From micro to macro damages: climate impacts in agent based economic models

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- **Warning**
  - Very (very) preliminary
- **Outline**
  1. Micro level damages
  2. A "brute-force" approach (with the DSK model)
  3. A simple model of production network
  4. Preliminary results

Micro level impacts

- **Impacts literature**
  - typically employs macro-level data (Tol 2009...but also Burke et al. 2015; Dell et al. 2012;)
  - evaluates impacts on production across “sectors” [e.g. agriculture, energy, industry, forestry ...] (Hsiang et al. 2017; Piontek et al. 2014, Tol 2002a,b)
  - eventually aggregates impacts in a GE framework

- **The “New Weather Economics” literature**
  - Great theoretical and empirical framework to assess impacts of climate/weather (Deryugina and Hsiang 2014; Burke et al. 2015; Burke and Emerick 2016; Carleton and Hsiang 2016; Hsiang et al. 2017)
  - Typically estimates panel-data models identifying the short-run “average response” of a statistical unit to a marginal change in weather conditions (Kolstad and Moore 2019 for a review)
  - Draws on a linear aggregation between micro and macro (next slide)

Micro level impacts (aggregation)

From Burke et al. 2015 (Nature)

We partition a macroeconomy into "industries" indexed by i, with all individual units of production within each industry assumed to respond identically to temperature. Each industry could thus be highly specific—for example, one industry could be all maize farms using a given technology to produce a specific variety of maize. Production in each industry occurs at numerous small locations in space, indexed by ℓ; countries, indexed by $\mathcal{L}$, are large collections of locations. The incremental moments in time that micro studies have analyzed (e.g. hours) are indexed by t and longer periods of time composed of many sequential moments (e.g. years) are indexed by τ.

We follow the notation of Deryugina and Hsiang (2014)[7] and describe capital K_i and labor L_i in each industry as having respective productivities A_i^K and A_i^L that are functions of instantaneous temperature $T_{\ell t}$ experienced at a location ℓ and time t. The total quantity of capital and labor allocated to industry i could also potentially change with temperature. The price of a unit of output is p and α is a constant in this stylized production function. For a subunit of the economy at a location ℓ at time t using technologies described by i, total production $Y_{i\ell t}$ is then

$$Y_{i\ell t}(T_{\ell t}) = p_i \left(A_i^K(T_{\ell t})K_{i\ell t}(T_{\ell t})\right)^{\alpha} \left(A_i^L(T_{\ell t})L_{i\ell t}(T_{\ell t})\right)^{1-\alpha}. \qquad (2)$$

Micro level impacts (aggregation)

From Burke et al. 2015 (Nature)

To form a measure of aggregate output, such as Gross Domestic Product (GDP), we must sum across all industries i and integrate production across all locations in a country and all moments in time within the period of observation. Thus total output in country $\mathcal{L}$ during year τ is then:

$$
\begin{aligned}
Y_{\mathcal{L}\tau} &= \sum_i Y_{i\mathcal{L}\tau} \\
&= \sum_i \int_{t \in \tau} \int_{\ell \in \mathcal{L}} f_i(T_{\ell t}) U_{i\ell t} \, d\ell \, dt. \qquad (4)
\end{aligned}
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- **Caveats**
  - Weather conditions affect production factors (labour, capital, soil) locally
  - Different stages of the production process are located across different countries (GVC literature)
  - Each stage of production concerns particular tasks (GVC literature)

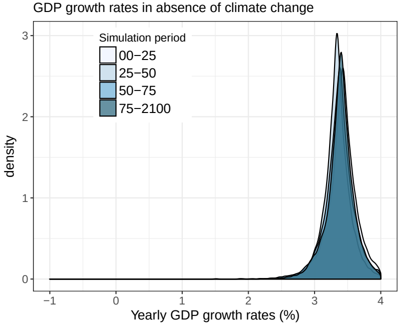
A "brute-force" approach - Lamperti et al. 2017 [WP], 2018 [ECOLEC], 2019 [NCC]

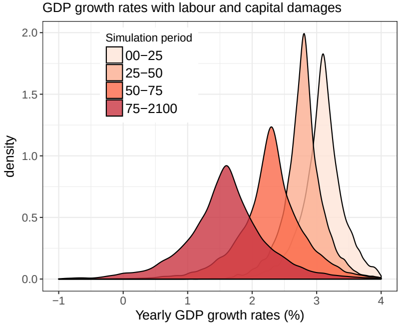
Production unit damages

Climate shocks hit the productive units (i.e. firms) at the end of each period according to the following specification:

$$X_{i,\tau}(t) = X_i'(t)[1 - D_i(t)], \tag{1}$$

where i indexes firms in the economy, D represents the micro-level climate shock determined as $D_i(t) = \Omega(t) + \epsilon_i$ with $\epsilon_i \approx$ i.i.d. $\mathrm{N}(0, 0.01)$ and Ω from Nordhaus (2017).





A less brute-force approach

Building blocks

- **Industry-level damage functions**
  - $gVA_{i,j,l,t} = f(T_{l,t}) + \mu_i + \eta_j + \delta_l t + \epsilon_{i,j,l,t}$
  - gVA is growth rate of value added
  - idea: rely on climate econometrics techniques, using firm level data
- **A model of growth with intermediate inputs and industry competition**
  - Production networks and fluctuations (e.g. Gabaix 2011, Acemoglu et al. 2012),
  - Post-disaster analysis (Hallegatte et al. 2007/8, Henriet et al. 2012, Otto et al. 2017)
  - Technical change, industry competition, growth (Gualdi and Mandel, 2018; Nelson and Winter, 1982)
- **Spatial distribution of productive units and climate projections**

A simple model of production and climate damages propagation

- Stylized model to explore role of heterogeneity and interactions in the micro-to-macro path
- Builds on 3 literatures:
  - evolutionary competition of firms/industries
  - network origins of aggergate flucutuations
  - simple economy-climate modeling (e.g. DICE)
- Agents are firms or industries and are embedded in a production supply chain
- They also compete to improve phase-specific production technique and gain market shares (of total value added)
- Production involves emissions, which contribute to climate change

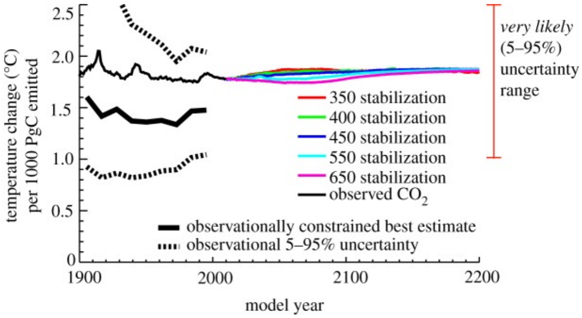
Main equations

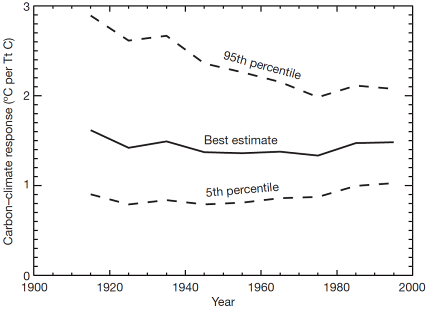
- production function
  - $Y_i(t) = A_i(t) I_i^{\alpha} L^{1-\alpha}$
  - $I_i = f(I_{i,j})$, where $I_{i,j}$ is a vector of intermediate input/task performed by productive units $j \neq i$ and received by i
  - intermediate inputs/tasks for each productive unit defined by a production network

- technical change
  - there is an exogenous growth rate of productivity + endogenous access to innovation
  - $A_i(t+1) = A_i(t) * (1 + g_i^A)$ if innovation successful
  - $A_i(t+1) = A_i(t)$ if innovation unsuccessful
  - $P(inno) = \phi_1 (NH(t) - NH(t)^2)^{1/2} + \phi_2 (A_i(t) - \bar{A}(t))/\bar{A}(t)$

- competition in the provision of intermediate inputs/tasks
  - demand for input/task quasi-replicator dynamics
  - $I_{i,j}(t+1) = I_{i,j}(t) \left(1 + \xi \frac{A_j(t) - \bar{A}(t)}{\bar{A}(t)}\right)$

The carbon-climate relationship





Matthews et al (2012, Philos Trans A) on the left; Matthews et al (2009, Nature) on the right

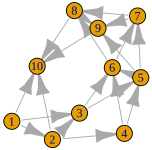
Preferred estimate: 1.8°C per 1000 GtC; 95% CI: [1°C-2.1°C]

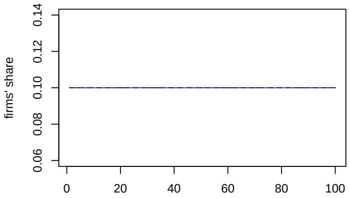
Climate damages

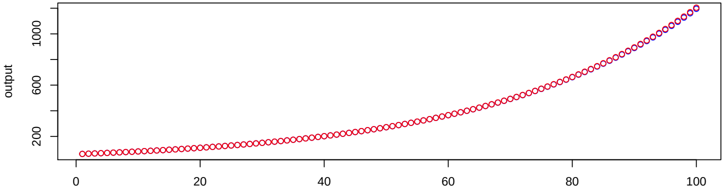
- $A_i(t) = A_i(t)^{\text{no damage}} * (1 - \Omega_i(t))$
- **Experiment 1. homogeneous** : $\Omega_i(t) = L_{\text{Nordhaus}} * s_i(t)$
- **Experiment 2. heterogeneous**: $\Omega_i(t) = L_{\text{Nordhaus}} * s_i(t) + e_i$, where $e_i \sim i.i.d.\ N(0,1)$
- **Experiment 3. heterogeneous**: $\Omega_i(t) = D_i$, where $D_i \sim N(\mu(T), \sigma(T))$ with μ and σ from a "quasi-empirical" distribution

Preliminary results: homogenous damages

Economic structure and GDP







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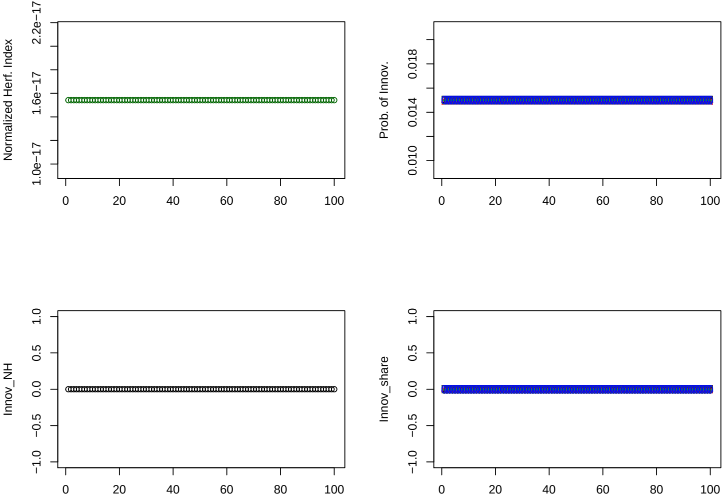
Technical change and industry



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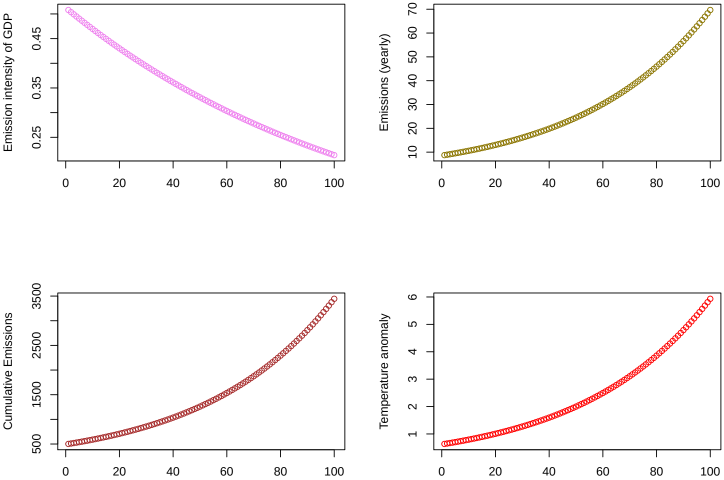
Climate variables



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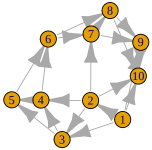

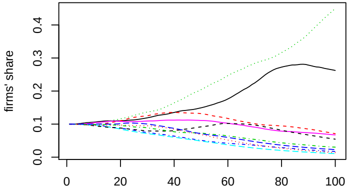

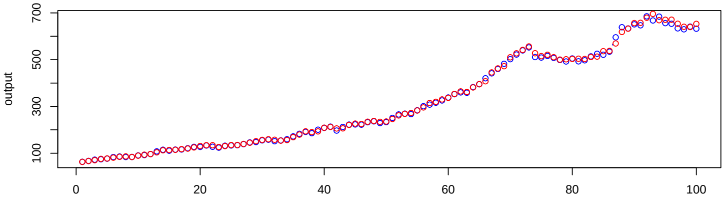

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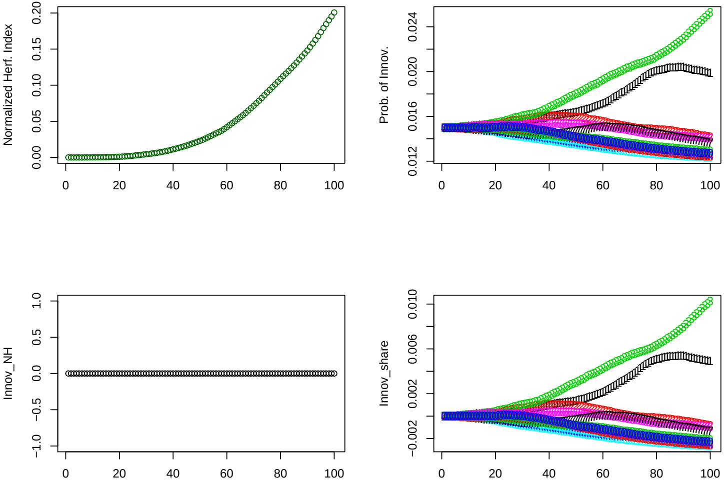

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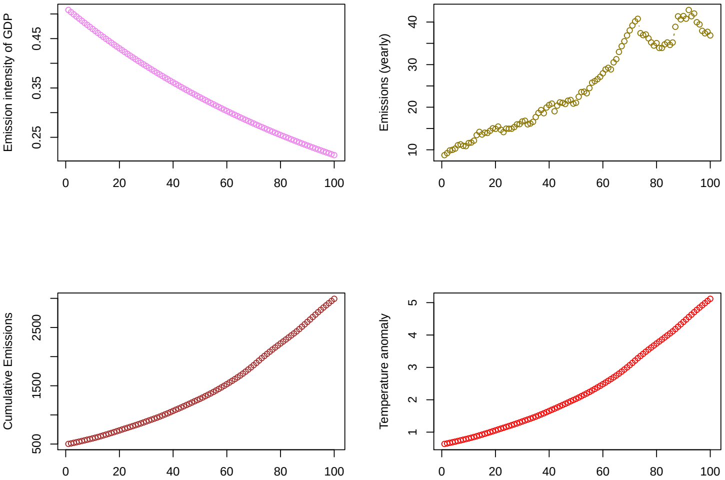
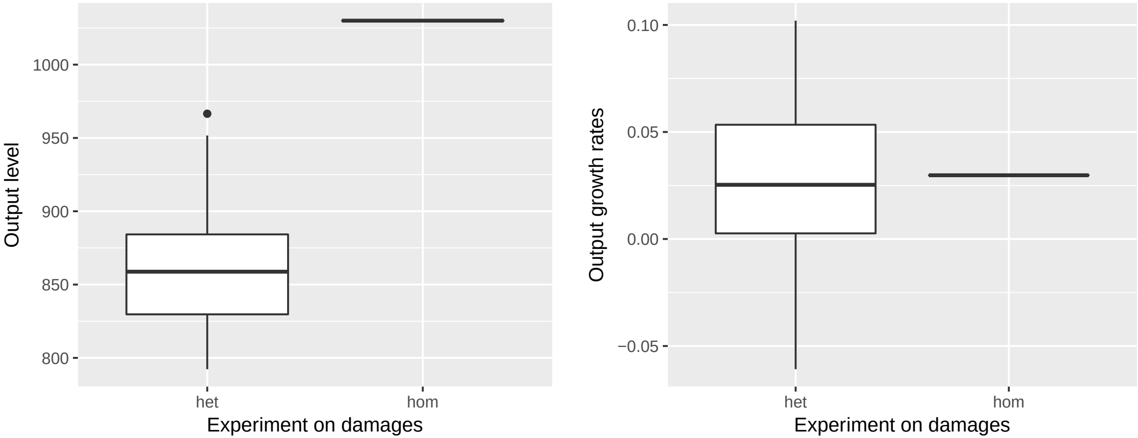


Preliminary results: level and growth effects

Out of 100 independent runs



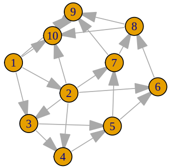
Preliminary results: heterogeneous ‘quasi-empirical” damages

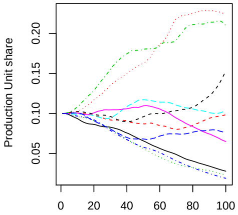
Source: Somanathan et al. 2018

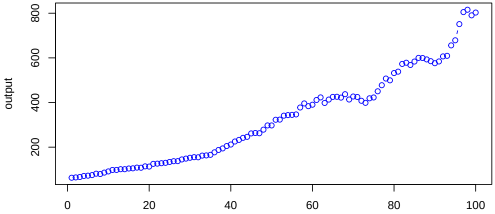
	Dependent variable					
	Steel Products	Garment Manufacture			Cloth Weaving	
	log(blooms)	log(output)	log(output)	log(output)	log(meters)	meters
	(1)	(2)	(3)	(4)	(5)	(6)
(1) rainfall	0.001***	0.083**	0.044	−0.067	0.006	1.512
	(0.0002)	(0.030)	(0.192)	(0.035)	(0.008)	(0.958)
(2) log(target output)		0.796***	0.421***	0.525***		
		(0.034)	(0.126)	(0.044)		
(3) WBT:[0-20)	−0.008*	0.014***	−0.026***	−0.15	0.001	0.530
	(0.003)	(0.004)	(0.007)	(0.097)	(0.008)	(0.596)
(4) WBT:[20-25)	−0.0002	−0.014**	−0.064***	−0.004	0.008	1.700**
	(0.005)	(0.007)	(0.020)	(0.009)	(0.008)	(0.813)
(5) WBT:[25-27)	0.011*	0.029**	−0.149***	0.004	−0.012	−0.417
	(0.006)	(0.014)	(0.026)	(0.020)	(0.013)	(1.091)
(6) WBT:[27-35]	0.016	0.001	−0.087***	−0.037**	−0.077**	−6.722**
	(0.011)	(0.007)	(0.024)	(0.016)	(0.033)	(2.803)
Number of Plants	1	5	1	2	3	3
Number of Observations	9,172	23,827	621	6,073	53,655	53,655
Climate Control	Y	Y	N	N	N	N

- We assume a long term average temperature of 23 C for each productive unit
- Construct a damage function for each of the estimation intervals in each of the 2 industries
- Randomly assign the 2 damages to the production units in the model
- Draw at each time step a shock from the relevant distribution

Preliminary results: heterogeneous ‘quasi-empirical” damages







Conclusions

- Production is increasingly dispersed across Global Value Chains
- Climate is/will be impacting production units locally, with shocks spreading (not just through relative prices)
- A production network model of growth can help grasp insights into how impacts aggregate up
- To do:
  - empirics: get done the empirical part
  - simulation: better explore the role of network structure and move towards localization of production units
  - merge the two!

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- **Thanks for your attention!**