Energy prices and growth: How to measure the costs of climate policies

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Climate policy

- Causes (unevenly distributed) economic **costs** and benefits, cf. inaction
- Global common action –> **international** negotiations
- Requires consideration of a **very long time horizon**
  - Greenhouse gas emissions cause economic damages only after a major time lag
  - But: myopic political decision making
- Includes various major **uncertainties**
  - Arrival and size of shocks
  - Policy recommendations often based on models with certainty

Costs of mitigation policies

- Depend on costs of
  - substituting fossil fuels
  - reducing energy input
  - CCS technologies
- Issues with energy
  - Level and growth effects
  - Time series and cross section analysis
  - Impact on investment
- CGE applications climate policy
  - Low growth countries
  - High growth countries

Energy and Growth

- Common belief: more is better
- 1973-74, 1978-80, 1989-90 and 2004-08: worldwide recessions after oil price jumps
- BUT: Cross sections of countries: (i) OECD countries, (ii) low energy use countries
- Exploitation of cross-country information seems indispensable; Durlauf et al. (2005), Hauk and Wacziarg (2009)

"Scarcity Paradox"

- (i) lower energy use leads to a reallocation of inputs toward capital accumulation and
- (ii) higher capital accumulation entails higher growth, which
- (iii) may be associated with higher welfare.
- Assuming positive externalities in capital accumulation (learning effects) and negative externalities of energy use (pollution of fossil fuels), (iii) is likely.

Related Theory

- Hicks (1932): "a change in the relative prices of the factors of production is itself a spur to invention"
- Böhm-Bawerk (1957): Purposeful use of capital to increase the productivity of other inputs –> "roundabout production."
- "Porter Hypothesis" (Porter 1991): stringent environmental regulation can be beneficial
- "Rybczynski theorem": a rise in the endowment of one factor will lead to a more than proportional expansion of the output in the sector which uses that factor intensively, and an absolute decline of the output of the other good.
- Peretto (2009): (higher) energy taxes increase welfare.

Time Series Econometrics

- Yuan et al. (2008), Lee and Chang (2008), Soytas and Sari (2007): positive impact of energy on growth
- number of observations
- key growth determinants display little time variation
- distinction between business cycles and growth effects (−> potential output, not the short- or medium-run deviations)
- Vector autoregressive regressions deal with *transitory* shocks, e.g. Kilian (2009), we are concerned with energy-driven *permanent* shifts in *long-run* growth rates
- Single substitution elasticities not useful, see Solow (1987)

First Empirical Evidence (37 OECD countries)

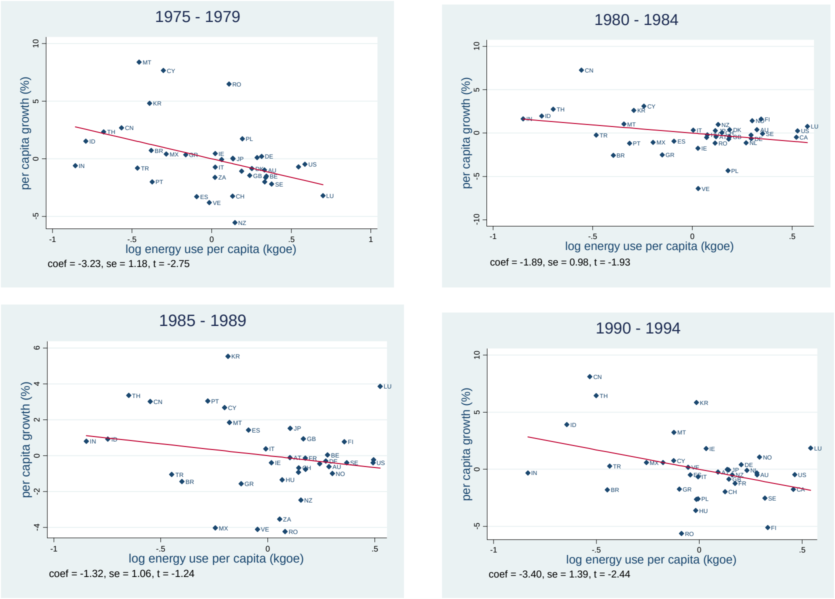
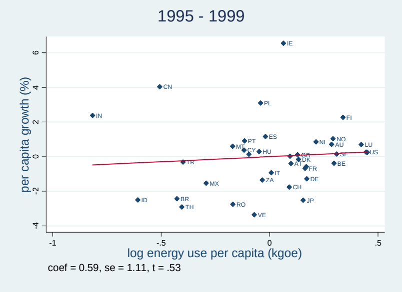
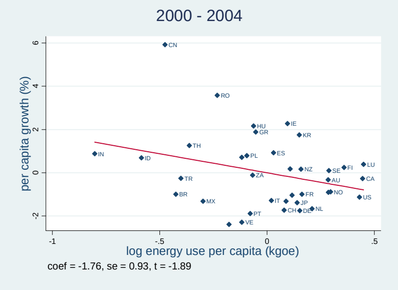
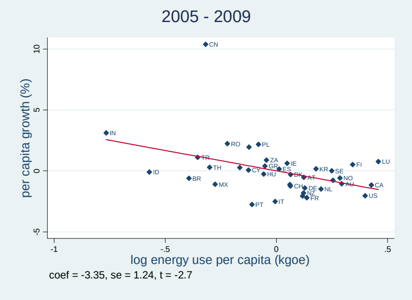


Figure 1: Per capita growth and log of energy per capita (OLS, 5 yr-av., ctry dummies)







Data source: WDI online (2012)

Figure1:Per capita growth and log of energy per capita (OLS,5yr-av.,ctrydummies)

Table 1: Investment and energy use in four selected countries 1975-2009

		investment rate	energy use per capita	energy use per GDP
USA	1975 - 1979	18.03	8,161.57	337.18
	1980 - 1984	18.19	7,498.28	287.87
	1985 - 1989	19.27	7,638.95	254.01
	1990 - 1994	18.31	7,689.49	238.33
	1995 - 1999	21.33	7,832.56	217.87
	2000 - 2004	22.13	7,876.77	195.67
	2005 - 2009	21.19	7,571.57	176.52
UK	1975 - 1979	15.24	3,678.52	218.50
	1980 - 1984	13.29	3,416.61	181.76
	1985 - 1989	16.13	3,607.41	163.97
	1990 - 1994	15.18	3,686.46	155.39
	1995 - 1999	16.16	3,787.17	141.04
	2000 - 2004	17.34	3,738.25	121.35
	2005 - 2009	17.24	3,468.40	104.39

Table 1: Investment and energy use in four selected countries 1975-2009

		investment rate	energy use per capita	energy use per GDP
	1975 - 1979	18.56	5,043.23	259.16
	1980 - 1984	16.87	5,000.68	241.26
	1985 - 1989	18.98	5,749.38	246.21
Sweden	1990 - 1994	17.33	5,505.82	230.78
	1995 - 1999	16.66	5,724.59	220.78
	2000 - 2004	17.47	5,669.23	187.58
	2005 - 2009	19.74	5,352.63	159.36
	1975 - 1979	37.08	576.16	1,322.68
	1980 - 1984	34.34	617.81	1,034.04
	1985 - 1989	38.27	694.16	732.82
China	1990 - 1994	37.34	776.58	580.54
	1995 - 1999	39.55	876.34	408.51
	2000 - 2004	40.50	978.60	310.22
	2005 - 2009	42.62	1,449.72	296.53

Growth Accounting

- Standard production function: final output Y, capital K, labor L, and energy E

$$Y(t) = F[K(t), L(t), E(t)]$$

- Growth rates

$$\hat{Y}(t) = \theta_{KY}\hat{K}(t) + \theta_{LY}\hat{L}(t) + \theta_{EY}\hat{E}(t)$$

- not based on optimizing behavior
- decomposition: ignores input supply conditions and causal relationships
- impact of energy on capital goods production: $\hat{K}$ in should be treated as an endogenous variable

Theoretical Framework

- Consumption goods

$$Y(t) = F(\cdot) = K(t)^{\alpha}\left[\phi L_Y(t)^{\frac{\sigma-1}{\sigma}} + (1-\phi)E_Y(t)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{(1-\alpha)\sigma}{\sigma-1}}, \tag{1}$$

- Capital accumulation

$$\dot{K}(t) = AB(t)I(t) = AB(t)L_K(t)^{\beta}E_K(t)^{1-\beta} \tag{2}$$

- Linear knowledge spillovers with diffusion intensity D

$$B(t) = D \cdot K(t), \quad \forall t \tag{3}$$

- Equilibria on primary input markets

$$L_Y(t) + L_K(t) = \bar{L} \tag{4}$$

$$E_Y(t) + E_K(t) = E. \tag{5}$$

Intertemporal Optimum

- Maximizing utility U

$$U(t) = \int_0^{+\infty} e^{-\rho t} \frac{C(t)^{1-\sigma_c}}{1-\sigma_c} dt$$

subject to the restrictions (1), (2), (4), (5) and

$$p_Y C(t) = p_Y Y(t) - p_E(t) E(t)$$

- The current-value Hamiltonian with the state variable K and the control variables C, L_Y, L_K, E_Y, E_K, and E reads

$$H = U(C) + \mu_Y \left[p_Y F(K, L_Y, E_Y) - p_Y C - p_E E \right] + \mu_K ADK \cdot I(L_K, E_K) + \mu_L (L - L_Y - L_K) + \mu_E (E - E_Y - E_K)$$

First-order conditions

$$
\begin{aligned}
H'(C) = 0 &\iff U'(C) = p_Y \mu_Y \\
H'(L_Y) = 0 &\iff \mu_Y p_Y F'(L_Y) = \mu_L \\
H'(L_K) = 0 &\iff \mu_K K I'(L_K) = \mu_L \\
H'(E_Y) = 0 &\iff \mu_Y p_Y F'(E_Y) = \mu_E \\
H'(E_K) = 0 &\iff \mu_K K I'(E_K) = \mu_E \\
H'(E) = 0 &\iff -\mu_Y p_E + \mu_E = 0 \\
H'(K) = \rho\mu_K - \dot{\mu}_K &\iff \mu_Y (p_Y F)'(K) + \mu_K I = \rho\mu_K - \dot{\mu}_K
\end{aligned}
$$

Steady state

- Constant sectoral allocation of inputs L and E
- Keynes-Ramsey rule

$$\hat{C} = \frac{ADI - \rho}{1 - \alpha(1 - \sigma_c)}$$

- Determinants of growth: close to familiar AK-models, especially Rebelo (1991)
- p_K decreases with knowledge spillovers, $\hat{p}_Y = \alpha \hat{p}_K < 0$ (multisector approach)
- Growth depends on investments I
  - Growth vs. level effects of energy
  - trade-off in energy use
  - permanent energy growth in one-sector model vs. shift in energy use in multisector approach

Energy impact

- If I was a single input: increasing input would cause higher growth
- Here: two inputs, two sectors; Rybczynski *effect* might be present
- Impact of (the percentage change of) energy prices $\hat{p}_E$ on (the percentage change of capital) growth $\hat{I}$

$$\hat{I} = \frac{1}{\lambda_{LK}} \left[(1 + \tilde{\theta}_E)(\lambda_{LY}\theta_{EY}(1 - \sigma) - \tilde{\theta}_E \right] \hat{p}_E$$

where $\tilde{\theta}_E > 0$

- higher energy prices are bad for growth when the elasticity of substitution between energy and labor in the Y-sector σ is larger than unity

Discussion

- Growth impact of energy ambiguous: Output vs. substitution effect in multisector model
- Low substitution elasticities and growth
  - in line with multi-sector simulation models
  - not in line with one-sector models in the tradition of Dasgupta and Heal (1974) and associated empirics (focus on capital demand)
  - including capital supply: reversed role of the substitution elasticities (Bretschger 1998)
- Bretschger and Smulders (2012): in models with multiple sectors, not the absolute value of the elasticities but the relative size matters for growth

Theoretical hypotheses

Nr.	Impact variables	Affected variables	Exp. sign
(i)	investment (shares)	(per capita) growth	$+$
(ii)	initial income	(per capita) growth	$-$
(iii)	energy use (per GDP)	investment (shares)	$+/-$
(iv)	income level	energy use	$+$
(v)	energy price	energy use	$-$

Estimation equations

$$\hat{\imath} = \epsilon_0 c_y + \epsilon_1 \ln s_P + \epsilon_2 \ln s_H + \epsilon_3 \ln s_B + \epsilon_4 \ln i_0 + \epsilon_5 \ln X + \xi_g$$

$$\begin{aligned}
\ln s_P &= \phi_{P0} \cdot c_P + \phi_{P1} \cdot \ln e + \phi_{P2} \cdot \ln Z_P + \xi_P \\
\ln s_H &= \phi_{H0} \cdot c_H + \phi_{H1} \cdot \ln e + \phi_{H2} \cdot \ln Z_H + \xi_H \\
\ln s_B &= \phi_{B0} \cdot c_B + \phi_{B1} \cdot \ln e + \phi_{B2} \cdot \ln Z_B + \xi_B,
\end{aligned}$$

$$\ln e = \zeta_0 \cdot c_e + \zeta_1 \cdot \ln i_0 + \zeta_2 \cdot \ln p_E + \zeta_3 \cdot \ln Q + \xi_E$$

Econometric issues

- Simultaneity: macroeconomic variables highly interdependent
- endogeneities: possible correlation with the disturbances in the empirical equation
- instrumental variables: difficult to identify valid instruments
- single structural equations or systems of equations: efficiency gains, provided that all the equations are properly specified.

Estimation strategy

- different estimation methods with different instrumentation strategies
- panel-corrected standard errors estimation
- fixed effects and random effect models: country-specific effects
- lagged levels of the series as instruments for lagged first differences: system GMM
- estimate the system consisting of equations jointly using three-stage least squares: take care of all possible cross-equation correlations
- sample of 37 developed countries (energy and carbon reduction policies)
- five-year average panel data over the period 1975-2009, price data less observations

Table 2: Estimation results, growth equation; different estimation techniques

Endogenous variable: Per capita growth

	(A)	(B)	(C)	(D)	(E)	(F)
growth	PCSE	RE	FE	SYS-GMM	SYS-GMM	SYS-GMM
logingdp	-0.0348***	-0.0353***	-0.0527***	-0.0391***	-0.0384***	-0.0392***
	(0.0112)	(0.00996)	(0.0185)	(0.00784)	(0.00790)	(0.00795)
logci	0.0741***	0.0785***	0.0978***	0.0725***	0.0734***	0.0738***
	(0.0163)	(0.0158)	(0.0224)	(0.0125)	(0.0126)	(0.0126)
logeduexp	-0.0198***	-0.0194	-0.0253	-0.0260***	-0.0308***	-0.0280**
	(0.00669)	(0.0126)	(0.0195)	(0.00991)	(0.0107)	(0.0112)
logrdshare	0.0233***	0.0257***	0.0337***	0.0227***	0.0226***	0.0214***
	(0.00471)	(0.00647)	(0.0125)	(0.00536)	(0.00538)	(0.00554)
logpop	-0.000737	0.000386	0.0272	-0.000986	-0.00114	0.000302
	(0.00248)	(0.00299)	(0.0371)	(0.00242)	(0.00243)	(0.00293)
popgro	-0.00213	-0.00334	-0.00563*	-0.00368*	-0.00332	-0.00306
	(0.00239)	(0.00218)	(0.00298)	(0.00208)	(0.00211)	(0.00213)
logopen	0.0299***	0.0363***	0.0618***	0.0292***	0.0286***	0.0285***
	(0.00806)	(0.00831)	(0.0175)	(0.00595)	(0.00600)	(0.00601)

Table 3: Estimation results for investment share; different estimation techniques

Endgenous variable: logci

	(G)	(H)	(I)	(K)	(L)	(M)
logci	IV-FE	IV-FE	IV-FE	PCSE	SYS-GMM	SYS-GMM
logenusegdp	-0.336***	-0.358***	-0.572***	-0.214***	-0.276***	-0.324***
	(0.0921)	(0.0965)	(0.148)	(0.0479)	(0.0547)	(0.0589)
logagedep	-0.0168	-0.0126	-0.0487	-0.141	-0.693***	-0.824***
	(0.124)	(0.126)	(0.137)	(0.102)	(0.101)	(0.118)
logpop	-0.399***	-0.419***	-0.344***	-0.291**	-0.0125	-0.0115
	(0.129)	(0.131)	(0.132)	(0.122)	(0.00876)	(0.00878)
loggovshare	0.0475	0.0717	0.358**	0.118	-0.0546	-0.0436
	(0.0912)	(0.0945)	(0.139)	(0.104)	(0.0474)	(0.0477)
goveff		-0.0543	-0.0719	-0.0457	0.0411***	0.0372***
		(0.0436)	(0.0458)	(0.0299)	(0.00733)	(0.00755)
logenimp		0.00302	-0.0106	-0.0209	-0.0270	-0.0308*
		(0.0271)	(0.0277)	(0.0171)	(0.0173)	(0.0175)
logstructure			-0.271***	-0.116***	-0.0752*	-0.0274
			(0.0797)	(0.0428)	(0.0451)	(0.0501)
L.logci					0.233***	0.230***

Table 4: Results for the simultaneous equation system

3 SLS; dependent variables: growth, logci, logeduexp, logrdshare, logenusegdp

	(N)	(O)	(P)	(Q)	(R)	(S)
growth						
logingdp	-0.0843***	-0.0849***	-0.0810***	-0.0830***	-0.0836***	-0.0839***
	(0.0154)	(0.0154)	(0.0154)	(0.0149)	(0.0152)	(0.0152)
logci	0.157**	0.150**	0.103*	0.121**	0.109**	0.111**
	(0.0644)	(0.0645)	(0.0608)	(0.0549)	(0.0550)	(0.0550)
logeduexp	0.0309	0.0242	0.00668	0.00955	0.0156	0.0165
	(0.0314)	(0.0315)	(0.0301)	(0.0293)	(0.0289)	(0.0290)
logrdshare	0.0499**	0.0505**	0.0496**	0.0519**	0.0501**	0.0503**
	(0.0220)	(0.0220)	(0.0221)	(0.0215)	(0.0234)	(0.0234)
logpop	0.0179	0.0185	0.00624	0.00909	0.00984	0.0113
	(0.0429)	(0.0429)	(0.0428)	(0.0424)	(0.0441)	(0.0441)
popgro	-0.00389	-0.00410	-0.00413	-0.00412	-0.00366	-0.00316
	(0.00282)	(0.00284)	(0.00285)	(0.00283)	(0.00282)	(0.00283)
logopen	0.0552***	0.0559***	0.0613***	0.0597***	0.0611***	0.0612***
	(0.0187)	(0.0187)	(0.0184)	(0.0177)	(0.0177)	(0.0177)

Table 4: Results for the simultaneous equation system

3 SLS; dependent variables: growth, logci, logeduexp, logrdshare, logenusegdp

	(N)	(O)	(P)	(Q)	(R)	(S)
logci						
logenusegdp	-0.253***	-0.289***	-0.292***	-0.268***	-0.280**	-0.241**
	(0.0888)	(0.0998)	(0.0997)	(0.0995)	(0.112)	(0.112)
logagedep	-0.144	-0.146	-0.130	-0.174	-0.131	-0.203
	(0.116)	(0.116)	(0.116)	(0.118)	(0.121)	(0.125)
logpop	-0.238*	-0.238*	-0.240*	-0.233*	-0.263**	-0.269**
	(0.126)	(0.126)	(0.126)	(0.126)	(0.128)	(0.127)
loggovshare		0.0588	0.0898	0.0670	0.136	0.136
		(0.0879)	(0.0891)	(0.0891)	(0.111)	(0.110)
goveff			-0.0410	-0.0416	-0.0480	-0.0418
			(0.0382)	(0.0382)	(0.0393)	(0.0391)
logenimp				-0.0363	-0.0341	-0.0331
				(0.0250)	(0.0251)	(0.0249)

Table 4: Results for the simultaneous equation system, contd.

3 SLS; dependent variables: growth, logci, logeduexp, logrdshare, logenusegdp

	(N)	(O)	(P)	(Q)	(R)	(S)
logeduexp						
logenusegdp	0.464***	0.292***	0.291***	0.307***	0.157	0.135
	(0.0950)	(0.105)	(0.105)	(0.105)	(0.117)	(0.118)
logagedep	-0.767***	-0.777***	-0.773***	-0.776***	-0.720***	-0.677***
	(0.124)	(0.122)	(0.121)	(0.124)	(0.127)	(0.132)
logpop	-0.328**	-0.323**	-0.342**	-0.343**	-0.358***	-0.355***
	(0.136)	(0.134)	(0.134)	(0.134)	(0.135)	(0.135)
loggovshare		0.236**	0.263***	0.255***	0.395***	0.395***
		(0.0923)	(0.0936)	(0.0936)	(0.115)	(0.115)
goveff			-0.0610	-0.0601	-0.0696*	-0.0732*
			(0.0406)	(0.0406)	(0.0414)	(0.0414)
logenimp				-0.00305	-0.00164	-0.00229
				(0.0261)	(0.0261)	(0.0260)
logstructure					-0.158**	-0.153**
					(0.0650)	(0.0649)

Table 4: Results for the simultaneous equation system, contd.

3 SLS; dependent variables: growth, logci, logeduexp, logrdshare, logenusegdp

	(N)	(O)	(P)	(Q)	(R)	(S)
logrdshare						
logenusegdp	-0.0908	-0.324**	-0.323**	-0.288*	-0.243	-0.244
	(0.146)	(0.163)	(0.164)	(0.163)	(0.153)	(0.153)
logagedep	-0.398**	-0.415**	-0.420**	-0.420**	-0.399**	-0.400**
	(0.190)	(0.192)	(0.192)	(0.191)	(0.189)	(0.189)
logpop	0.123	0.124	0.116	0.109	0.182	0.180
	(0.205)	(0.203)	(0.203)	(0.203)	(0.205)	(0.205)
loggovshare		0.340**	0.360**	0.339**	0.278*	0.278*
		(0.145)	(0.148)	(0.147)	(0.143)	(0.143)
goveff			-0.0277	-0.0251	0.00257	0.00252
			(0.0616)	(0.0615)	(0.0620)	(0.0620)
Constant	-0.0149	0.141	0.232	0.221	-0.415	-0.396
	(1.623)	(1.610)	(1.628)	(1.628)	(1.627)	(1.627)

Table 4: Results for the simultaneous equation system, contd.

3 SLS; dependent variables: growth, logci, logeduexp, logrdshare, logenusegdp

	(N)	(O)	(P)	(Q)	(R)	(S)
logenusegdp						
logingdp	-0.424*	-0.471*	-0.488*	-0.492*	-0.524**	-0.552**
	(0.257)	(0.253)	(0.253)	(0.254)	(0.258)	(0.258)
sqlogingdp	0.0188	0.0258	0.0281	0.0284	0.0336	0.0376
	(0.0334)	(0.0328)	(0.0329)	(0.0330)	(0.0335)	(0.0336)
logagedep	-0.578***	-0.583***	-0.595***	-0.598***	-0.602***	-0.605***
	(0.102)	(0.102)	(0.102)	(0.102)	(0.102)	(0.102)
loggovshare	0.254***	0.272***	0.279***	0.276***	0.262***	0.264***
	(0.0619)	(0.0640)	(0.0641)	(0.0639)	(0.0642)	(0.0642)
logopen	-0.256***	-0.251***	-0.252***	-0.254***	-0.247***	-0.244***
	(0.0462)	(0.0455)	(0.0455)	(0.0457)	(0.0466)	(0.0467)

Table 5: Results for energy prices

3 SLS; dependent: energy use per capita/GDP

	(N)	(O)
	logenusecap	logenusegdp
logenprice	-0.213***	-0.230***
	(0.0317)	(0.0330)
logingdp	0.800***	-0.110**
	(0.0452)	(0.0470)
logpop	0.00306	-0.00136
	(0.0199)	(0.0207)
logopen	0.0838	0.0600
	(0.0548)	(0.0569)

Summary

- Framework to show how energy affects investments and economic growth
- empirical estimations, single equation methods and a system with five simultaneous equations
- sample of 37 developed countries (energy and carbon reduction policies)
- five-year average panel data over the period 1975-2009, price data less observations
- result: decreasing energy input induces investments in physical and knowledge capital.
- A ten percent increase in energy prices is found to raise the growth rate by 0.2 percentage points.

Conclusions

- often-cited negative impact of lower energy input on growth is not evident
- channels working through physical and knowledge capital accumulation
- general intuition too much on the business cycle, not necessarily on long-run growth experience
- growth effect is moderate but not negligible
- dealing with energy scarcity is more productive in the long run than dealing with energy abundance.
- empirical results are robust to using different specifications
- model results can also be used when estimating the dynamic costs of climate policies

Thank you