How Costly is Global Warming? Implications for Welfare, Business Cycles, and Asset Prices.

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BoE-CEP workshop: "Central Banking, Climate Change and Environmental Sustainability"

Goal

Quantify the short- and long-run effects of global warming on asset prices and productivity

To do so, we build a production economy along the lines of Croce (2014, JME) featuring:

- long run-temperature risk as in Bansal and Ochoa (2011, NBER)
- recursive preferences
- long-run productivity risk
- investment adjustment costs
- sticky wages

Background and motivation

Popular approach:

- Integrated assessment models (IAMs): integrate climate change with standard economic modeling
- Stern Review (2007), Nordhaus (2010, PNAS) and Nordhaus (2014, *Journal of the Association of Environmental and Resource Economists*)

Pindyck (2013,JEL): "*IAMs have crucial flaws that make them close to useless as tools for policy analysis*":

- certain inputs (e.g., the discount rate) are arbitrary, but have huge effects on models' output
- IAMs can be thus used to obtain almost any result one desires.
- models' descriptions of the impact of climate change are completely `ad hoc`, with no theoretical or empirical foundation
- no theoretical support on the shape of the loss functions (e.g., T=$3^{\circ}C$ or T=$7^{\circ}C$ $\rightarrow$ no diff)
- some effects of warming may be permanent $\rightarrow$ a growth rate effect allows warming to have a permanent impact

Background and motivation

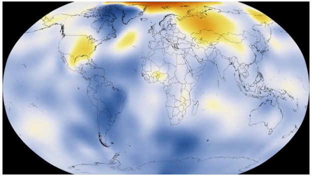
Moreover....

- Revesz et al. (2014, *Nature*) point out that current models omit adverse effects on labor productivity, productivity growth and the value of capital stock
- Empirical literature suggests effects of global warming on growth rates (Dell et al. (2012, AEJ); Bansal and Ochoa (2011, NBER) and Colacito et al. (2016, UNC WP))
- Weitzman (2007, JEL) and Nordhaus (2007, JEL) criticize that the model of Stern is not consistent with financial market facts
- Remark: data exhibit small fluctuations in temperature and other whether variables (i.e., we cannot study the effect of a $5^{\circ}C \uparrow$). We cannot thus specify and calibrate damage functions of the sort used in IAMs

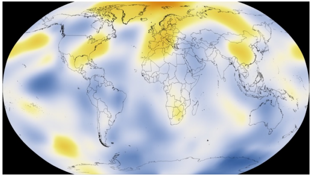
Temperature Anomalies

Figure: Global Temperature Anomalies. Source: NASA

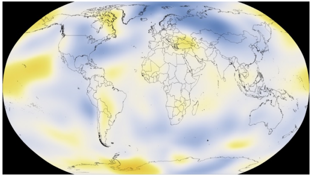
Panel A: 1925



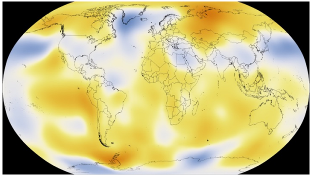
Panel B: 1950



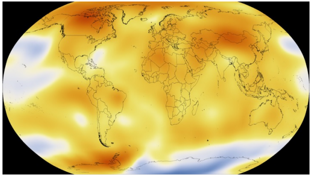
Panel C: 1970



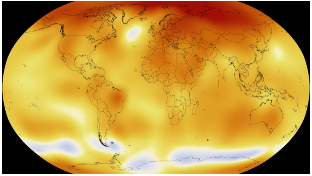
Panel D: 1985



Panel E: 2000

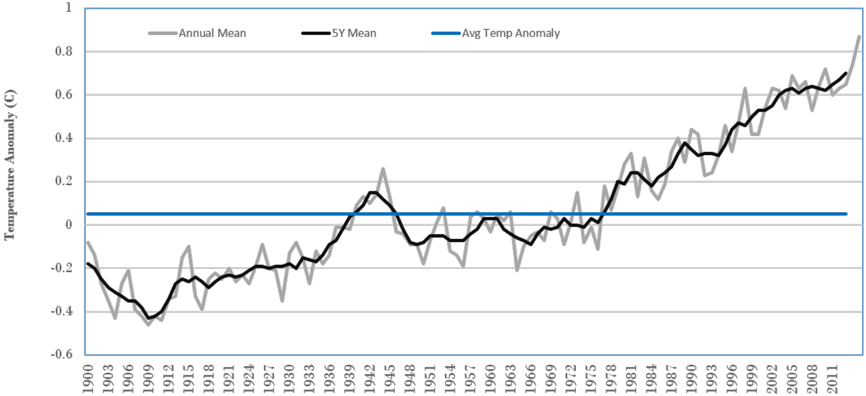


Panel F: 2015



Temperature Anomalies

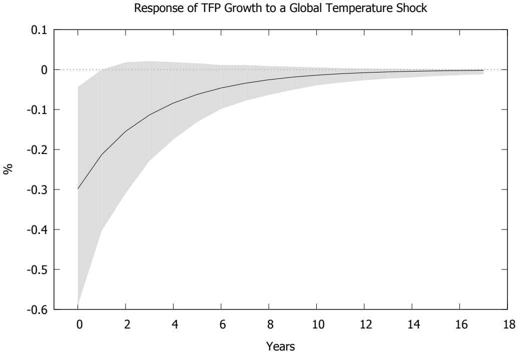
Figure: Global Temperature Anomaly Index (1900-2015). Source: NASA



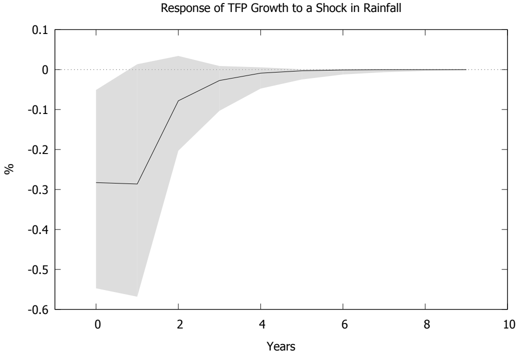
Global Warming and Aggregate Productivity

Figure: Global Temperature, Rainfall and Productivity

Panel A:



Panel B:



Global Warming (???)

Do people care?

- Apparently, yes!!!
- First of all, it's still at the center of the policy debate

From the Democrat and Republican presidential front-runners:

- Hillary Clinton: → Hillary will:
  - ... national plan to get 500 million solar panels installed
  - ... bring greenhouse gas emissions to 30 percent below the 2005 level
  - ... and other hundreds things to fight against climate change....
  - (See https://www.hillaryclinton.com/issues/climate/)
- Donald Trump: He isn't "a believer" that humans have played a significant role in the Earth's changing climate (The Washington Post, March 2016)

News from last summer,

- The *3 amigos* met in Ottawa and announced the North American Climate, Clean Energy and Environment Partnership

Households

The representative household is equipped with recursive preferences:

$$U_t = \left[(1-\beta)\tilde{C}_t^{1-\frac{1}{\psi}} + \beta\left(\mathbb{E}_t[U_{t+1}^{1-\gamma}]\right)^{\frac{1-1/\psi}{1-\gamma}}\right]^{\frac{1}{1-1/\psi}},$$

where $\tilde{C}_t$ is a Cobb-Douglas aggregator for consumption and leisure:

$$\tilde{C}_t := \tilde{C}(C_t, L_t) = C_t^{\nu}(A_t(1-L_t))^{1-\nu}.$$

In each period, the representative household chooses consumption C_t and labor L_t to maximize (1) subject to the following budget constraint

$$C_t + B_{t+1} + \vartheta_{t+1}(V_t - D_t) = W_t^u L_t + B_t R_t^f + \vartheta_t V_t.$$

where ϑ_t denotes equity shares in the firm held from time $t-1$ to time t, V_t is the cum-dividend market value of the production sector, D_t represents the production sector's dividends, B_t denotes bond holdings from time $t-1$ to time t, R_t^f is the gross risk-free rate, and W_t^u represents the frictionless wage.

Firms

The production sector admits a representative perfectly competitive firm utilizing capital and labor to produce the final good. The production technology is given by:

$$Y_t = K_t^{\alpha}(A_t L_t)^{1-\alpha},$$

where α is the capital share, labor L_t is supplied by the household, and A_t is the exogenous labor-augmenting productivity. The capital stock evolves according to:

$$K_{t+1} = (1-\delta_K)K_t + G\left(\frac{I_t}{K_t}\right)K_t,$$

where δ_K is the depreciation rate of capital. G_t is a function transforming investment into new capital which entails convex adjustment costs of investments as in Jermann (1998):

$$G_t := G\left(\frac{I_t}{K_t}\right) = \frac{\alpha_1}{1-\frac{1}{\tau}}\left(\frac{I_t}{K_t}\right)^{1-\frac{1}{\tau}} + \alpha_2.$$

Firms

Firms choose capital, labor and investment to maximize their value:

$$V_0 = \max_{L_t, I_t, K_{t+1}} \mathbb{E}_0\Big[\sum_{t=0}^{\infty} M_{0,t} D_t\Big],$$

Firms' optimal decisions lead to:

$$q_t = \frac{1}{G'\left(\frac{I_t}{K_t}\right)}.$$

where q_t defines the marginal value of standardized capital which is equal to the marginal rate of transformation between new capital and consumption. The firm chooses capital such that:

$$1 = \mathbb{E}_t\Big[M_{t,t+1}\frac{1}{q_t}\Big(\frac{\alpha Y_{t+1} - I_{t+1}}{K_{t+1}} + q_{t+1}(G_{t+1} + 1 - \delta_K)\Big)\Big].$$

Firms

EE:

$$1 = \mathbb{E}_t\Big[M_{t,t+1}R_{t+1}\Big],$$

where

$$R_{t+1} = \frac{d_{t+1} + q_{t+1}}{q_t},$$

and

$$d_{t+1} = \alpha\frac{Y_{t+1}}{K_{t+1}} - \frac{I_{t+1}}{K_{t+1}} + q_{t+1}G_{t+1} - \delta_K q_{t+1}$$

Labor Market

We assume that labor supply is subject to frictions. In the spirit of Uhlig (2007), we impose that a fraction of the labor supply does not reach the market. This results in sticky wages:

$$W_t = (e^{\mu_a} W_{t-1})^{\xi} (W_t^u)^{1-\xi}.$$

Productivity and Temperature Dynamics

The productivity growth rate, $\Delta a_{t+1} = \log(A_{t+1}/A_t)$, has a long-run risk component, x_t, and evolves according to

$$\Delta a_{t+1} = \mu_a + x_t + \sigma_a \epsilon_{a,t+1},$$

where

$$x_{t+1} = \rho_x x_t + \tau_z \sigma_\zeta \zeta_{t+1} + \sigma_x \epsilon_{x,t+1}.$$

Temperature dynamics are given by

$$z_{t+1} = \mu_z + \rho_z (z_t - \mu_z) + \sigma_\zeta \zeta_{t+1}.$$

- Temperature shocks ζ_t indicate long-run shocks which affect the stochastic component in expected productivity growth x_t.
- The parameter $\tau_z \leqslant 0$ captures the impact of temperature shocks on long-run productivity growth.
- We assume that productivity does not affect temperature in turn.

Resource Constraint

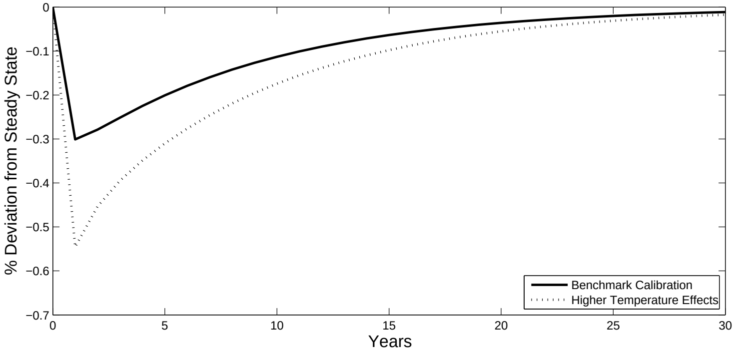
$$Y_t = C_t + I_t$$

Benchmark calibration

Preferences		
β	Subjective time discount factor	0.999
ψ	Elasticity of intertemporal substitution	1.85
γ	Relative risk aversion	7.5
ν	Consumption share in utility bundle	0.3484
Labor Market		
ξ	Wage rigidity parameter	0.35
Production and Investment Parameters		
α	Capital share in final good production	0.345
δ_K	Depreciation rate of physical capital	0.005
τ	Capital adjustment costs elasticity	0.7
TFP		
μ_a	Long-run mean of TFP	0.0004
σ_a	Volatility of short-run shocks to TFP	0.008
ρ_x	Long-run TFP shock persistence	0.982
σ_x	Volatility of long-run shocks to TFP	$0.045^*\sigma_a$
Global Temperature		
μ_z	Long-run mean of global temperature	14.18
τ_z	Impact of temperature innovations on TFP growth	-0.0025
ρ_z	Temperature persistence parameter	0.99
σ_z	Volatility of shocks to global temperature	0.041

Benchmark calibration

Figure: Model-Implied Response of Productivity to a Temperature Shock



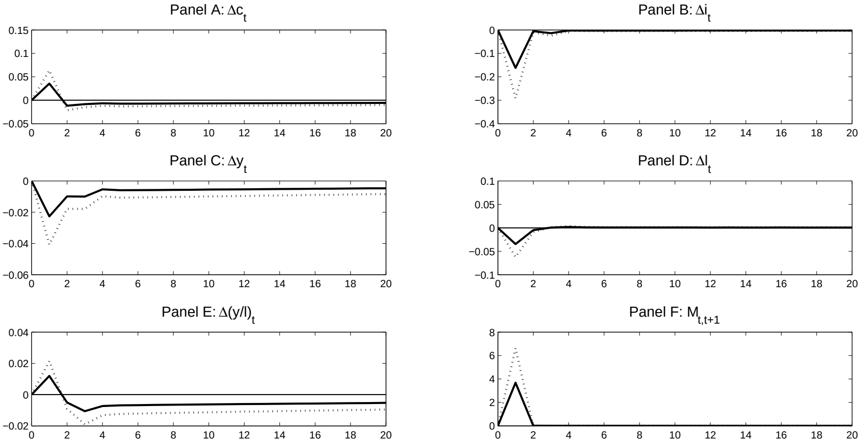
Quantitative results: Macro Quantities

Variable	**Data**	**Benchmark calibration**	$\tau_z = 0$	**CRRA**	$\tau_z = -0.0045$
		[1]	**[2]**	**[3]**	**[4]**
MACRO QUANTITIES					
$\mathbb{E}[\Delta a]$	0.49	0.51	0.53	0.51	0.50
$\sigma(\Delta l)$	0.28	0.99	0.98	0.99	1.01
$\sigma(\Delta c)/\sigma(\Delta y)$	0.82	0.96	0.96	0.96	0.96
$\sigma(\Delta i)/\sigma(\Delta y)$	2.98	1.90	1.88	1.89	1.92
$\sigma(\Delta l)/\sigma(\Delta y)$	0.19	0.39	0.39	0.39	0.39
$\rho(\Delta c, \Delta y)$	0.90	0.85	0.85	0.84	0.84
$\rho(\Delta c, \Delta i)$	0.73	0.31	0.32	0.31	0.29
$\rho(\Delta i, \Delta l)$	0.24	0.22	0.20	0.23	0.24

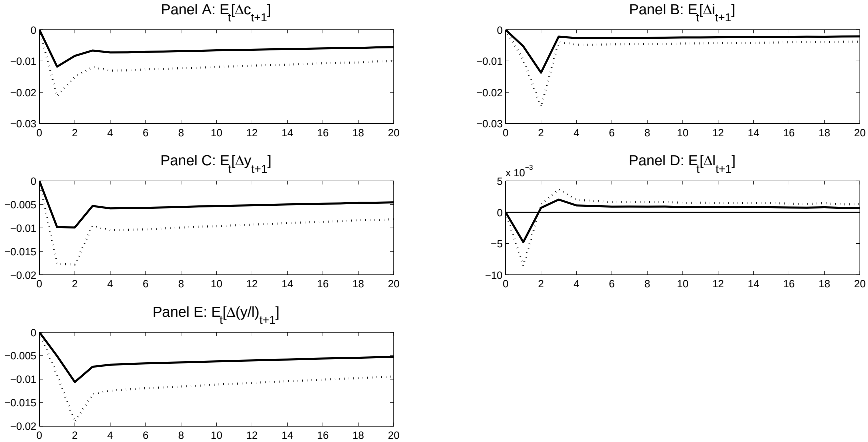
Quantitative results: Temp and Asset Prices

Variable	Data	Benchmark calibration	$\tau_z = 0$	CRRA	$\tau_z = -0.0045$
		[1]	[2]	[3]	[4]
TEMPERATURE					
$\mathbb{E}[z]$	14.18	14.19	14.19	14.19	14.19
$\sigma(z)$	0.24	0.24	0.24	0.24	0.24
$\rho(\Delta z, \Delta a)$	-0.01	0.00	-0.01	0.00	0.00
$\rho(\Delta z^{5Y}, \Delta a^{5Y})$	-0.05	-0.05	-0.02	-0.05	-0.06
$\rho(\Delta z^{10Y}, \Delta a^{10Y})$	-0.16	-0.05	0.01	-0.05	-0.10
$\rho(\Delta z, \Delta y)$	-0.03	-0.05	-0.02	-0.05	-0.07
$\rho(\Delta z^{5Y}, \Delta y^{5Y})$	-0.10	-0.05	-0.01	-0.05	-0.07
$\rho(\Delta z^{10Y}, \Delta y^{10Y})$	-0.38	-0.04	0.03	-0.03	-0.08
ASSET PRICES					
$\mathbb{E}[R_f]$	1.54	0.56	0.62	1.47	0.46
$\sigma(R_f)$	2.17	0.56	0.56	0.56	0.57
$\mathbb{E}[R_m - R_f]$	6.93	3.70	3.47	-0.04	4.24
$\sigma(\mathbb{E}[R_m - R_f])$	16.76	6.61	6.47	6.60	6.92

Transmission of a Temperature Shock I ($\sigma_\zeta > 0$)



Transmission of a Temperature Shock II ($\sigma_\zeta > 0$)



Welfare costs

In the spirit of Lucas (1987), Bansal and Ochoa (2011), Croce(2013) and Evers (2015) costs are computed by comparing the utility of an agent living in an economy with temperature risk to the utility of an agent living in a economy without temperature risk:

$$\mathbb{E}[U_0((1+\Delta)\tilde{C})] = \mathbb{E}[U_0(\tilde{C}^*)],$$

where

$\tilde{C} = \{\tilde{C}_t\}_{t=0}^{\infty}$ denotes the consumption path with temperature risk
$\tilde{C}^* = \{\tilde{C}_t^*\}_{t=0}^{\infty}$ is the consumption path without temperature effects.

Welfare costs

Temperature risk generates non-negligible welfare costs:

Table: Temperature Risk vs. Macroeconomic Risk: A Welfare Analysis

IES (ψ)	Benchmark calibration [1]	$\tau_z = -0.0045$ [2]	Short-run macro risk [3]	Long-run macro risk [4]
0.90	9%	32%	21%	185%
1.85	12%	44%	27%	299%

- composite consumption of the agent living in the economy with temperature effects: (12%) ↑
- this brings him/her to the utility level of an agent living in an economy without temperature risk

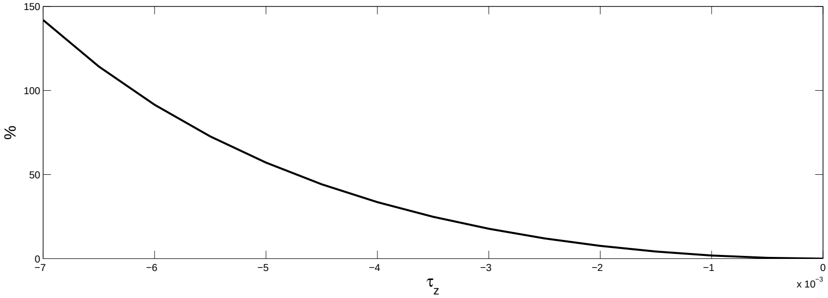
Welfare costs

Welfare costs of temp risk in the endowment economy of Bansal and Ochoa (2011) are around 1%

- welfare costs produced by the volatility in productivity are amplified in economies with capital adjustment costs (Barlevy, 2004)
- welfare costs in a production economy are higher than those observed in an endowment economy (Croce, 2006)
- $\Rightarrow$ most of the difference in welfare costs can be attributed to effects actually coming from the real side of the economy (i.e. investment)

Welfare costs

Figure: Welfare Costs



Long-Term Effects of Global Warming

Table: The Long-run Effect of a Global Temperature Shock

Panel A: $\sum_{j=1}^{N} \Delta y_{t+j} - N \cdot \Delta y^*$					
Difference in expected output growth after a shock to global temperature					
Shock size	1Y	5Y	10Y	20Y	50Y
1 std. dev. σ_z	−0.09	−0.27	−0.37	−0.44	−0.52
5 std. dev. σ_z	−0.44	−1.33	−1.84	−2.21	−2.60
Panel B: $\sum_{j=1}^{N} \Delta lp_{t+j} - N \cdot \Delta lp^*$					
Difference in expected labor productivity growth after a shock to global temperature					
Shock size	1Y	5Y	10Y	20Y	50Y
1 std. dev. σ_z	−0.06	−0.26	−0.37	−0.45	−0.52
5 std. dev. σ_z	−0.28	−1.30	−1.85	−2.25	−2.61

Concluding Remarks

We find that Global warming

- decreases asset valuations and increases risk premium
- reduces long-run growth perspectives for output and labor productivity
- produces sizable welfare costs

Possible extensions:

- Climate change in a stochastic endogenous growth model
- Fiscal policy and global warming adverse effects
- Include social factors of global warming (social unrest etc.)
- Feedback between technology and temperature dynamics