Integrated Policy Assessment in the Context of Global Warming

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Current Policy Debates

The role of renewable subsidies in the context of carbon pricing

- Schould renewable energy be subsidized ?
  - No – *price only crowd* (Sinn, Nordhaus)
  - Yes – *hybrid crowd* (Acemoglou)
- Can renewable subsidies replace a carbon price?
- Can renewable subsidies improve a delayed carbon pricing policy?

The role of technology instruments and renewable subsidies

- Are renewable subsidies necessary if no optimal technology policy (in production sector) is feasible? (Nordhaus)
- Are higher carbon prices welfare increasing if no optimal technology policy is feasible? (Hart)

The role of timing

- Can capital taxes lower resource extraction? (Sinn)
- Suboptimal (private) risk premiums in intertemporal markets? (Sinn)

Integrated policy assessment model (IPAM) to answer these questions

Outline

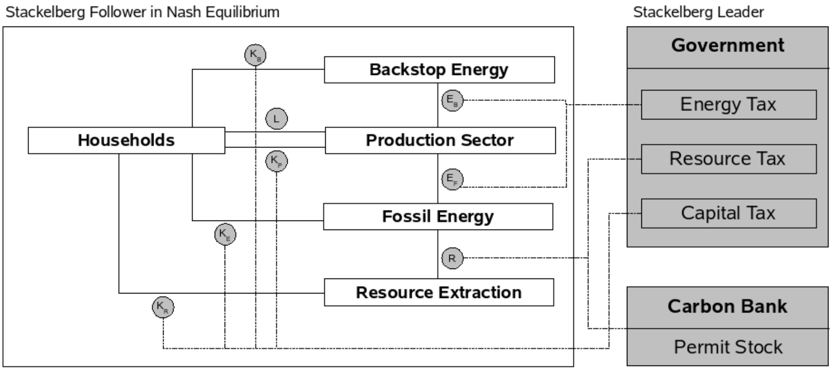
Introduction: Policy Instruments against Global Warming

- Optimization of two stocks:
  - Fossil resources in the ground
  - GHG concentration in the atmosphere
- IAMs neglect strategical interactions
- Climate policy instruments focus on the demand-side
- Consider intertemporal incentive structure explicitly (Sinn, green paradox)
- Distribution and transformation of rents
- Interplay of multiple market failures (carbon pricing, technology)
- 2nd-best policy instruments and *policy option values*

Model Framework

- Dynamic Stackelberg game: Government as Stackelberg Leader
- Decentralized general equilibrium model
- Endogenous growth model (Ramsey)
- Endogenous technological change
- Finite fossil resource stock
- Carbon-Budget approach (cost-benefit approach to be added)

Game-theoretic Structure



Economy-wide and sectoral implementation of instruments, e.g.:

- Capital taxes: production, energy, resource sectors
- Energy taxes: fossil and renewable energy

Government's Optimization Problem (Stackelberg leader)

Ojective:

$$\max_{\{\tau_i, P\}} \quad \int_0^T L \ u\left(C/L\right) e^{-\rho t} dt \tag{1}$$

Constraints:

- *Political*: mitigation target
- *Technological*: production technologies
- *Strategical*: reaction functions of followers: analytic first-order conditions from intertemporal optimization

Control variables / policy instruments:

- Price instruments: taxes and subsidies $\{\tau_i\}$ on factor prices
- Quantity instruments: permits P

Policy Instruments

Price instruments

- Ad-valorem and unit taxes on factor prices for capital, labor, energy and resources
- E.g. net resource price for resource owners and net interest rate for households read:

$$\bar{p}_R = p_R - \tau_R \tag{2}$$
$$\bar{r} = r(1 - \tau_K) \tag{3}$$

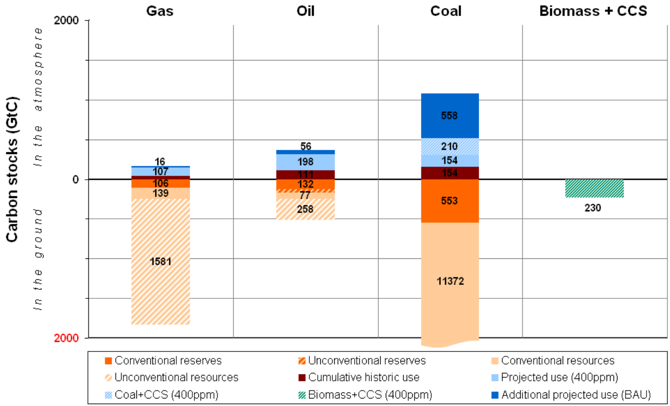
Quantity instrument / carbon bank

- Restrict emissions for economy through permits P
- Allow for intertemporal trading of permits

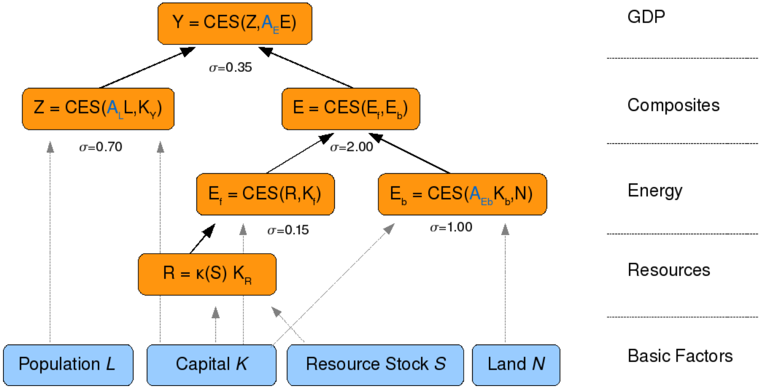
Government runs clear budget: tax incomes and subsidy expenditures are compensated by lump-sum transfers

Carbon budget approach

- Mitigation target: 2C with $p > 67\%$,
- Meinshausen et al. (2009): Cumulative emissions until 2050 $\leq 200 GtC$



Production Technologies



Endogenous Technological Change

Learning-by-Doing (Romer 1986):

- Investments into firm's capital stock K^i increases sector-wide factor productivity A
- General functional form: $A = A_0 + \xi \left(\sum_i K^i\right)^\varsigma$
- Individual firms do not anticipate this effect, i.e. $\frac{\partial A}{\partial K^i} = 0$ (underinvestment)
- Pigouvian spillover subsidy internalizes positive investment externalities

Investment spillovers in production sector:

- Labor-productivity increasing: $A_L = A_L(K_Y)$
- Energy-productivity increasing $A_E = A_E(K_Y)$

...and in renewable sector:

- Productivity increasing: $A_{E,ren} = A_E(K_{E,ren})$

Endogenous Technological Change

Labor productivity augmenting ETC:

$$A_L = A_{L,0} + \xi_L K_Y^{\varsigma_L} + A_{L,exog} \tag{4}$$

$$\hat{A}_{L,exog} = \frac{g}{e^{\zeta t} - g} \tag{5}$$

$$A_{L,exog}(0) = A_{L,exog,0} \tag{6}$$

Energy productivity augmenting ETC:

$$A_E = A_{E,0} + \xi_E K_Y^{\varsigma_E} \tag{7}$$

Renewable energy production augmenting ETC:

$$A_{E,b} = A_{E,b,0} + \xi_{E,b} K_{E,b}^{\varsigma_{E,b}} \tag{8}$$

Reaction Function: Households (1)

Objective:

$$\max_{\{C\}} \quad \int_0^T L\ u\left(C/L\right) e^{-\rho t} dt \tag{9}$$

Constraints:

$$u = \frac{\left(\frac{C}{L}\right)^{1-\eta}}{1-\eta} \tag{10}$$

$$C = wL + (1-\tau_K) rK - I + \Pi + \Gamma \tag{11}$$

$$K = \sum_j K_j \quad I = \sum_j I_j \quad \Pi = \sum_j \Pi_j \tag{12}$$

$$\dot{K} = I - \delta K \tag{13}$$

$$K(0) = K_0 \tag{14}$$

Γ = lump-sum tax; Π_j = sectoral profits

Reaction Function: Households (2)

Hamiltonian:

$$H = L\ u(C/L) + \lambda_H(wL + (1-\tau_K)rK - C + \Pi + \Gamma - \delta K) \tag{15}$$

First-order and transversality conditions:

$$\frac{\partial u}{\partial C} = \lambda_H \tag{16}$$

$$\dot{\lambda}_H = \lambda_H(\rho + \delta - (1-\tau_K)r). \tag{17}$$

$$0 = \lambda_H(T)K(T) \tag{18}$$

Ramsey-rule:

$$r(1-\tau_K) - \delta = \rho + \eta\hat{C} \tag{19}$$

Reaction Function: Resource Sector (1)

Objective:

$$\max_{\{K_R\}} \quad \int_0^\infty \Pi_R \; e^{-\int_0^t \tilde{r}+\gamma \; ds} dt \tag{20}$$

Constraints:

$$\Pi_R = (p_R - \tau_R)R - rK_R \tag{21}$$

$$R = \kappa K_R \tag{22}$$

$$\kappa = \frac{\chi_1}{\chi_1 + \chi_2 \left(\frac{S_0 - S}{\chi_3}\right)^{\chi_4}} \tag{23}$$

$$\dot{S} = -R \tag{24}$$

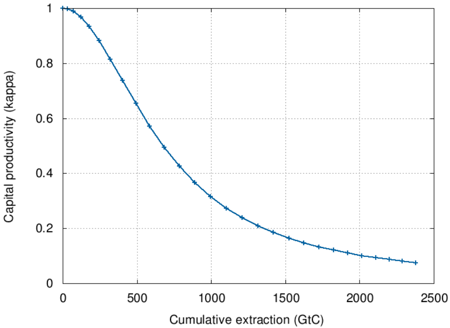
$$\tilde{r} = (1 - \tau_K)r - \delta \tag{25}$$

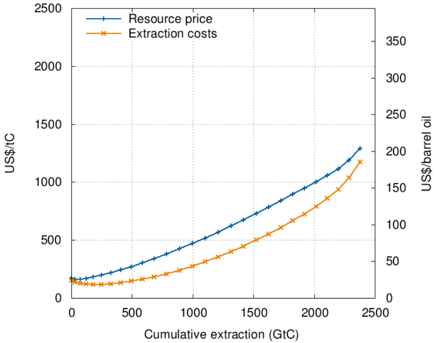
$$S(0) = S_0 \tag{26}$$

Rogner Curve

Productivity of capital κ decreases with cumulative extraction $S_0 - S$:

$$\kappa(S) = \frac{\chi_1}{\chi_1 + \chi_2 \left(\frac{S_0 - S}{\chi_3}\right)^{\chi_4}} \quad , \quad \frac{\partial \kappa(S)}{\partial S} > 0 \tag{27}$$





Reaction Function: Resource Sector (2)

Hamiltonian:

$$H_R = (p_R - \tau_R)\kappa K_R - rK_R - \lambda_R \kappa K_R \qquad (28)$$

First-order and transversality conditions:

$$\lambda_R = p_R - \tau_R - r/\kappa \qquad (29)$$

$$\dot{\lambda}_R = \tilde{r}\lambda_R - (p_R - \tau_R - \lambda_R) K_R \frac{\partial \kappa}{\partial S} \qquad (30)$$

$$\lambda_R(T)S(T) = 0 \qquad (31)$$

Production Sector

Objective and constraints:

$$\Pi_Y = Y - (1+\tau_{K,Y})rK_Y - (1+\tau_L)wL - p_{E,f}E_f - p_{E,b}E_b \tag{32}$$

$$Y = CES(Z, A_E E)\ , \quad Z = CES(K_Y, A_L L)\ , \quad E = CES(E_f, E_b) \tag{33}$$

First-order conditions:

$$(1+\tau_{K,Y})r = \frac{\partial Y}{\partial K_Y} \tag{34}$$

$$(1+\tau_L)w = \frac{\partial Y}{\partial L} \tag{35}$$

$$p_{E,f} = \frac{\partial Y}{\partial E_f} \tag{36}$$

$$p_{E,b} = \frac{\partial Y}{\partial E_b} \tag{37}$$

Energy Sectors

Fossil energy:

$$\Pi_{E,f} = p_E(1-\tau_{E,f})E_f(K_{E,f},R) - rK_{E,f} - (p_R+p_C)R \tag{38}$$

$$p_R + p_C = p_{E,f}(1-\tau_{E,f})\frac{\partial E_f}{\partial R} \tag{39}$$

$$r = p_{E,f}(1-\tau_{E,f})\frac{\partial E_f}{\partial K_{E,f}} \tag{40}$$

Renewable energy:

$$\Pi_{E,b} = p_{E,b}(1-\tau_{E,b})E_b - rK_{E,b} \tag{41}$$

$$E_b(1-\tau_{E,b}) = \kappa_b A_{E,b} K_{E,b}^{\nu} N^{\nu-1} \tag{42}$$

$$r = p_{E,b}\frac{\partial E_b}{\partial K_{E,b}} \tag{43}$$

Calibration and Implementation

Calibration:

- Model results grossly harmonized with ReMIND results and parameters from literature (e.g. elasticities of substitution)
- Carbon budget: 450 GtC for fossil resources (without CCS)
- Time horizon: 2005-2150
- Population: increase up to 9.5 billion
- Mitigation costs: 2.2 % GDP losses; 3.8 % consumption losses

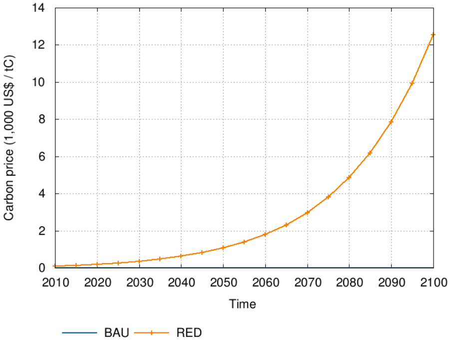
Elasticities of substitution		**Utility function**	
Capital-Labor	0.70	STPR ρ	0.03
Composite-Energy	0.35	EIS η	1.00
Fossile-Renewable	2.00		
Capital-Resources	0.15	**Initial values**	
Capital-Land	1.00	K_0 (trill USD)	98.69
Depreciation δ	0.03	S_0 (GtC)	4,000

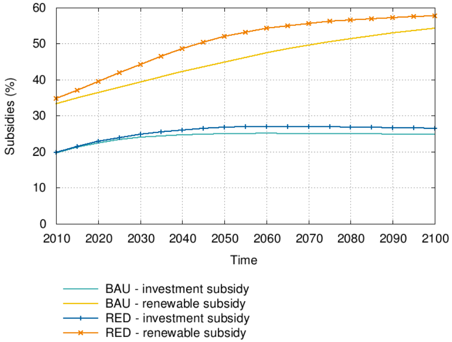
Implementation Details

- Discrete NLP model
- Maximize welfare subject to technological, political and strategical constraints
- Find optimal instruments numerically with GAMS
- Restrict policy space by restricting specific taxes in GAMS (i.e. $\tau_R = 0$: do not use carbon taxes)

Optimal Policy Instruments

- Carbon price (tax or permit price)
- Investment subsidy (production sector)
- Renewable subsidy (renewable energy sector)





Carbon Pricing within the Carbon-Budget Approach

Why do we observe a Hotelling carbon price?

- Optimal carbon price within cost-benefit analysis (Hoel and Kverndokk 1996):

$$\tau_R = \int_t^{\infty} -d_S(S(\xi))e^{r(t-\xi)}\, d\xi$$

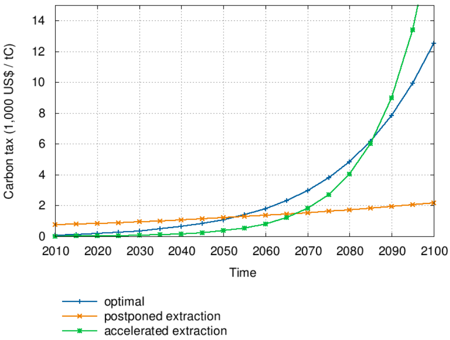
- Carbon budget is a politically created exhaustible resource
- Optimal carbon tax is a Hotelling scarcity price:

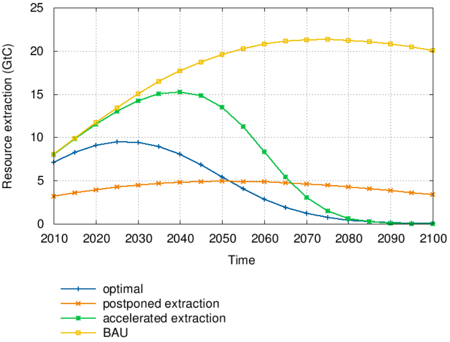
$$\tau_R = \tau_0 e^{rt}$$

- Free permit trading also leads to Hotelling price (Kling and Rubin 1996)
- Carbon-Budget Approach does not achieve an intertemporally efficient allocation of climate damages

Is a Carbon Tax a Robust Policy Instrument?

- Regulator imposes exponentially increasing ad-hoc carbon tax: $\tau = \tau_0 e^{\theta t}$
- Fast increasing tax ($\tau_0 = 10, \theta = 0.08$): Accelerated extraction
- Slow increasing tax ($\tau_0 = 700, \theta = 0.01$): Posponed extraction
- Model resuluts confirm Sinn (2008) and Kalkuhl and Edenhofer (2010)





Is a Carbon Tax a Robust Policy Instrument?

- Sinn (2008): increasing ad-valorem taxes lead to accelerated resource extraction
- Kalkuhl and Edenhofer (2010): increasing unit tax $\tau = \tau_0 e^{\theta t}$ on carbon
- Green paradox does only occur for critical (τ_0, θ) in Hotelling model without extraction costs:

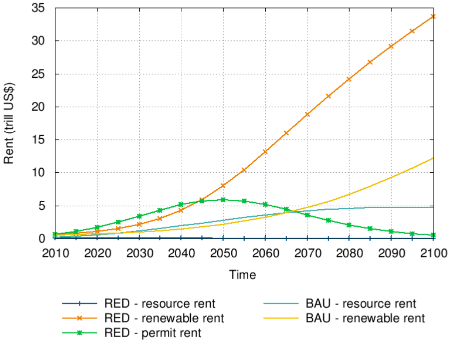
	Slowly increasing tax $\theta < r$		**Tax increases at discount rate** $\theta = r$		**Fast increasing tax** $\theta > r$	
	τ_0 small $\tau_0 \leq \tau_0^*$	τ_0 large $\tau_0 > \tau_0^*$	τ_0 small $\tau_0 \leq \tau_0^*$	τ_0 large $\tau_0 > \tau_0^*$	τ_0 small $\tau_0 \leq \tau_0^*$	τ_0 large $\tau_0 > \tau_0^*$
Timing effect	postpone extraction	postpone extraction	none	none	accelerate extraction	accelerate extraction
Volume effect	none	conservative	none	conservative	none	conservative
Green paradox	none	none	none	none	yes	ambiguous
Impact on damages compared to zero-tax case	- timing effect	-- timing and volume effect	none	- volume effect	++ timing effect	-/+ timing vs. volume effect

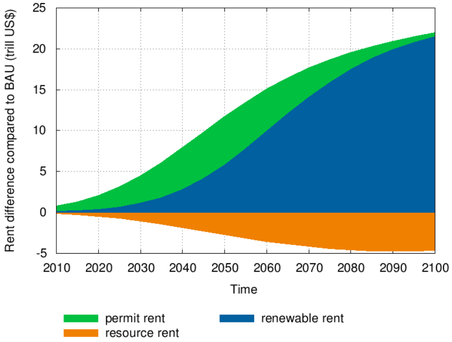
Critical initial tax level τ_0^* such that $S_0 = \int_0^\infty D\left(\tau_0^* e^{\theta t}\right) \, dt$.

Changing Rents

Mitigation changes scarcity rents:

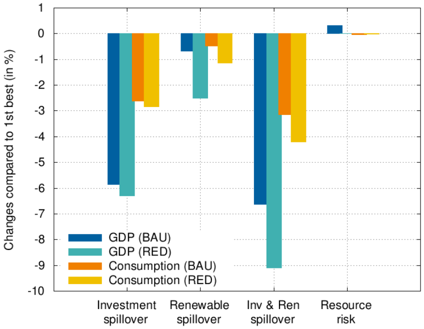
1. Fossil resource rent is reduced
2. Renewable (land) rent increases
3. Permit (carbon budget) rent increases





The Size of Market Failures

- Investment spillovers (production sector)
- Investment spillovers (renewable energy sector)
- Insecure property rights (resource sector)



- Mitigation makes renewable spillovers more severe (compared to BAU)

Second-best Instruments

Why analyze second-best instruments?

Optimal policies not always feasible in practice due to *additional constraints* for the government:

- Carbon price restriction (infeasible or delayed)
- Innovation and technology policy (asymmetric and costly information)
- Further political economy aspects (commitment, tax system, rent seeking)

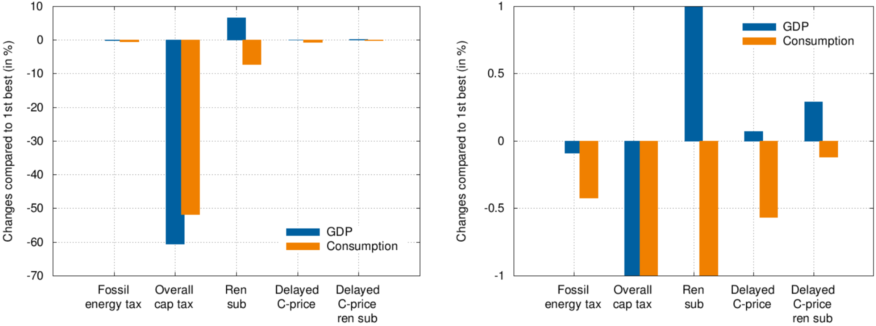
In the following, we study alternative policies:

1. 2nd-best carbon pricing instruments (no optimal carbon price feasible)
2. 2nd-best technology instruments (on optimal subsidies feasible)

Carbon Pricing Instruments

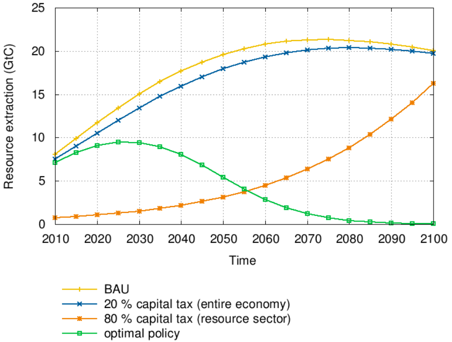
In the following: no carbon price; but technology instruments

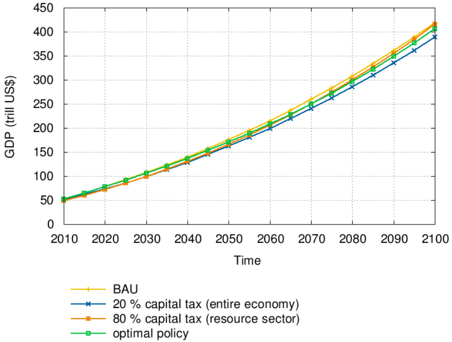
- Tax on fossil energy
- Capital tax on entire economy
- High renewable subsidy
- Delayed carbon pricing (with additional renewable subsidy)



Capital Taxes (Sinn 2008)

- Capital source tax for resource owners cannot change cumulative extraction (transversality condition)
- 80% tax leads to 450 GtC extraction until 2100
- But economy is not decarbonized (increasing resource extraction)
- 20% economy-wide capital tax: little reduction, slow down economic growth

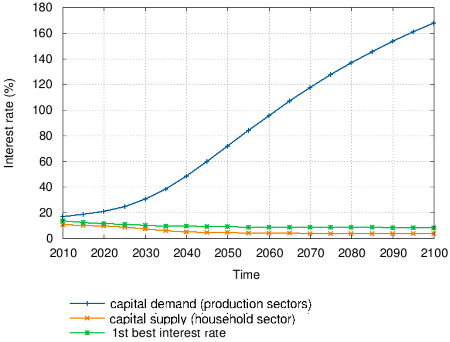


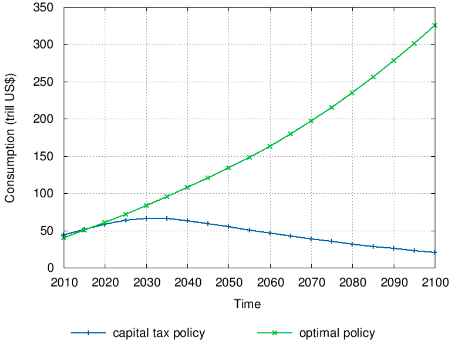


Capital Taxes (2nd-best)

Can capital taxes achieve the carbon budget without carbon pricing?

- High capital tax necessary
- 2nd-best capital tax stalls economic growth completely
- 60.5 % GDP and 51.8 % consumption losses

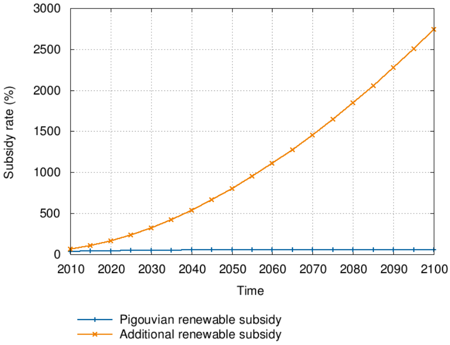


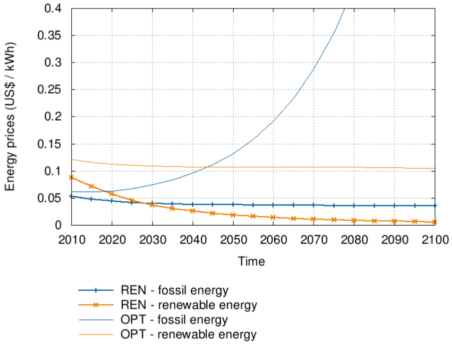


Renewable Subsidies (2nd-best)

Can renewable subsidies achieve the carbon budget without carbon pricing?

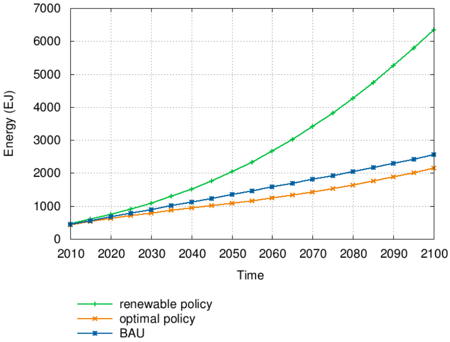
- High subsidy (up to 50 % of GDP used for subsidizing)
- Renewable energy price falls below fossil energy price

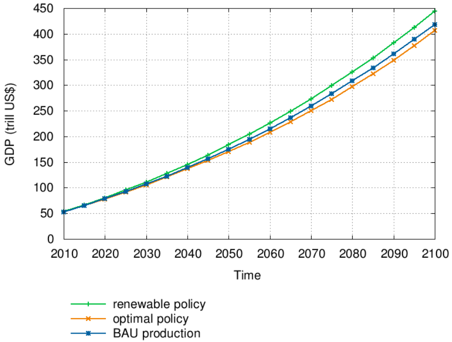




Renewable Subsidies (2nd-best)

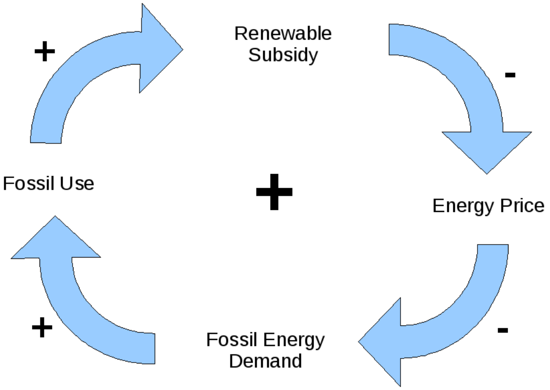
- 'Green growth' due to cheap energy
- 7.3 % consumption losses compared to 1st-best (GDP is used for up-scaling renewable energy)





Renewable Subsidies (2nd-best)

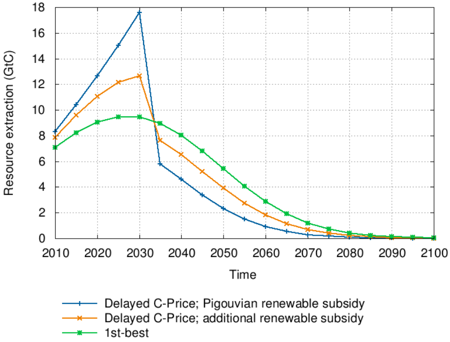
- Rebound effect:
- Renewable subsidies imply higher fossil energy demand

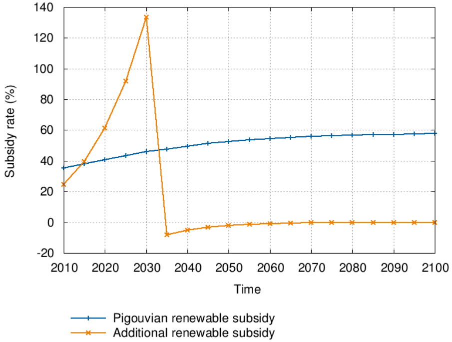


Delayed Carbon Pricing (2nd best)

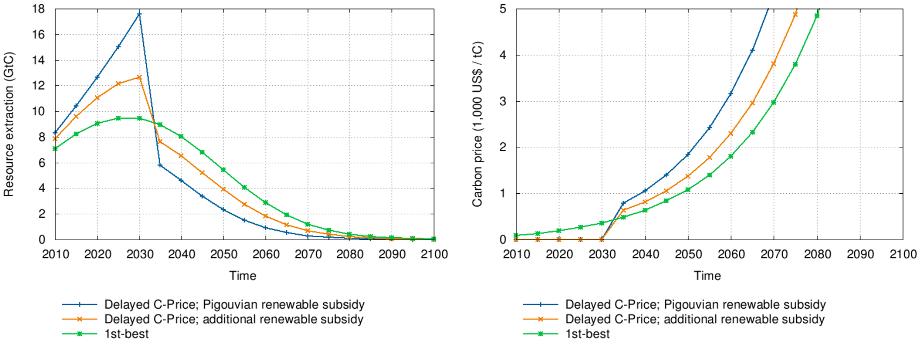
Can renewable subsidies reduce welfare losses of a delayed carbon pricing policy?

- Global carbon price established from 2035 on: 0.6 % consumption losses
- High early extraction; carbon price starts at higher level
- Additional renewable subsidies: only 0.1 % consumption losses





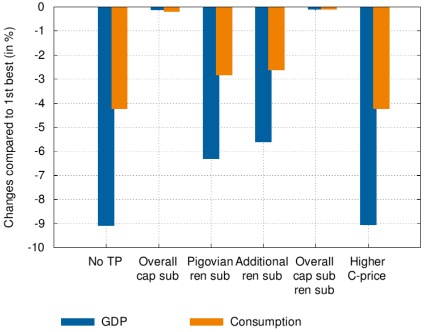
Delayed Carbon Pricing (2nd best)



Second-best Technology Instruments

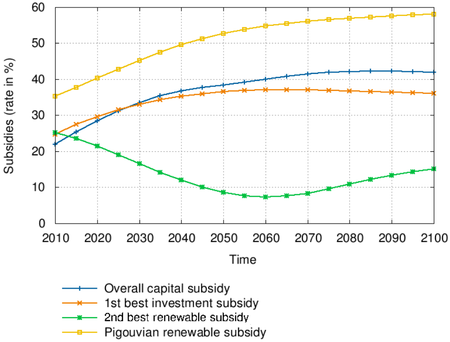
In the following: no (optimal) technology instruments; but carbon price

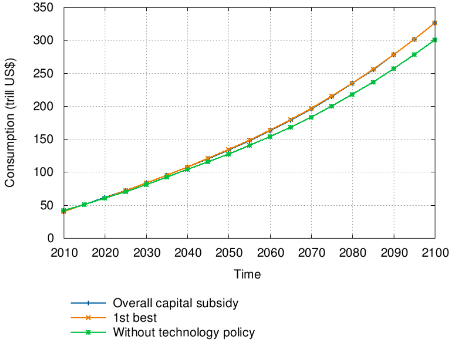
- First-best technology policy (TP) in production sector might not be feasible
- Economy-wide capital subsidy and renewable subsidies as 2nd-best option
- Higher carbon prices as substitute for missing renewable subsidies



Capital Subsidies (2nd-best)

- Economy-wide capital subsidy approx. sectoral Pigouvian investment subsidy
- Welfare losses due to investment distortions in other sectors
- Optimal renewable subsidy has to be lower than Pigouvian level

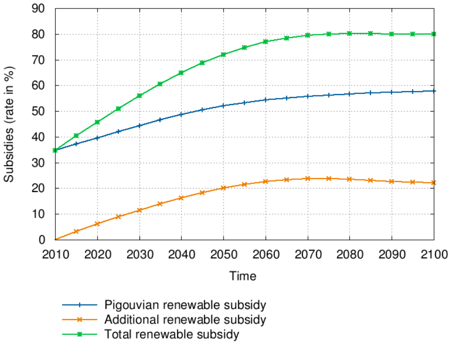


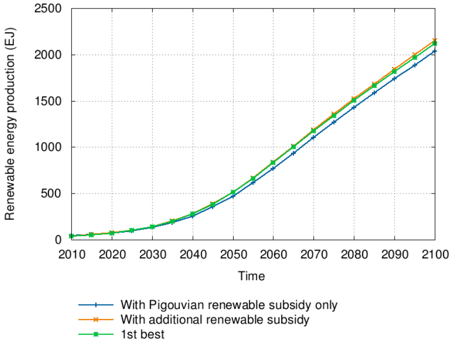


Renewable Subsidies (2nd-best)

If spillovers in production sector cannot be internalized:

- Pigouvian renewable subsidy is welfare-improving
- Optimal renewable subsidy is higher than Pigouvian level





Summary

Main results:

- Optimal instruments: carbon price (tax or permit) and spillover subsidies
- Market failure in renewable sector becomes more severe under mitigation
- Renewable subsidies have important role:
  - Lowering mitigation costs
  - Substituting missing or delayed carbon price
- Capital taxes dilute economic growth
- Higher carbon pricing is a poor substitute for renewable subsidies

Approach is capable to integrate several market failures

- Climate externality
- Technological spillovers
- Insecure property rights

Outlook

Several model extensions:

- Fine-tuning calibration
    - Technological realism ?
- Introduce damage function
    - Cost-benefit framework
- Irreversible investments / costly deinvestment
- Exclude lump-sum transfers
    - Rent seeking aspects
- Introduce government consumption
    - Public finance
    - Double-dividend
- Transaction and information costs (monitoring)

Thank You for Your Attention!

For further questions contact:

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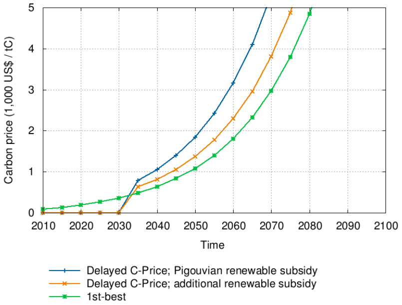
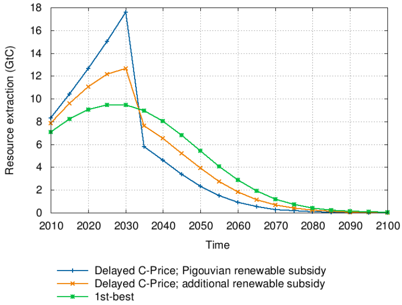
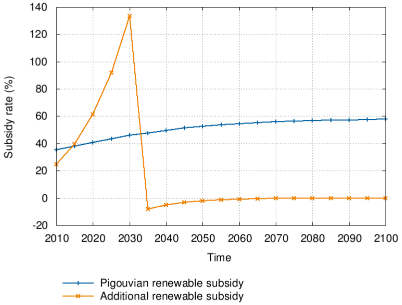
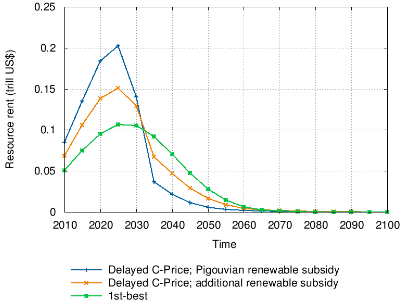
Backup Slides

Delayed Carbon Pricing

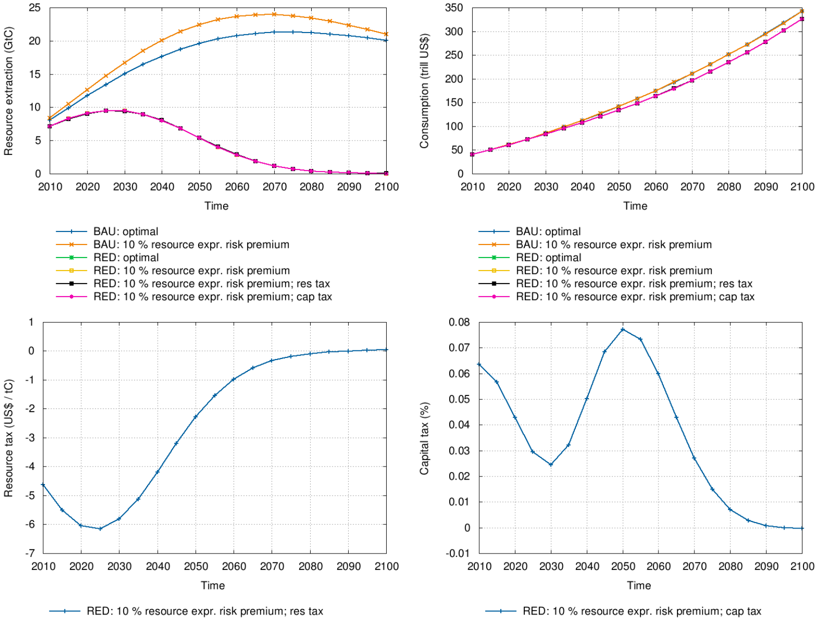




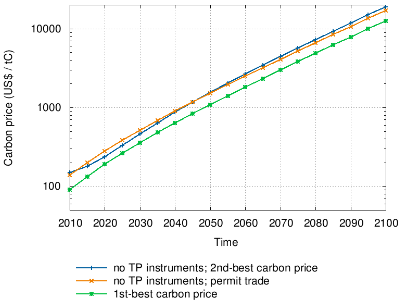


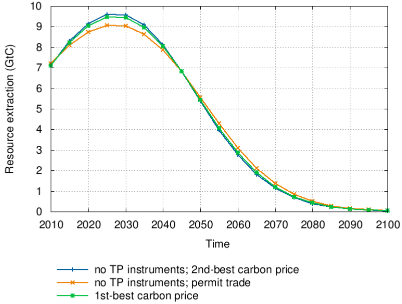


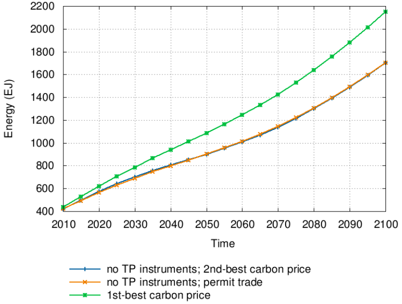
Resource Expropriation Risk

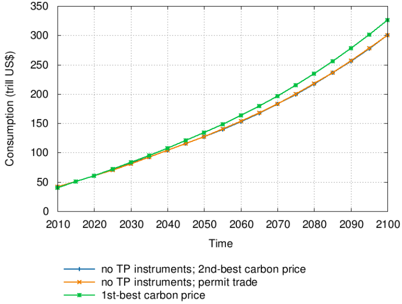


Carbon Pricing as Second-best Technology Instrument

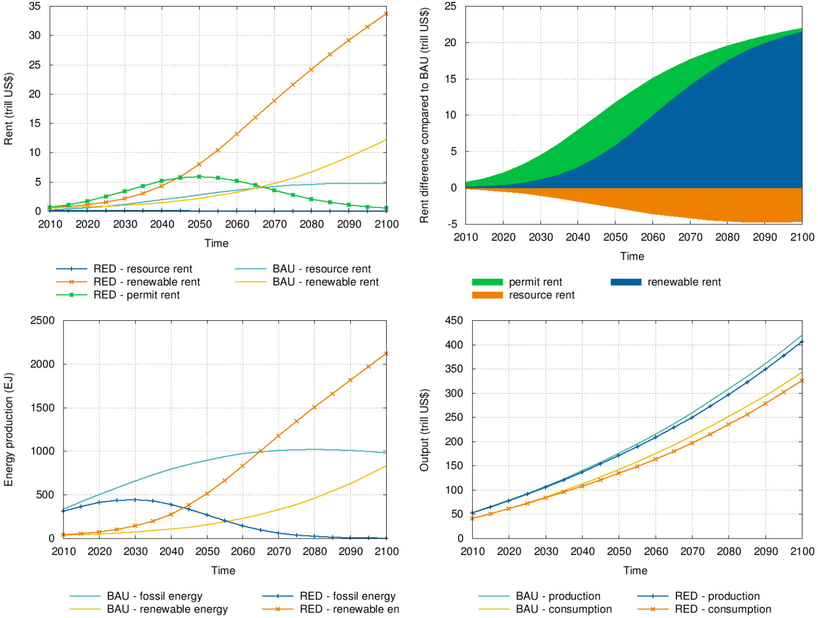








Mitigation



Rent (trill US$)
Time
RED - resource rent
RED - renewable rent
RED - permit rent
BAU - resource rent
BAU - renewable rent
Rent difference compared to BAU (trill US$)
Time
permit rent
renewable rent
resource rent
Energy production (EJ)
Time
BAU - fossil energy
BAU - renewable energy
RED - fossil energy
RED - renewable en
Output (trill US$)
Time
BAU - production
BAU - consumption
RED - production
RED - consumption

Market Failures: Rent (BAU and RED)