PUBLIC FINANCE RESILIENCE IN THE TRANSITION TOWARDS CARBON NEUTRALITY

Modelling policy instruments
in a global net zero emissions scenario

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INTEGRATING CLIMATE AND ECONOMIC RESILIENCE

OECD
BETTER POLICIES FOR BETTER LIVES

Horizontal OECD project on climate and economic resilience

INTEGRATING CLIMATE AND ECONOMIC RESILIENCE

- Provides analysis and insights for governments looking at the whole climate picture:
  - driving a rapid and resilient transition to net-zero while building resilience to physical climate impacts

- This work contributes to the synthesis report “Net Zero+” already available

Motivation and research question

- Most countries have pledged to some form of carbon neutrality (“NZE”), necessitating a scaling up of climate change mitigation

- Different approaches to climate change mitigation coexist: carbon pricing, subsidies, tax exemptions, etc.

- Question on the sustainability of public finances
  - Non-climate related (e.g. COVID-19 aftermaths)
  - Several climate objectives (mitigation, sequestration, just transition)

How climate change mitigation policies impact public finances?

Existing litterature

- Most NZE papers use an IAM framework
  - AR6 Chapter III (Riahi et al., 2022) ; NGFS (Bertram et al., 2021), etc.
- Fiscal implications mostly analyzed using spreadsheet models
  - IMF (CPAT model)
  - UK, USA: partial equilibrium, or taxation models
- Scarce examples in CGE, especially to 2050
  - Several examples to 2030: IMF, JRC
  - 2050: Drummond et al. (2021) global, Ballingal (2018) NZL, Fujimori et al. (2021) JPN
  - No GE analysis on fiscal implications

Key contributions

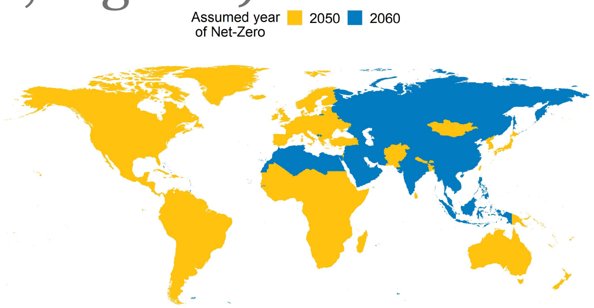
- A global pathway to 2050 compatible with the limitation to +1.5°C in a CGE model framework

- A policy mix with a broad range of instruments
  - carbon pricing
  - fossil fuel support removal
  - investment-related instruments (buildings, power generation, decarbonization of households energy)

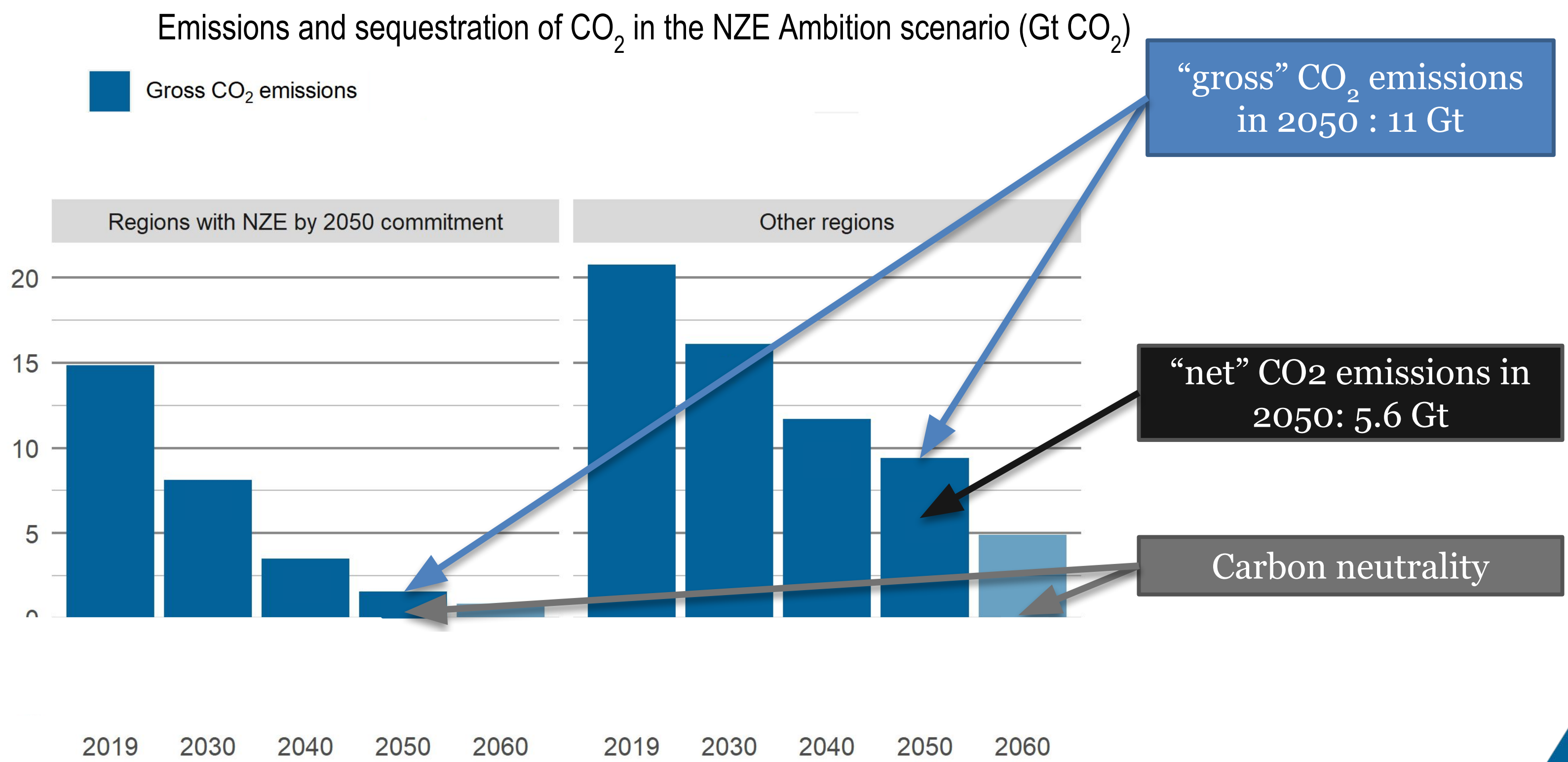
- Quantification of both direct and indirect effects on public finances

A CGE framework using ENV-Linkages

- A dynamic global Computable General Equilibrium (CGE) model (Chateau, Dellink and Lanzi, 2014)
- Scope :
  - Global: 26 regions, 37 sectors
  - CO_2 emissions (fuel combustion, process, fugitive)
  - 2050 horizon
- 2 Scenarios
  - Baseline : Legislated Policies
  - NZE Ambition : Carbon neutrality
    - in 2050 for regions where countries have such a pledge
    - in 2060 otherwise



Gross and net CO_2 emissions in the *NZE Ambition* scenario



Source: OECD ENV-Linkages model and IMAGE dataset (Van Vuuren et al., 2021).

Policy instruments in the NZE Ambition scenario (1/3)

Carbon pricing

Emission trading systems with full auctioning, all combustion and process CO2, all sectors except power generation

Fossil fuel support removal

Subsidies are reduced to 0 by 2030

Regulations in Power sector

Shift away from fossil fuels towards renewables and nuclear

Regulations to decarbonise buildings and transport

Electrification and energy efficiency improvements

Policies to stimulate firms' energy efficiency improvement

Small improvements, without specific costs

Subsidies to reduce and decarbonise household energy consumption

Electrification and energy efficiency improvements of households

Policy instruments in the NZE Ambition scenario (2/3)

- Price-based instruments are regular instruments in CGE models: carbon pricing and other taxes
- Challenges with regulations or incentives (subsidies):
  - Impact of an investment (e.g. EVs) on energy demand, but commodities only available at aggregate level (e.g. transport equipment)
  - Data needed to inform the CGE as a full endogenous response is hard to calibrate

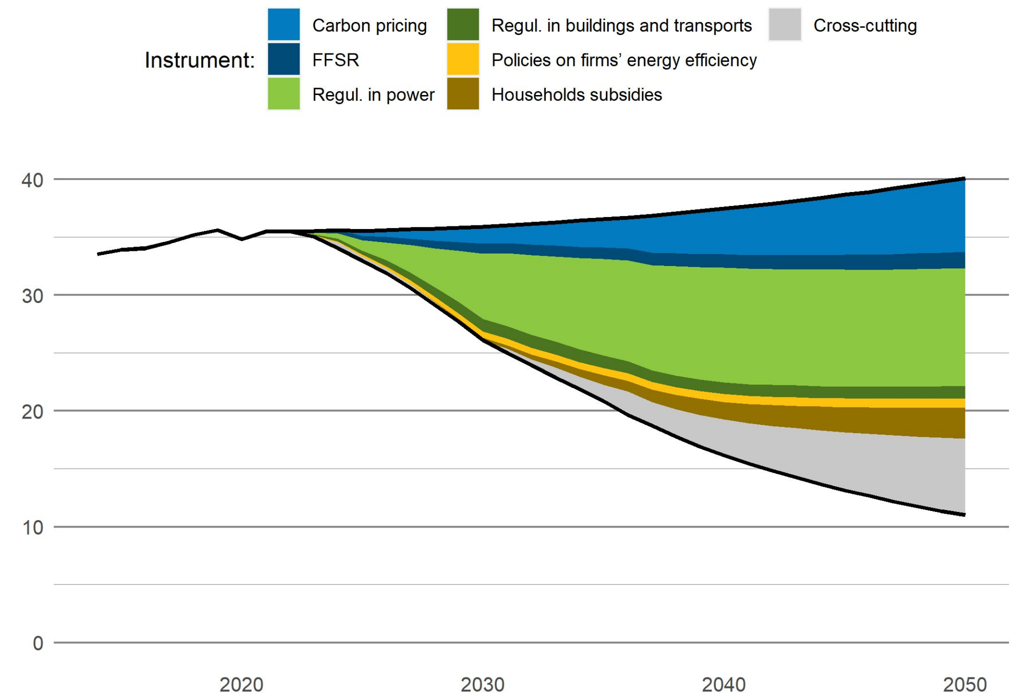
Policy instruments in the NZE Ambition scenario (3/3)

- A mixed complementarity problem (MCP) using soft-link with energy model (International Energy Agency, 2021)
  - Power generation mix, energy demand and investment
- Example of households subsidies (similar logic for regulations)
  - Electrification of road transport, buildings refurbishment
  - Related costs
    - Covers transport equipment (EV), construction and electric equipment
    - $paTax_{r,i,a,t}$: $paTax_{r,i,a,t} = paTax^{BAU}_{r,i,a,t} + paTax^{cost}_{r,i,a,t}$
    - $paTax^{cost}_{r,i,a,t}$: $xa_{r,i,a,t} \geq xa^{BAU}_{r,i,a,t} + Expenditure_{r,i,a,t} \quad \perp \quad paTax^{cost}_{r,i,a,t} \leq 0$

Not all policy instruments contribute equally to emission mitigation

- Varied policy mix
- Largest contributors:
  - Regulation in power generation
  - Carbon pricing
  - CCUS and other cross cutting

Contribution of the different policy instruments to *NZE Ambition* CO_2 emission mitigation (Mt CO_2)

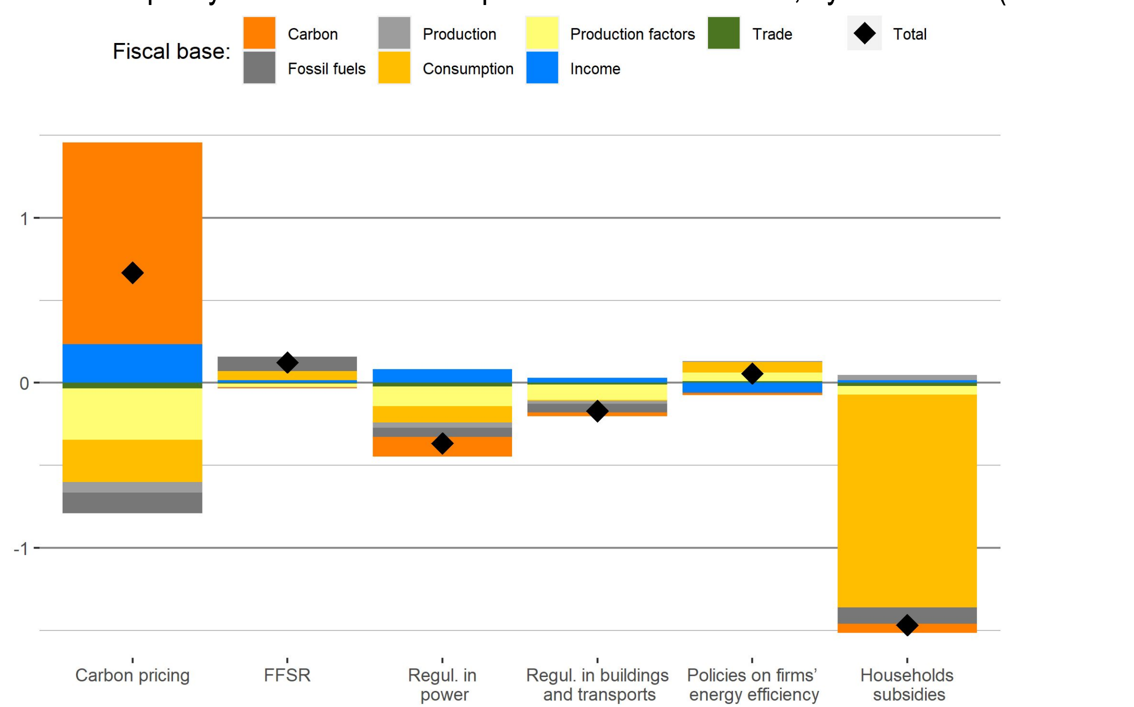


Source: OECD ENV-Linkages model.

Direct effect of market-based instruments entail the largest changes

- Largest effects:
  - revenues from carbon pricing
  - Expenditure on subsides
- All policies have significant indirect effects (on other tax bases)

Effect of individual policy instruments on net public revenues in 2050, by fiscal base (% of GDP)

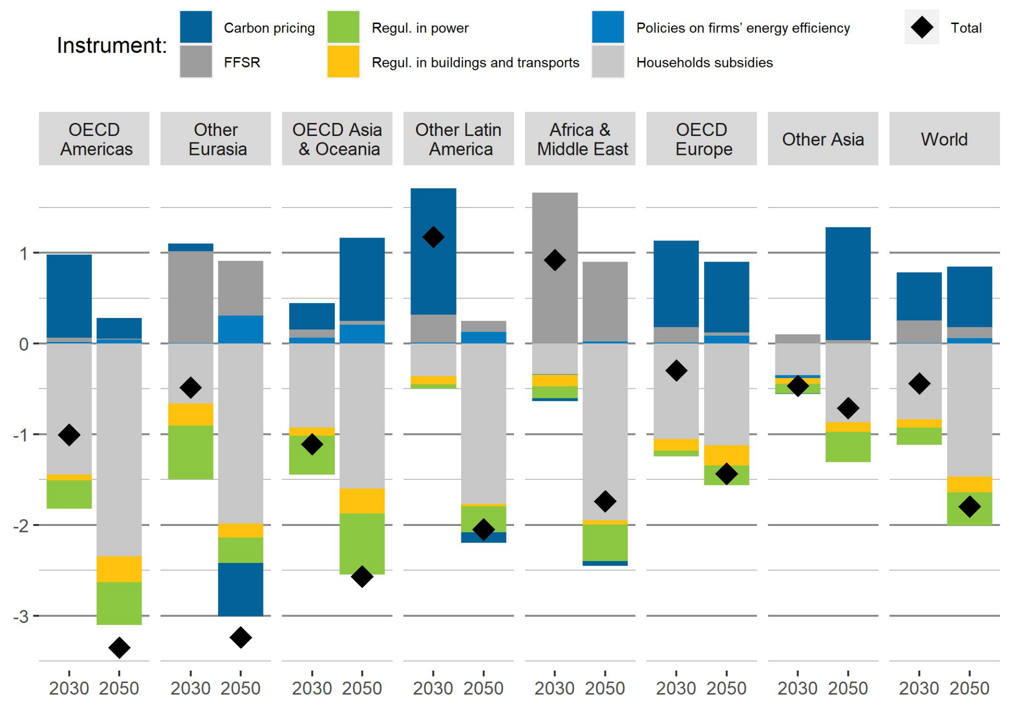


Source: OECD ENV-Linkages model.

Decreases in net public revenues vary over time and per region

- Large positive effect of FFSR in certain regions
- Overall, loss in 2050 between -0.7% and -3.4%

Changes in net public revenues in the *NZE Ambition scenario* compared to the *Baseline* in 2050 (% of *Baseline* GDP)



Source: OECD ENV-Linkages model.

Key take-aways

- Transition pathways to limit climate change to +1.5°C are available
- The transition is feasible with respect to its fiscal consequences, and maintains economic growth
- Fiscal effects reflect a trade-off between
  - Instruments that increase public revenues (carbon pricing) or reduce public expenditure (FFSR)
  - More costly instruments (subsidies)
  - Indirect effects on tax base erosion of all instruments

THANK YOU FOR YOUR ATTENTION

BETTER POLICIES FOR BETTER LIVES

SUPPLEMENTARY MATERIAL

Existing litterature

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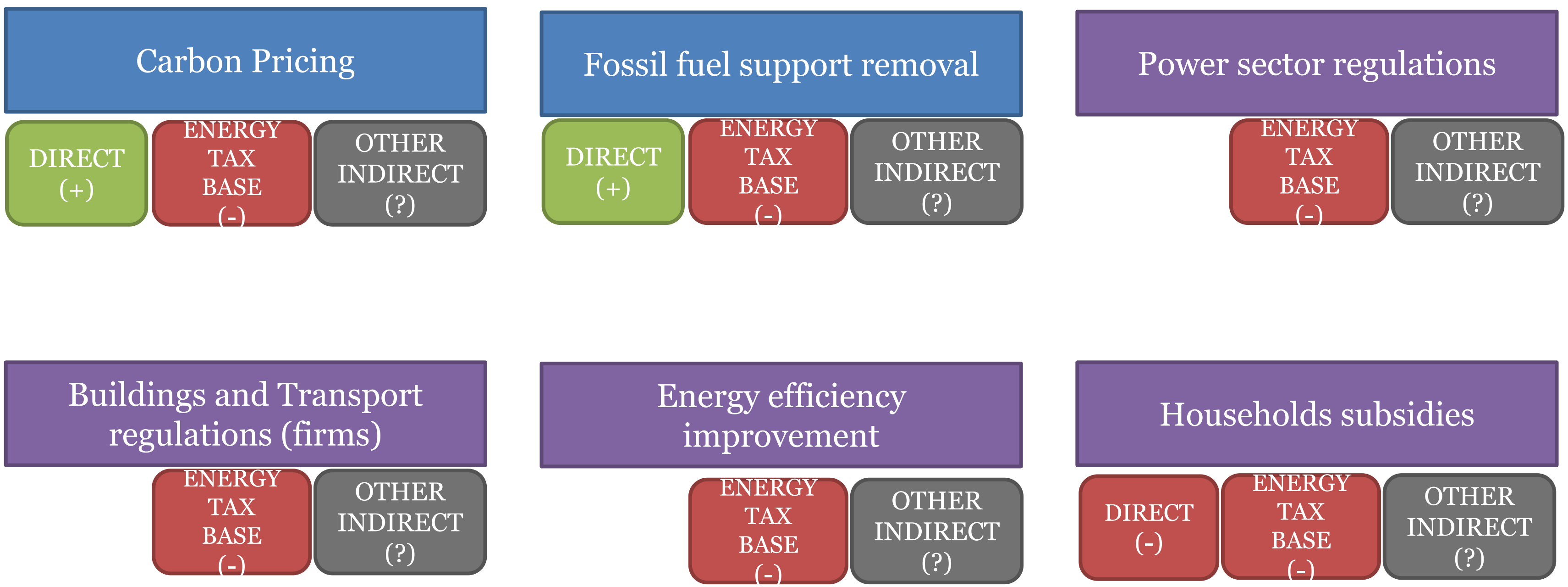
Six policy instruments with mixed fiscal impacts



Net public revenues as an indicator of the different pressures (+ or -) on public budgets: difference between tax revenues and subsidy expenditures

Defining carbon neutrality

- Carbon neutrality: **equilibrium between CO_2 emissions** ("gross" emissions) **and carbon sequestration** ("sinks"), resulting in "net" zero emissions
  - CO_2 only: consistent with IPCC 1.5°C report scope, includes emissions from fossil fuel combustion, as well as process and fugitive emissions
  - Sequestration : from Aforestation, forestry and other land use (AFOLU) and limited use of carbon capture and storage (CCS)

* Will be updated for the final report

The *NZE Ambition* emissions scenario

- In the *NZE Ambition* scenario, 3 types of regions **based on Dec. 2021 pledges*** (Climate Watch, 2021):
  - Regions with a carbon neutrality pledge in 2050: carbon neutrality achieved in 2050
  - Regions with a carbon neutrality pledge in 2060: reduction in 2050 on a path to achieve carbon neutrality in 2060
  - Other regions: Reduction in 2050 consistent with a joint achievement of carbon neutrality in 2060

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Regional emission targets ($GtCO_2$)

<table>
<tr><th>Region</th><th>2019 Emissions</th><th>2030 Emissions (NDC)</th><th>2050 Gross emissions</th><th>2050 Net emissions</th></tr>
<tr><td colspan="5">Regions with a stated NZE target in 2050</td></tr>
<tr><td>Australia and New Zealand</td><td>0.45</td><td>0.31</td><td>0.15</td><td>0</td></tr>
<tr><td>Brazil</td><td>0.43</td><td>0.22</td><td>0.33</td><td>0</td></tr>
<tr><td>Canada</td><td>0.63</td><td>0.41</td><td>0.17</td><td>0</td></tr>
<tr><td>Chile & Colombia</td><td>0.18</td><td>0.26</td><td>0.07</td><td>0</td></tr>
<tr><td>Other Latin America</td><td>0.67</td><td>-</td><td>0.52</td><td>0</td></tr>
<tr><td>European Union</td><td>3.21</td><td rowspan="3">2.6</td><td rowspan="3">1.21</td><td rowspan="3">0</td></tr>
<tr><td>Other OECD Europe</td><td>0.55</td></tr>
<tr><td>UK</td><td>0.41</td></tr>
<tr><td>Japan</td><td>1.15</td><td>0.98</td><td>0.24</td><td>0</td></tr>
<tr><td>Korea</td><td>0.59</td><td>0.51</td><td>0.13</td><td>0</td></tr>
<tr><td>Mexico</td><td>0.50</td><td>-</td><td>0.19</td><td>0</td></tr>
<tr><td>Other Africa</td><td>0.35</td><td>-</td><td>0.73</td><td>0</td></tr>
<tr><td>South Africa</td><td>0.50</td><td>0.61</td><td>0.12</td><td>0</td></tr>
<tr><td>United States</td><td>5.58</td><td>2.97</td><td>1.01</td><td>0</td></tr>
<tr><td>Other Asia</td><td>0.72</td><td>-</td><td>0.26</td><td>0</td></tr>
</table>

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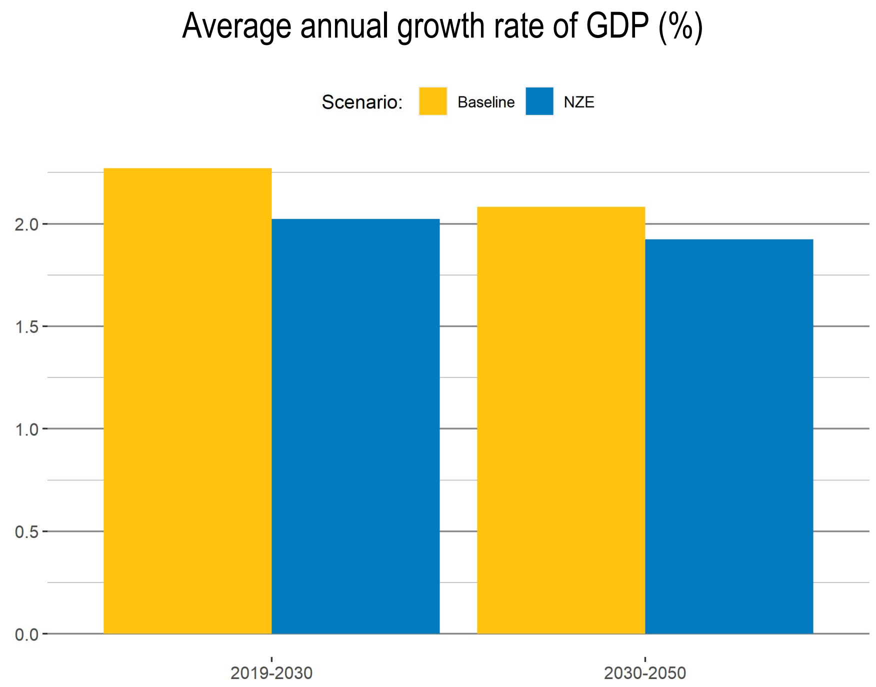
<tr><td colspan="5">Regions with a stated NZE target in 2060</td></tr>
<tr><td>China</td><td>11.3</td><td>13.41</td><td>4.54</td><td>2.45</td></tr>
<tr><td>Indonesia</td><td>0.54</td><td>-</td><td>0.78</td><td>0.03</td></tr>
<tr><td colspan="5">Regions with an assumed joint NZE target in 2060</td></tr>
<tr><td>Middle East</td><td>2.08</td><td>-</td><td rowspan="7">6.59</td><td rowspan="7">3.11</td></tr>
<tr><td>India</td><td>2.75</td><td>4.59</td></tr>
<tr><td>North Africa</td><td>0.58</td><td>-</td></tr>
<tr><td>Russia</td><td>1.62</td><td>1.80</td></tr>
<tr><td>Caspian</td><td>0.56</td><td>-</td></tr>
<tr><td>Other Southeast Asia</td><td>1.18</td><td>-</td></tr>
<tr><td>Other Europe</td><td>0.37</td><td>-</td></tr>
<tr><td>World</td><td>36.9</td><td></td><td>17.0</td><td>5.6</td></tr>
</table>

Source: Own computations based on Climate Watch (2020) for 2030, and sequestration in 2050 based on IMAGE dataset (Stehfest et al., 2014; IMAGE team, 2022) and IEA (2021).

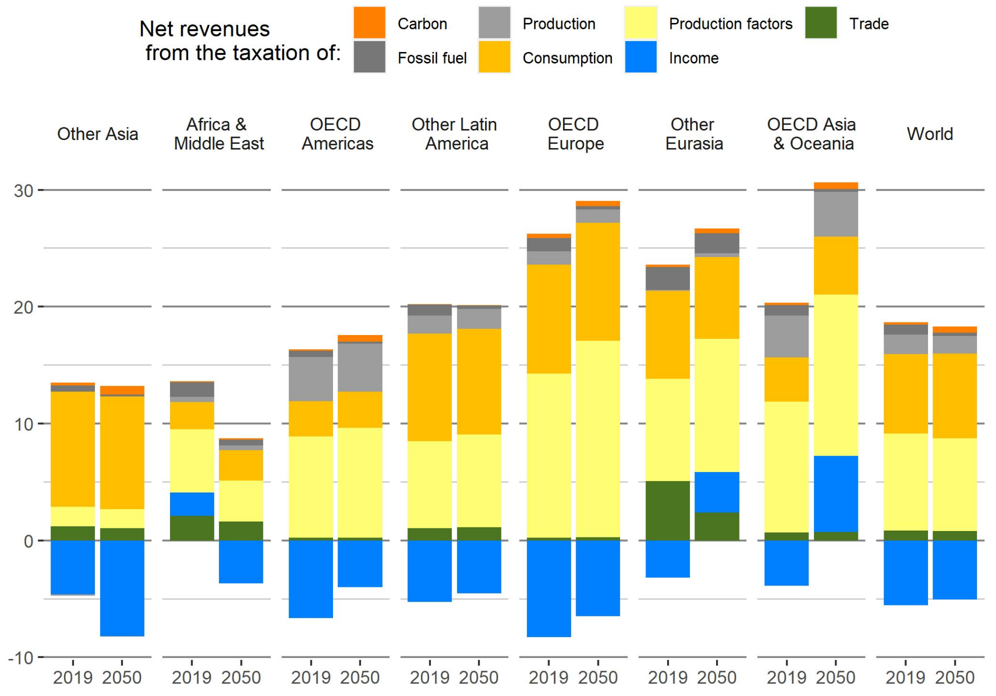
Growth of the global economy gradually declines after 2030



Source: OECD ENV-Linkages model.

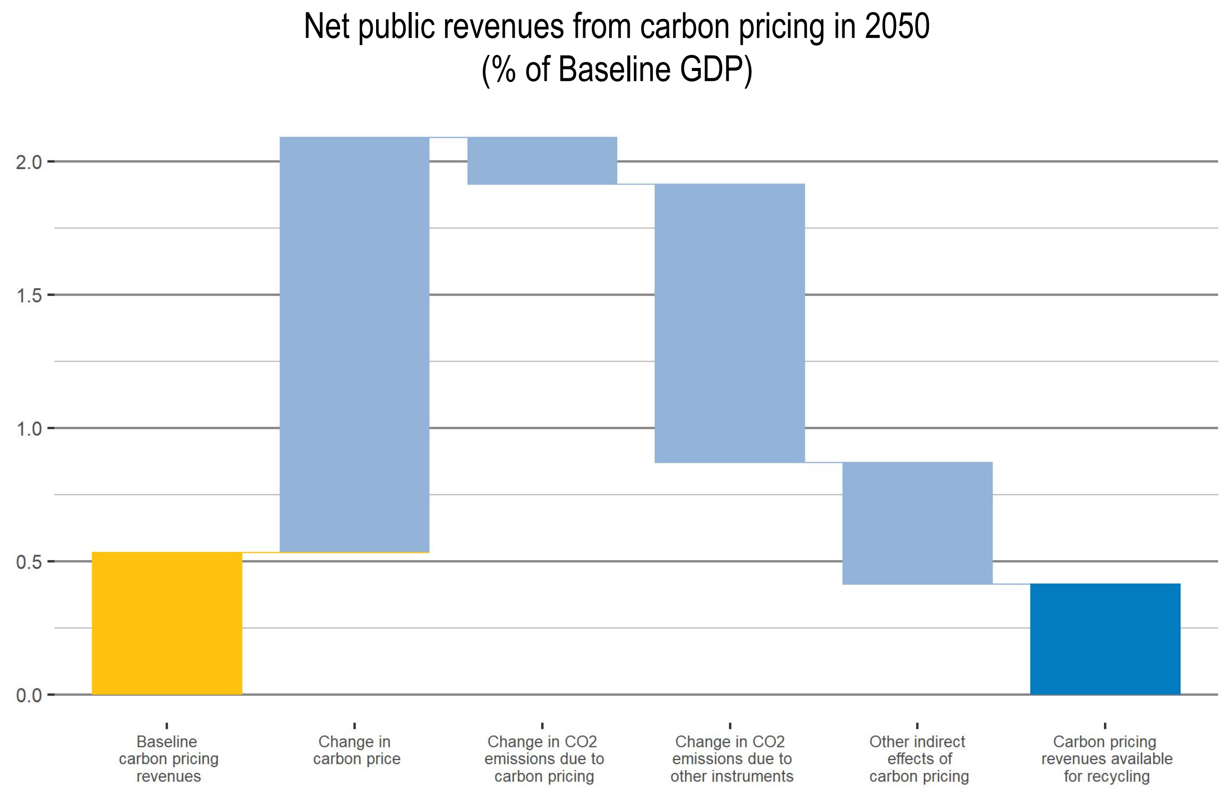
Net public revenues in the Baseline scenario

Net public revenues in the *Baseline* scenario in 2019 and 2050, by fiscal base (% of GDP)



Source: OECD ENV-Linkages model.

Direct and indirect effects of carbon pricing



Source: OECD ENV-Linkages model.

Fiscal Rules and Green Investment in developing countries

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October 11, 2023

Introduction

- Budgetary drift and debt crises have revealed the importance of financial institutions in the execution of fiscal policy

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- In the 1990s, following the economic and financial crises, the issue of fiscal rules became one of the major concerns of international financial institutions
- Green Investment is an important resource for financing development and fight against climate change

Motivations

- Analyzing the link between fiscal rules and Green Investment in developing countries

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- Analyzing the link between fiscal rules and Green Investment in developing countries
- Identify the factors that allow the increase of Green Investment
- Propose economic policy implications for increasing Green Investment in developing countries

Research question

- How does adopting fiscal rules affect Green Investment in developing countries?

Literature review

- The first stream demonstrates the importance of fiscal rules (Debrun et Kumar, 2007 ; Debrun, 2007 ; Debrun et al., 2008 ; Debrun et al., 2009 ; Rose, 2006 ; Kumar et Ter-Minassian, 2007 ; Beetsma et al., 2018 ; Combes et al., 2021) and Green Investment (GI) (Eyraud et al. (2013); Cottarelli (2020))

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- The link between fiscal policy and GI (Eyraud et al., 2011 ; Eyraud et al., 2013 ; Cottarelli, 2020 ; Regling, 2022 ; Barabanov et al., 2021 ; Jaraite et al., 2014 ; Darvas et Anderson, 2020 ; Darvas et Wolff, 2021 ; Mathieu et al., 2022°).

Contributions

- Analyze the causal effect of the adoption of fiscal rules on Green Investment in developing countries

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Assumptions

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- Assumption 2: The ability of different types of rules to attract more Green Investment

Data

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- Fiscal rules data are from the International Monetary Fund (IMF) Fiscal Rules Dataset
- Green Investment data are from the Organisation for Economic Co-operation and Development (OECD)
- The institutional data comes from the International Country Risk Guide (ICRG) database

The measurement of Fiscal Rules and GI

- In this study, fiscal rules are measured by a binary variable that takes the value 1 if the country has adopted a fiscal rule and 0 otherwise.

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- The Green Investment data in this study represent the ratio of inward Green Investment to GDP

Identification strategy

- In this study, the causal effect is analyzed through the entropy balancing method (Hainmueller, 2012; Hainmueller et Xu, 2013).

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- The model developed in this study is based on the work of Badinger et Reuter (2017)
- We use the propensity score matching (PSM) method of Rosenbaum et Rubin (1983), the IPW method, the GMM estimator, and the Mahalanobis distance balancing method to test the robustness of our results

Identification strategy

$$ATT = E[(Yi1Yi0)|FR = 1] = E[(Yi1|FR = 1)] - E[(Yi0|FR = 1)](1)$$

In equation(above), we replace E[Yi0 FR=1, Xi] with the term E[Yi0 FR=0, Xi] and we obtain this equation :

ATT = E[(Y i1Y i0)|FR = 1] = E[Y i1FR = 1,Xi] − E[Y i0FR = 0,Xi] (2)

Results

TABLE 1 – Descriptive statistics

	(1)	(2)	3=(2-1)		
Variables	FR	Non-FR	Difference	t value	p-value
finclimat	0.665	0.371	-0.294	-4.3810	0.0000
lagfineclassi	6.377	7.086	0.709	3.0460	0.0024
laggrowth	4.0737	4.691	0.617	2.9113	0.0037
lagggdy	45.547	53.818	8.270	3.7344	0.0002
lagtradeindex	118.291	120.609	2.317	1.2007	0.2300
lagbureaucracy	1.8325	1.7200	-0.112	-2.6090	0.0092
Nomber of observations	416	603			

Results

TABLE 2 – Covariate balancing

	(1)	(2)	3=(2-1)		
Variables	FR	Non-FR	Difference	t value	p-value
finclimat	0.455	0.454	-0.001	-0.002	0.999
lagfinclassi	6.404	6.483	0.079	-0.323	0.747
laggrowth	4.451	4.495	0.044	-0.178	0.859
lagggdy	41.21	42.82	1.61	-0.992	0.322
lagtradeindex	120.7	120.4	-0.3	0.100	0.920
lagbureaucracy	1.775	1.763	-0.012	0.266	0.790
Nomber of observations	416	603			

Results

TABLE 3 – Entropy balancing : Baseline model

	1	2	3	4	5	6	7	8
	Baseline	Adding Year	Adding Country	Adding Year/Country	Adding controls	Adding controls/Year	Adding controls/Country	Adding controls/Year/Country
VARIABLES	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp
rule	0.078*	0.059	0.045***	0.031**	0.064	0.045	0.049***	0.038**
	(0.047)	(0.046)	(0.014)	(0.014)	(0.045)	(0.046)	(0.014)	(0.015)
lfine$_{c}lassi$					-0.023***	-0.024***	0.006*	0.010***
					(0.007)	(0.007)	(0.003)	(0.003)
lggdy					0.002	0.002	0.001	-0.0001
					(0.001)	(0.002)	(0.001)	(0.001)
lbureaucracy$_{i}crg$					-0.353***	-0.349***	0.082**	0.066**
					(0.060)	(0.060)	(0.041)	(0.032)
lgrowth					-0.010	-0.007	-0.001	0.003
					(0.006)	(0.006)	(0.002)	(0.002)
lterm$_{a}di$					-0.001	-0.001**	-0.0001	0.0002
					(0.000)	(0.000)	(0.0002)	(0.0002)
Constant	0.377***	0.239***	0.134***	0.122***	1.186***	1.114***	-0.031	-0.093
	(0.027)	(0.044)	(0.017)	(0.021)	(0.130)	(0.147)	(0.118)	(0.099)
Observations	1,019	1,019	1,019	1,019	1,019	1,019	1,019	1,019
R-squared	0.003	0.025	0.946	0.960	0.188	0.207	0.947	0.960
Country FE	No	No	Yes	No	No	No	Yes	Yes
Year	No	Yes	No	No	No	Yes	No	Yes

Notes : In this table, we use the entropy balancing method. The treatment variable indicates 1 if the country has adopted at least one fiscal rule and 0 otherwise. The dependent variable is the ratio of inward green investment to GDP. ***p<0.001, **p<0.01, *p<0.05. Standard errors in parentheses.

Results

TABLE 4 – Robutness checks : Entropy balancing : Types of fiscal rules

	1	2	3	4	5
Variables	Reg1	Reg2	Reg3	Reg4	Reg5
rule	0.038**				
	(0.0151)				
bbr		0.030**			
		(0.0137)			
dr			0.027*		
			(0.0153)		
er				0.003	
				(0.0219)	
rr					1.805***
					(0.0993)
N	1019	1019	1019	1019	1019
r2	.9603	.9603	.9603	.9602	.9602

Robustness check

TABLE 5 – Robutness : Fixed effect

	1	2	3	4	5	6	7	8	9	10	11
VARIABLES	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp
rule	0.066**	0.066**	0.066**	0.066**	0.084**	0.066**	0.071**	0.067**	0.064**	0.069**	0.065**
	(0.031)	(0.031)	(0.031)	(0.031)	(0.032)	(0.031)	(0.031)	(0.031)	(0.031)	(0.030)	(0.031)
fisc_lassi	0.011**	0.012**	0.012**	0.011**	0.017**	0.011**	0.011**	0.011**	0.011**	0.011**	0.010**
	(0.005)	(0.005)	(0.005)	(0.005)	(0.007)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)	(0.005)
ggdy	-0.001	-0.001	-0.001	-0.001	-0.002*	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
bureaucracy_crg	0.032	0.032	0.033	0.032	-0.028	0.033	0.037	0.035	0.029	0.033	0.066
	(0.062)	(0.061)	(0.062)	(0.062)	(0.081)	(0.061)	(0.061)	(0.061)	(0.062)	(0.060)	(0.052)
growth	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
term_edi	-0.0001	-0.0001	-0.0001	-0.0001	0.0001	-0.0001	-0.0001	-0.0001	-0.0001	0.0001	-0.0001
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
socio_crg		0.004									
		(0.008)									
corruption_crg			0.003								
			(0.013)								
stability_crg				-0.002							
				(0.007)							
credit					0.001						
					(0.001)						
iconflicts_crg						-0.002					
						(0.007)					
econflicts_crg							-0.018*				
							(0.009)				
democracy_crg								-0.014			
								(0.009)			
fby									-0.002		
									(0.002)		
fdi										0.002	
										(0.001)	
polity_wid											-0.001
											(0.002)
Constant	0.184	0.170	0.173	0.209	0.241	0.196	0.358**	0.232	0.190	0.173	0.148
	(0.157)	(0.156)	(0.173)	(0.204)	(0.194)	(0.184)	(0.174)	(0.156)	(0.157)	(0.156)	(0.147)
Observations	1,006	1,006	1,006	1,006	841	1,006	1,006	1,006	1,003	1,005	998
R-squared	0.318	0.318	0.318	0.318	0.332	0.318	0.321	0.320	0.316	0.321	0.320
Number of idcoun	68	68	68	68	68	68	68	68	68	68	68
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes : In this table, we use the fixed effect model. The treatment variable indicates 1 if the country has adopted at least one fiscal rule and 0 otherwise. The dependent variable is the ratio of inward green investment to GDP.

Robustness check: GMM

TABLE 6 – Robutness : GMM

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
VARIABLES	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp
L.finclimatgdp	0.222***	0.221***	0.226***	0.222***	0.222***	0.219***	0.222***	0.223***	0.221***	0.223***	0.210***	0.222***	0.223***	0.222***	0.223***	0.224***
	(0.030)	(0.031)	(0.029)	(0.030)	(0.031)	(0.031)	(0.030)	(0.030)	(0.030)	(0.030)	(0.031)	(0.030)	(0.030)	(0.031)	(0.030)	(0.031)
rule	0.083**	0.081**	0.091***	0.080**	0.085**	0.076**	0.081**	0.081**	0.080**	0.083**	0.081**	0.081**	0.081**	0.089**	0.075**	0.077**
	(0.035)	(0.035)	(0.034)	(0.035)	(0.037)	(0.035)	(0.035)	(0.035)	(0.035)	(0.035)	(0.035)	(0.035)	(0.035)	(0.036)	(0.036)	(0.035)
fine_lassi	0.012***	0.013***	0.011***	0.013***	0.014***	0.012***	0.012***	0.012***	0.012***	0.012***	0.013***	0.012***	0.013***	0.012***	0.012***	0.016***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)
ggdy	0.003***	0.003***	0.003***	0.003***	0.003***	0.003***	0.003***	0.003***	0.003***	0.003***	0.003***	0.003***	0.003***	0.003***	0.003***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
bureaucracy_cry	0.130	0.130	0.168**	0.135	0.113	0.134	0.138	0.138	0.129	0.130	0.137	0.135	0.138	0.135*	0.117	0.137
	(0.079)	(0.079)	(0.077)	(0.079)	(0.087)	(0.080)	(0.079)	(0.080)	(0.079)	(0.079)	(0.079)	(0.080)	(0.079)	(0.081)	(0.080)	(0.088)
growth	-0.003	-0.002	-0.002	-0.003	-0.003	-0.003	-0.003	-0.002	-0.003	-0.003	-0.003	-0.003	-0.000	-0.002	-0.003	-0.003
	(0.001)	(0.002)	(0.001)	(0.001)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.007)	(0.002)	(0.001)	(0.002)
term_di	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
fdi		-0.0003														
		(0.001)														
rola			0.007***													
			(0.002)													
corruption_cry				0.024												
				(0.019)												
lcrg_ag					0.178											
					(0.289)											
stability_cry						-0.006										
						(0.006)										
socio_cry							0.005									
							(0.014)									
oil								-0.0004								
								(0.003)								
iconflicts_cry									-0.005							
									(0.010)							
econflicts_cry										0.001						
										(0.014)						
remit											0.004					
											(0.004)					
hard_t												0.023				
												(0.084)				
gdpgr													-0.002			
													(0.007)			
kaopen														0.035*		
														(0.021)		
gdppc															0.0003	
															(0.0002)	
inflation																-0.0001
																(0.001)
Constant	-0.118	-0.115	-0.322	-0.159	-0.159	-0.063	-0.136	-0.118	-0.063	-0.130	-0.150	-0.112	-0.119	-0.113	-0.133	-0.138
	(0.145)	(0.146)	(0.144)	(0.149)	(0.176)	(0.163)	(0.154)	(0.146)	(0.175)	(0.213)	(0.148)	(0.146)	(0.146)	(0.147)	(0.147)	(0.158)
Observations	844	843	844	844	790	844	844	844	844	844	839	844	844	824	844	828
Number of idcoun	67	67	67	67	63	67	67	67	67	67	67	67	67	65	67	67

Notes : In this table, we use the GMM estimator. The treatment variable indicates 1 if the country has adopted at least one fiscal rule and 0 otherwise. The dependent variable is the ratio of inward green investment to GDP.

Robustness check

TABLE 7 – Robustness : Additive controls

	1	2	3	4	5	6	7	8
	Reg0	Reg1	Reg2	Reg3	Reg4	Reg5	Reg6	Reg7
VARIABLES	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp
rule	0.038**	0.038**	0.037**	0.039**	0.034**	0.037**	0.039**	0.038**
	(0.015)	(0.015)	(0.015)	(0.016)	(0.017)	(0.015)	(0.015)	(0.015)
lfinc_lassi	0.010***	0.010***	0.010***	0.010***	0.011***	0.010***	0.010***	0.010***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.003)	(0.003)
lggdy	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
lbureaucracy_icrg	0.066**	0.069**	0.068**	0.066**	0.073**	0.065**	0.067**	0.066**
	(0.032)	(0.031)	(0.032)	(0.031)	(0.035)	(0.032)	(0.031)	(0.031)
lgrowth	0.003	-0.003	0.003	0.003	0.003	0.003	0.003	0.003
	(0.002)	(0.006)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
lterm_wdi	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
lexelec	-0.016							
	(0.013)							
lgdppcg		0.005						
		(0.006)						
lcorruption_icrg			0.013					
			(0.009)					
lconflicts_icrg				-0.003				
				(0.007)				
lpvr					0.001			
					(0.001)			
lremit						-0.001		
						(0.006)		
lsocio_icrg							0.005	
							(0.005)	
ldemocracy_icrg								0.002
								(0.006)
Constant	-0.091	-0.074	-0.129	-0.063	-0.151	-0.098	-0.103	-0.098
	(0.099)	(0.107)	(0.108)	(0.119)	(0.113)	(0.102)	(0.097)	(0.097)
Observations	1,019	1,019	1,019	1,019	977	1,006	1,019	1,019
R-squared	0.960	0.960	0.960	0.960	0.961	0.961	0.960	0.960
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes : In this table, we use the entropy balancing method. The treatment variable indicates 1 if the country has adopted at least one fiscal rule and 0 otherwise. The dependent variable is the ratio of inward green investment to

Robustness check

TABLE 8 – Robutness : Enforcement rule

	1	2	3	4	5	6	7	8
	Baseline	Adding Year	Adding Country	Adding Year/Country	Adding controls	Adding controls/Year	Adding controls/Country	Adding controls/Year/Country
VARIABLES	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp
enforcement	0.761***	0.741***	0.333***	0.296***	-0.158	-0.173	0.290***	0.334***
	(0.157)	(0.156)	(0.101)	(0.075)	(0.208)	(0.202)	(0.104)	(0.085)
lline_laxet					-0.024***	-0.025***	0.006*	0.010***
					(0.006)	(0.006)	(0.003)	(0.003)
lggdy					0.002	0.002	0.001	-0.000
					(0.001)	(0.001)	(0.001)	(0.001)
lbureaucracy_crg					-0.360***	-0.355***	0.075*	0.059*
					(0.065)	(0.064)	(0.041)	(0.031)
lgrowth					-0.011*	-0.007	-0.001	0.002
					(0.006)	(0.007)	(0.002)	(0.002)
lterm_di					-0.0001	-0.001**	-0.0001	0.0001
					(0.0002)	(0.0002)	(0.0003)	(0.0003)
Constant	0.372***	0.227***	0.134***	0.121***	1.250***	1.164***	-0.031	-0.091
	(0.028)	(0.041)	(0.017)	(0.021)	(0.144)	(0.157)	(0.117)	(0.098)
Observations	1,019	1,019	1,019	1,019	1,019	1,019	1,019	1,019
R-squared	0.018	0.040	0.946	0.960	0.186	0.207	0.947	0.961
Country FE	No	No	Yes	Yes	No	No	Yes	Yes
Years	No	Yes	No	Yes	No	Yes	No	Yes

Notes : In this table, we use the entropy balancing method. The treatment variable indicates 1 if the country has adopted the enforcement rule and 0 otherwise. The dependent variable is the ratio of inward green investment to GDP. ***p<0.001, **p<0.01, *p<0.05. Standard errors are in parentheses.

Robustness check

TABLE 9 – Robutness : Flexibility rule

	1	2	3	4	5	6	7	8
	Baseline	Adding Year	Adding Country	Adding Year/Country	Adding controls	Adding controls/Year	Adding controls/Country	Adding controls/Year/Country
VARIABLES	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp
flexibility	0.170***	0.154***	0.039***	0.037	0.113*	0.095	0.040***	0.035**
	(0.060)	(0.059)	(0.015)	(0.017)	(0.062)	(0.062)	(0.015)	(0.017)
lfinc_laxm					-0.020**	-0.021***	0.006*	0.010***
					(0.008)	(0.008)	(0.003)	(0.003)
lggdy					0.002	0.002	0.001	-0.0001
					(0.001)	(0.001)	(0.001)	(0.001)
lbureaucracy_crg					-0.356***	-0.351***	0.081*	0.065**
					(0.060)	(0.060)	(0.041)	(0.032)
lgrowth					-0.010	-0.006	-0.001	0.002
					(0.006)	(0.007)	(0.002)	(0.002)
lterm_di					-0.001	-0.001**	-0.0001	0.0001
					(0.0002)	(0.0002)	(0.0002)	(0.0002)
Constant	0.361***	0.228***	0.134***	0.121***	1.178***	1.103***	-0.031	-0.095
	(0.021)	(0.044)	(0.017)	(0.021)	(0.125)	(0.143)	(0.118)	(0.099)
Observations	1,019	1,019	1,019	1,019	1,019	1,019	1,019	1,019
R squared	0.013	0.034	0.946	0.960	0.191	0.210	0.947	0.960
Country FE	No	No	Yes	Yes	No	No	Yes	Yes
Years	No	Yes	No	Yes	No	Yes	No	Yes

Notes : In this table, we use the entropy balancing method. The treatment variable indicates 1 if the country has adopted the flexibility rule and 0 otherwise. The dependent variable is the ratio of inward green investment to GDP. ***p<0.001, **p<0.01, *p<0.05. Standard errors are in parentheses.

Robustness check

TABLE 10 – Robutness : Legal basis rule

	1	2	3	4	5	6	7	8
	Baseline	Adding Year	Adding Country	Adding Year/Country	Adding controls	Adding controls/Year	Adding controls/Country	Adding controls/Year/Country
VARIABLES	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp
legal_axis2	0.091*	0.068	0.028**	0.025*	0.038	0.015	0.032**	0.031**
	(0.050)	(0.048)	(0.013)	(0.013)	(0.042)	(0.042)	(0.013)	(0.015)
lfine_lassi					-0.023***	-0.024***	0.006*	0.010***
					(0.007)	(0.007)	(0.003)	(0.003)
lggdy					0.002	0.002	0.001	-0.0001
					(0.001)	(0.001)	(0.001)	(0.001)
lbureaucracy_crg					-0.352***	-0.348***	0.081*	0.065**
					(0.059)	(0.059)	(0.041)	(0.031)
lgrowth					-0.010	-0.006	-0.001	0.003
					(0.006)	(0.007)	(0.003)	(0.003)
lterm_di					-0.001	-0.001**	-0.0001	0.0001
					(0.000)	(0.0001)	(0.0002)	(0.0002)
Constant	0.377***	0.243***	0.134***	0.122***	1.207***	1.132***	-0.027	-0.089
	(0.035)	(0.043)	(0.017)	(0.021)	(0.138)	(0.145)	(0.118)	(0.099)
Observations	1,019	1,019	1,019	1,019	1,019	1,019	1,019	1,019
R-squared	0.004	0.035	0.946	0.960	0.186	0.206	0.947	0.960
Country FE	No	No	Yes	Yes	No	No	Yes	Yes
Years	No	Yes	No	Yes	No	Yes	No	Yes

Notes : In this table, we use the entropy balancing method. The treatment variable indicates 1 if the country has adopted the legal basis rule and 0 otherwise. The dependent variable is the ratio of inward green investment to GDP. ***p<0.001, **p<0.01, *p<0.05. Standard errors are in parentheses.

Robustness check

TABLE 11 – Robutness : Strength of fiscal rules

	1	2	3	4	5	6	7	8
	Baseline	Adding Year	Adding Country	Adding Year/Country	Adding controls	Adding controls/Year	Adding controls/Country	Adding controls/Year/Country
rule2	0.212***	0.090***	0.188***	0.061**	0.097**	0.089***	0.068*	0.067***
	(0.0556)	(0.0272)	(0.0503)	(0.0241)	(0.0471)	(0.0236)	(0.0405)	(0.0228)
N	1019	1019	1019	1019	1019	1019	1019	1019
r2	.0207	.9528	.0409	.9637	.216	.9537	.2421	.9651
Country FE	No	No	Yes	Yes	No	No	Yes	Yes
Years	No	Yes	No	Yes	No	Yes	No	Yes

Notes : In this table, we use the entropy balancing method. The treatment variable indicates the strength of fiscal rules. The dependent variable is the ratio of inward green investment to GDP. ***p<0.001, **p<0.01, *p<0.05. Standard errors are in parentheses.

Robustness check

TABLE 12 – Robustness : Alternative

	1	2	3	4	5	6	7
VARIABLES	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp	finclimatgdp
rule	0.040***	0.035**	0.038**	0.038**	0.038**	0.038**	0.036***
	(0.015)	(0.016)	(0.015)	(0.015)	(0.015)	(0.015)	(0.010)
lfine$_{c}lassi$	0.010**	0.008**	0.010***	0.010***	0.010***	0.010***	0.000
	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.001)
lggdy	-0.000	0.001	-0.0004	-0.0003	-0.0006	-0.0008	0.001***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
lbureaucracy$_{i}crg$	0.075**	0.077**	0.066**	0.066**	0.066**	0.066**	0.063***
	(0.033)	(0.033)	(0.032)	(0.032)	(0.032)	(0.032)	(0.015)
lgrowth	0.003*	0.004*	0.003	0.003	0.003	0.003	-0.0004
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)
lterm$_{w}di$	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0003
	(0.0002)	(0.0002)	(0.0004)	(0.0005)	(0.0003)	(0.0002)	(0.0001)
Constant	-0.112	-0.149	-0.093	-0.093	-0.093	-0.093	-0.210***
	(0.105)	(0.091)	(0.099)	(0.099)	(0.099)	(0.099)	(0.036)
Observations	987	889	1,019	1,019	1,019	1,019	223
R-squared	0.962	0.960	0.960	0.960	0.960	0.960	0.975
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes : In this table, we use the entropy balancing method. The treatment variable indicates 1 if the country has adopted the fiscal rule and 0 otherwise. The dependent variable is the ratio of inward green investment to GDP. ***p<0.001, **p<0.01, *p<0.05. Standard errors are in parentheses.

Robustness check

TABLE 13 – Robustness : Mahalanobis distance matching

ATT : FR and GI

	1	2	3	4	5	6	7
	Mahalanobis1	Mahalanobis2	Mahalanobis3	Mahalanobis4	Mahalanobis5	Mahalanobis6	Mahalanobis7
rule2	0.3127***	0.2810***	0.3203***	0.3404***	0.3618***	0.3028***	0.2943***
	(0.0484)	(0.0705)	(0.0528)	(0.0541)	(0.0450)	(0.0490)	(0.0554)
N	1019	866	1019	1015	996	1019	1019

Notes : In this table, we use the Mahalanobis distance matching method. The treatment variable indicates the strength of fiscal rules. The dependent variable is the ratio of inward green investment to GDP. ***p<0.001, **p<0.01, *p<0.05. Standard errors are in parentheses.

Heterogeneity

TABLE 14 – Heterogeneity

VARIABLES	1 finclimatgdp	2 finclimatgdp	3 finclimatgdp
rule	0.027*	0.083***	0.028*
	(0.016)	(0.022)	(0.016)
FR$_g rowth$	0.108**		
	(0.050)		
growth	-0.004**		
	(0.002)		
lfine$_c lassi$	0.009***	0.010***	0.012***
	(0.003)	(0.003)	(0.004)
lggdy	0.0002	-0.0002	-0.0002
	(0.001)	(0.001)	(0.001)
lbureaucracy$_i crg$	0.058*	0.072**	0.061**
	(0.032)	(0.032)	(0.029)
lgrowth	0.003*	0.002	0.003
	(0.002)	(0.002)	(0.002)
lterm$_w di$	0.0004	0.0004	0.0004
	(0.0002)	(0.0002)	(0.0002)
FR$_r ents$		-0.060***	
		(0.020)	
rents		0.002	
		(0.003)	
FR$_i crg_q og$			0.052*
			(0.030)
icrg$_q og$			0.332***
			(0.121)
Constant	-0.069	-0.147	-0.236*
	(0.099)	(0.138)	(0.123)
Observations	1,019	1,019	956

Validation of transmission channels

Variables	Growth	Hard-it	Fiscal balance	Primary balance	Sovereign debt	GDP per capital	Regime
Before FR adoption	4.349698	.133	-1.770138	.0187243	10.12991	2.471264	.1736909
During FR	3.525141	.3181818	-2.788337	-.7821559	10.59572	1.98096	.349345
Control group	4.609513	.1662859	-1.262876	0.3303537	10.52494	2.581666	.2195666

Conclusion

- Adoption of fiscal rules helps increase Green Investment in developing countries

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- Adoption of fiscal rules helps increase Green Investment in developing countries
- Economic performance, primary balance, fiscal balance, inflation targeting, sovereign debt rating, and fixed exchange rate regime as the main factors through which fiscal rules affect climate-friendly investments (GI)
- To better deepen the reflection on the effects of fiscal rules on Green Investment, it is helpful to explore the possibilities of a study on the severity of the rules in developing countries. Also, it is desirable to extend the reflection on the neighborhood effects of fiscal rules.

Economic Policy Implications

- it is desirable that countries consider the challenges of climate change in developing economic policies. Implementing social programs is paramount as these programs provide immediate responses and help build resilience to the effects of climate change rapidly

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Economic Policy Implications

- it is desirable that countries consider the challenges of climate change in developing economic policies. Implementing social programs is paramount as these programs provide immediate responses and help build resilience to the effects of climate change rapidly
- It is also essential for developing countries to put in place a green initiative
- It is also recommended that countries that have not yet adopted fiscal rules put in place on inflation and budget deficit to reassure investors on the management of fiscal policy and thus quickly mobilize resources to fight against the effects of climate change.

Economic Policy Implications

- In order to stimulate green investments, it helps developing countries lower the cost of borrowing through a program to strengthen the credibility of economic agents. This will allow individual economic agents to borrow easily from the financial market and banking institutions to finance their green transition.

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Self-enforcing climate coalitions with farsighted countries: integrated analysis of heterogeneous countries

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CEC
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Our Research Question

- We model the negotiations of countries to form self-enforcing climate coalitions to reduce emissions.
  - Signatories commit to maximising payoffs of all coalition members when choosing their emission reduction levels.
  - Non-signatories maximise their individual payoff
- Countries/ policymakers are farsighted: rationally predict the overall coalition structure
- We allow for heterogeneity across countries and a dynamic game.
- Our goal is to bring together two strands of literature: standard IAM and Coalition Formation Theory

Our Contribution

- We offer a simple algorithm to **fully characterise** the equilibrium number of climate coalitions and their number of signatories and **closed form** solutions for the equilibrium strategies and payoffs.
- Our main result:

  If $\beta \to 1$, for any number of countries N, a grand coalition occurs in equilibrium if N is an element of

$$\mathcal{T}^* = \{1, 2, 4, 7, 13, 24, 44, 79, 146, 268, ...\}$$

- **So how do we find the equilibrium numerical coalition structure?**
  - if $N \in \mathcal{T}^*$, then $\pi^* = \{N\}$
  - if $N \notin \mathcal{T}^*$, then $\pi^* = D(N)$

Our Contribution

Example

If $N = 195$, there will be **4** coalitions with the following sizes $\pi^* = \{146, 44, 4, 1\}$.

- Under certain conditions, the problem of coalition formation of heterogeneous countries can be decoupled: number coalitions and number of signatories
- The policy message:
  - allow multiple climate coalitions
  - large coalitions can be stable: no small coalition paradox
  - efficiency loss might not be that high even when the grand coalition is not stable

Literature Review

- **Coalition Formation: two strands of literature**
  - **Cooperative Game Theory**: Which transfer scheme or bargaining rule allows sustaining the grand coaltion?
    - solution concepts: Core, Sharpley Value, Nash Bargaining Solution, Stable Set
    - binding agreements without the question of how to reach such an agreement
    - Scarf(1971), Tulkens(1979), Chandler/Tulkens(1991,1992) and many others
  - **Noncooperative Game Theory:** Which coalition structure can be sustained as an equilibrium for a given transfer scheme or bargaining rule?
    - solution concept: internal-external stability (cartel stability)
    - non binding agreements hence negotiations are a noncooperative process
    - small coalition paradox $m^* \leq 3$ unless some remedy is employed: Stackelberg and particular functions
    - Vast literature: Carraro/Siniscalco (1991,1993), Barrett (1991, 1992, 1994), Diamantoudi and Sartzetakis(2006)

Literature Review

- **Coalition Formation: two strands of literature**
  - Critical assumption about coalition formation: How do the rest of the countries/ coalitions react when a country/coalition deviates?
    - "conventional" cooperative game theory: the whole coalition structure collapses (depending on the particular concept,core)$\rightarrow$punishment not credible, hurts the punishers as well
    - noncooperative game theory: other coalitions do not react to a potential deviation other by adjusting their policies to the size of the remaining coalition
  - More Realistic Approach: **Farsightedness**
    - no a priory assumption about what the remaining coalitions will do
    - a coalition must predict the whole coalition structure: a deviation may trigger further deviations
    - Chatterjee et al. (1993); Chwe(1994); Bloch (1996); Ray and Vohra (1999), Farsightedness + public goods: Ray and Vohra (2001); Diamantoudi and Sartzetakis (2006, 2018); A De Zeeuw(2008)

- **IAMs**
  Nordhaus (1993); Nordhaus and Yang (1996); Nordhaus (2014)
  Closed form solution: Golosov et al. (2014); Hassler and Krusell (2012,); Van den Bremer and Van der Ploeg (2021)
- **Climate coalitions + IAMs**
  Cartel Stability and Numerical Approach: Lessmann et al.(2009, 2015); Bosetti et al (2013)
- **What we do:**

  We combine Ray and Vohra (2001) and a **multi-country** simplified version of Golosov et al. (2014). Our model

  - is dynamic: infinite horizon climate model (game) after the coalition formation stage
  - incorporates heterogeneous countries (players)

Setup

- N countries, each country is indicated by i and $I = \{1, 2, ..., N\}$
- Time is discrete and infinite, $t = 0, 1, 2, ...$
- Each country has a planner who is player in a coalition formation game(climate negotiations): he makes proposals to coalitions and respond to proposals made to him following a negotiation protocol (to be defined)
- The planner can implement any desired policy in the decentralized economy e.g using taxes.

Timing of the game

Two-stage climate coalition formation

- Beginning of period t: membership stage
- From period t onwards : action(compliance) stage (no renegotiation-irreversible agreements)
  - cooperative decision on emissions reduction (SCC) within each coalition
  - but cross-coalition interaction is non-cooperative
  - country-level decisions on the implementation of the agreed policies (taxation)
- At the end of each period t, emissions are observed and payoffs are realised
- Solve by **backwards induction**: we start with the action stage and move to the membership stage

- consumers derive utility from the consumption of the final good where $\beta \in (0, 1)$ is the discount factor: $\sum_{t=0}^{\infty} \beta^t ln(C_{it})$
- **Energy sector:** $R_{it+1} = R_{it} - E_{it}$ (1)
- **Final output:** $Y_{it} = exp(-\gamma T_t) A_i K_{it}^{1-\nu} E_{it}^{\nu}$

  where R_{it} is the stock of fossil fuel, E_{it} is energy use(**and emissions)**, Y_{it} is final output, K_{it} is capital stock, T_t is global temperature, γ is the damage coefficient, A_i is TFP, ν is output elasticity of energy
- countries are **heterogeneous** with respect to K_{i0}, R_{i0}, A_i
- full capital depreciation and no trade
- Market clearing: fossil fuel eq.(1) and final good

$$C_{it} + K_{it+1} = Y_{it}$$

The Economy

Climate Dynamics (Allen et al.(2009),Matthews et al. (2009))

- **global temperature(change):**

$$T_t = T_0 + \xi S_t$$

where T_0 is the pre-industrial temperature, S_t is the stock of cumulative emissions of CO_2 and ξ is the transient climate response

- **cumulative emissions:**

$$S_t = S_0 + \sum_{i=1}^{N} \sum_{s=0}^{t} E_{it-s}$$

where S_0 is the pre-industrial stock of cum. emissions.

- Dynamic Game between different coalitions (also singletons): coalitions act non cooperatively against other coalitions (and cooperatively within)
- Strategies of country $i \in M$:

  $\{E_{it}(M, \Pi), C_{it}(M, \Pi), K_{it+1}(M, \Pi), R_{it+1}(M, \Pi)\}$ from $t = 0$ to infinity given a coalition structure Π to be explained later
- Pure strategy Markov Perfect equilibrium
  $\rightarrow$ **current state**: the formed coalitions (if any); identity (and number) of those negotiating (if any); proposal (if ongoing or signed); S_t; K_{it} and R_{it}.
- once signed, agreements are binding and irreversible: no point in history dependent strategies/punishments

The problem of the planner of country i in a coalition M with m members is to maximise

$$\sum_{i \in M} \sum_{t=0}^{\infty} lnC_{it}$$

subject to the resource and feasibility constraints.

- the planner chooses the optimal level of emissions taking into account the effect her emissions on **other countries**
- **but** chooses C_{it}, K_{it+1} independently
- the FOC's give us the following results

Two-Stage climate coalition formation

Second Stage: action stage

Proposition1

- $C_{it}(M,\Pi) = (1-s)Y_{it}(M,\Pi)$ and $K_{it+1}(M,\Pi) = sY_{it}(M,\Pi)$
- optimal emissions of $i \in M$

$$E_{it}(m) = \nu/[\mu_{it}(1-s) + \hat{\Lambda}(m)]$$

where s is the savings rate, μ_{it} is the per unit scarcity rent and $\hat{\Lambda} = \frac{\xi\gamma m}{1-\beta}$ is the per-unit "SCC".

- emission strategies are dominant against what other coalitions choose
- SCC depends **only** on exogenous parameters and the size of the coalition FOC
- optimal emissions can differ among members of the same coalition but the SCC is the **same** for all: this is what coalitions negotiate for

Some Preliminaries

We assume:

- Open membership: no clubs, any country is allowed to negotiate its membership and no country is forced in
- Costless to sign
- Binding: once signed, there is no compliance issue in the action stage
- Irreversible: once signed, countries cannot renegotiate their membership
- No delay equilibria: countries make acceptable offers
- Farsightedness

Some Preliminaries

- **Coalition structure** is a partition of set I into coalitions,
$$\Pi = \{M_1, M_2, ..., M_k\}$$
- **Numerical coalition structure**, $\pi = \{m_1, m_2, ..., m_k\}$
- m is the number of signatories of M
- Coalition formation as a non-cooperative bargaining game
- Coalitions are formed sequentially following an exogenous **negotiation protocol**: Deterministic order of the initial proposers (P) and respondents (R) + unanimity rule + first rejector is the next P
- Strategy of P is a proposal: identity of members of M + emission reduct. plan(or SCC) + payoffs of members of M
- Strategy of R: accept or reject

- Farsightedness: countries are required to rationally predict the entire coalition structure when considering a deviation, no a priori assumption about the coalitions' behaviour- far more realistic!
  - internal-external stability(cartel stability): upon deviation, the rest of the coalitions remain intact
  - core stability: upon deviation, the rest of the coalitions disintegrate
- the equilibrium coalition structure Π^* is immune to unilateral and multilateral deviations by the deviating group and all the active players in the negotiation room
- So how do we find Π^* ?

- So how do we find Π^* ?
- Second stage of the game (action stage): **Optimal Value function** of $i \in M$ is $V_i(S_t, K_{it}R_{it}, M, \Pi) \rightarrow$ a country considers a coalition M with the purpose of maximizing its value function value function
- the value function depends not only on the coalition M but also on the whole coalition structure in which M is going to be embedded: external effects of other coalitions **and** farsightedness
- The equilibrium Π^* can be found recursively:
  - if $N = 2$, then $\Pi^*=$?, if $N = 3$, then $\Pi^* =$? ....
  - each stage of the recursion informs the next one
- Extra demanding with heterogeneous countries but not in our case!

First Stage: Membership

Symmetric countries

Symmetric case: Two Simplifications

- $V_i(S_t, K_{it}, R_{it}, M, \Pi)$ simplifies to $V_i(S_t, K_{it}, R_{it}, \boldsymbol{m}, \boldsymbol{\pi})$: only the size and number of coalitions matters

  Important Assumption: We assume that countries are very patient, $\beta \to 1$

- **3 steps in the solution method**
  1. We check for which group of countries, a grand coalition forms in equilibrium $\to \mathcal{T}^*$ is the set of number of countries for which a grand coalition forms in equilibrium
  2. $D(N) = \{m_1, m_2, ..., m_k\}$ is a decomposition of N, such that m_k is the largest integer in $\mathcal{T}^*$ that is strictly smaller than N. Then any other element is the largest integer that is not greater than $N - \sum_{j=i+1}^{k} m_j$
  3. Ray and Vohra (1999,2001) show that under low bargaining frictions ($\sigma \to 1$), $D(N)$ coincides with the numerical equilibrium structure π^*

- **How do we construct $\mathcal{T}^*$?**
- It is easy to show that the first 2 elements of $\mathcal{T}^*$ are 1 and 2 so $\mathcal{T}^* = \{1, 2\}$ Example
- Next, we consider $N = 3$. $\pi = \{1, 1, 1\}$, $\{1, 2\}$, or $\{3\}$ forms in equilibrium?
  - we always have to check whether a country has an incentive to deviate from the grand coalition: Which possible coalitions do we actually have to check?
  - $D(3) = \{1, 2\} \rightarrow$ the only deviation we have to check
  - Why? Only the coalitions in the decomposition are farsighted stable.
  - $\lim_{\beta \rightarrow 1} V_i(\{1\}, \{1, 2\}) > V_i(\{3\}$ so for $N = 3$, $\pi^* = \{1, 2\}$: the grand coalition does not form and $\{3\} \notin \mathcal{T}^*$

- we do the same process for $N = 4$, $N = 5$, ... and check whether a grand coalition forms. If it forms, then we add N to T^*
- this can be very demanding. In our model, it turns out that there is an easy way to generate this set

Proposition 1

Let $D(N) = \{m_1, m_2, ..., m_k\}$ be the decomposition of N such that m_1 is the smallest element of $D(N)$. If $\beta \to 1$, a grand coalition forms in equilibrium if

$$\frac{N}{m_1} < e^{k-1}$$

- Using Proposition 1, we show that

  Corollary 1

  If $\beta \to 1$, for any number of countries N, a grand coalition occurs in equilibrium if N is an element of

$$\mathcal{T}^* = \{1, 2, 4, 7, 13, 24, 44, 79, 146, 268, ...\}$$

- **So how do we find the equilibrium numerical coalition structure?**
  - if $N \in \mathcal{T}^*$, then $\pi^* = \{N\}$
  - if $N \notin \mathcal{T}^*$, then $\pi^* = D(N)$

Our algorithm

$$\mathcal{T}^* = \{1, 2, 4, 7, 13, 24, 44, 79, 146, 268, ...\}$$

Example

If $N = 195$, there will be **4** coalitions with the following sizes $\pi^* = \{146, 44, 4, 1\}$.

- Cartel stability: $m^* = 3$
- Very different than the cartel stability predictions: average SCC is 120 times larger!
- Large coalitions are stable $\rightarrow$ efficiency losses might not be that high even when the grand coalition is not stable

- For $\beta \to 1$, any heterogeneity related to K_{i0}, A_{i0}, R_{i0} and μ_{it} vanishes!
- What does this imply?

  Decoupling result

  - algorithm for **symmetric countries** applies in the case of **asymmetric countries** too
  - focus on equilibrium numerical coalition structure but the identity of members is important for questions of **efficiency**

Efficiency

- When the grand coalition is not stable (fully efficient outcome), equilibrium payoffs and global temperature depend on identity of the proposer and the composition of countries across coalitions.
- For $0 < \beta < 1$, global emissions are lower when the high-emitting countries are in larger coalitions
- BUT, for $\beta \to 1$, the case for which we have established the equilibrium, global emissions become asymptotically independent of the identity of the coalitions members

Callibration

We generalise our model to include oil, coal and green energy sectors (Golosov Model) and we relax the assumption $\beta \to 1$

- solve the model numerically
  - for $\beta = 0.999^{10}$, T^* very similar to the analytical model
  - for $\beta = 0.985^{10}$, grand coalition occurs less often in equilibrium
  - robustness check for ξ: results change only for $\beta = 0.985^{10}$
  - robustness checks for K_0 and TFP: no change

Conclusions

- Capturing various aspects of climate negotiations: farsightedness + heterogeneity + economic growth + general equilibrium + climate dynamics
- Decoupling result: characterising Π^* independent of composition
- A simple algorithm to fully characterise Π^* in climate coalition + IAM
- Suggesting a more ambitious architecture for climate treaties

Action Stage

First-order conditions

- **Problem of a planner within coalition M (coalition level):**
  F.O.C w.r.t. E_{it}:

$$\frac{\nu Y_{it}}{E_{it}(m)} = \mu_{it} C_{it} + \hat{\Lambda}(m) Y_{it}$$

- **Problem of a planner within each country: (country level)**
  F.O.C w.r.t. C_{it} and K_{it+1}:

$$\frac{s_{it}}{1 - s_{it}} = \beta \frac{1}{1 - s_{it+1}} (1 - \nu)$$

$$\Rightarrow s_{it} = s = \beta(1 - \nu), \quad \text{for all } t \text{ and } i.$$

F.O.C w.r.t. R_{it+1}:

$$\mu_{it} = \beta \mu_{it+1}$$

back

Value function

$$V_i(S_t, K_{it}, \mu_{it}, M, \mathbb{M}) = ln(C_{it}(M, \mathbb{M})) + \beta ln(C_{it+1}(M, \mathbb{M})) + ...$$
$$= \frac{(1-\nu)ln(K_{it}) + H_1 + H_2 + H_3}{1-s}$$

where

$$H_1 \equiv \frac{sln(s) - sln(1-s) + ln(A_i) - \gamma T_0}{1-\beta}$$

$$H_2 \equiv -\gamma\xi[S_t + \beta S_{t+1} + \beta^2 S_{t+2} + ...]$$

and

$$H_3 \equiv \nu[ln(E_{it}(m)) + \beta ln(E_{it+1}(m)) + \beta^2 ln(E_{it+2}(m)) + ...]$$

back

Example: $N = 2$

For the case $N = 2$, the problem reduces to whether $\{1,1\}$ or $\{2\}$ forms. It can be shown that this depends on the sign of

$$\begin{aligned} & V_i(1,\{1,1\}) - V_i(\{2\}) = \\ & \frac{1}{1-\beta(1-\nu)}\left\{\nu\{ln\left(\frac{E_{it}(1)}{E_{it}(2)}\right) + \beta ln\left(\frac{E_{it+1}(1)}{E_{it+1}(2)}\right) + ...\}\right. \\ & \left. -\frac{2\gamma\xi}{1-\beta}\{[E_{it}(1) - E_{it}(2)] + \beta[E_{it+1}(1) - E_{it+1}(2)] + ...\}\right\} \end{aligned} \quad (1)$$

- the 2^{nd} line is the discounted infinite sum of a ratio of the benefit of emitting in a singleton coalition relative to the benefit of emitting in a grand coalition, and is positive.
- the 3^{rd} line is the discounted infinite sum of the losses resulting from the damages of emitting in a coalition structure of singleton relative to the damages of emitting in a grand coalition, and is negative.
- $\lim_{\beta\to 1}(V_i(1,\{1,1\}) - V_i(\{2\})) < 0$ so the grand coalition forms

back