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Knowing the Damages Is Not Enough: The General Equilibrium Impacts of Climate Change

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DICE Model

- Damage function based on sectoral bottom-up studies on costs of warming $\boldsymbol{D(T) = \sum_i D_i(T)}$

- Integrated as multiplicative loss $\boldsymbol{\Omega(T)}$ in one-sector Ramsey-type growth model (Nordhaus 1990,2010)

$$Y = \boldsymbol{\Omega(T)} F(K, L)(1 - \Lambda(E))$$

- Much controversies have been on the calibration of $\boldsymbol{\Omega(\cdot)}$ and the associated uncertainties in the climate system, i.e. $E \rightarrow T$

This paper: New damage dynamics through inter-temporal and inter-sectoral equilibrium effects

Intertemporal Equilibrium Effects (1)

- Consider a Ramsey growth model with Cobb-Douglas Technology

$$Q^Y = \phi^Y F(K, L) = \phi^Y K^\alpha L^{1-\alpha}$$

- Neglecting population and technology growth, we set $L = 1$
- In the long run: $\rho = \phi^Y F_K$
- Multiplicative climate damages: $\frac{d \ln \phi^Y}{dT} < 0$

Intertemporal Equilibrium Effects (2)

What happens to the economy if T increases?

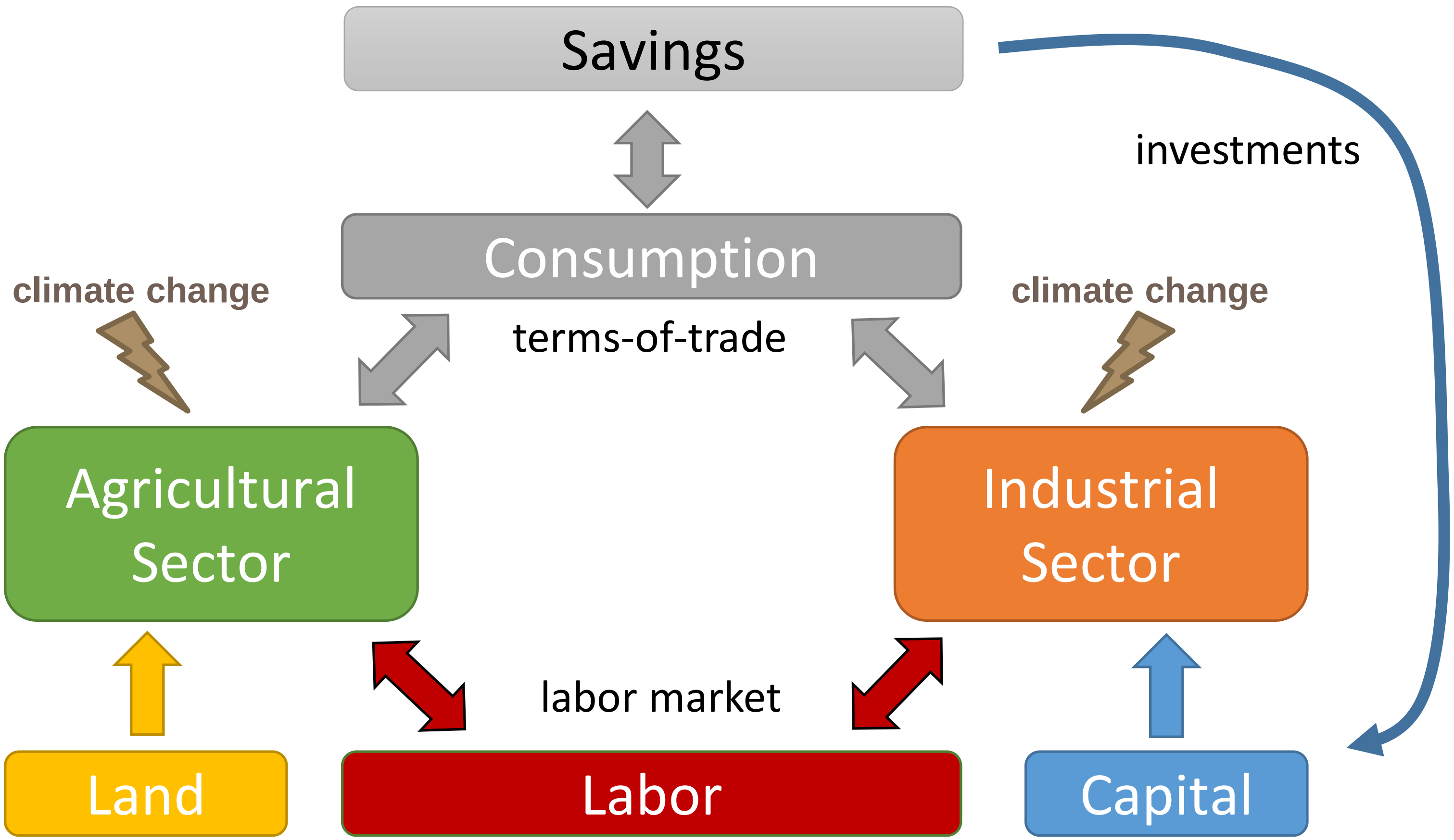
Capital stock adjusts: $$\frac{d(\ln K)}{dT} = \frac{1}{1-\alpha}\frac{d(\ln \phi^Y)}{dT} < \frac{d(\ln \phi^Y)}{dT} < 0$$

Output adjusts: $$\frac{d(\ln Q^Y)}{dT} = \frac{1}{1-\alpha}\frac{d(\ln \phi^Y)}{dT} < \frac{d(\ln \phi^Y)}{dT} < 0$$

Multiplier effect: $\frac{1}{1-\alpha} > 1$ implies over-proportional response

- $\alpha = 1/3$ ➔ 50%
- $\alpha = 2/3$ ➔ 200%

Multi-Sector Growth Model: Overview



Multi-Sector Model: Equations

Production

$$Q^Y = \phi^Y F(K, L) = \phi^Y K^\alpha L^{1-\alpha}$$
$$Q^A = \phi^A F(A, 1-L) = \phi^A A^\beta (1-L)^{1-\beta}$$

Balance

$$w + rK + qA = pC^A + C^Y + I$$
$$dK/dt = I$$

Utility $u(C)$ with aggregate consumption $C = v(C^A, C^Y)$
where C^A, C^Y are substitutable with constant elasticity σ

Steady state: $I = 0, C^A = Q^A, C^Y = Q^Y$

Equilibrium in Steady State

$$\phi^Y \frac{\partial F^Y(\cdot)}{\partial K} = \rho$$ ← Investment (Euler equation)

$$p = \frac{\partial v(\cdot)/\partial C^A}{\partial v(\cdot)/\partial C^Y}$$ ← Relative prices (terms of trade)

$$\phi^Y \frac{\partial F^Y(\cdot)}{\partial L} = p\phi^A \frac{\partial F^A(\cdot)}{\partial (1-L)}$$ ← Labor market

$$p\phi^A \frac{\partial F^A(\cdot)}{\partial A} = q$$ ← Land prices

Next, we shock the equilibrium by a marginal change in the productivities ϕ

Impact on Factor Allocation

Lemma 1. *(Factor allocation) The elasticity of the equilibrium labor and capital response to changes in productivity* ϕ^A *and* ϕ^Y *is given by:*

$$\frac{d\ln K}{d\ln\phi^A} = -\frac{s\,(1-L)}{\Gamma} \qquad \frac{d\ln K}{d\ln\phi^Y} = \frac{1}{1-\alpha} + \frac{s\,(1-L)}{\Gamma} > 0 \tag{8}$$

$$\frac{d\ln L}{d\ln\phi^A} = -\frac{s\,(1-L)}{\Gamma} \qquad \frac{d\ln L}{d\ln\phi^Y} = \frac{s\,(1-L)}{(1-\alpha)\Gamma} \tag{9}$$

with $\Gamma := s(\beta L - 1) + 1 > 0.$

with $s = (\sigma - 1)/\sigma$ ➔ $s > 0$ if and only if $\sigma > 1$

Impact on Output

Lemma 2. *(Output) A relative change in agricultural factor productivity* ϕ^A *affects sectoral and aggregate production as follows:*

$$\frac{d\ln V^Y}{d\ln\phi^A} = -\frac{s(1-L)}{\Gamma} \qquad \frac{d\ln V^Y}{d\ln\phi^Y} = \frac{1}{1-\alpha} + \frac{s(1-L)}{(1-\alpha)\Gamma} \tag{10}$$

$$\frac{d\ln V^A}{d\ln\phi^A} = \frac{sL}{\Gamma} \qquad \frac{d\ln V^A}{d\ln\phi^Y} = \frac{\Gamma - sL}{(1-\alpha)\Gamma} \tag{11}$$

$$\frac{d\ln V}{d\ln\phi^A} = -\frac{s(\eta-L)}{\Gamma} \qquad \frac{d\ln V}{d\ln\phi^Y} = \frac{1}{1-\alpha} + \frac{s(\eta-L)}{(1-\alpha)\Gamma} \tag{12}$$

with $s = (\sigma - 1)/\sigma$ ➔ $s > 0$ if and only if $\sigma > 1$

with η = share of the industrial sector on total GDP

$\eta > \mathrm{L}$ ⇔ labor productivity higher in industrial sector

Biased Climate Change

Climate change reduces sectoral factor productivities

Bias of relative damage to the agricultural sector

$$\chi := \frac{d(\ln \phi^A)/dT}{d(\ln \phi^Y)/dT}$$

Impacts of climate change on production

inter-temp.   inter-sectoral

$$\frac{d(\ln V)}{dT} = \left(\boxed{\frac{1}{1-\alpha}} + \boxed{\frac{s(\eta - L)}{\Gamma} \left(\frac{1}{1-\alpha} - \chi \right)} \right) \frac{d(\ln \phi^Y)}{dT}$$

$\frac{1}{1-\alpha}$: >0 $\frac{d(\ln \phi^Y)}{dT}$: <0

Impact on Labor Migration

$$\frac{d(\ln L)}{dT} = \left(\frac{s(1-L)}{\Gamma} \left(\frac{1}{1-\alpha} - \chi \right) \right) \frac{d(\ln \phi^{Y})}{dT}$$

Urbanization increases if s>0 and strong bias $\chi > 1/(1-\alpha)$

Distributional Implications

- Existing works analyzed distributional impacts by heterogeneity in damages between *countries*
- Developing countries are often considered to be stronger affected (agriculture) (Tol et al., 2004; Mendelsohn et al., 2006)
- No analysis on impacts within countries or factor incomes (exception: World Bank Shock Waves Report (2015))

Model framework allows to analyze **impacts on factor incomes**

- Capital income
- Land rent
- Labor income

Distributional Implications

With Cobb-Douglas function follows

- Capital income share: $rK/GDP = \eta\alpha$
- Land rent share: $qA/GDP = (1-\eta)\beta$
- Labor income share: $w/GDP = 1-\beta+\eta(\beta-\alpha)$

Distributional impacts depend on change of industrial VA share η:

	Capital income	Land income	Labor income	
			$\psi^Y > \psi^A$	$\psi^Y < \psi^A$
$d\eta > 0$	+	−	−	+
$d\eta < 0$	−	+	+	−

Numerical Assessment

Results so far

- Multiplier effect due to intertemporal and inter-sectoral equilibrium adjustments → *endogenous macroeconomic adaptation*
- Even positive GDP effects possible although sectoral productivities decrease
- Inequality may increase or decrease

But, how important are these impacts for real-world economies?

Data

All we need is:

- η - World Development Indicators: 1 – share of agricultural value added

- L - World Development Indicators: 1 – share of labor in agriculture

- s - by scenario: -0.5; 0.5 (corresponds to $\sigma = 0.5; 2$)

- χ - by scenario: 0.5 – 1.0 – 2.0

Dell et al: 30-76% higher damages in agriculture for temp shocks

But: climate change has additional damages (sea-level rise) that might

hit industry harder than agriculture

Data

Country	Base year	capital income	land income	η	α	β	Source for SAM
Bangladesh	1993/94	0.435	0.129	0.741	0.59	0.50	Fontana and Wobst (2001)
Brazil	1995	0.514	0.033	0.942	0.55	0.57	Cattaneo (2002)
China	2007	0.453	0.020	0.892	0.51	0.19	Zhang and Diao (2013)
El Salvador	2000	0.649	0.015	0.895	0.73	0.14	Acevedo (2004)
Ghana	2005	0.238	0.076	0.591	0.40	0.19	Breisinger et al. (2007)
Indonesia	1995	0.424	0.062	0.829	0.51	0.36	Bautista et al. (1999)
Kenya	2003	0.511	0.048	0.710	0.72	0.17	Kiringai et al. (2006)
Malawi	1998	0.336	0.108	0.644	0.52	0.30	Chulu and Wobst (2001)
Mexico	2008	0.652	0.014	0.967	0.67	0.42	Debowicz and Golan (2012)
Nigeria	2006	0.433	0.110	0.680	0.64	0.34	Nwafor et al. (2010)
Peru	2002	0.507	0.043	0.917	0.55	0.52	Nin-Pratt et al. (2011)
Tanzania	2001	0.397	0.041	0.671	0.59	0.12	Thurlow and Wobst (2003)
Uganda	1999	0.237	0.226	0.615	0.38	0.59	Dorosh et al. (2002)
Vietnam	1997	0.282	0.093	0.742	0.38	0.36	Nielsen (2002)
Zambia	2001	0.528	0.012	0.780	0.68	0.05	Thurlow et al. (2008)
Zimbabwe	1991	0.488	0.023	0.847	0.58	0.15	Thomas and Bautista (1999)
Mean		0.443	0.066	0.779	0.56	0.31	
Median		0.444	0.046	0.761	0.56	0.32	

Table 2: Factor income shares and derived α and β from various social accounting matrices. The share of the non-agricultural sector on total GDP, η, is obtained from the World Development Indicators. $\alpha = \tilde{\alpha}/\eta$ and $\beta = \tilde{\beta}/(1-\eta)$ with $\tilde{\alpha}$ and $\tilde{\beta}$ the capital and land income share of the entire economy.

Damage Function?

- We do not know the damages, so we normalize our findings with a naive damage function ➔ Multiplier

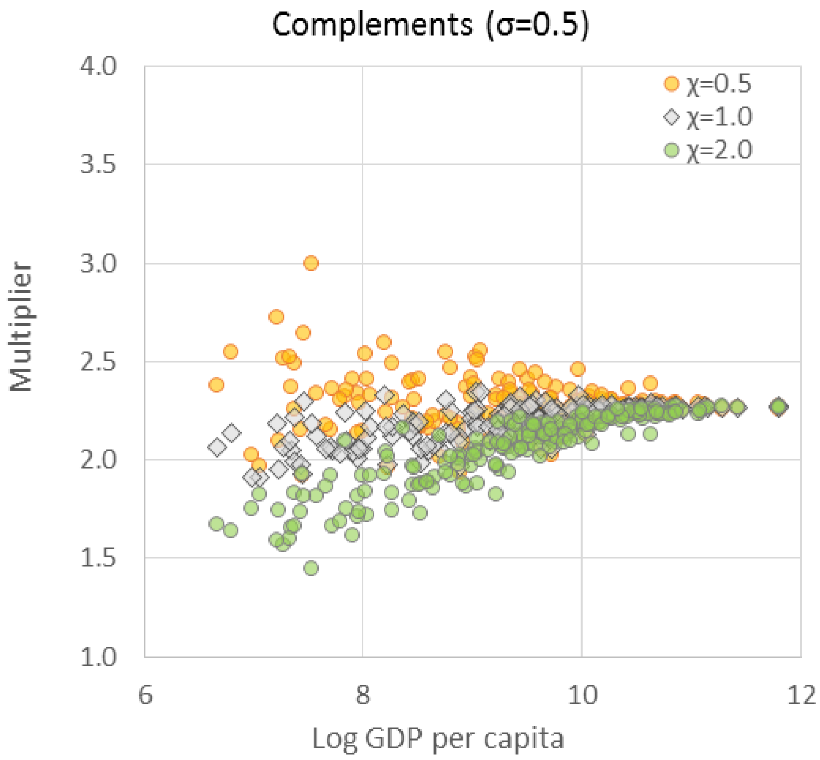
Naïve approach (“summing up the damages”):

$$\frac{d\,\widehat{GDP}}{d\,T} = (\chi(1-\eta)+\eta)\Omega'(T)$$

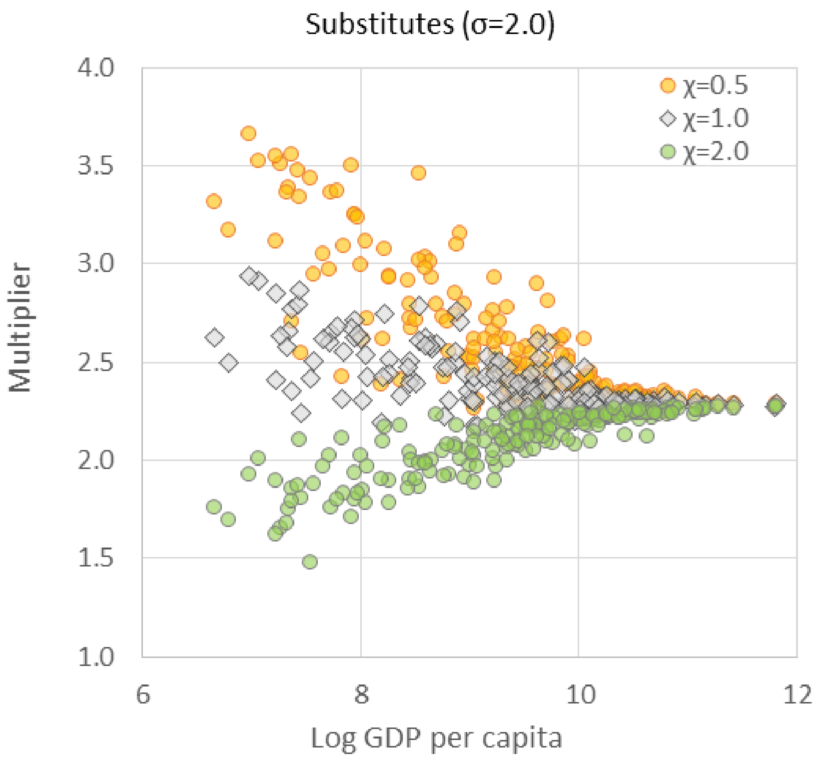
Inter-temporal and inter-sectoral equilibrium effects:

$$\frac{d\,GDP}{d\,T} = \left(\frac{1}{1-\alpha} + \frac{s(\eta-L)}{\Gamma}\left[\frac{1}{1-\alpha} - \chi\right]\right)\Omega'(T)$$

Food and manufactured goods are **complements**
(e.g. closed economies)



Food and manufactured goods are **substitutes**
(e.g. small open economies)

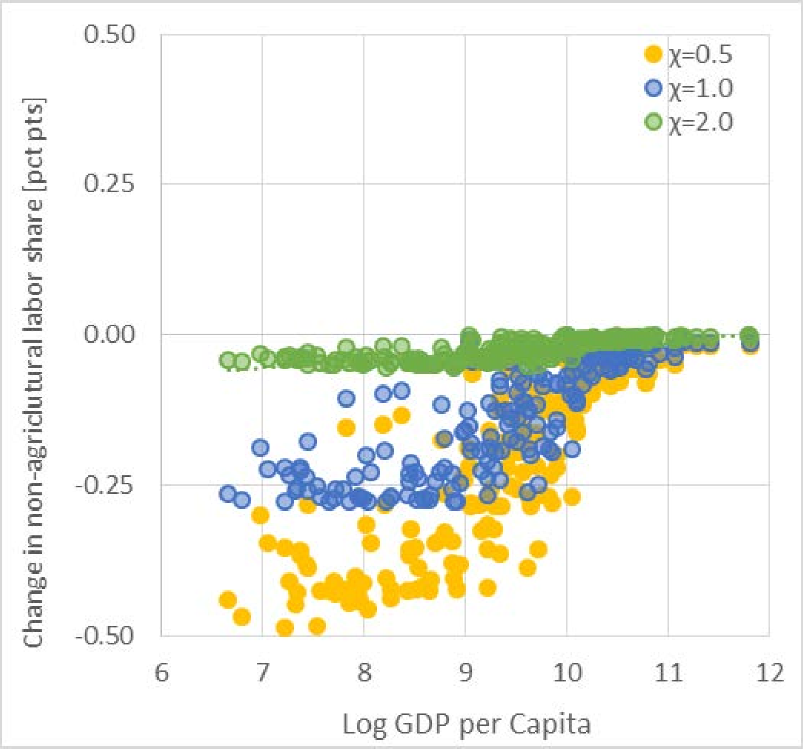


Multiplier effect:

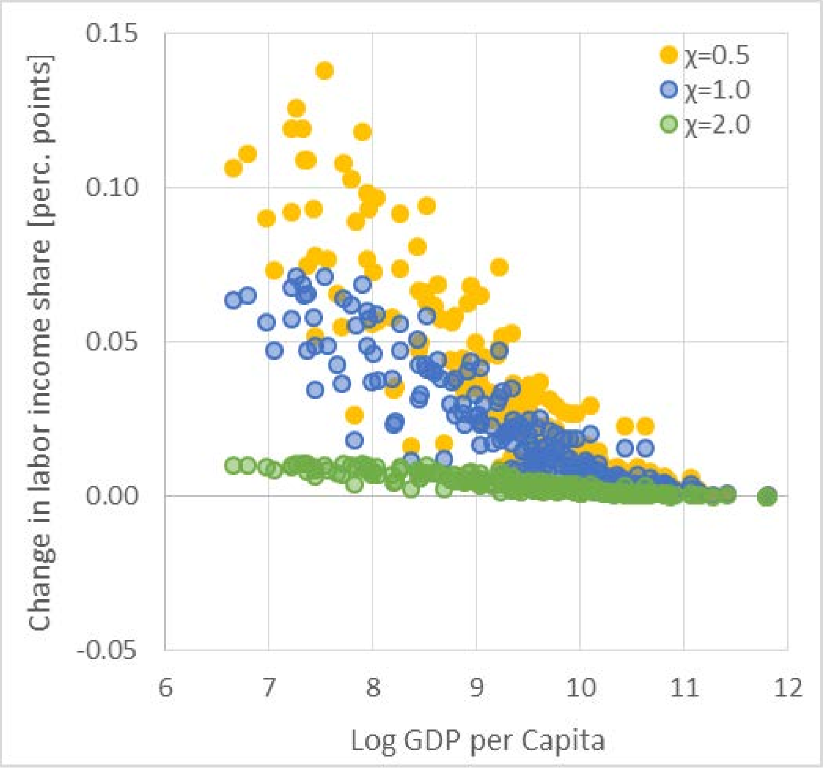
- particular relevant for poor countries (as $\eta \approx L$ in developed countries)
- lower for poor countries if damages are biased to agricultural sector
- more important for open economies, in particular, when damages to industrial sector are high

Labor Shifts & Labor Income (substitutes, $\sigma = 2$)

Labor in Non-Agriculture



Labor Income Share



Conclusions

- Intertemporal and intersectoral **multiplier effect** is sizeable, but never negative
- **Heterogeneity of impacts** due to differences in sectoral labor productivity
- **Developing countries** might be strongly affected by climate change because of divergence in labor productivity
- Endogenous **adaptation** may amplify damages

Major critique:

➔ Damage functions are used in a too aggregated form

Outlook

- IA growth models with three sectors and sectoral damage functions?
- Empirical testing of equilibrium effects?
  - So far, little evidence of inter-temporal effects as investments seem to not respond to weather shocks (Dell et al. 2009)
  - Test on longer time scales?
  - Test on sectoral re-allocation? Test on differential impacts (depending on relative productivity and openness)
- Climate change, trade patterns and globalization

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Positive Climate Change Impacts?

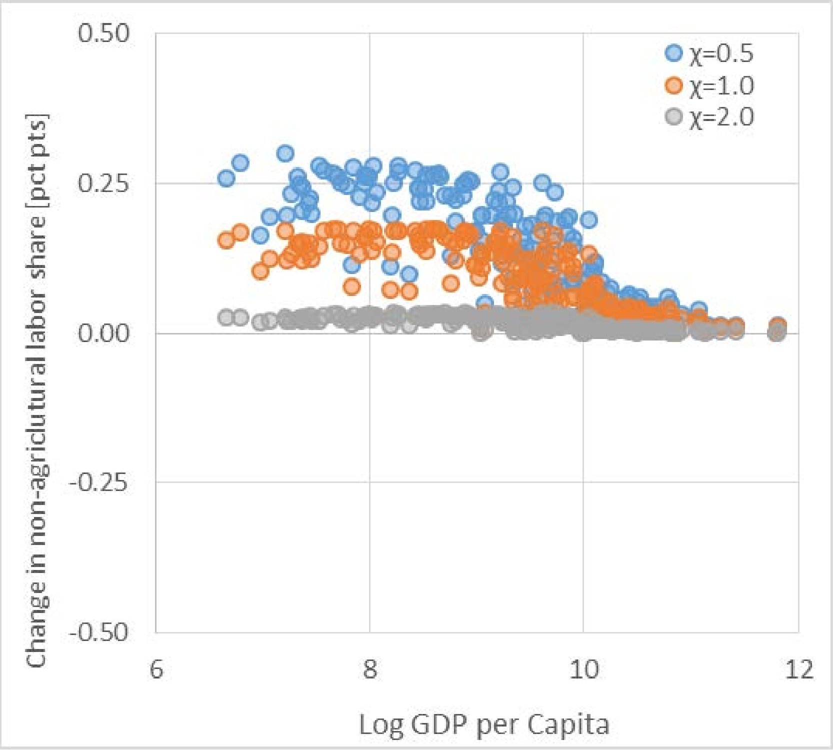
ISO3	GDP/cap	L	η	χ_{crit}
BTN	7,456	0.44	0.82	9.0
BFA	1,545	0.33	0.66	9.8
CMR	2,836	0.39	0.78	8.8
GEO	7,233	0.47	0.91	8.2
GIN	1,165	0.25	0.80	6.8
LAO	5,076	0.29	0.72	7.9
MDG	1,373	0.25	0.74	7.3
MOZ	1,077	0.20	0.75	6.6
NPL	2,265	0.34	0.66	9.9
PNG	2,724	0.28	0.62	9.4
RWA	1,584	0.25	0.67	8.1
TZA	2,421	0.33	0.69	9.3
UGA	1,689	0.28	0.73	7.8
ZMB	3,725	0.48	0.90	8.4
ZWE	1,709	0.34	0.86	7.1

Damage bias necessary to reverse the negative impacts of climate change in the case of substitutes (s > 0). Only countries with $\chi_{crit} < 10$ and positive are shown.

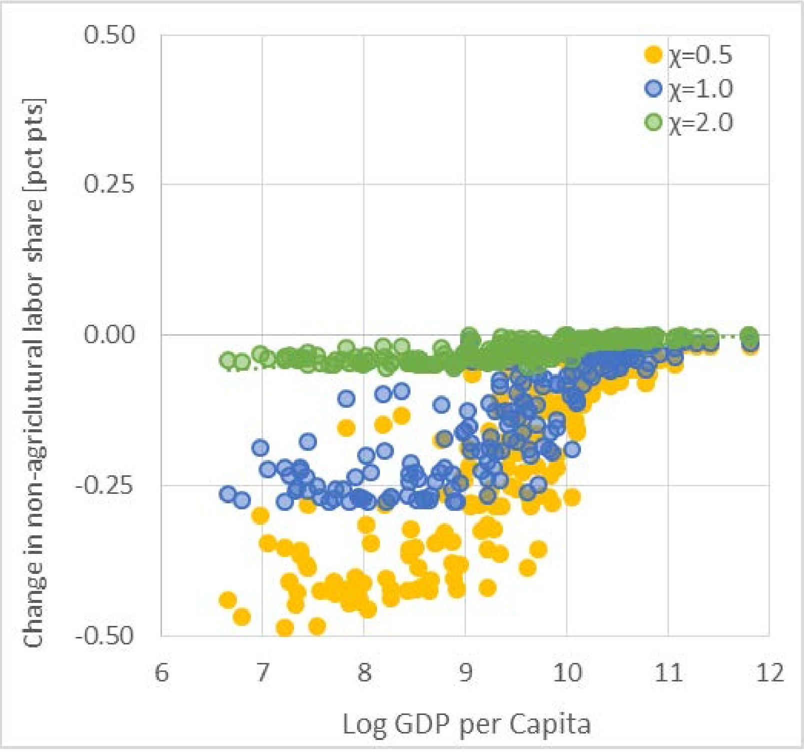
GDP is in PPP in constant 2011 international US$ per capita

Labor Shifts (Urbanization)

complements

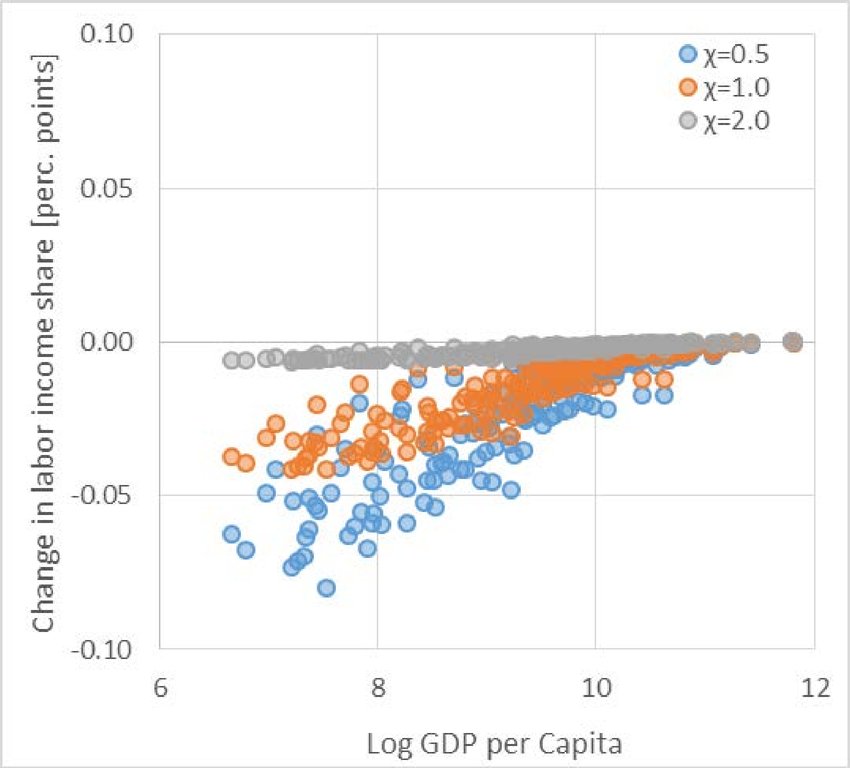


substitutes

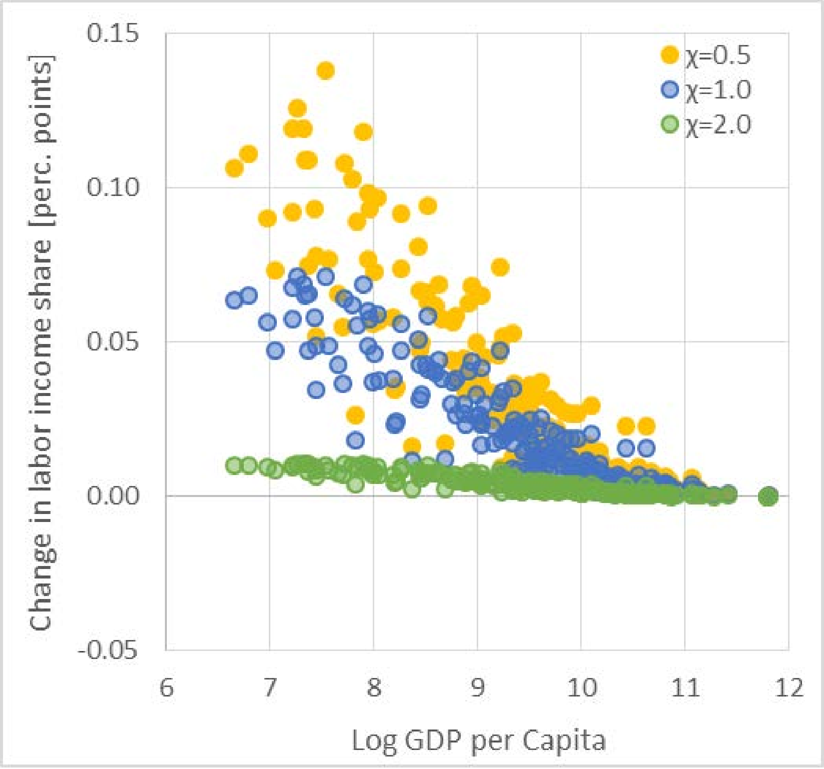


Labor Income

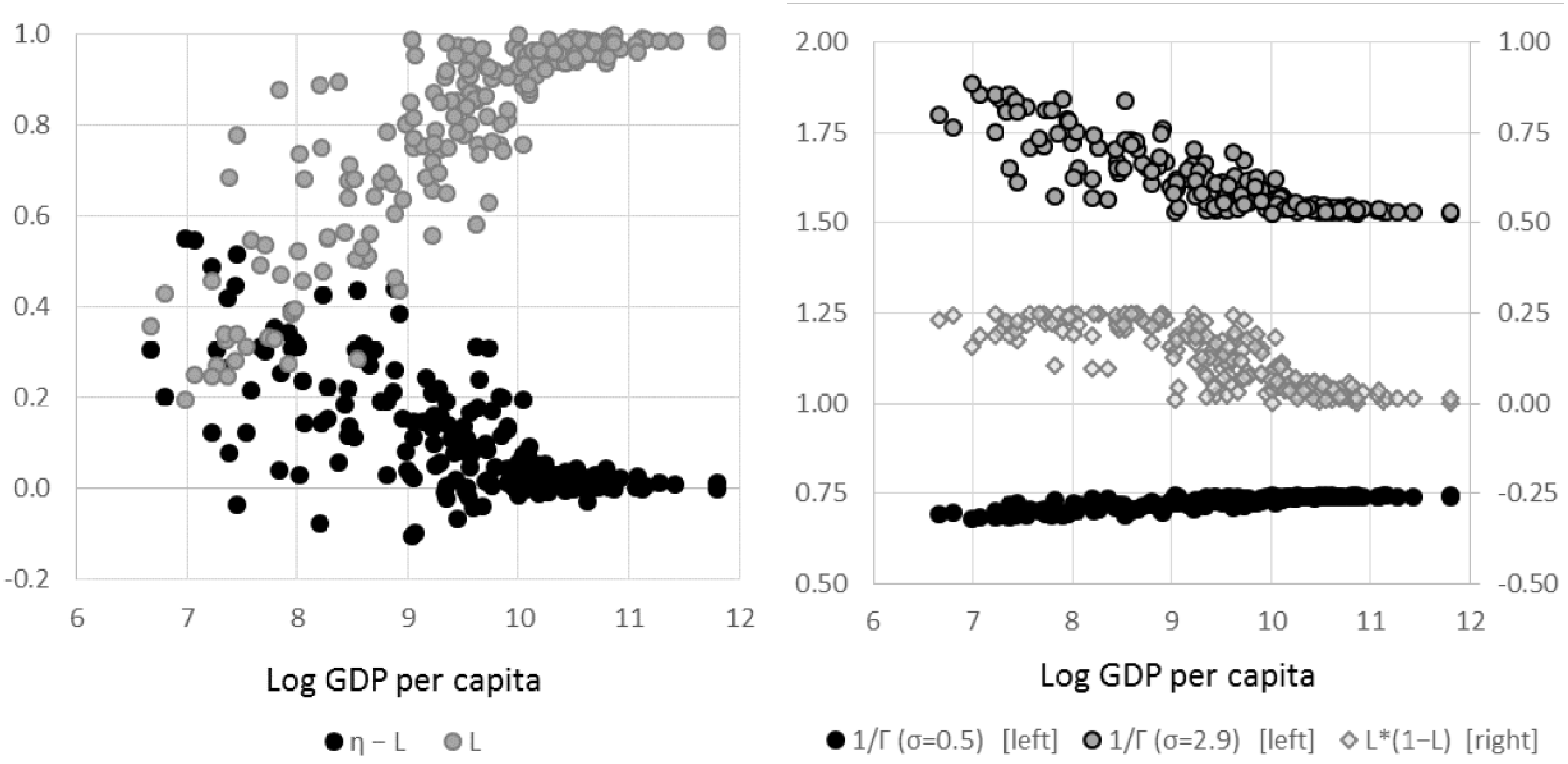
complements



substitutes



Appendix


1.0
0.8
0.6
0.4
0.2
0.0
-0.2
6
7
8
9
10
11
12
Log GDP per capita
η − L
L
2.00
1.75
1.50
1.25
1.00
0.75
0.50
1.00
0.75
0.50
0.25
0.00
-0.25
-0.50
6
7
8
9
10
11
12
Log GDP per capita
1/Γ (σ=0.5) [left]
1/Γ (σ=2.9) [left]
L*(1−L) [right]

Climate Change Impacts: The Damage Function

Prevailing approach for assessing climate damages (Tol, Nordhaus):

- Estimate costs as a function of a change in global mean temperature
- Damage function $D(T)$

Damage function consists typically of disaggregated damage estimates over sector or activity i

$$D(T) = \sum_i D_i(T)$$

DICE Model

- Damages $\boldsymbol{\Omega}(\boldsymbol{T})$ and abatement costs $\Lambda(E)$ as multiplicative factor on the production function:

$$Y = \boldsymbol{\Omega}(\boldsymbol{T}) F(K, L)(1 - \Lambda(E))$$

- Typical question: Choose emission E^* optimally so that social welfare is maximized

- Much controversies have been on the calibration of $\boldsymbol{\Omega}(\cdot)$ and the associated uncertainties in the climate system, i.e. $E \rightarrow T$

This paper: New damage dynamics through inter-temporal and inter-sectoral equilibrium effects

Labor Income Share

$$\frac{d\eta}{d\ln(\phi^A)} = -\eta s \frac{1-\eta}{\Gamma} \qquad \frac{d\eta}{d\ln(\phi^Y)} = \eta s \frac{1-\eta}{(1-\alpha)\Gamma}$$

Sign a-priori not clear but tends to be in opposite direction as the multiplier effect:

$$\frac{d(w/V)}{dT} = (\beta - \alpha)\left[\frac{1}{1-\alpha} - \chi\right]\eta s \frac{1-\eta}{\Gamma}\frac{d(\ln\phi^Y)}{dT}$$

In the one-sector (Ramsey) economy, wages decrease proportionally to GDP ➔ no distributional effects