POTSDAM INSTITUTE FOR CLIMATE IMPACT RESEARCH

Renewable Energy Subsidies: Second-best Policy or Fatal Aberration for Mitigation?

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Rationales for renewable energy subsidies

1. **Efficiency based arguments**
   - Innovation and learning spillovers
   - Network externalities and scale effects
   - Energy security concerns / diversification

➔ Introducing an optimal renewable energy subsidies to existing carbon pricing policy is efficiency-improving

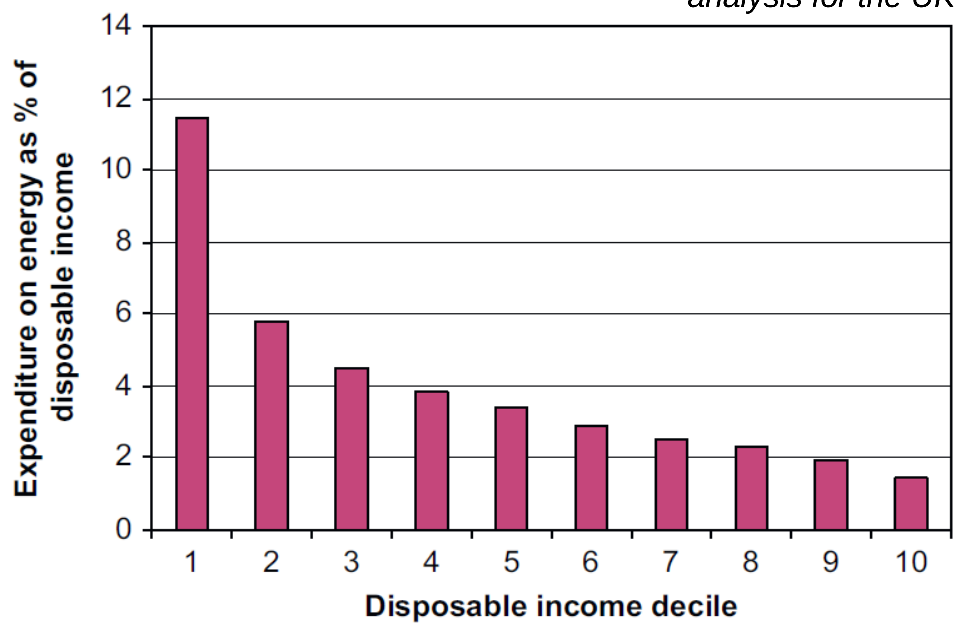
Rationales for renewable energy subsidies

2. Pragmatic / second-best arguments

In reality, it is difficult to implement the optimal carbon price:

- Carbon taxes reduce fossil industry's rents
- Unilateral carbon prices provoke relocation
- Carbon pricing has a regressive effect due to higher energy prices

Druckman & Jackson (2008); analysis for the UK



➔ Subsidies often provoke less public resistance than taxes
Subsidies as second-best alternative to missing/imperfect carbon prices?

Research Questions of this Paper

- What are the efficiency losses of renewable energy subsidies as second-best instrument if carbon pricing is imperfect?
- Which parameters determine the efficiency losses?
- How do second-best subsidies affect rents and energy prices?
- How do second-best subsidies affect fossil resource extraction and mitigation targets?

Model Set-up

Intertemporal general equilibrium model

- Endogenous savings (Ramsey)
- Endogenous resource extraction (Hotelling)
- Endogenous learning-by-doing (Arrow)

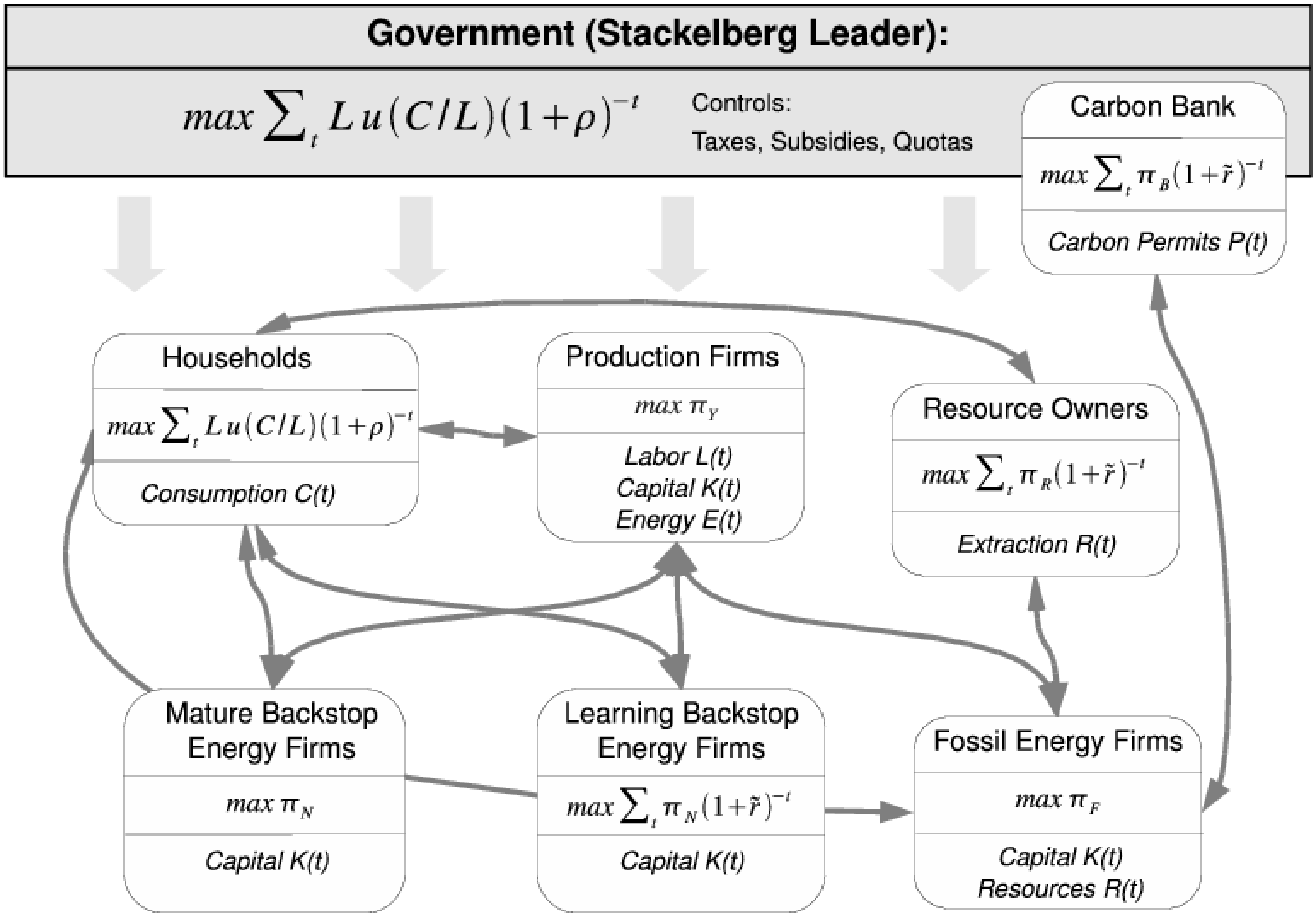
Three energy technologies

- fossil
- non-learning backstop (i.e. nuclear)
- learning backstop (i.e. renewable)

Mitigation target: cumulative carbon budget: 450 GtC ($p \approx 50\%$ for $\Delta T < 2°C$)

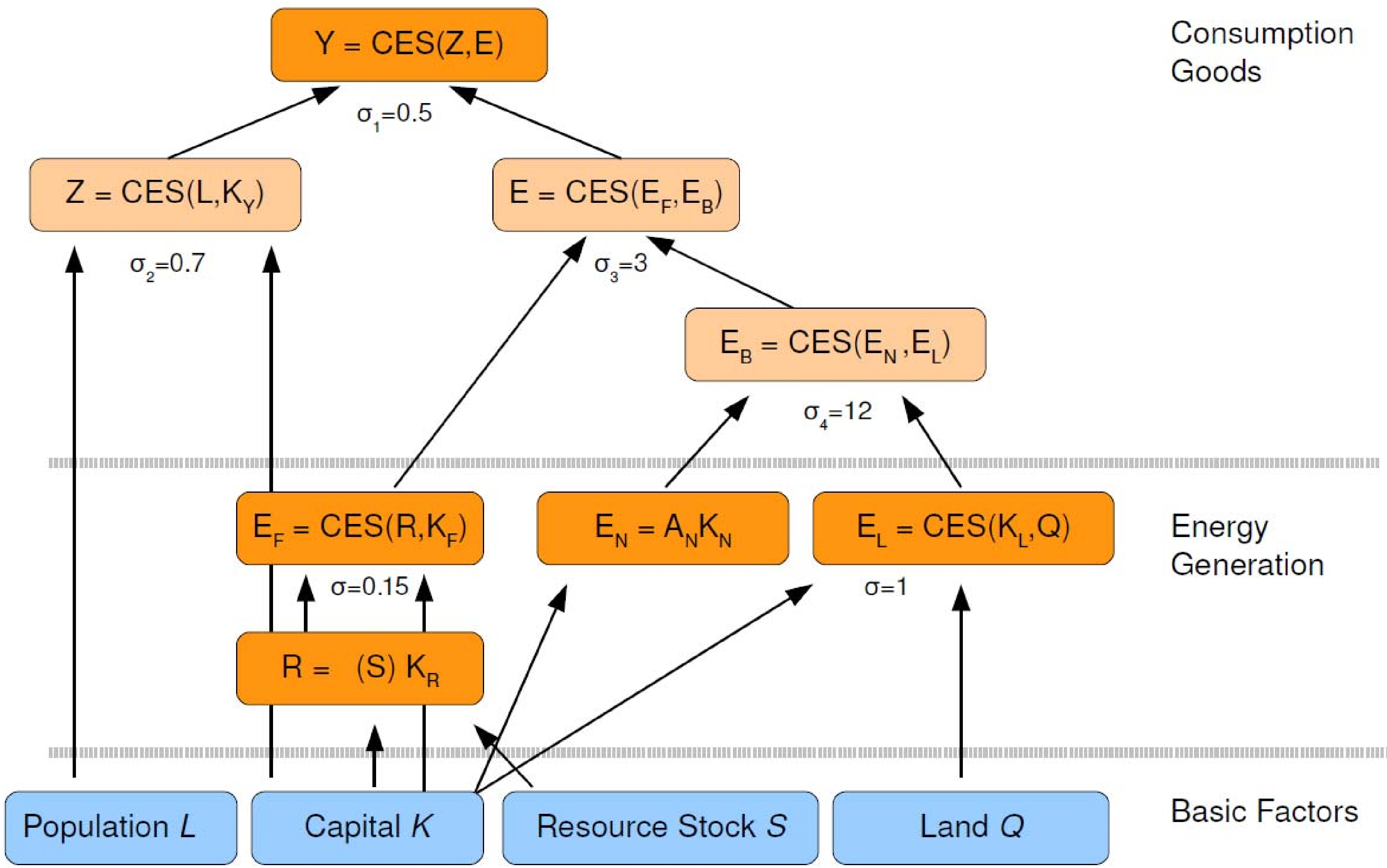
Top-level optimization: Government maximizes welfare subject to intertemporal market equilibrium

Model Set-up



Government (Stackelberg Leader):
$max \sum_t L u(C/L)(1+\rho)^{-t}$
Controls:
Taxes, Subsidies, Quotas
Carbon Bank
$max \sum_t \pi_B (1+\tilde{r})^{-t}$
Carbon Permits P(t)
Households
$max \sum_t L u(C/L)(1+\rho)^{-t}$
Consumption C(t)
Production Firms
$max \ \pi_Y$
Labor L(t)
Capital K(t)
Energy E(t)
Resource Owners
$max \sum_t \pi_R (1+\tilde{r})^{-t}$
Extraction R(t)
Mature Backstop Energy Firms
$max \ \pi_N$
Capital K(t)
Learning Backstop Energy Firms
$max \sum_t \pi_N (1+\tilde{r})^{-t}$
Capital K(t)
Fossil Energy Firms
$max \ \pi_F$
Capital K(t)
Resources R(t)

Technology



Y = CES(Z,E)
σ1=0.5
Z = CES(L,K_Y)
E = CES(E_F,E_B)
σ2=0.7
σ3=3
E_B = CES(E_N,E_L)
σ4=12
E_F = CES(R,K_F)
E_N = A_N K_N
E_L = CES(K_L,Q)
σ=0.15
σ=1
R = (S) K_R
Population L
Capital K
Resource Stock S
Land Q
Consumption Goods
Energy Generation
Basic Factors

Fossil Resource Extraction

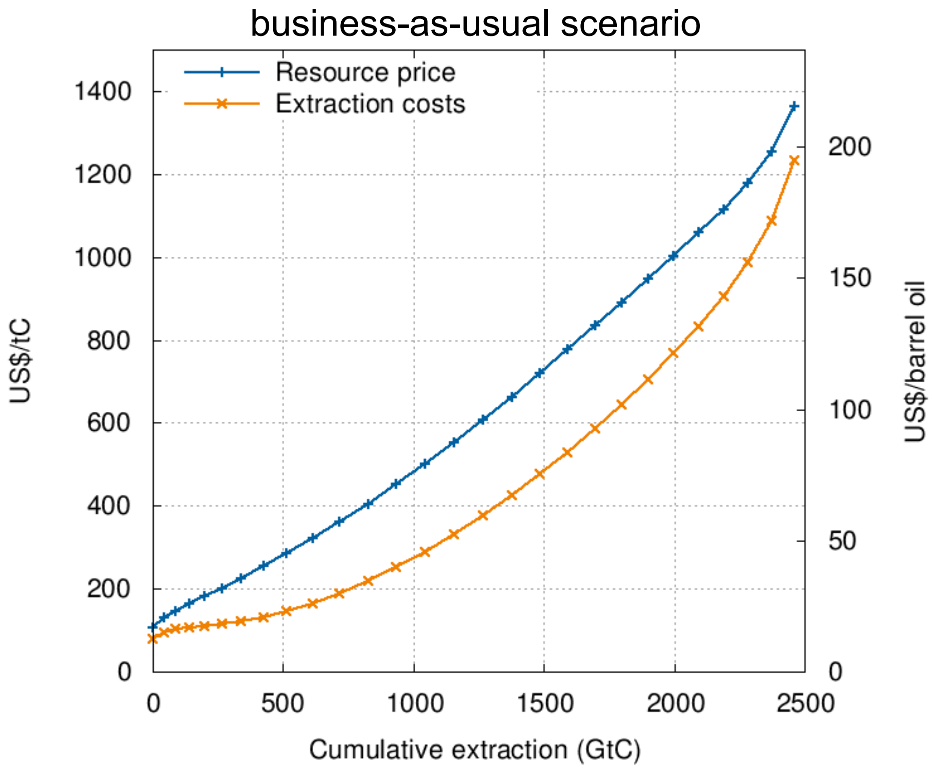
- Intertemporally profit-maximizing resource owners (supply-side dynamics)

$$\max_{R_t} \sum_{t=0}^{T} \pi_{R,t} \Delta\Pi^{t}_{s=0} \left[1 + (r_s - \delta)\right]^{-\Delta}$$

- Increasing extraction costs

$$\mathbf{R}(S, K_R) = \kappa(S) K_R$$

$$\kappa(S) = \frac{\chi_1}{\chi_1 + \chi_2 \left(\frac{S_0 - S}{\chi_3}\right)^{\chi_4}}$$



Learning Renewable Energy

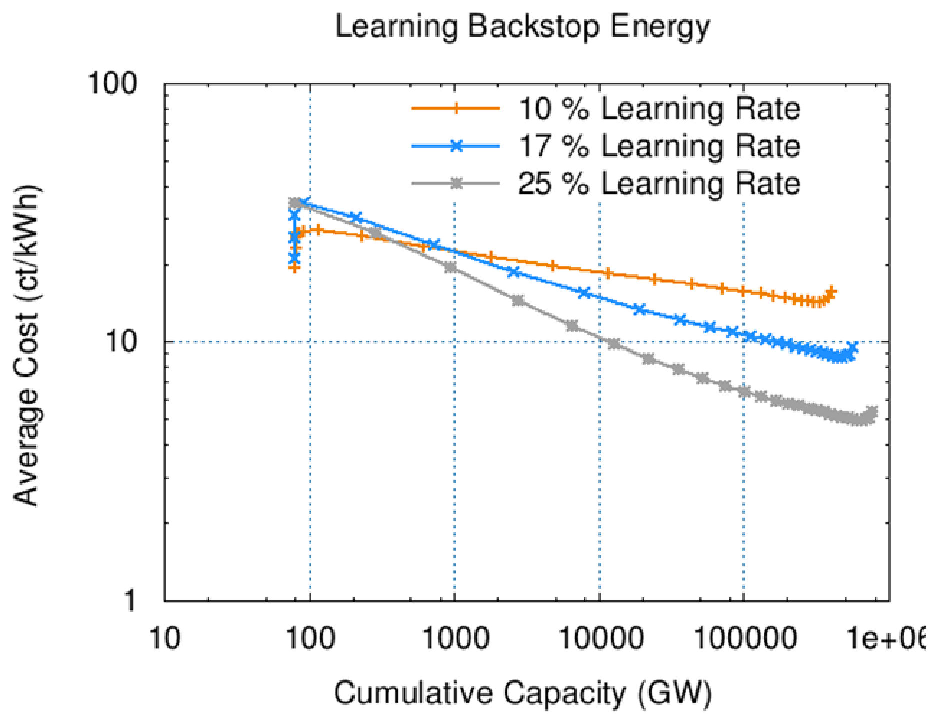
- Intertemporally profit-maximizing RE firms: Perfect anticipation of learning-by-doing dynamics

$$\max_{K_{L,t}} \sum_{t=0}^{T} \pi_{L,t} \Delta \Pi_{s=0}^{t} \left[1 + (r_s + v - \delta)\right]^{-\Delta}$$

$$\pi_{L,t} = p_{L,t} \mathbf{E_L}(\mathbf{A_L}(H_t) K_{L,t}, N) - r K_L$$

$$H_{t+1} = H_t + \Delta(E_{L,t} - E_{L,t-1}),$$

$$\mathbf{A_L}(H) = \frac{A_{L,max}}{1 + \left(\frac{\Omega}{H}\right)^{\gamma}}$$

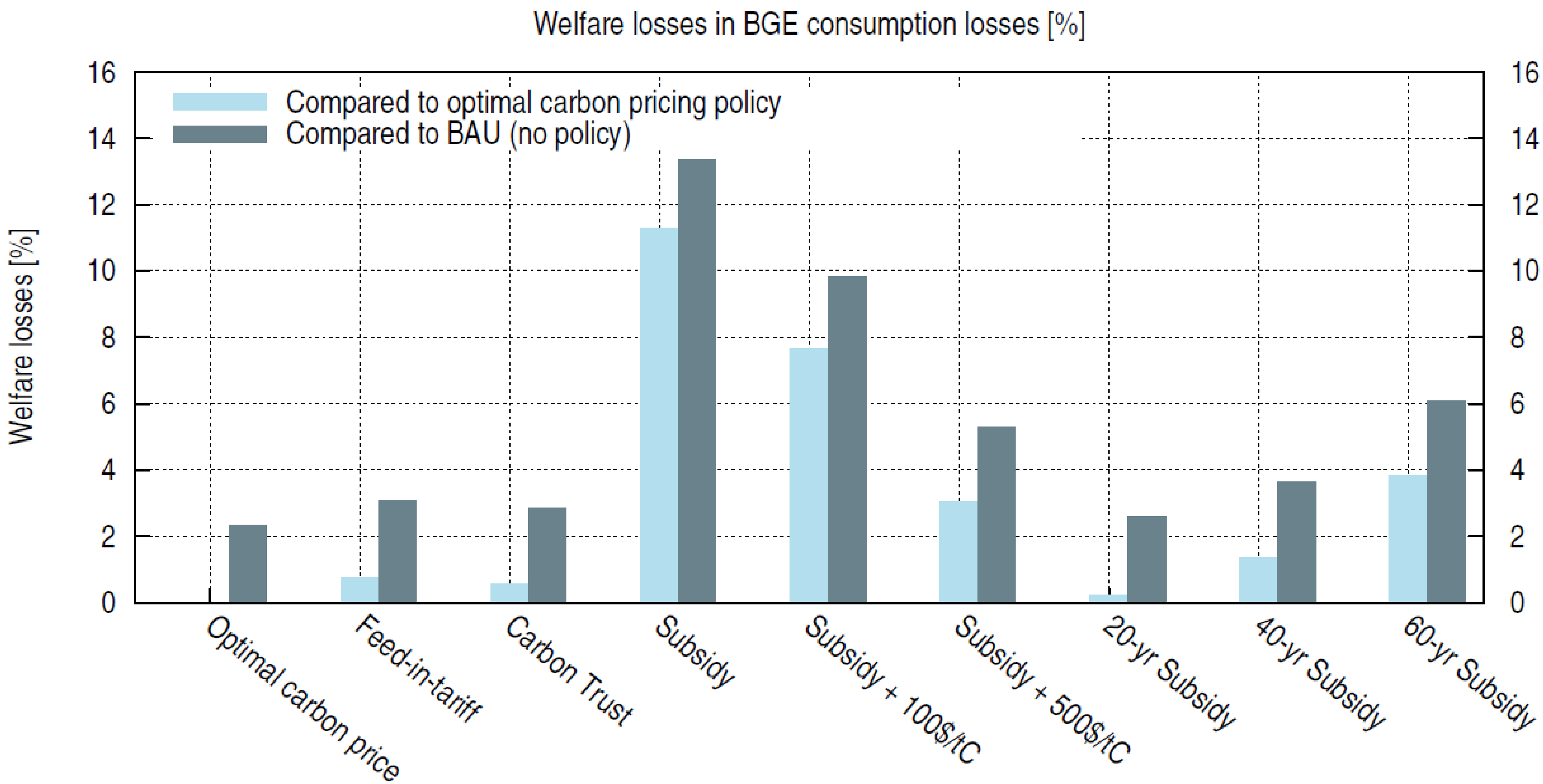


Policy Instruments

1. **Carbon pricing** (“first-best benchmark”)
2. **Feed-in-tariff:** fossil energy tax revenues are recycled as renewable energy subsidy
3. **Carbon trust:** carbon tax revenues are recycled as renewable energy subsidy
4. **Pure renewable energy subsidy** (paid by lump-sum taxes on households)
5. **Renewable energy subsidy with a (low) constant carbon tax**
6. **Temporary renewable energy subsidy** that is displaced after 20/40/60 years by a carbon tax
7. **No policy** (“business-as-usual benchmark”)

Only market failure considered in the model: carbon emissions (innovation and learning by doing effects are completely anticipated or internalized by agents)

Welfare Effects

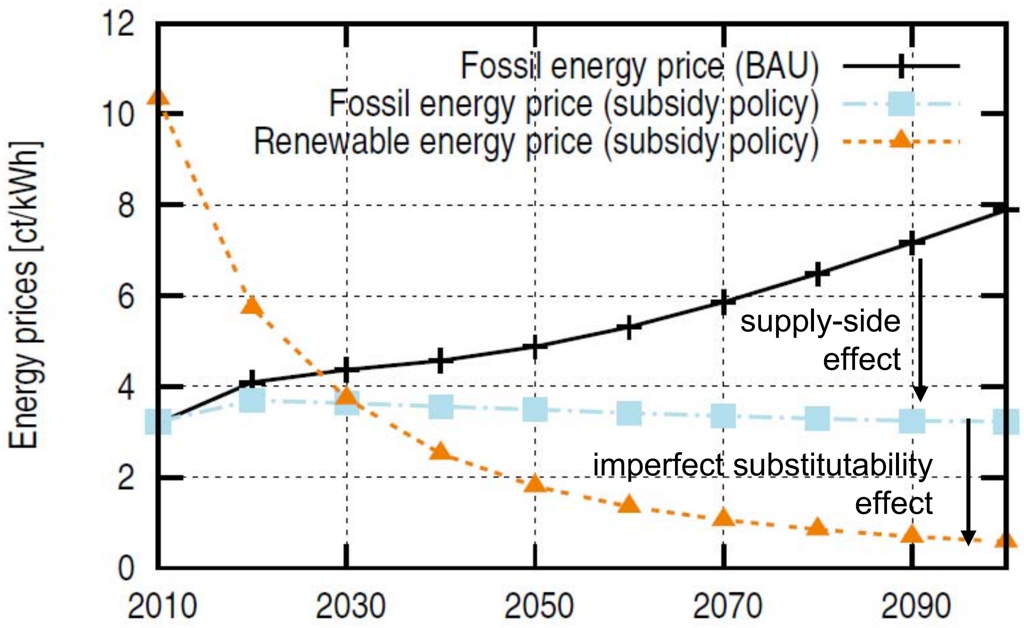


➔ Pure subsidy policy has disastrous welfare effects

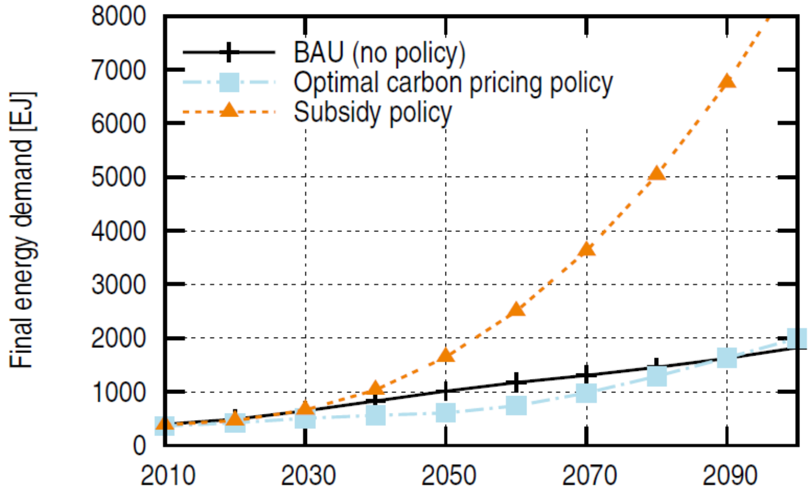
➔ Hybrid instruments can have only moderate efficiency costs

Why is the Renewable Energy Subsidy so Expensive?

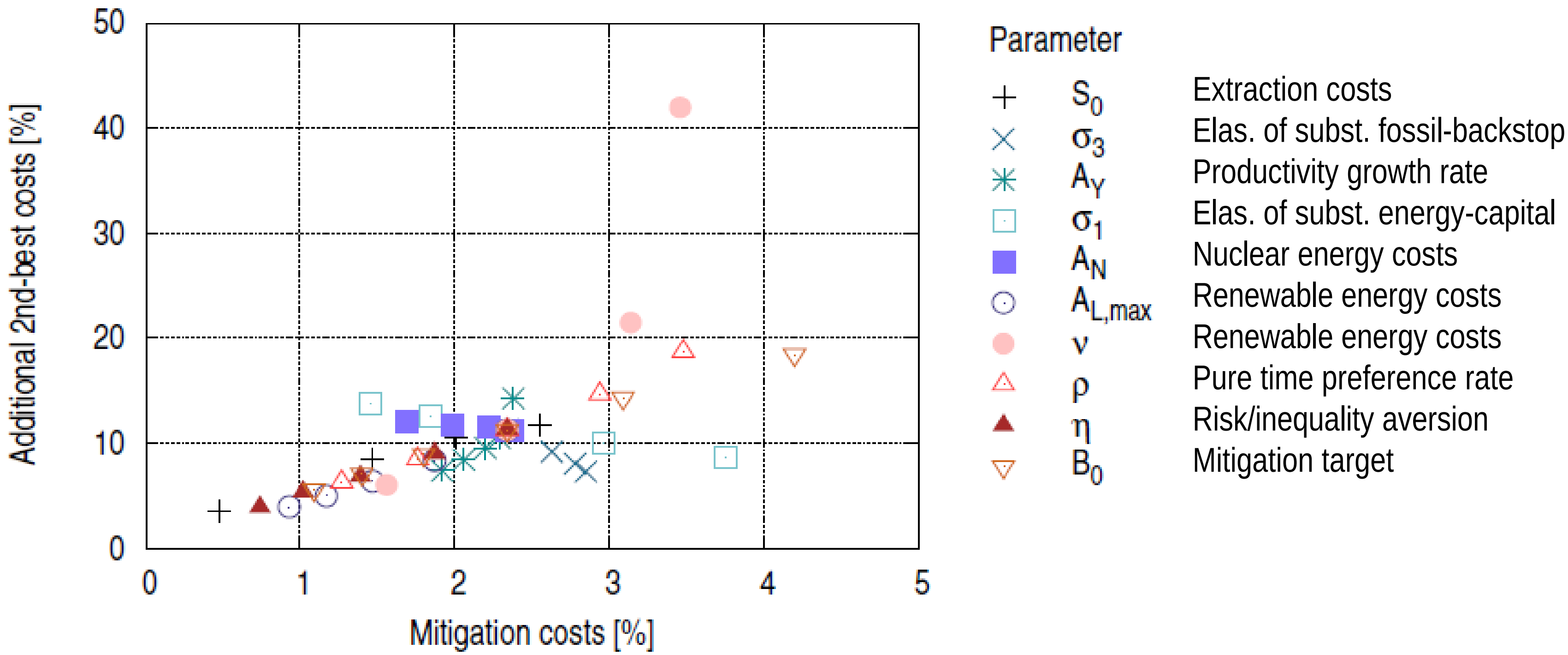
- Supply-side dynamics: Fossil energy price decreases due to renewable energy subsidy ➔ higher subsidies needed
- Substitutability: Good, but imperfect substitutability requires high price differential ➔ high subsidies needed



Subsidies increase energy demand:

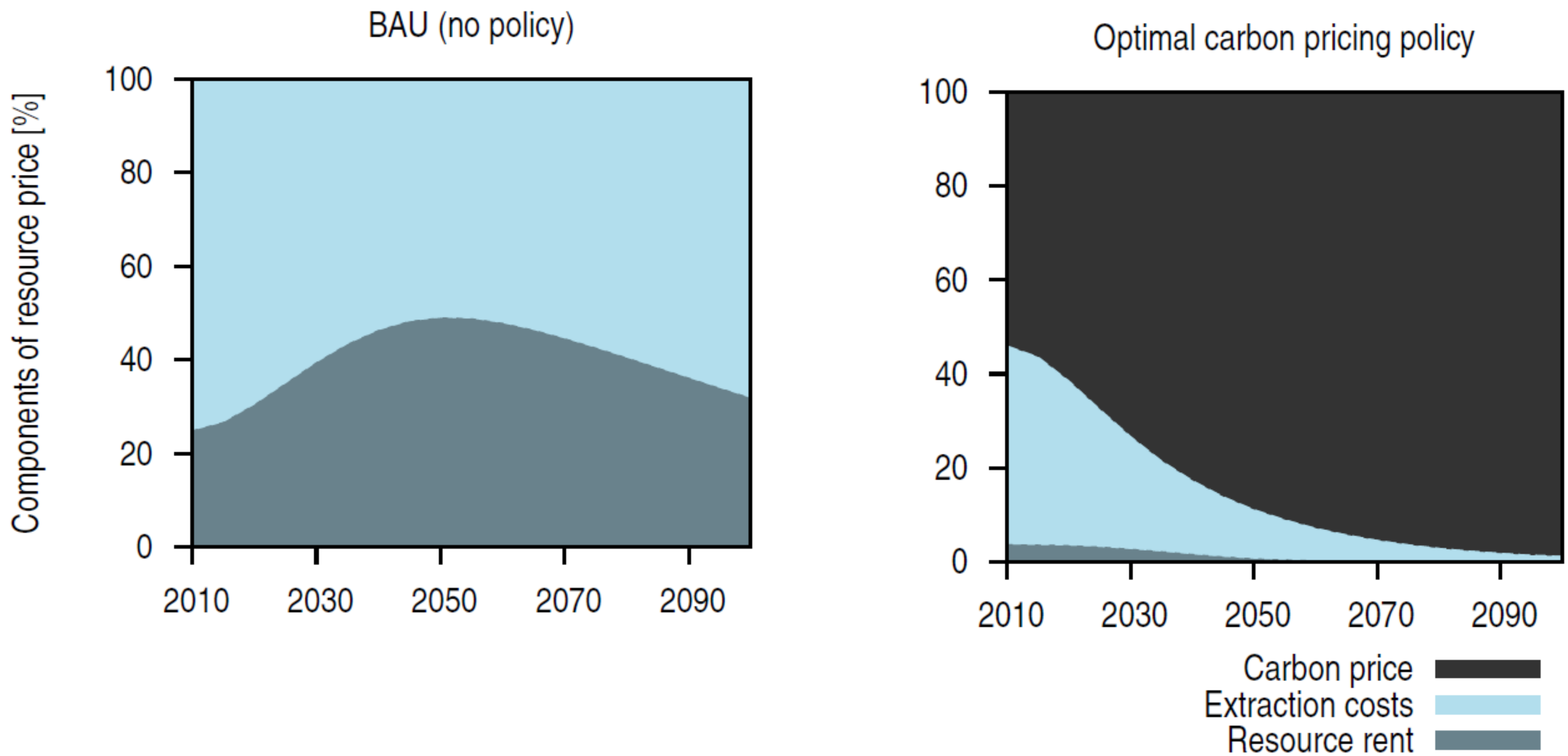


Why is the Renewable Energy Subsidy so Expensive?



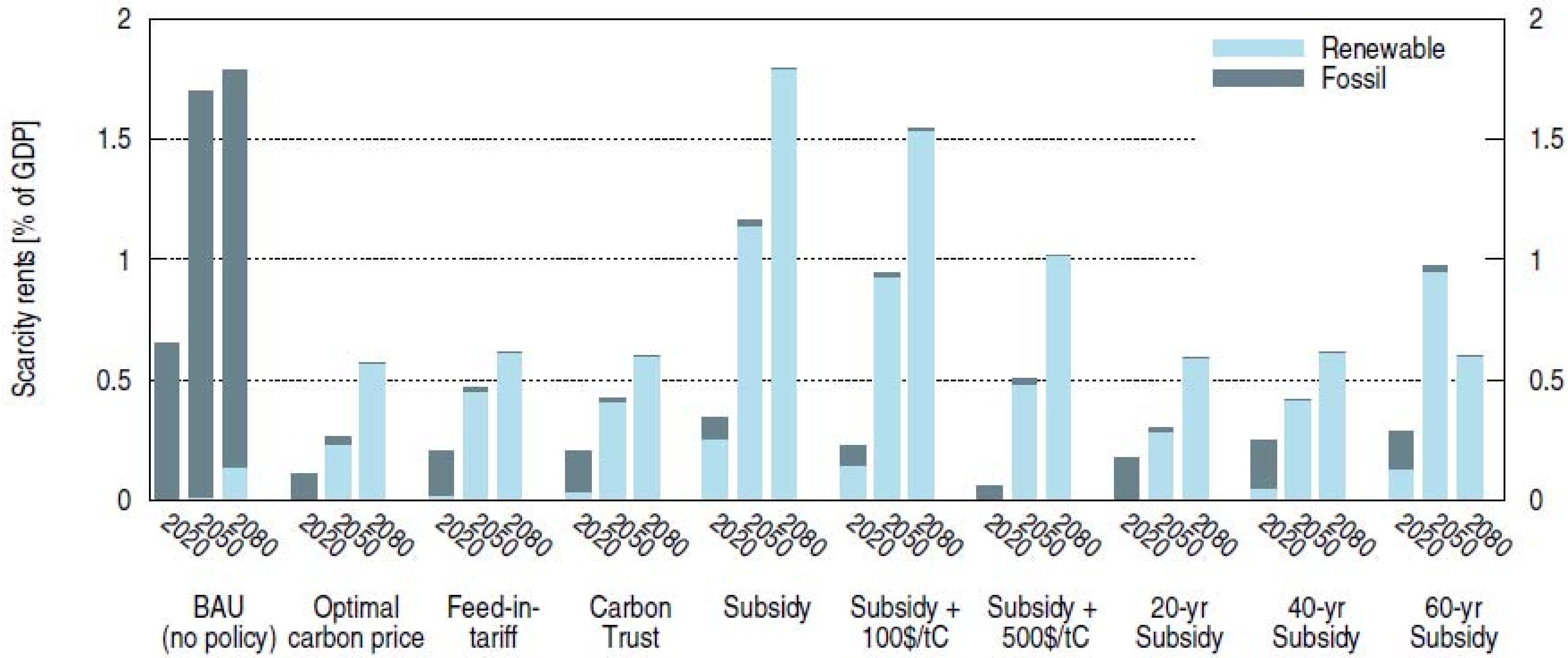
- For a wide range of parameter variations, welfare losses remain substantial
- Performance of subsidies correlates in many cases with mitigation costs

Rent Analysis



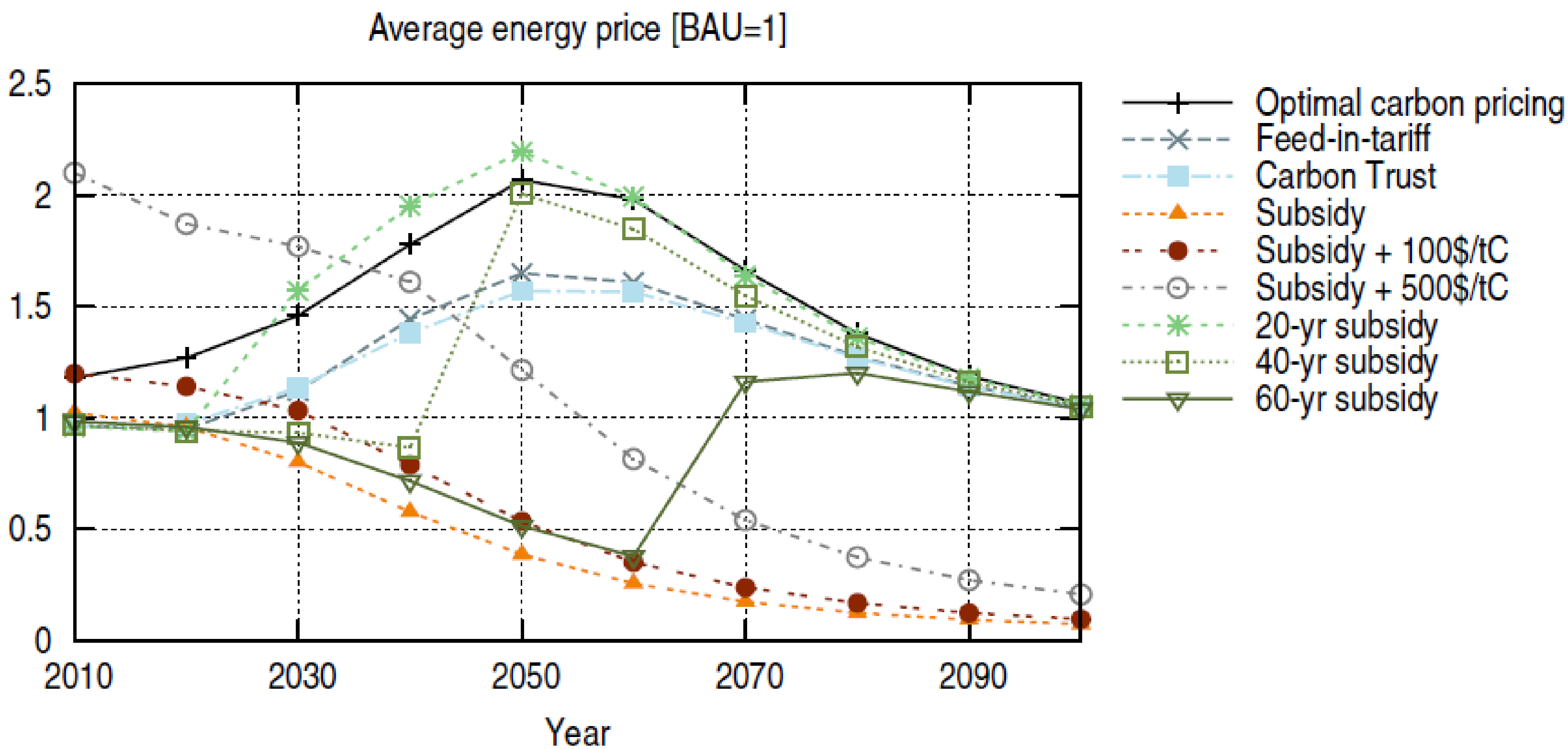
- Carbon pricing reduces the fossil resource rent (per unit of extracted carbon) substantially
- Amount of extracted carbon is reduced, too

Rent Analysis



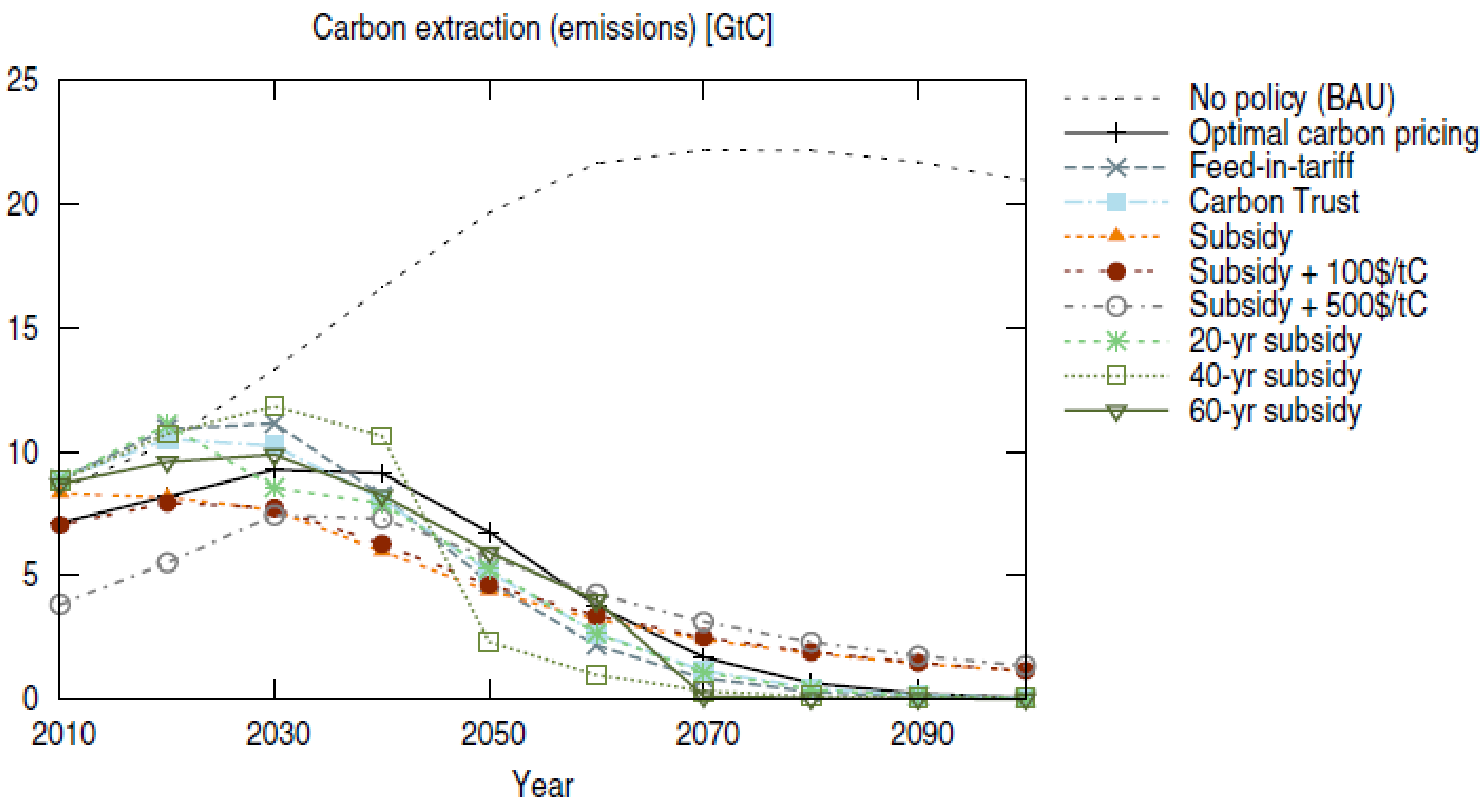
- All mitigation policies reduce fossil rents
- Subsidy policies doe not necessarily imply lower fossil rent cuts

Energy Price Analysis



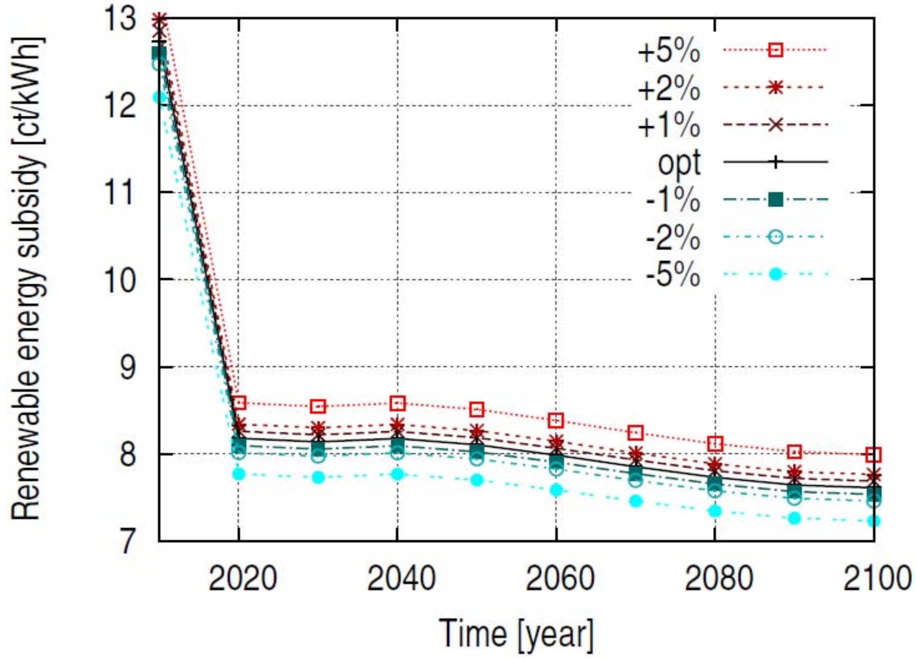
- Carbon pricing almost doubles energy prices
- Pure subsidy policies reduce energy prices enormously
- Income-neutral policies (FIT & carbon trust) lead only to moderate price increases

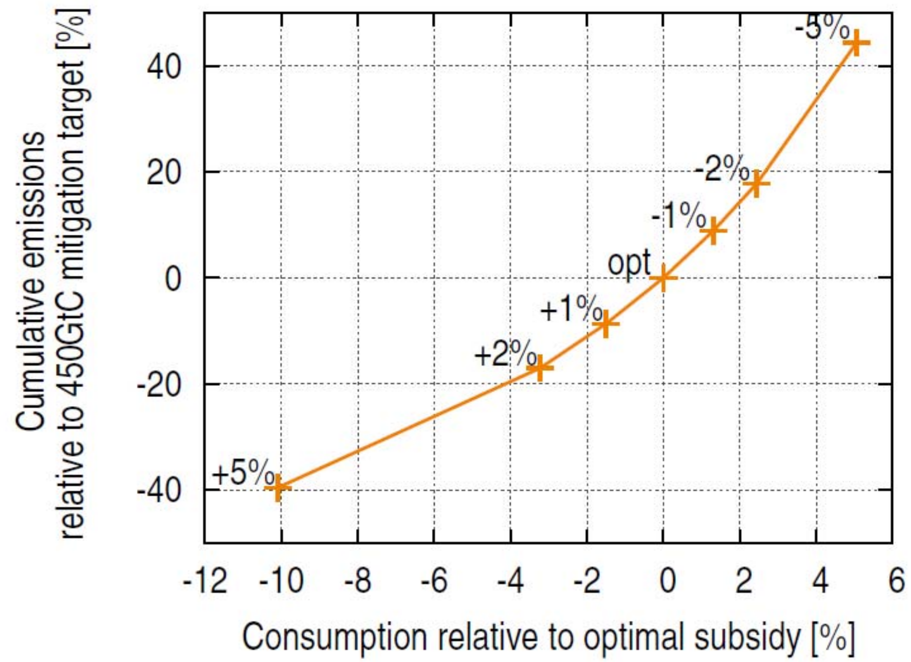
Fossil Resource Extraction



- Regulator anticipates supply-side dynamics (no green paradox can occur)
- Optimal second-best policies lead to initially higher emissions
- Subsidies can reduce accelerated extraction under delayed carbon pricing policies

Fossil Resource Extraction





- Small deviations from optimal second-best subsidy have high impact on emissions and welfare
- A weak green paradox may occur under imperfect information

Conclusions

- Although substantial carbon prices are difficult to implement, a pure subsidy policy is no pragmatic alternative
- Although supply-side dynamics is considered by regulator, imperfect information increases the risk of green paradoxes (due to suboptimal subsidies)
- Even if there is no efficiency rationale for RE subsidies, using carbon pricing revenues for additional RE subsidies might ease implementation:
  - lower impact of mitigation target on energy prices
- Although carbon pricing seems to be inevitable in the long-run, RE subsidies might be a valuable short-term option

Thank you for your attention!

Paper is available as:

Kalkuhl, M., O. Edenhofer and K. Lessmann (2011): "Renewable energy subsidies: Second-best policy or fatal aberration for mitigation?" *FEEM Working Paper 48.2011*

Backup Slides

Model Equations: Household

$$\max_{C_t} \quad \sum_{t=0}^{T} (1+\rho)^{-\Delta t} \Delta L_t \mathbf{U}\left(C_t / L_t\right)$$

$$C_t = w_t L_t + r_t K_t - I_t + \pi_t + \Gamma_t$$

$$K_t = \sum_j K_{j,t}, \qquad I_t = \sum_j I_{j,t}, \qquad \pi_t = \sum_j \pi_{j,t}$$

$$K_{j,t+1} = K_{j,t} + \Delta(I_{j,t} - \delta K_{j,t}), \qquad K_0 \text{ given}$$

First-order conditions:

$$L_t \frac{\partial \mathbf{U}}{\partial C_t} = \lambda_{H,t}$$

$$\lambda_{H,t} - \lambda_{H,t-1}(1+\rho)^{\Delta} = -\Delta \lambda_{H,t}(r_t - \delta)$$

$$0 = \lambda_{H,T} K_{T+1}$$

Model Equations: Resource Sector

$$\max_{R_t} \sum_{t=0}^{T} \pi_{R,t} \Delta \Pi_{s=0}^{t} \left[1 + (r_s - \delta)\right]^{-\Delta}$$

$$\pi_{R,t} = p_{R,t} \mathbf{R}(S_t, K_{R,t}) - r_t K_{R,t}$$

$$S_{t+1} = S_t - \Delta R_t, \qquad S_t \geq 0, \qquad S_0 \text{ given}$$

$$\mathbf{R}(S, K_R) = \kappa(S) K_R$$

$$\kappa(S) = \frac{\chi_1}{\chi_1 + \chi_2 \left(\frac{S_0 - S}{\chi_3}\right)^{\chi_4}}$$

First-order conditions:

$$\lambda_{R,t} = p_{R,t} - r_t / \kappa_t$$

$$\lambda_{R,t} - \lambda_{R,t-1}(1 + (r_t - \delta))^{\Delta} = -\Delta(p_{R,t} - \lambda_{R,t}) \frac{\partial \mathbf{R}}{\partial S_t}$$

$$\lambda_{R,T} S_{T+1} = 0$$

Model Equations: Renewable Sector

$$\max_{K_{L,t}} \sum_{t=0}^{T} \pi_{L,t} \Delta \Pi_{s=0}^{t} \left[1 + (r_s + v - \delta)\right]^{-\Delta}$$

$$\pi_{L,t} = p_{L,t} \mathbf{E_L}(\mathbf{A_L}(H_t) K_{L,t}, N) - r K_L$$

$$H_{t+1} = H_t + \Delta(E_{L,t} - E_{L,t-1}), \qquad H_0 \text{ given}$$

$$\mathbf{E_L}(A_L, K_L, N) = A_L K_L^{\nu} N^{\nu-1}$$

$$\mathbf{A_L}(H) = \frac{A_{L,max}}{1 + \left(\frac{\Omega}{H}\right)^{\gamma}}$$

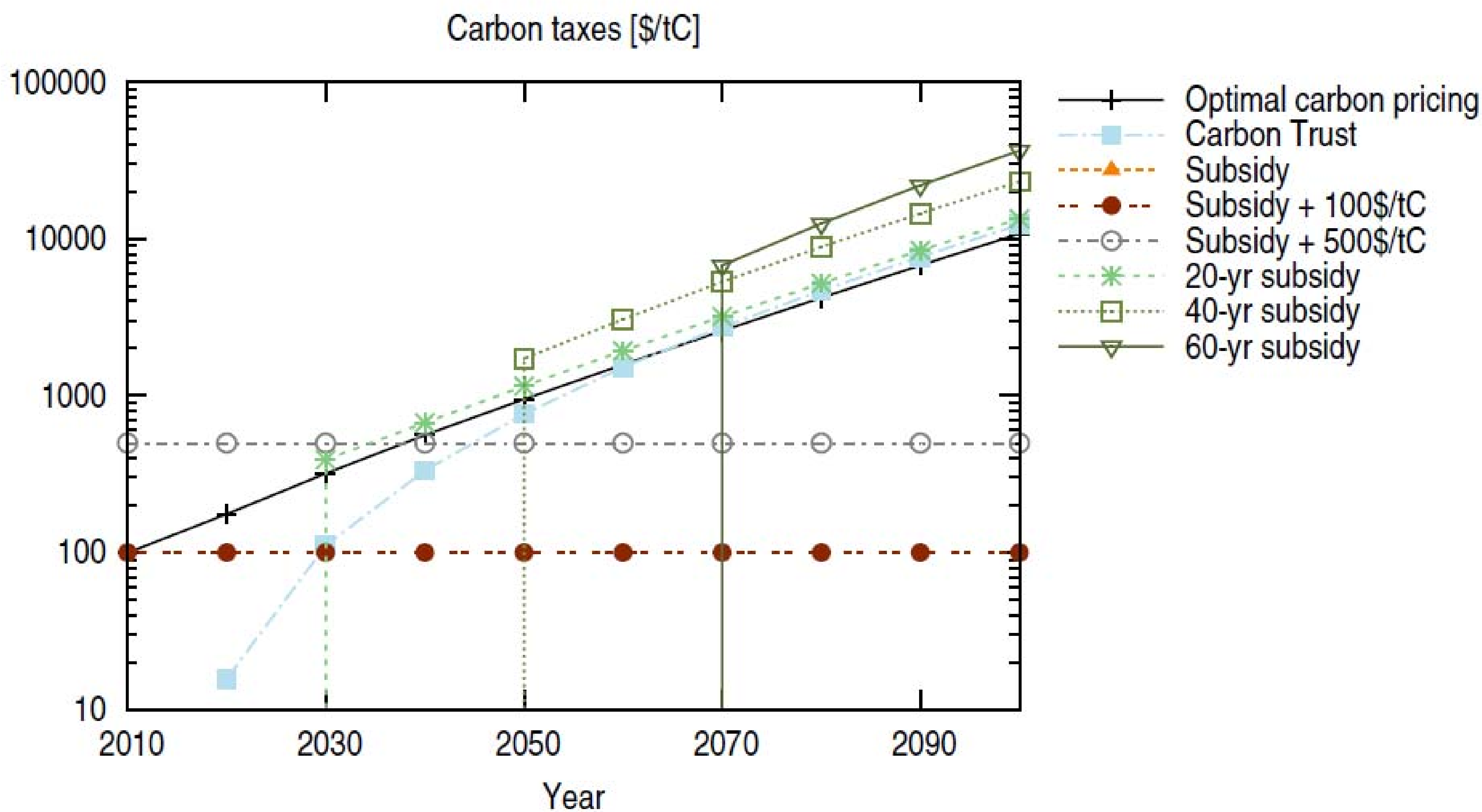
First-order conditions:

$$r_t = \left(p_{L,t} - \mu_t + \frac{\mu_{t+1}}{(1 + r_{t+1} + v - \delta)^{\Delta}} \right) \frac{\partial \mathbf{E_L}}{\partial K_{L,t}}$$

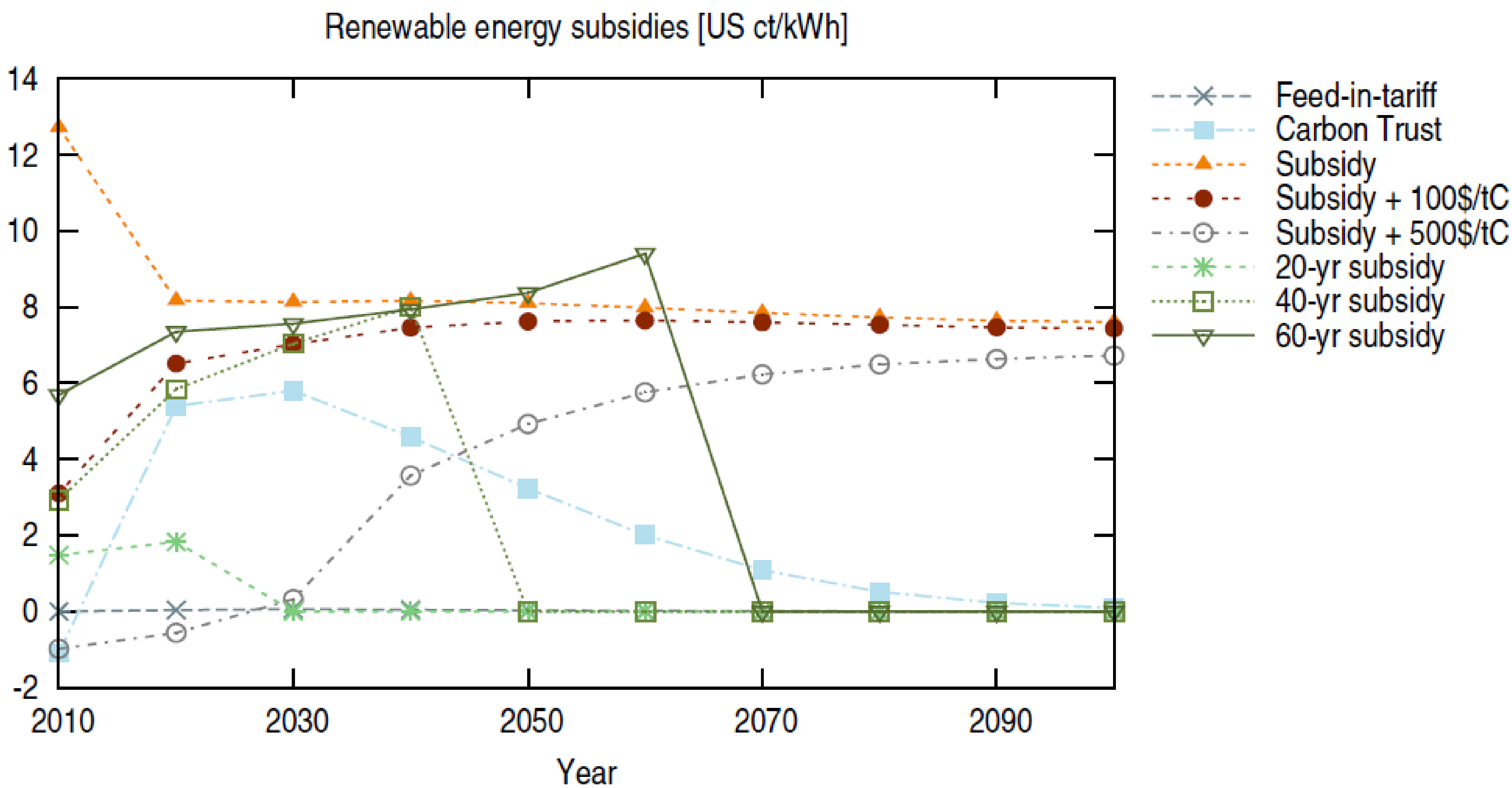
$$\mu_t - \mu_{t-1}(1 + r_t + v - \delta)^{\Delta} = \Delta(1 - \phi) \frac{\partial \mathbf{E_L}}{\partial H_t} \left(p_{L,t} - \mu_t + \frac{\mu_{t+1}}{(1 + r_{t+1} + v - \delta)^{\Delta}} \right)$$

$$\mu_T = 0$$

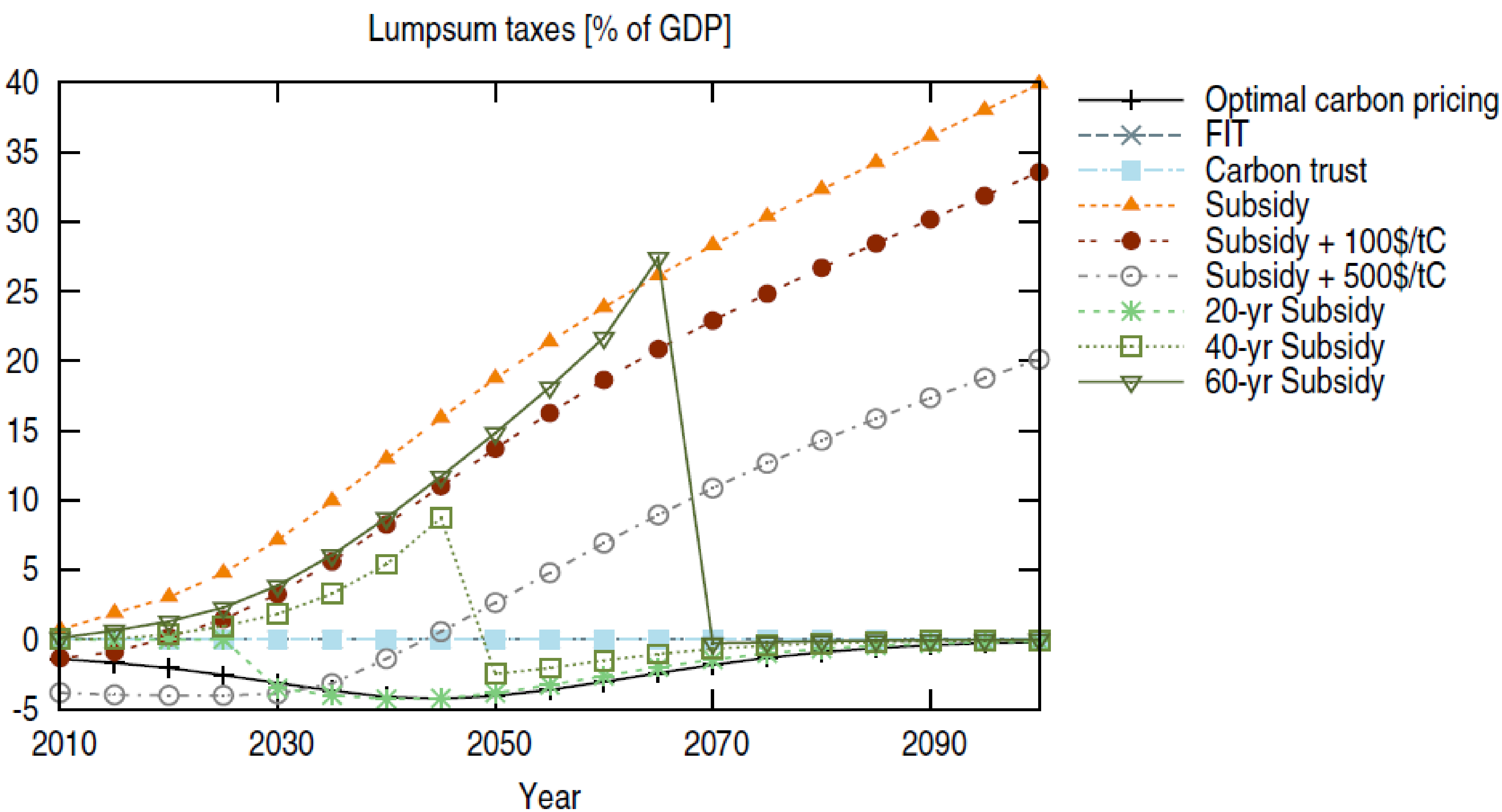
Carbon taxes



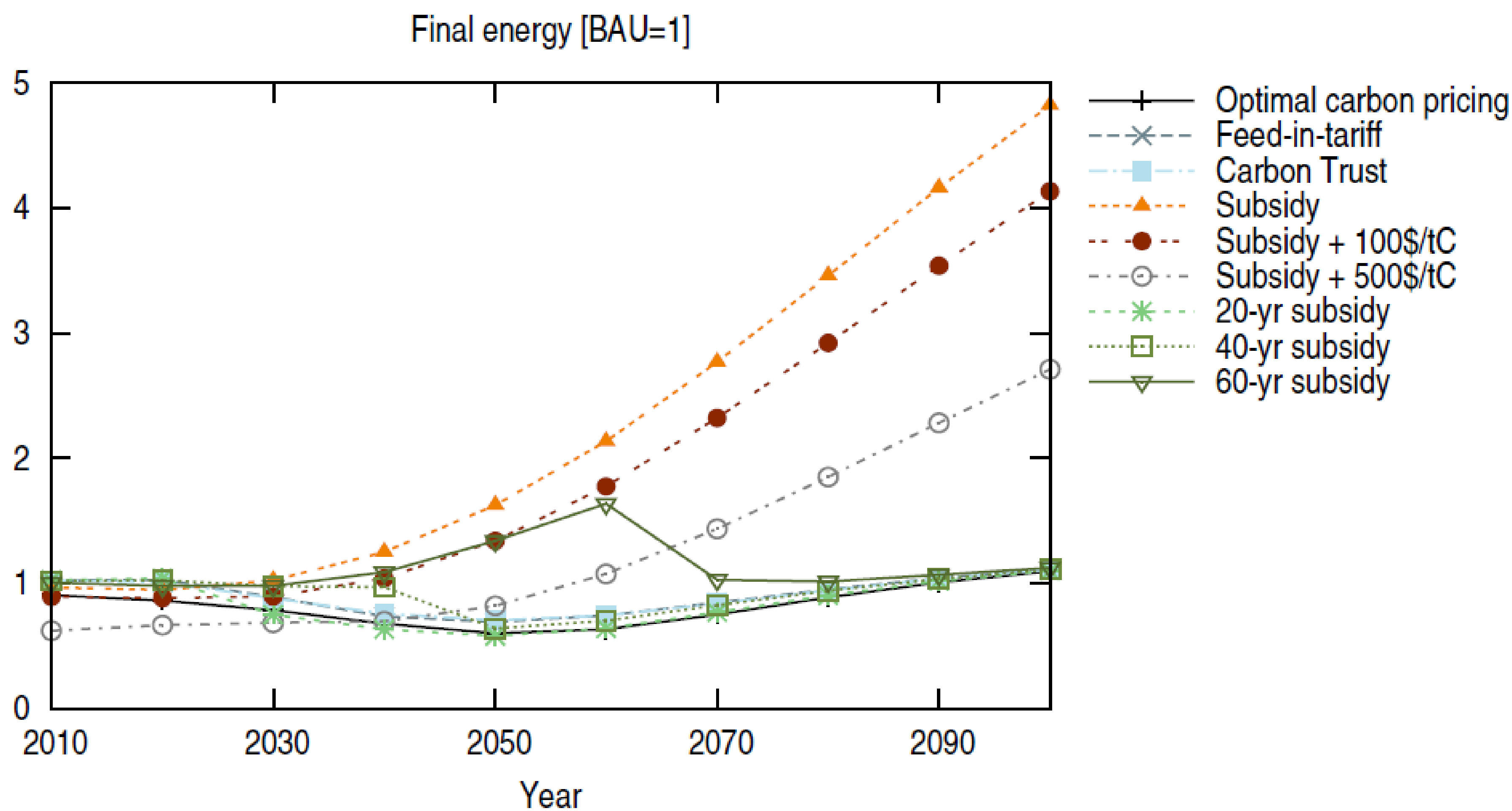
RE Subsidies



Government Expenditures / Lump-sum Taxes



Energy Consumption



Sensitivity Analysis

Fossil resource stock [GtC] S_0	5000	4000*	3000	2000	1000	
Mitigation costs [%]	2.55	2.34	2.01	1.47	0.48	
Additional 2nd-best costs [%]	11.68	11.27	10.45	8.56	3.56	
Fossil-backstop substitutability σ_3	3*	4	5	6		
Mitigation costs [%]	2.34	2.63	2.78	2.85		
Additional 2nd-best costs [%]	11.27	9.19	8.05	7.31		
Initial labor productivity growth rate $\hat{A}_Y$	0.010	0.015	0.020	0.024	0.026*	0.028
Mitigation costs [%]	1.92	2.06	2.2	2.29	2.34	2.38
Additional 2nd-best costs [%]	7.39	8.42	9.54	10.51	11.27	14.27
(KL)–E substitutability σ_1	0.3	0.4	0.5*	0.6	0.7	
Mitigation costs [%]	3.75	2.96	2.34	1.84	1.45	
Additional 2nd-best costs [%]	8.58	9.99	11.27	12.5	13.73	
Nuclear energy productivity A_N	0.15	0.2*	0.25	0.3	0.35	
Mitigation costs [%]	2.37	2.34	2.22	1.99	1.69	
Additional 2nd-best costs [%]	11.18	11.27	11.48	11.79	12.12	
Renewable energy productivity $A_{L,max}$	0.6*	0.7	0.8	0.9	1	
Mitigation costs [%]	2.34	1.87	1.47	1.17	0.93	
Additional 2nd-best costs [%]	11.27	8.36	6.38	4.98	3.95	
Cobb-Douglas exponent for renewable energy ν	0.85	0.9	0.95*	1		
Mitigation costs [%]	3.46	3.14	2.34	1.56		
Additional 2nd-best costs [%]	41.96	21.47	11.27	6.04		
Pure social time discount rate ρ	0.01	0.02	0.03*	0.04	0.05	
Mitigation costs [%]	3.48	2.94	2.34	1.76	1.27	
Additional 2nd-best costs [%]	18.7	14.68	11.27	8.47	6.29	
Risk aversion η	1*	1.5	2	2.5	3	
Mitigation costs [%]	2.34	1.87	1.39	1.02	0.74	
Additional 2nd-best costs [%]	11.27	9.02	6.82	5.36	3.92	
Carbon budget [GtC] B	250	350	450*	550	650	750
Mitigation costs [%]	4.2	3.09	2.34	1.8	1.4	1.09
Additional 2nd-best costs [%]	18.45	14.32	11.27	8.92	7.07	5.6