ASSA 2023 Session "Firm Productivity, Environment and Industrial Policies"

Endogenous Economic Structure, Climate Change, and the Optimal Abatement Path

Authors: Hua Liao, Huiying Ye (presenter)

Center for Energy & Environmental Policy Research (CEEP),

Beijing Institute of Technology

Jan 7, 2023

CEEP-BIT

Outline

- Background
- Methodology
- Results and Discussion

CEEP-BIT

Background：Climate Change

- Climate change poses great threats for both human society and ecological environment: sea level rise, temperature-related mortality, drought, biological diversity.
- According to the 6th assessment report of the Intergovernmental Panel on Climate Change *(IPCC,2021),* the global surface temperature was 1.09 ℃ higher in 2011-2020 than pre-industrial levels, and global warming of between 1.5℃ and 2 ℃ will be exceeded during the 21st century unless deep reductions in CO2 occur.
- Analytical tools are needed to find an optimal abatement path, so as to coordinate emission reduction and development, in both the short and long term.

CEEP-BIT

Background： IAM

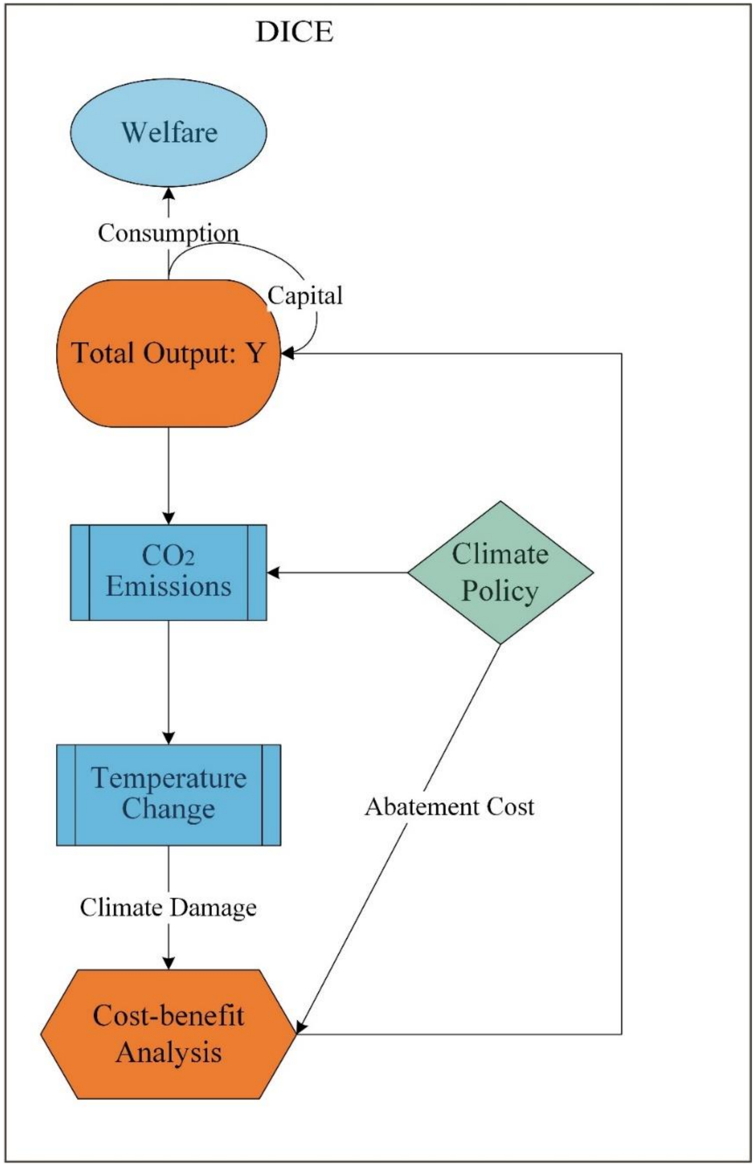
- Address climate change is a very complicated matter of long-lasting impacts and global scope. It involves multiple subjects: natural science, engineering technology, social economics et al.
- Integrated Assessment Models (IAM) through interdisciplinary modeling, couple climate and economic systems into one analytical framework, allowing for coherent analysis of social and physical processes.
- IAMs have gained a prominent role in the climate science policy interface *(Beek et al., 2020)*

CEEP-BIT

Background： IAM

- CGE, Scenario simulation models (Detail-Based), Intertemporal optimization models (Maro-level) *(Yang, 2008)*.
- Compared with common economic system modeling, current IAM has more challenges:

Uncertainty and tipping point； Complex feedback between climate and economy； Long term economic structure； Game theory Mechanism； Complex Algorithm



Background

Economic Structure is tightly related to Carbon emissions

- Index like per capita emission (or carbon intensity) is hard to comprehensively explain the correlation between carbon emission and economic development.
- The evolution of per capita emissions or carbon intensity varies greatly between countries with similar level of economic development (per capita GDP). Economic structure plays an important role.*(Liao, 2013)*
- Endogenous economic structure has been widely studied in economic growth literature *(Herrendorf et al,2014)* .

CEEP-BIT

Dynamic Interaction between Economic Structure and Climate Change

- Carbon intensity varies between sectors *(Ciarli and Savona, 2019; Ramaswami et al, 2017; Fankhauser and Tol 2005)*
- Climate Change causes different level of damage across sectors *(Martinich and Crimmins 2019 ; Dell et al, 2012 ; Roson and Sartori, 2016)*
- Macro-level Optimization IAM unable to capture such dynamic endogenous mutual feedback. DICE (Dynamic Integrated model of Climate and the Economy) built by *Nordhaus (1992, 2017)* aggregates economy into one sector. But it does not explicitly represent the role of economic structure, which may lead to different results.

CEEP-BIT

Our Research： Incorporating two sectors in DICE one producing consumer goods, another producing capital goods

- Trade-of between simplicity and complexity: illustrate economic structure but keep the highly aggregated, transparent and macroeconomic features of the model.
- Capital and consumer goods are two basic macroeconomic sector, also is an initial extension that incorporates structural transformation *(Uzawa, 1961; Herrendorf et al, 2020)* .
- More detailed sectoral division will be associated with greater uncertainty: dynamic mechanism， basic data, computational algorithm.
- Previous research indicates that, we can get quite accurate estimations for macro variables (long term economic growth, Inflation rate) , but not for more specific variables (steel production, oil price). Thus, for long term scale research, detailed sector division faces great challenge *(Smil, 2000; Liao et al， 2016)*.

CEEP-BIT

Capital Goods VS Consumer Goods

- Play different role in long term economic growth, and divergent carbon intensity *(Peng and Liao, 2021).*

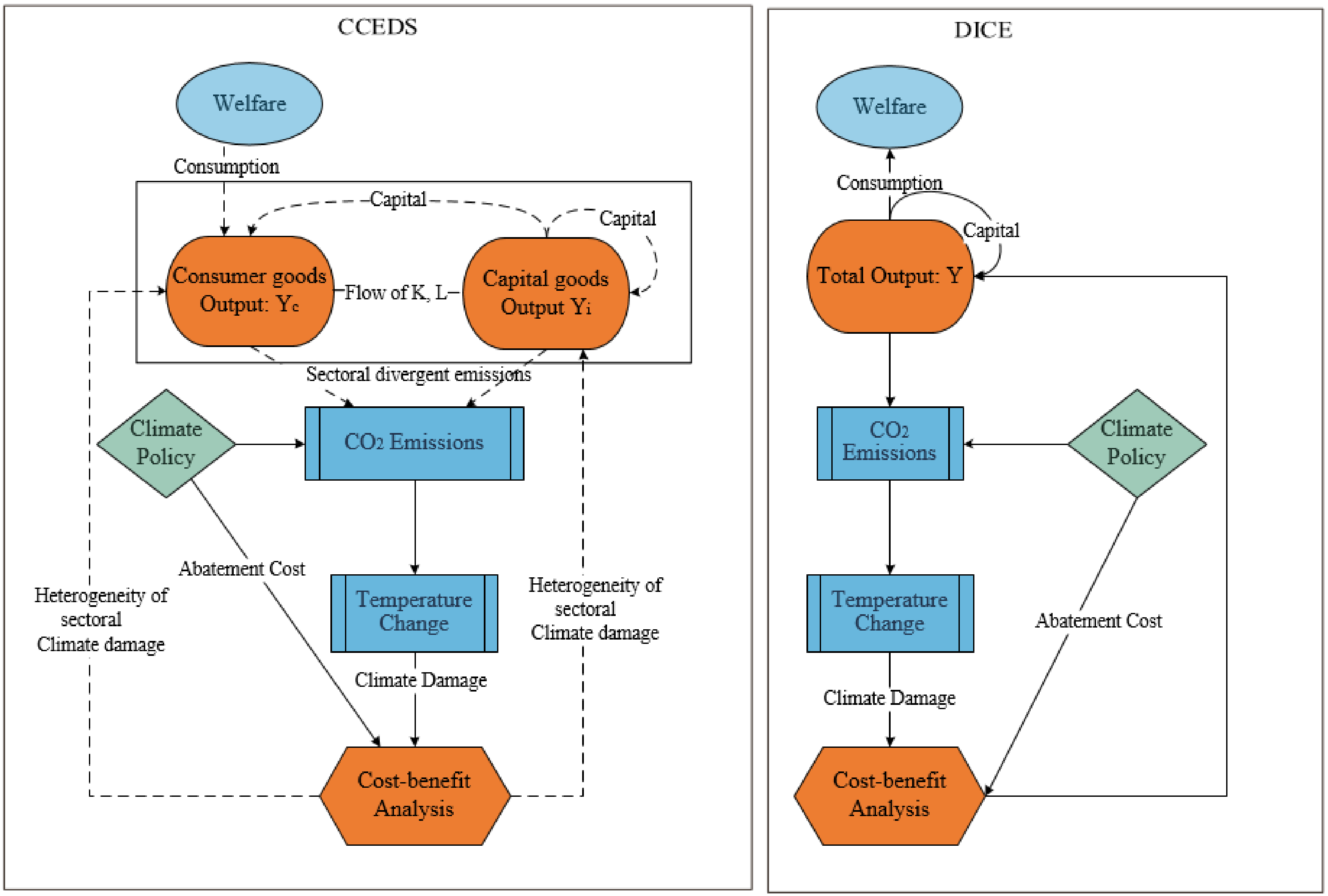
VS

- Diverse technological progress rate: Capital goods sector is faster *(Herrendorf et al， 2020）.*
- Expose to varies level of climate damage *(Martinich and Crimmins, 2019； Casey et al， 2021).*
- Different capital or labor income share *(Valentinyi and Herrendorf, 2008).*

CEEP-BIT

Methodology

Schematic of CCEDS (Coupled Climate and Economic Dynamics model with Endogenous Structure)



Key modified equations

DICE		CCEDS
$Y_t = \Omega_t(1-\Lambda_t)A_tK_t^{\alpha}L_t^{1-\alpha}$	Total output division →	$Y_t = p_{c,t}Y_{c,t} + Y_{i,t}$ $Y_{i,t} = \Omega_{i,t}(1-\Lambda_{i,t})A_{i,t}K_{i,t}^{\beta 1}L_{i,t}^{1-\beta 1}$ $Y_{c,t} = \Omega_{c,t}(1-\Lambda_{c,t})A_{c,t}K_{c,t}^{\beta}L_{c,t}^{1-\beta}$
$E_{ind,t} = (1-\mu_t)A_{i,t}K_{i,t}^{\alpha}L_{i,t}^{1-\alpha}$	Heterogeneous carbon intensity →	$E_{ind,t} = (1-\mu_t)\left(\sigma_{c,t}p_{c,0}A_{c,t}K_{c,t}^{\beta}L_{c,t}^{1-\beta} + \sigma_{i,t}A_{i,t}K_{i,t}^{\beta 1}L_{i,t}^{1-\beta 1}\right)$
$Y_t = \Omega_t(1-\Lambda_t)A_tK_t^{\alpha}L_t^{1-\alpha}$	Heterogeneous climate damage →	$\Omega_{i,t} = \frac{1}{1+a_{1i}T_t+a_{2i}T_t^{a3}}$ $\Omega_{c,t} = \frac{1}{1+a_{1c}T_t+a_{2c}T_t^{a3}}$

Flow of production factor →

$$(1-\Lambda_{i,t})\Omega_{i,t}\alpha A_{i,t}K_{i,t}^{\beta 1-1}L_{i,t}^{1-\beta 1} = p_{c,t}\beta A_{c,t}K_{c,t}^{\beta-1}L_{c,t}^{1-\beta}\Omega_{c,t}(1-\Lambda_{c,t})$$

$$(1-\Lambda_{i,t})\Omega_{i,t}(1-\alpha)A_{i,t}K_{i,t}^{\beta 1}L_{i,t}^{-\beta 1} = p_{c,t}(1-\beta)A_{c,t}K_{c,t}^{\beta}L_{c,t}^{-\beta}\Omega_{c,t}(1-\Lambda_{c,t})$$

CEEP-BIT

Methodology: Calibration

Preserve most of the parameter values from DICE-2016R, except those reflecting the heterogeneity between the two sectors

- Capital Income Share: 0.4(capital goods sector), 0.25(consumer goods sector)
- TFP Progress： Capital goods sector is 1.5 times that of consumer goods sector. The aggregate growth rate in base year is consistent with DICE-2016R
- Heterogeneous Carbon Intensity: Capital goods sector is 2 times that of consumer goods sector. The aggregate intensity in base year is consistent with DICE-2016R
- Heterogeneous Climate Damage： Capital goods sector is 1.3 times that of consumer goods sector.， The aggregate damage in base year is consistent with DICE-2016R *(Roson and Sartori, 2016 ; Timmer et al, 2015)*
- Sectoral Output in base year: investment rate, total output is consistent with DICE-2016R
- Other Trends on Parameters is consistent with DICE

CEEP-BIT

Methodology: Scenarios

Model Cases:

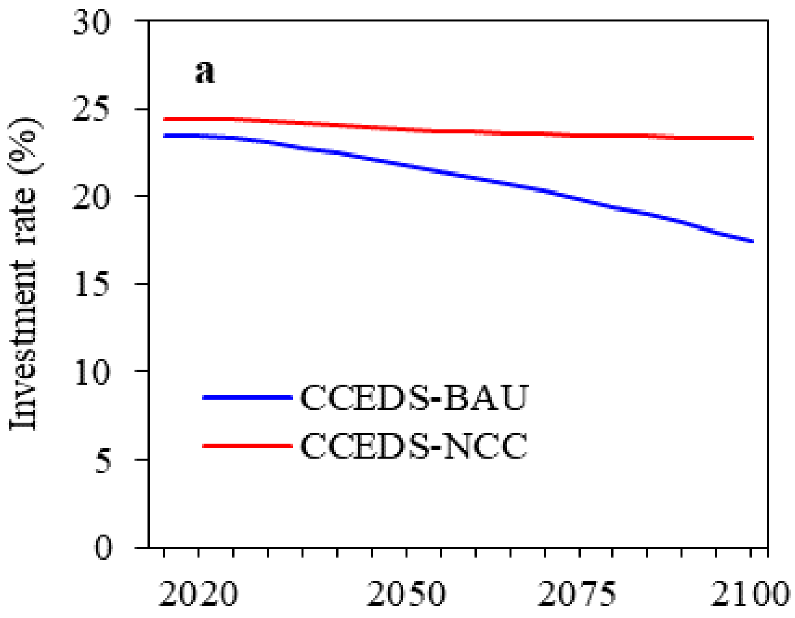
- DICE： The standard one-sector DICE-2016R model
- CCEDS: Coupled Climate and Economic Dynamics with Endogenous Structure
- CCEDS-NCC: The whole climate part in CCEDS is deleted. Ideal two-sector economic growth model

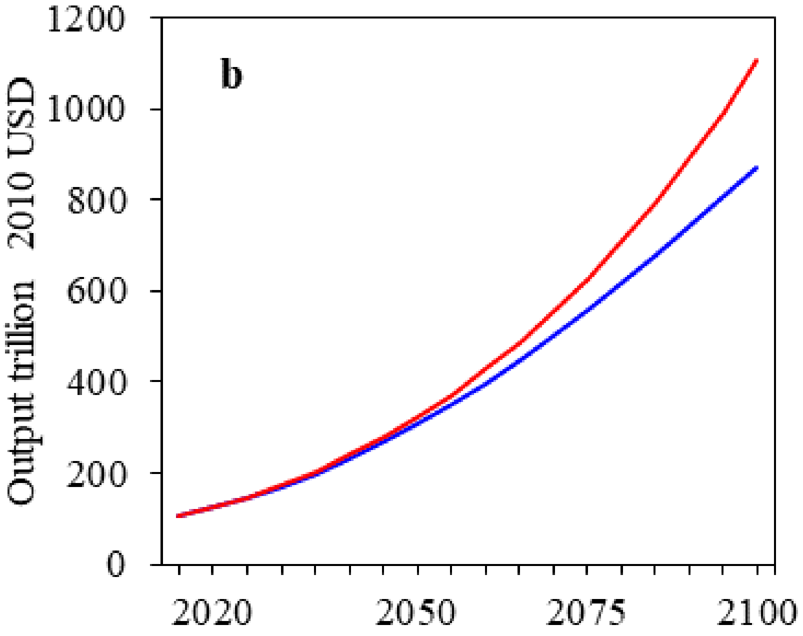
Policy Scenarios:

- BAU: No emission reduction policy is adopted to address climate change (μ=0)
- Opt: Optimal climate policies, which are chosen to maximize the welfare within the model from 2015 forward.
- T<2: 2°C temperature constraint scenario

CEEP-BIT

Results and Discussion:
The impact of climate change on two-sector economic structure





- Decreases the output ratio of capital goods to consumer goods (investment rate).
- Drives down the total output of the economy (two channel)

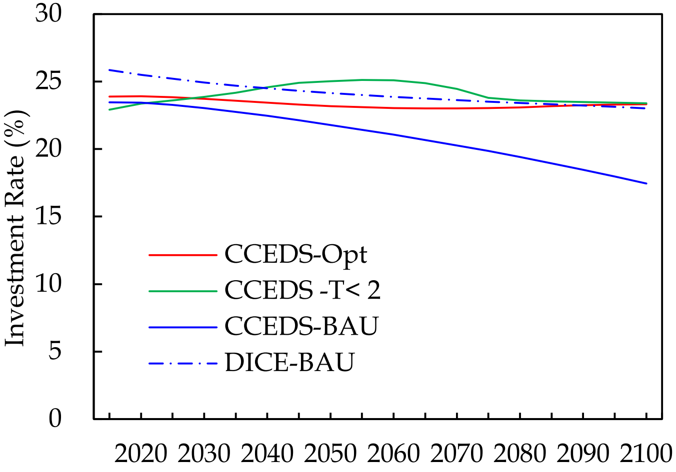
short-term consumption effect, long-term investment effect, heterogeneous carbon intensity effect and heterogeneous climate damage effect.

CEEP-BIT

The impact of economic structure on climate change and climate policy

Results in Economic System

Investment rate



Total output & consumption

		DICE					CCEDS				
Variable	**Scenario**	**2015**	**2020**	**2030**	**2050**	**2100**	**2015**	**2020**	**2030**	**2050**	**2100**
GDP	BAU	105.0	125.0	171.5	291.5	746.6	105.0	123.4	170.5	307.1	872.6
	Opt	105.0	125.0	171.7	292.6	764.5	105.0	123.6	171.6	313.4	1022.0
	T<2	105.0	123.3	167.2	276.2	773.7	105.0	121.6	166.3	296.1	1052.0
Consumption	BAU	77.9	93.1	128.7	221.1	574.8	80.4	93.4	126.1	217.7	584.4
	Opt	77.6	92.9	128.4	220.5	578.0	79.9	92.9	125.6	216.6	589.7
	T<2	77.7	91.8	124.3	206.4	585.0	80.9	92.3	122.2	201.4	603.4
		2015-2510					2015-2510				
Welfare Change	Opt	1.2%					3.1%				
	T<2	-0.9%					1.2%				

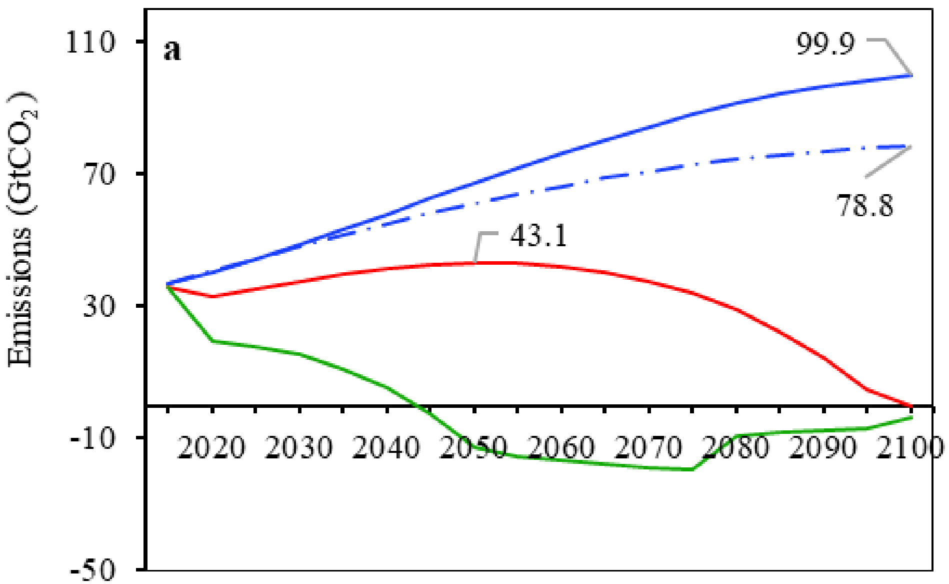
Unit: PPP, trillion 2010 USD

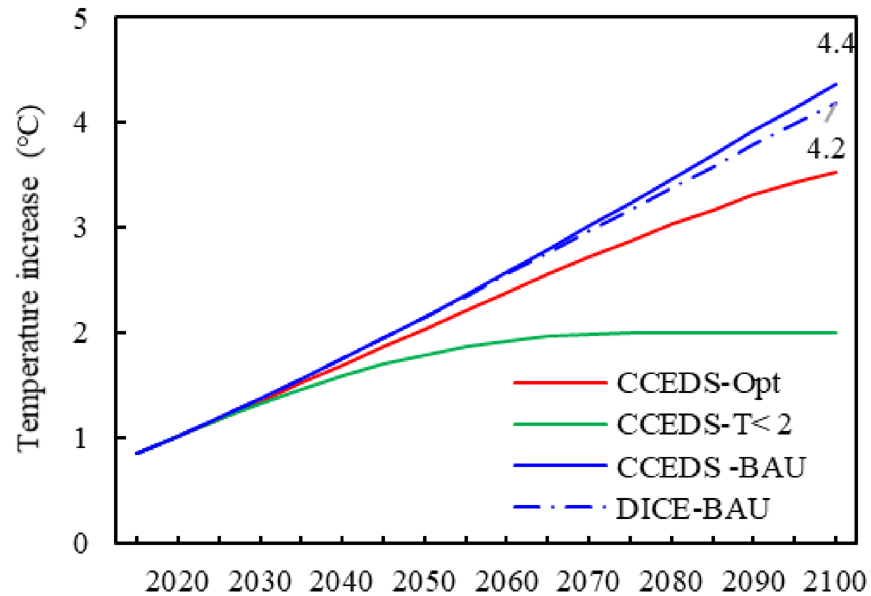
- Investment rate is quite sensitive to climate policies.
- Mitigation efforts are much more effective in alleviating economic loss.
- Mitigation efforts affect economic growth both directly, by reducing carbon emissions, and indirectly, by promoting investment

CEEP-BIT

Results and Discussion

Emissions and Temperature Trajectory





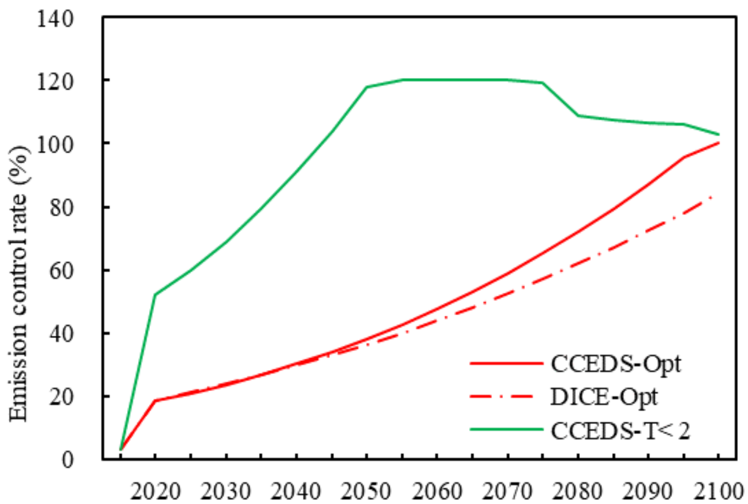
- More severe climate situation
- To limit global warming to below 2°C, net-zero emission is required by 2045, and need to rely heavily on negative emissions technologies.

CEEP-BIT

Results and Discussion

Abatement Efforts & Cost

Emission Control Rate



Abatement cost: DICE & CCEDS

		DICE					CCEDS				
Variables	Scenario	2015	2020	2030	2050	2100	2015	2020	2030	2050	2100
Abatement cost (Absolute value)	Opt	0.0	0.1	0.2	0.8	7.1	0.0	0.1	0.2	1.0	17.2
	T<2	0.0	1.8	4.1	17.5	12.4	0.0	1.5	3.7	19.5	18.8
Abatement cost (Relative value)	Opt	0.0%	0.1%	0.1%	0.3%	0.9%	0.0%	0.1%	0.1%	0.3%	1.7%
	T<2	0.0%	1.4%	2.5%	6.3%	1.6%	0.0%	1.3%	2.2%	6.6%	1.8%
Abatement cost ı consumer goods sector	Opt	-	-	-	-	-	61.4%	60.2%	57.7%	52.7%	40.1%
	T<2	-	-	-	-	-	62.7%	61.0%	57.7%	50.3%	39.9%

Unit： Absolute value: PPP, trillion 2010 USD
Relative value : proportion of GDP

To achieve 2℃ warming target, deeper efforts are called for:

- Our results ask for much deeper emission reductions compared with some existing research or aspirations.
- This demands investing an average of 3.5% of GDP per year from 2015-2100.

CEEP-BIT

Results and Discussion

Sensitivity Analysis

Parameter		Investment rate (BAU, 2100)	Output (BAU, 2100)	Emissions (BAU, 2100)	Reduction Rate (Opt, 2050)
$\lambda_1=\sigma_{i,0}/\sigma_{c,0}$ Heterogeneity of carbon intensity	-20%	17.8%	881.9	98.6	37.7%
	20%	17.2%	865.6	101.0	38.3%
$\lambda_2=g_{i,0}^{A}/g_{c,0}^{A}$ Heterogeneity of TFP progress	-20%	20.2%	780.5	86.3	37.0%
	20%	16.7%	879.6	104.3	38.7%
$\lambda_3=a_{2i}/a_{2c}$ Heterogeneity of climate damage	-20%	17.4%	874.1	99.9	38.1%
	20%	17.5%	871.1	99.9	38.1%
$\lambda_4=\alpha$ Heterogeneity of capital income share	-20%	18.2%	790.3	89.6	37.0%
	20%	15.4%	966.6	111.1	40.0%
CCEDS: $\lambda_1,\lambda_2,\lambda_3,\lambda_4$	0%	17.5%	872.6	99.9	38.1%
DICE		23.0%	746.6	78.8	36.3%

Main comparative results between DICE and CCEDS are not affected by changes in these parameters

CEEP-BIT

Summary

- Economic structure evolution affects the choice of policies for managing climate change
- Our Coupled Climate and Economic Dynamics model with Endogenous Structure indicates:
  - ◆Investment rate is sensitive to climate policy, which will be determined not only by the normal intertemporal trade-off between present-day and future consumption, but also by another trade-off between high- and low carbon-intensity goods.
  - ◆Mitigation efforts can become more effective for the economy both by reducing carbon emissions and by changing future investment incentives.
  - ◆We are likely to face a more severe climate situation; therefore, deeper mitigation efforts are called for, negative emissions technologies are highly demand.
- Future work: incorporating uncertainty into CCEDS

CEEP-BIT

Main Reference

Boppart, Timo. (2014) Structural change and the Kaldor facts in a growth model with relative price effects and non- Gorman preferences. ***Econometrica*** 82, 2167-2196

Chenery, H. B., Taylor, L. (1968) Development patterns: among countries and over time. ***Review of Economics and Statistics***, 391-416.

Herrendorf, B., Rogerson, R., Valentinyi, Á. (2020) Structural change in investment and consumption—A unified analysis. ***Review of Economic Studies*** 88, 1311-1346.

Herrendorf, B., Rogerson, R., Valentinyi, K. (2014) Growth and structural transformation. ***Handbook of Economic Growth*** 2, 855-941.

Martinich, J., Crimmins, A. (2019) Climate damages and adaptation potential across diverse sectors of the United States. ***Nature Climate Change*** 9, 397-404.

Nordhaus, W.D. (2017) Revisiting the social cost of carbon. Proceedings of the National Academy of ***Sciences*** 114, 1518-1523

Stern, N., Stiglitz, J.(2022) The economics of immense risk, urgent action and radical change: towards new approaches to the economics of climate change. ***Journal of Economic Methodology,*** *1-36.*

Thanks for your attention!

Comments welcome!