bar{P}_{it} + \beta_4 \bar{P}_{it}^2 + \beta_5 t + \theta_i + v_{it} - u_{it}$$

- Inefficiency

$$u_{it} \sim \mathcal{N}^+(0, \sigma_{it}^2)$$

$$\sigma_{it}^2 = \lambda_i + \lambda_1 \left| \frac{T_{it} - \bar{T}_{it}}{\tau_t} \right| + \lambda_2 \left| \frac{P_{it} - \bar{P}_{it}}{\pi_t} \right|$$

$$\mathbb{E}u_{it} = \sigma_{it} \sqrt{2/\pi}\,; \mathbb{V}\mathrm{ar}u_{it} = \sigma_{it}^2 (1 - 2/\pi)$$

Estimation

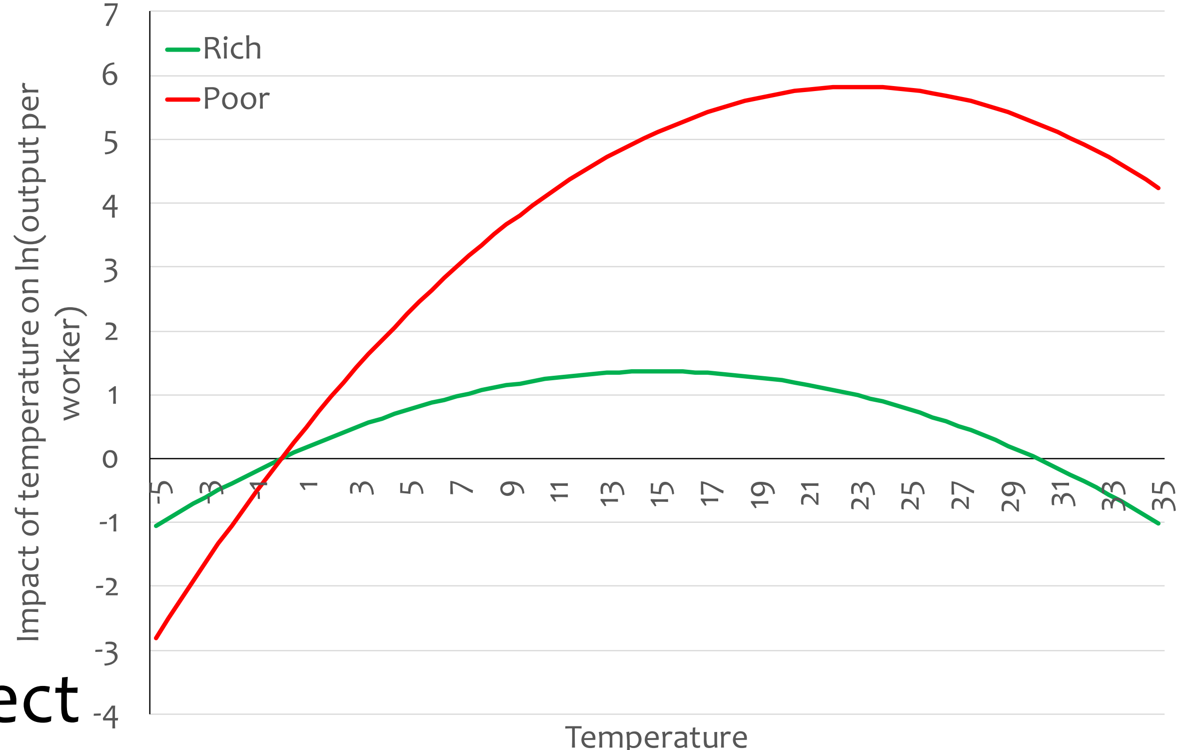
- Computationally cumbersome, issues with convergence in ML estimation
- Stata, SFMODEL (Kumbhakar et al. 2015)
  - Avoid SFCROSS and particularly SFPANEL (Belotti et al. 2013)
- Exponential as robustness
- Squared anomalies, asymmetries as robustness
- Heterogeneity in income vs climate

- Key concern: Non-stationarity

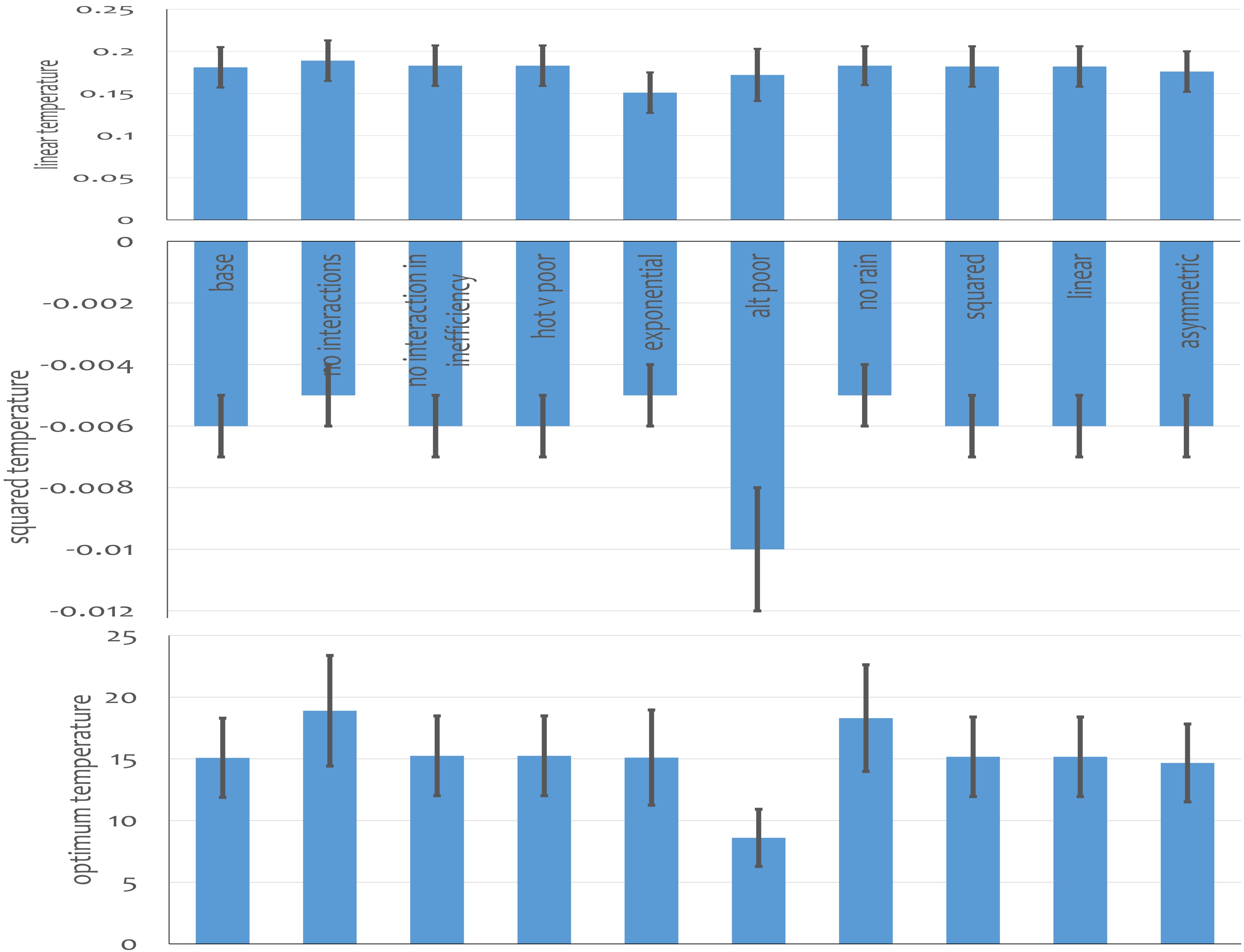
Frontier	Capital	0.616***	(0.008)
	Temperature	0.181***	(0.024)
	Temperature squared	-0.006***	(0.001)
	Rainfall	0.007	(0.011)
	Rainfall squared	-0.0005	(0.0004)
	Temp * poor	0.325**	(0.147)
	Temp squared * poor	-0.005*	(0.003)
	Rain * poor	0.024	(0.036)
	Rain squared * poor	0.001	(0.001)
Inefficiency	Abs temp anomaly	-0.053	(0.036)
	Abs rain anomaly	-0.086**	(0.041)
	Temp * poor	0.193***	(0.058)
	Rain * poor	0.272***	(0.066)

Baseline results - Frontier

- Shallow parabola in temperature for rich countries, steep one in poor countries



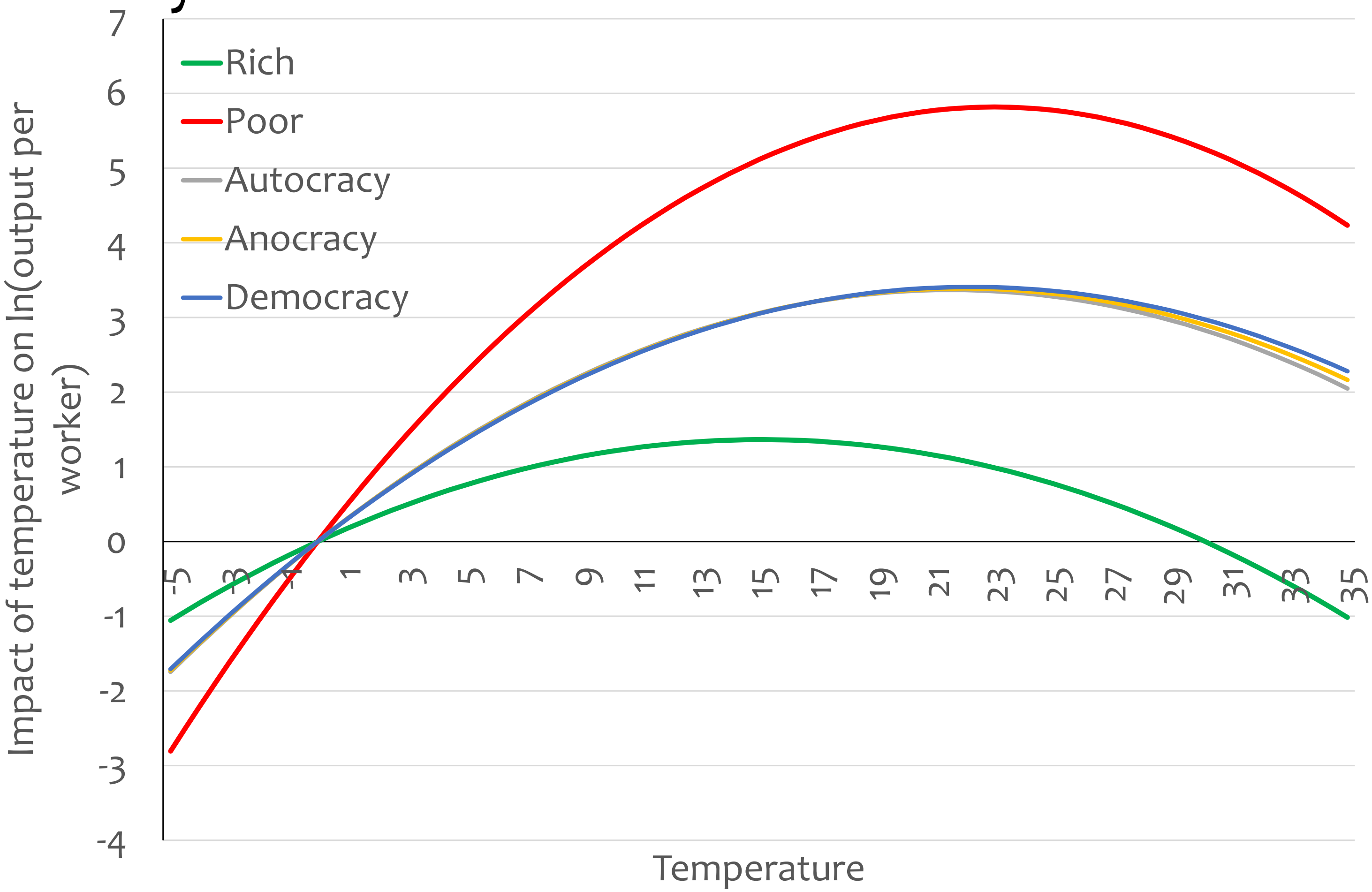
- Rainfall has no effect
- Robust, except for definition of poor



linear temperature
0.25
0.2
0.15
0.1
0.05
0
squared temperature
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
base
no interactions
no interaction in inefficiency
hot v poor
exponential
alt poor
no rain
squared
linear
asymmetric
optimum temperature
25
20
15
10
5
0

Further tests

- Same qualitative results if interaction of temperature with capital per worker replaces poverty dummy
- Polity IV does not do much



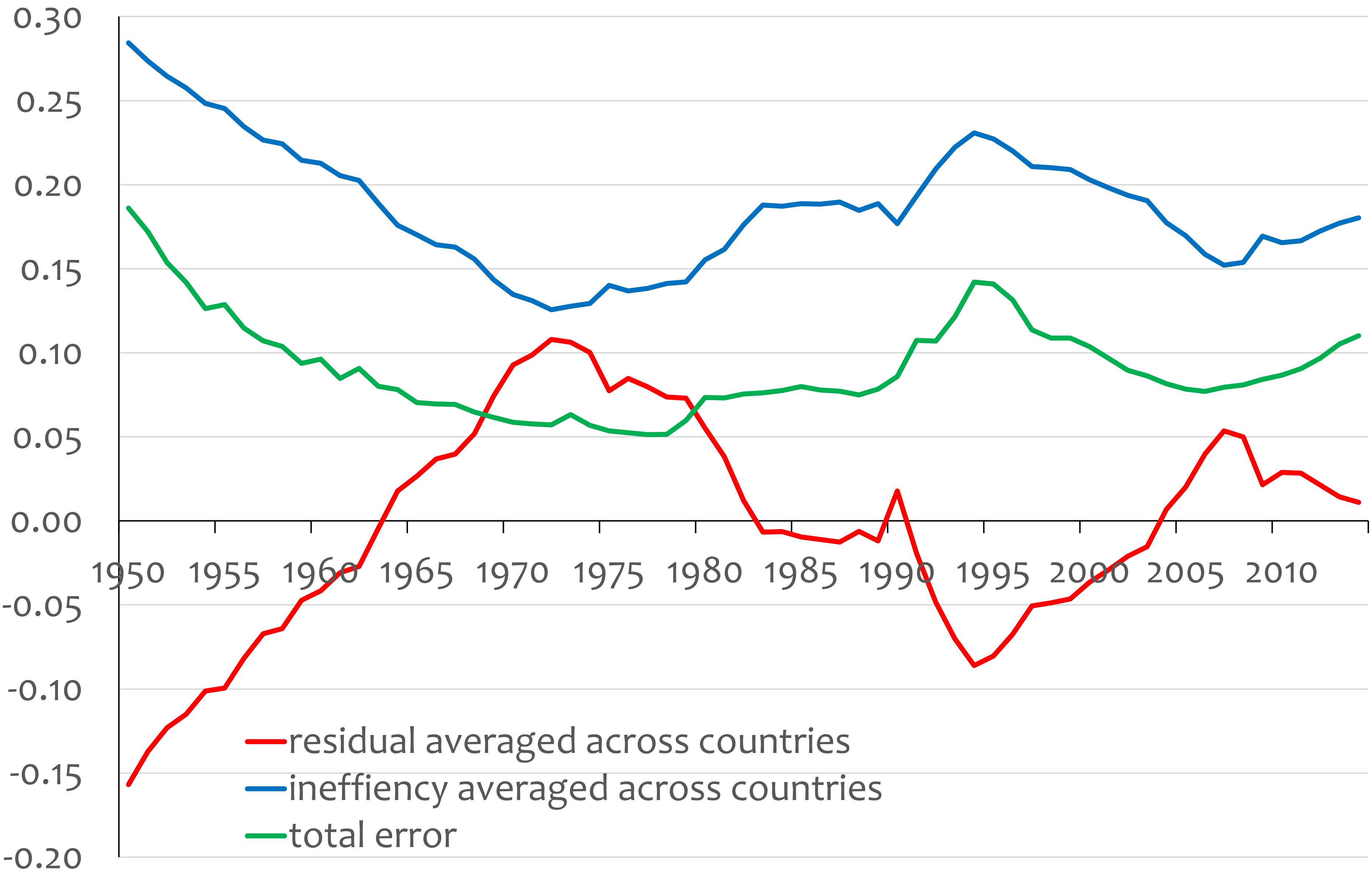
Inefficiency	poor	v	hot	
Abs temp anomaly	-0.053	(0.036)	-0.062	(0.038)
Abs rain anomaly	-0.086**	(0.041)	-0.109**	(0.040)
Temp * poor	0.193***	(0.058)	0.183***	(0.060)
Rain * poor	0.272***	(0.066)	0.257***	(0.068)
Temp * hot			0.071	(0.059)
Rain * hot			0.098	(0.072)

Baseline results - Inefficiency

- Temperature and rainfall shocks are bad for poor countries
  - Not for hot countries, poor countries
- Positive effect of unusual rain in rich countries
  - Puzzling
  - Perhaps GDP v NDP
  - Perhaps inflation

Non-stationarity

- Both the dependent variable and the variables of interest are non-stationary
- Both error terms are assumed to be stationary
- Unfortunately, there are no tests for cointegration for stochastic frontier models, let alone panel cointegration
- Stochastic frontier panels are hard to estimate, so we opted for
  - country fixed effects, a joint linear trend in the frontier
  - country fixed effects in inefficiency


0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
residual averaged across countries
ineffiency averaged across countries
total error

Remedies

- Recast model as error-correction

- Sample split
    - Split sample by decade
    - Re-estimate model
    - Shrink decadal estimates

    - If non-stationarity would influence parameter estimates, the shrunk parameters would be different

Frontier	Whole sample		Decadal split, shrunk	
Capital	0.616***	(0.008)	0.587***	(0.012)
Temperature	0.181***	(0.024)	0.169***	(0.036)
Temp squared	-0.006***	(0.001)	-0.005***	(0.001)
Rainfall	0.007	(0.011)	0.003	(0.013)
Rainfall squared	-0.0005	(0.0004)	-0.0001	(0.0004)
Temp * poor	0.325**	(0.147)	0.382***	(0.122)
Temp sq * poor	-0.005*	(0.003)	-0.000	(0.003)
Rain * poor	0.024	(0.036)	-0.103*	(0.055)
Rain sq * poor	0.001	(0.001)	0.002	(0.002)
Inefficiency				
Abs temp	-0.053	(0.036)	-0.035	(0.066)
Abs rain	-0.086**	(0.041)	-0.125**	(0.057)
Temp * poor	0.193***	(0.058)	0.101*	(0.092)
Rain * poor	0.272***	(0.066)	0.429***	(0.092)

Error correction

- Climate in equilibrium, weather in growth

$$\ln(y_{it}) = \beta_1 ln(k_{it}) + \beta_2 \bar{T}_{it} + \beta_3 \bar{T}_{it}^2 + \beta_3 \bar{P}_{it} + \beta_4 \bar{P}_{it}^2 + \beta_5 t + \theta_i + v_{it}$$

$$\Delta\ln(y_{it}) = \lambda_1 \hat{v}_{it} + \lambda_2 \left| \frac{T_{it} - \bar{T}_{it}}{\tau_t} \right| + \lambda_3 \left| \frac{P_{it} - \bar{P}_{it}}{\pi_t} \right| + \lambda_4 t + \vartheta_i + u_{it}$$

- Long-run
  - Parabolic relationship with temperature, stronger in poor countries
  - *Too much water is bad for rich countries, too little for poor countries*
- Short-run
  - Rainfall shocks reduce growth in poor countries
  - *No effect in rich countries*

Findings

- Climate affects the production potential of economies
- Weather affects economic activity

- Stronger effects in poor countries

Implications

- Schelling Conjecture holds

- Studies that regress income on climate should account for weather-induced heteroskedasticity
- In a short panel or cross-section, there is a good chance of bias

- Studies that regress growth on weather should account for lagged variables, because if our specification is correct, economies bounce back quickly

Thank you!