An Investigation Into Cross-Country Economic Response Heterogeneity to Temperature Shocks

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Introduction

1. We use local projections to estimate the impulse response of per capita real GDP growth over horizons ranging from 0 to 7 years in response to
   - Global temperature shocks
   - Idiosyncratic (country-specific) temperature shocks

   This analysis gives significant differences across countries. A large number of countries have benefitted (historically) from positive temperature shocks.
2. Investigate the mechanism driving the response patterns.
3. Investigate country characteristics that may explain the different response patterns.
4. Counterfactual analysis to help inform specifications of damage functions.
5. Study is motivated by
   - Regional integrated-assessment models find heterogeneity of temperature effects across regions
   - Empirical studies with panel data constrain the responses to be identical across regions or investigate very limited degrees of heterogeneity.

Contact to the Literature

1. Dell, Jones, and Olken (2012), Burke, Hsiang, and Miguel (2015) find that poor countries are per capita GDP is hurt most by local temperature shocks.
2. Letta and Tol (2018) and Hensler et al. (2019) get similar results with total factor productivity.
3. Colacito, Hoffmann, and Pham (2019) find that hot states are hurt most by high summer temperatures.
4. These studies run panel regressions with individual and time-specific fixed effects.
5. Kahn et al. find no difference between hot and cold, rich and poor with panel ADRL regression.

Panel Regression with Fixed and Time Effects

The basic panel regression:

$$\Delta y_{it} = \theta_i + \theta_t + \beta T_{it} + \epsilon_{it} \tag{1}$$

TABLE 2—MAIN PANEL RESULTS

Dependent variable is the annual growth rate	(1)	(2)	(3)
Temperature	−0.325 (0.285)	0.261 (0.312)	0.262 (0.311)
Temperature interacted with...			
Poor country dummy		−1.655*** (0.485)	−1.610*** (0.485)
Hot country dummy			

Measured Variation in $\hat{\beta}$

Including individual and time-specific fixed effects is identical to regressing

$$\underbrace{\left(\Delta y_{it} - \frac{1}{T}\sum_{j=1}^{T}\Delta y_{ij}\right)}_{\text{Dev. from T.S. mean}} - \underbrace{\left(\frac{1}{N}\sum_{i=1}^{N}\Delta y_{it} - \frac{1}{T}\sum_{j=1}^{T}\frac{1}{N}\sum_{i=1}^{N}\Delta y_{ij}\right)}_{\text{Deviation of global average from its t.s. mean}}$$

on

$$\underbrace{\left(T_{it} - \frac{1}{T}\sum_{j=1}^{T}T_{ij}\right)}_{\text{Dev. from T.S. mean}} - \underbrace{\left(\frac{1}{N}\sum_{i=1}^{N}T_{it} - \frac{1}{T}\sum_{j=1}^{T}\frac{1}{N}\sum_{i=1}^{N}T_{ij}\right)}_{\text{Deviation of global average from its t.s. mean}}$$

and it constrains coefficients to be identical across individuals. Global and idiosyncratic effects are confounded.

Instead, we want measurement of

$$\hat{\beta}_i = \frac{\partial \Delta y_{it}}{\partial T_{it}}$$

Explanation

Take time-series average of (1),

$$\frac{1}{T}\sum_{t=1}^{T}\Delta y_{it} = \alpha_i + \frac{1}{T}\sum_{t=1}^{T}\theta_t + \beta\frac{1}{T}\sum_{t=1}^{T}T_{it} + \frac{1}{T}\sum_{t=1}^{T}u_{it} \tag{2}$$

subtracting (2) from (1) eliminates the country fixed effect,

$$\left(\Delta y_{it} - \frac{1}{T}\sum_{j=1}^{T}\Delta y_{ij}\right) = \left(\theta_t - \frac{1}{T}\sum_{j=1}^{T}\theta_t\right) + \beta\left(T_{it} - \frac{1}{T}\sum_{j=1}^{T}T_{ij}\right) + \left(u_{it} - \frac{1}{T}\sum_{j=1}^{T}u_{ij}\right) \tag{3}$$

Take the cross-sectional average of (3),

$$\left(\frac{1}{N}\sum_{i=1}^{N}\Delta y_{it} - \frac{1}{NT}\sum_{i=1}^{N}\sum_{j=1}^{T}\Delta y_{ij}\right) = \left(\theta_t - \frac{1}{T}\sum_{j=1}^{T}\theta_t\right) + \left(\frac{1}{N}\sum_{i=1}^{N}T_{it} - \frac{1}{NT}\sum_{i=1}^{N}\sum_{j=1}^{T}T_{ij}\right) \tag{4}$$

$$+\left(\frac{1}{N}\sum_{i=1}^{N}u_{it} - \frac{1}{NT}\sum_{i=1}^{N}\sum_{j=1}^{T}u_{ij}\right) \tag{5}$$

Subtract (5) from (3)

$$\left(\Delta y_{it} - \frac{1}{T}\sum_{j=1}^{T}\Delta y_{ij} - \frac{1}{N}\sum_{i=1}^{N}\Delta y_{it} + \frac{1}{NT}\sum_{i=1}^{N}\sum_{j=1}^{T}\Delta y_{ij}\right)$$

$$= \beta\left(T_{it} - \frac{1}{T}\sum_{j=1}^{T}T_{ij} - \frac{1}{N}\sum_{i=1}^{N}T_{it} + \frac{1}{NT}\sum_{i=1}^{N}\sum_{j=1}^{T}T_{ij}\right)$$

$$+ \left(u_{it} - \frac{1}{T}\sum_{j=1}^{T}u_{ij} - \frac{1}{N}\sum_{i=1}^{N}u_{it} + \frac{1}{NT}\sum_{i=1}^{N}\sum_{j=1}^{T}u_{ij}\right)$$

Global and Idiosyncratic Temperature Shocks

$$
\begin{aligned}
T_{it} &= \lambda_i T_t + T_{it}^o \\
\tau_t &= \left(T_t - \frac{1}{t} \sum_{j=1}^{t} T_t \right) - a - bt \\
\tau_{it}^o &= \left(T_{it}^o - \frac{1}{t} \sum_{j=1}^{t} T_{it}^o \right) - a - bt
\end{aligned}
$$

- This is a factor decomposition of local temperatures.
- We can drop the factor loading λ_i because it will get compounded into the slope coefficient.
- Deviation from historical norm–backward looking average still needs to be detrended.
- The global and idiosyncratic temperature shocks are orthogonal components. Hence, we consider them separately in the local projections.

Local Projections

Let y_{it} be log per capita GDP. For $h = 0, .., 7$, the local projection on global temperature shocks

$$100(y_{it+h} - y_{it-1}) = \alpha_i + \beta_{ih}\tau_t + \epsilon_{it+k} + \delta_i' x_{it}$$

- Asymptotically, $\beta_{i,h}$ is the impulse response of a τ_{it} shock in a vector autoregression (Jorda). $\delta_i' x_{it}$ are two lags of output growth included as controls.
- Do this also for the idiosyncratic temperature shock τ_{it}^o
- For $h > 0$, overlapping observations induce serial correlation in error term. Standard errors by Newey-West.

Panel Local Projections

$$
\begin{aligned}
100(y_{it+h} - y_{it}) &= \alpha_i + \beta\tau_{it} + \epsilon_{it+k} + \delta_i' x_{it} \\
&= z_{it}'\gamma_i + \epsilon_{it} \\
z_{it}' &= (1, \tau_{it}, x_{it}') \\
\gamma_i' &= (\alpha_i, \beta, \delta_i')
\end{aligned}
$$

OLS orthogonality conditions

$$
E\left(z_{it}\epsilon_{it}\right) = 0
$$

Panel Local Projections

Let

$$\omega_t = \begin{pmatrix} z_{1t}\epsilon_{1t} \\ z_{2t}\epsilon_{2t} \\ \vdots \\ z_{nt}\epsilon_{nt} \end{pmatrix}$$

We minimize

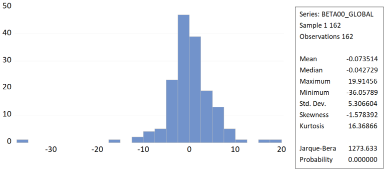
$$\left(\frac{1}{T}\sum_{t=1}^{T}\omega_t'\right) W_T^{-1} \left(\frac{1}{T}\sum_{t=1}^{T}\omega_t\right)$$

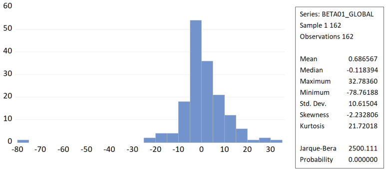
$$W_T = \hat{\Omega}_0 + \frac{1}{T}\sum_{j=1}^{m}\left(1 - \frac{j+1}{T}\right)\left(\hat{\Omega}_j + \hat{\Omega}_j'\right)$$

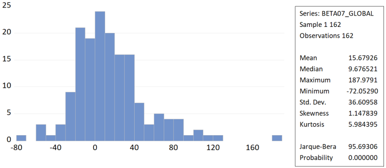
$$\hat{\Omega}_j = \frac{1}{T}\sum_{t=j+1}^{T}\omega_t\omega_{t-j}'$$

- W_t is the multivariate version of Newey-West.
- This is joint estimation by least squares but we get GMM standard errors.
- z_{it} is 4×1. We have 40-57 observations on y_{it}, which limits $n \simeq 10$

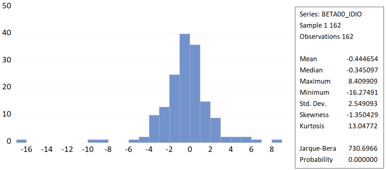
Local Projections: Global Temperature Shocks

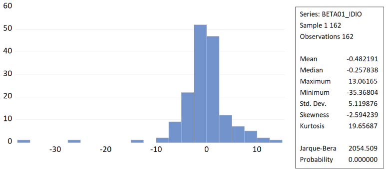


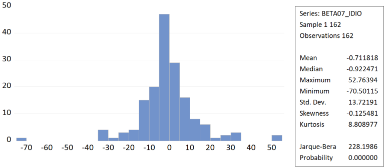




The left tail outlier is Equatorial Guniea, in coastal central Africa.
The right tail outlier is Libya, in northern Africa.

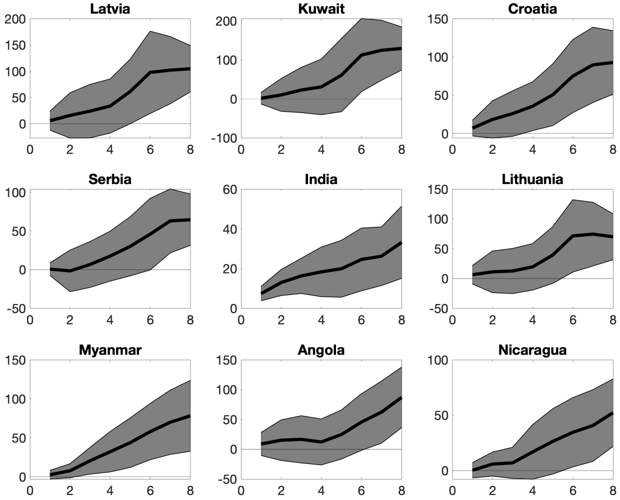




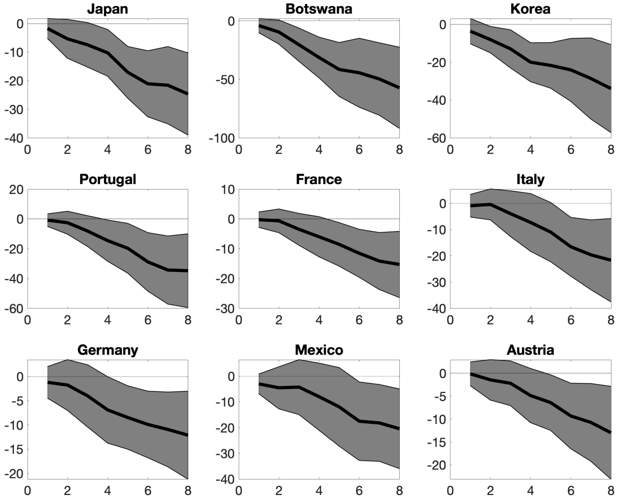


The left tail outlier is again Equatorial Guniea.
The right tail outlier is, depending on horizon, Gabon or Nigeria.

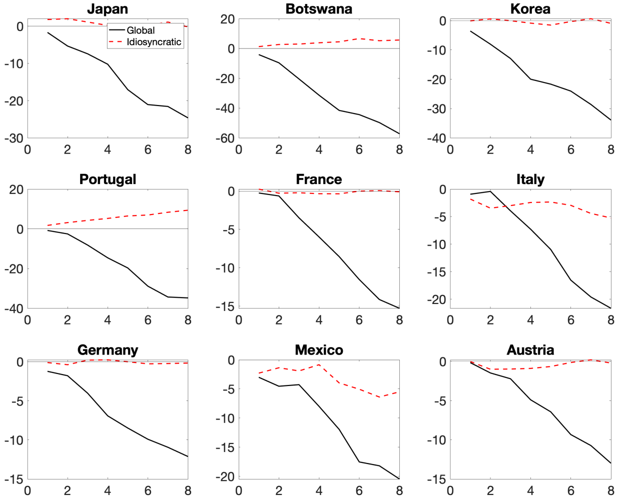
Some Positive Impulse Responses: Global



Some Negative Impulse Responses: Global



Some Negative Impulse Responses: Global and Idio



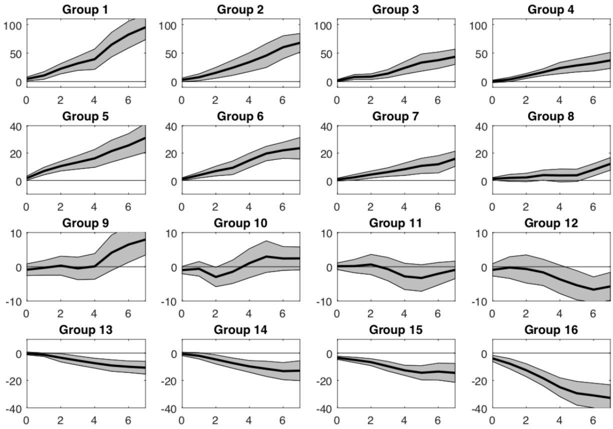
What Happens When You Constrain the Slope?

$$100(y_{it+h} - y_{it}) = \alpha_i + \beta\tau_{it} + \epsilon_{it+h} + \delta_i' x_{it} \quad (6)$$
$$100(y_{it+h} - y_{it}) = \alpha_i + (\beta_p + \beta_n)\tau_{it} + \epsilon_{it+h} + \delta_i' x_{it}$$

Table: Panel Local Projection for All 162 Countries System LS

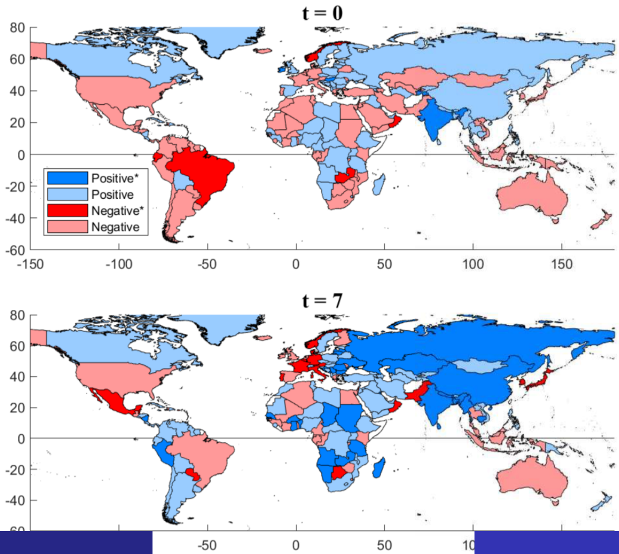
Global	β	t-ratio	β_p	t-ratio	β_n	t-ratio	$\beta_p = \beta_n$	p-val
1	-0.487	-1.393	2.886	5.388	-2.942	-6.436	68.494	0
2	-0.134		6.136		-4.858			
3	0.170		8.655		-6.599			
4	0.577		11.464		-8.806			
5	1.290		16.386		-10.937			
6	3.445		20.072		-14.118			
7	6.283		23.637		-15.154			
8	8.621		26.642		-16.453			
Idiosyncratic	β	t-ratio	β_p	t-ratio	β_n	t-ratio	$\beta_p = \beta_n$	p-val
1	-0.221	-1.495	1.167	5.439	-1.452	-7.189	79.003	0
2	-0.267		2.251		-2.351			
3	-0.286		2.841		-3.297			
4	-0.348		4.114		-3.557			
5	-0.267		5.180		-3.815			
6	-0.195		6.020		-4.273			
7	-0.193		6.410		-5.527			
8	-0.391		7.682		-5.667			

Figure: Global Shock. (Significance)



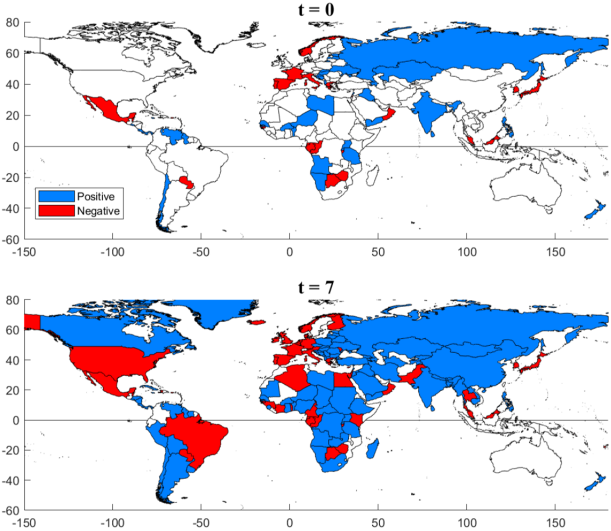
Single-equation Local Projection Coefficients

Figure 3: Global Shock: Positive and negative responses



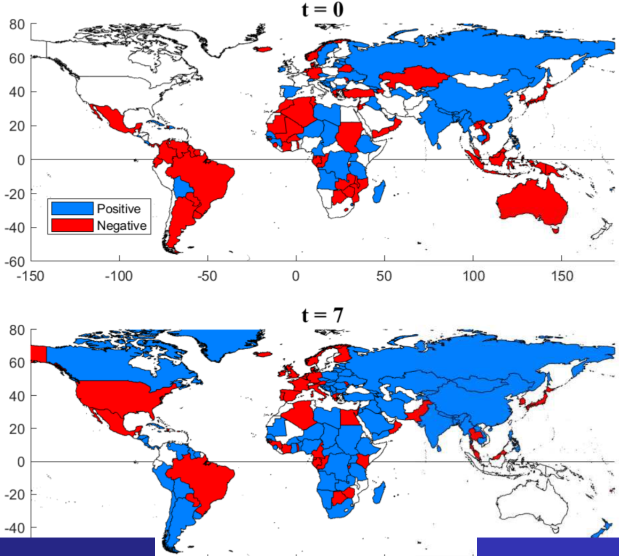
Significant Responses from Panels of 10 (or 11) Grouped by Horizon 8

Figure 8: Global Shock Panel: Statistically significant responses in the Panel



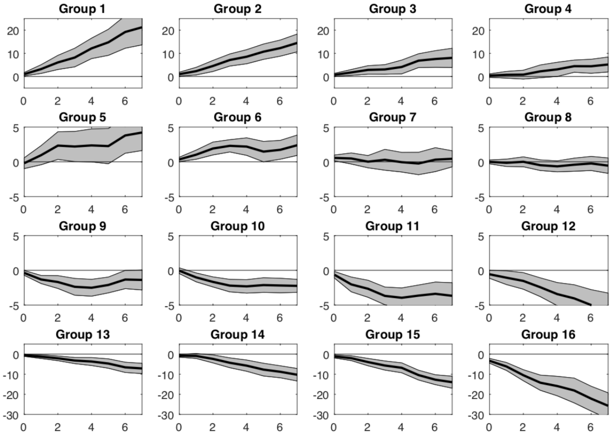
Significant Responses from Pseudo-Panels of 10 (or 11)

Figure 10: Global Shock Pseudo Panel: Statistically significant responses in the Pseudo Panel



Panels of 10 (or 11) Grouped by Horizon 8 Betas.

Figure: Idiosyncratic Shock. (Significance)



Single-equation Local Projection Coefficients

Figure 4: Idiosyncratic Shock: Positive and negative responses

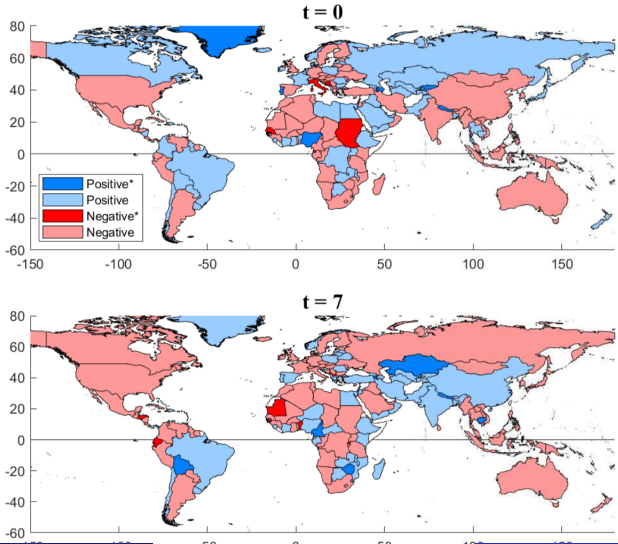


Figure 9: Idiosyncratic Shock Panel: Statistically significant responses in the Panel

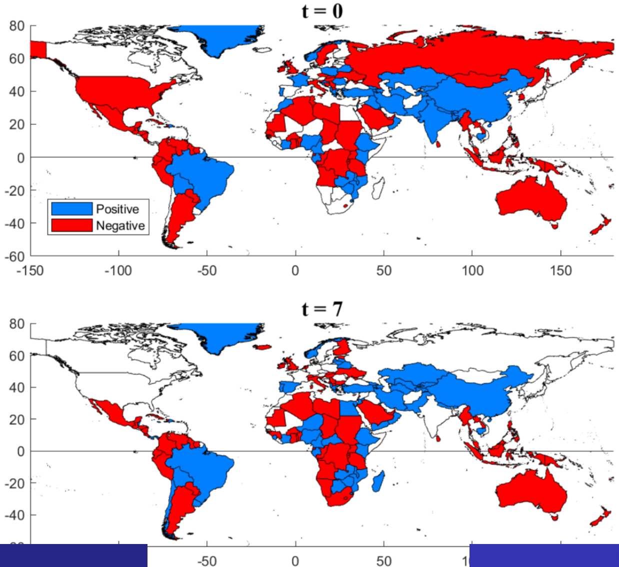
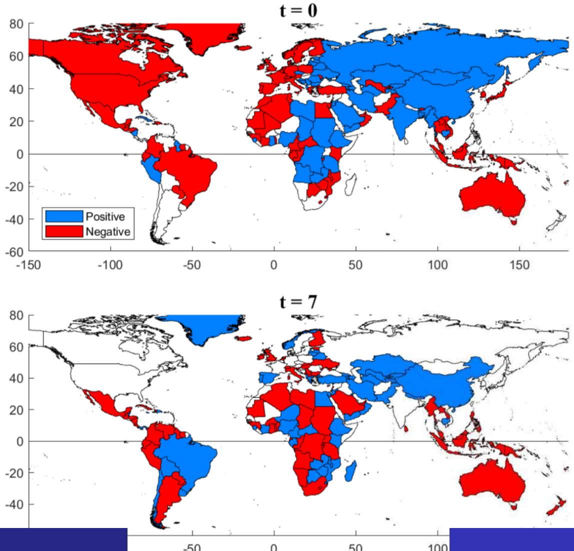


Figure 11: Idiosyncratic Shock Pseudo Panel: Statistically significant responses in the Pseudo Panel



Level and/or Growth Effects

Is average growth over h years above or below the contemporaneous effect on growth?

$$\frac{1}{h}100\left(y_{t+h} - y_{t-1}\right) = 100\frac{1}{h}\left(\Delta y_{t+h} + \Delta y_{t+h-1} + \cdots \Delta y_t\right) = \frac{\beta_h}{h}\tau_t$$

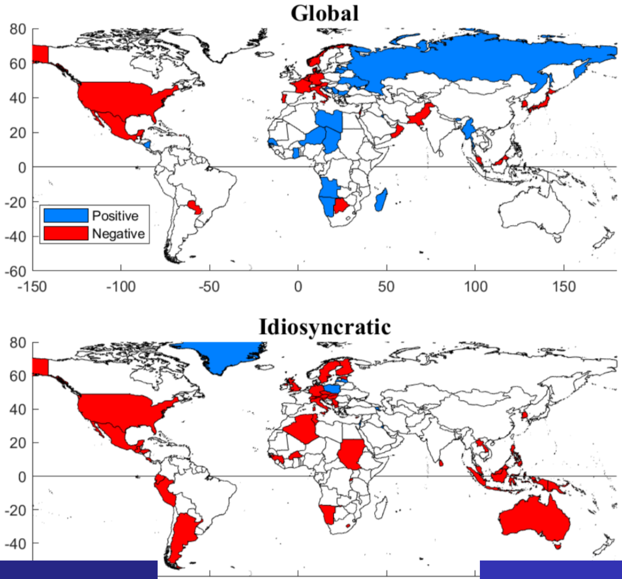
$$\frac{\beta_h}{h} - \beta_0 = 100\frac{1}{h}\left(\Delta y_{t+h} + \Delta y_{t+h-1} + \cdots \Delta y_t\right) - 100\Delta y_t$$

- If $\beta_0 < 0$ and $\beta_7 = \beta_0$, there is a negative level effect but no growth effect.
- If $\beta_0 < 0$ and $\beta_7 < \beta_0$, there is a negative level and growth effect.
- If $\beta_0 > 0$ and $\beta_7 = \beta_0$, there is a positive level effect but no growth effect.
- If $\beta_0 > 0$ and $\beta_7 > \beta_0$, there is a positive level and growth effect.

If $\beta_h < \beta_1$, run $(1/h)(y_{t+h} - y_{t-1}$ to get β_h/h test $\beta_h/h - \beta_1 = 0$.
Estimate for $h = 0$ and $h = 7$ jointly by GMM. Test these hypotheses.

Level and/or Growth Effects

Figure 7: Grwoth Effects at $t = 7$: Statistically significant responses



Investigating Potential Mechanisms

Let β_{ih} be the GDP growth beta at horizon h. Let's run the local projections with per capita agricultural value added in place of per capita GDP. Call the local projection coefficients γ_{ih}. I want to ask if the cross-sectional impulse response patterns for GDP growth (β_{ih}) are similar or different from the cross-sectional impulse response patterns for agricultural value added (γ_{ih}). That is, to what extent is the GDP response to temperature shocks being driven by the agricultural value-added response? Suppress the horizon index. I want to run the cross-sectional regression

$$\hat{\beta}_i = a + b\hat{\gamma}_i + \epsilon_i$$

and study the slope $\hat{b}$.
The fact that $\hat{\beta}_i$ is estimated poses no problem because it is the dependent variable. That $\hat{\gamma}_i$ is estimated does pose a problem because it is a regressor. This is but one example of the "generated regressor" problem. In elementary econometrics we assume the regressors are exogenous, but here they are random variables. An adjustment must be made for bias in $\hat{b}$ and in the standard error of $\hat{b}$.
Meng, Wu, and Zhan (2016) show how to do this.

	Global			Idiosyncratic		
Horizon	Corr	Adj.Slope	Adj.tratio	Corr	Adj.Slope	Adj.tratio
			Agriculture Value Added			
1	0.567	0.852	0.526	0.534	-0.979	0.185
2	0.623	0.687	1.442	0.557	-0.974	0.193
3	0.656	0.711	1.943	0.658	-2.780	0.039
4	0.685	0.962	1.082	0.571	1.433	0.240
5	0.692	0.840	1.972	0.426	0.729	0.808
6	0.720	0.755	**3.670**	0.499	1.144	0.384
7	0.749	0.763	**4.161**	0.548	1.420	0.306
8	0.744	0.706	**5.869**	0.574	1.131	0.611
			Manufacturing Value Added			
1	0.366	0.239	**6.193**	0.424	0.502	1.707
2	0.559	0.407	**4.143**	0.470	0.529	1.746
3	0.474	0.381	**5.491**	0.488	0.401	**4.195**
4	0.474	0.439	**4.722**	0.586	0.553	**2.578**
5	0.512	0.441	**6.539**	0.443	0.453	**2.697**
6	0.546	0.460	**8.405**	0.366	0.485	1.703
7	0.511	0.451	**8.428**	0.336	0.440	**2.601**
8	0.429	0.388	**10.912**	0.453	0.638	1.677

	Global			Idiosyncratic		
Horizon	Corr	Adj.Slope	Adj.tratio	Corr	Adj.Slope	Adj.tratio
Services Value Added						
1	0.477	1.739	0.176	0.501	-2.209	0.067
2	0.514	0.720	**2.149**	0.467	-2.576	0.049
3	0.599	1.107	1.096	0.552	8.628	0.007
4	0.665	1.417	0.808	0.553	1.417	0.389
5	0.607	1.087	1.665	0.524	1.158	0.612
6	0.589	0.882	**3.680**	0.583	0.763	**3.032**
7	0.576	0.853	**4.249**	0.619	0.795	**4.183**
8	0.591	1.008	**2.863**	0.625	0.919	**2.722**
Industry Value Added						
1	0.567	0.852	0.526	0.534	-0.979	0.185
2	0.623	0.687	1.442	0.557	-0.974	0.193
3	0.656	0.711	1.943	0.658	-2.780	0.039
4	0.685	0.962	1.082	0.571	1.433	0.240
5	0.692	0.840	1.972	0.426	0.729	0.808
6	0.720	0.755	**3.670**	0.499	1.144	0.384
7	0.749	0.763	**4.161**	0.548	1.420	0.306
8	0.744	0.706	**5.869**	0.574	1.131	0.611

	Global			Idiosyncratic		
Horizon	Corr	Adj.Slope	Adj.tratio	Corr	Adj.Slope	Adj.tratio
			Consumption Spending			
1	0.655	0.889	1.223	0.332	3.398	0.025
2	0.650	4.958	0.028	0.217	1.283	0.138
3	0.577	1.939	0.267	0.321	0.982	0.452
4	0.676	1.473	0.911	0.457	1.687	0.212
5	0.748	1.728	0.792	0.503	1.332	0.469
6	0.709	1.134	**3.323**	0.643	1.438	0.667
7	0.702	1.035	**5.057**	0.674	1.589	0.722
8	0.668	0.934	**8.067**	0.669	2.106	0.328
			Government Spending			
1	0.135	0.109	**10.333**	0.368	-1.382	0.064
2	0.193	0.270	**2.616**	0.267	0.991	0.139
3	0.257	0.685	0.489	0.179	-2.678	0.011
4	0.305	0.934	0.343	0.160	-0.466	0.289
5	0.348	0.911	0.506	0.153	29.222	0.000
6	0.330	0.468	**3.079**	0.176	0.194	**5.306**
7	0.322	0.315	**12.074**	0.241	0.810	0.301
8	0.357	0.369	**10.801**	0.313	23.172	0.000

Country Characteristics

Let X_i be a vector of country i characteristics. Here, we run the cross-sectional regression

$$\hat{\beta}_i = X_i' b + \epsilon_i$$

to see how country characteristics explain responses to temperature shocks.

Global Beta Horizon 1

nobs	rsq	Latitude	Avg. temp	GDPPC	LT Growth	Avg. Saving	Agri. Share	Indus Share	Manu Share
162	0.042	0.062							
		(2.670)							
162	0.022		-0.104						
			(-1.925)						
162	0.046	0.074		-0.028					
		(2.698)		(-0.801)					
162	0.052	0.115	0.106	-0.030					
		(2.196)	(0.930)	(-0.872)					
162	0.118	0.124	0.097	-0.036	-1.838				
		(2.434)	(0.877)	(-1.081)	**(-3.446)**				
151	0.076	0.072	0.005	-0.064	-0.981	0.083			
		(1.612)	(0.054)	(-1.941)	(-1.855)	**(2.005)**			
147	0.124	0.083	-0.024	-0.050	-0.592	0.089	0.045	0.042	-0.123
		(1.843)	(-0.248)	(-1.324)	(-1.049)	(1.512)	(1.023)	(0.831)	**(-2.122)**

Global Beta Horizon 2

rsq	Latitude	Avg. temp	GDPPC	LT Growth	Avg. Saving	Agri. Share	Indus Share	Manu Share
0.040	0.121							
	(2.585)							
0.028		-0.232						
		(-2.144)						
0.052	0.161		-0.098					
	(2.960)		(-1.432)					
0.053	0.194	0.084	-0.100					
	(1.849)	(0.369)	(-1.453)					
0.192	0.218	0.057	-0.118	-5.303				
	(2.244)	(0.271)	(-1.837)	**(-5.193)**				
0.130	0.093	-0.152	-0.120	-2.926	-0.019			
	(1.168)	(-0.870)	**(-2.042)**	**(-3.087)**	(-0.263)			
0.161	0.117	-0.167	-0.077	-3.259	0.107	0.134	-0.092	0.044
	(1.444)	(-0.948)	(-1.137)	**(-3.196)**	(1.007)	(1.676)	(-1.001)	(0.417)

Global Beta Horizon 8

rsq	Latitude	Avg. temp	GDPPC	LT Growth	Avg. Saving	Agri. Share	Indus Share	Manu Share
0.017	0.275							
	(1.687)							
0.020		-0.675						
		(-1.801)						
0.102	0.640		-0.893					
	(3.506)		**(-3.871)**					
0.103	0.524	-0.294	-0.886					
	(1.489)	(-0.383)	**(-3.819)**					
0.216	0.600	-0.378	-0.941	-16.500				
	(1.816)	(-0.525)	**(-4.315)**	**(-4.756)**				
0.319	0.634	-0.520	-1.318	-21.693	1.549			
	(2.003)	(-0.751)	**(-5.651)**	**(-5.788)**	**(5.285)**			
0.409	0.763	-0.853	-0.964	-17.006	0.665	0.750	1.394	-1.087
	(2.504)	(-1.285)	**(-3.769)**	**(-4.435)**	(1.668)	**(2.493)**	**(4.039)**	**(-2.760)**

Idiosyncratic Beta Horizon 1

nobs	rsq	Latitude	Avg. temp	GDPPC	LT Growth	Avg. Saving	Agri. Share	Indus Share	Manu Share
162	0.047	0.031							
		(2.797)							
162	0.033		-0.060						
			(-2.332)						
162	0.049	0.036		-0.011					
		(2.719)		(-0.636)					
162	0.050	0.042	0.016	-0.011					
		(1.662)	(0.297)	(-0.656)					
162	0.088	0.045	0.013	-0.013	-0.669				
		(1.814)	(0.239)	(-0.801)	**(-2.569)**				
151	0.072	0.025	-0.016	-0.018	-0.346	0.047			
		(1.090)	(-0.323)	(-1.109)	(-1.299)	**(2.236)**			
147	0.098	0.027	-0.024	-0.015	-0.205	0.033	0.009	0.023	-0.064
		(1.186)	(-0.480)	(-0.758)	(-0.713)	(1.097)	(0.420)	(0.891)	**(-2.177**

Idiosyncratic Beta Horizon 2

rsq	Lati-tude	Avg. temp	GDPPC	LT Growth	Avg. Saving	Agri. Share	Indus Share	Manu Share
0.001	0.009							
	(0.386)							
0.000		-0.001						
		(-0.024)						
0.001	0.006		0.006					
	(0.236)		(0.181)					
0.004	0.035	0.074	0.004					
	(0.681)	(0.654)	(0.128)					
0.046	0.042	0.067	0.000	-1.411				
	(0.821)	(0.601)	(-0.008)	**(-2.636)**				
0.017	-0.007	0.023	0.028	-0.236	-0.051			
	(-0.138)	(0.215)	(0.797)	(-0.415)	(-1.146)			
0.051	0.004	0.023	0.048	-0.515	0.012	0.062	-0.061	0.045
	(0.078)	(0.216)	(1.179)	(-0.839)	(0.181)	(1.277)	(-1.114)	(0.707)

Idiosyncratic Beta Horizon 8

rsq	Latitude	Avg. temp	GDPPC	LT Growth	Avg. Saving	Agri. Share	Indus Share	Manu Share
0.023	0.119							
	(1.960)							
0.018		-0.243						
		(-1.727)						
0.042	0.184		-0.159					
	(2.607)		(-1.778)					
0.043	0.199	0.039	-0.160					
	1.463	(0.131)	(-1.777)					
0.055	0.209	0.028	-0.167	-2.091				
	(1.537)	(0.096)	(-1.858)	(-1.465)				
0.019	0.099	-0.003	-0.080	0.586	-0.066			
	(0.775)	(-0.012)	(-0.854)	(0.389)	(-0.558)			
0.032	0.100	-0.055	-0.127	0.599	0.073	-0.030	0.007	-0.043
	(0.816)	(-0.204)	(-1.233)	(0.389)	(0.454)	(-0.249)	(0.050)	(-0.272)