Directed technical change and the resource curse

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Introduction

- Resource curse:
  - Abundant natural resources may hamper economic growth
- Possible reasons:
  - Political failures (Robinson et al., 2014)
  - Lack of technological progress (van der Ploeg, 2011)
- This paper:
  - *Wrong type* of technological progress?

Introduction

- Focus: Fossil fuels – currently (highly) profitable
  - Example: Norway!
- Future profits may be reduced for two main reasons:
  - Depletion effect → Higher extraction costs
  - Global climate policy → Lower prices
- Are current R&D activities optimally allocated?
  - Clean vs. dirty technology
    - Cf. Acemoglu et al. (2012): Directed technical change and path dependency
  - Does the innovation market need some correction?
  - Risk of becoming a laggard in new green technologies?

Our framework

- Small open economy with energy produced by non-renewable (“dirty”) and renewable (“clean”) resources
  - Prices of dirty and clean energy are given from abroad
    - → Disregard energy consumption
    - Future price paths for dirty and clean energy crucial
  - Scientists can be used in either clean or dirty innovation
  - Dirty innovation is initially more profitable
    - Standing on shoulders of previous research
    - Assume that scientists are short-sighted
  - Non-renewable resource costs increase with accumulated extraction
    - Accounted for by non-renewable producers? (Heal, 1976)
- Theoretical and numerical analysis

Our framework

- Main question:

  Will innovation markets induce a switch away from fossil fuels to clean technologies in time?

  - Or will innovators be locked in by history, leading to resource curse?
  - How do market failures in non-renewable extraction and R&D interact?

  → How do optimal R&D activities compare with BaU?

  → What are optimal (or second-best) policies?

- Point to two main effects:
  - Technology effect:

    Scientists do not factor in positive knowledge externalities on future R&D
  - Price effect:

    Scientists do not factor in changes in future energy prices

Previous literature

- Resource curse
  - Robinson et al. (2014); van der Ploeg (2011)
- Directed technical change and the environment
  - Acemoglu et al. (2012): Seminal paper
    - Technological change within energy technologies may be path dependent
    - → Need to redirect innovation towards clean technologies
  - Many follow-up studies
    - E.g. Acemoglu et al. (2016); Greaker et al. (2018); Hart (2019); Lemoine (2020)
    - None of these include non-renewable resource extraction
  - Hassler et al (2021): Only non-renewable resource (no clean energy)
- Standing on shoulders forever?
  - Pope et al. (2013): Fishing out in the long run

Analytical model

- Builds on (and modify) Acemoglu et al. (2012)
- Energy production of type *j*:

$$Y_{jt} = R_{jt}^{\alpha_2} \int_0^1 A_{jit}^{1-\alpha_1} x_{jit}^{\alpha_1} di,$$

  - *j* = *c* (clean), *d* (dirty)
  - *R*: Energy resource
  - *x*: Machine variants
  - *A*: Quality of machines (technology level)
- Costs of non-renewable resource extraction:

$$c_{dt} = c(Q_t) \qquad c' > 0, c'' > 0$$

  - *Q*: Accumulated extraction
  - Constant unit costs of clean (renewable) resource
- Assumption: Producers of dirty energy disregard depletion effect

  → Extraction tax necessary to implement optimal solution

Analytical model

- Each machine type is the result of an innovation
  - Heterogeneous machines → Monopolistic competition
    - Market power corrected for by subsidy → Efficient use of each machine type
- Innovation:
  - Total number of scientists is given:
    $$\ell_{ct} + \ell_{dt} = 1$$
  - Each scientist chooses whether to do clean or dirty R&D
  - Innovations occur with an endogenous probability: $\eta_j \ell_{jt}^{\varpi}$,
    - Decreasing returns to R&D within each period and for each technology
  - Quality of machines increases with new innovations:
    $$A_{jt} = \left(1 + (\eta_j \ell_{jt}^{\varpi} + \nu_j)\gamma\right) A_{jt-1}.$$
    - γ: Quality step
    - ν_j: Arrival of foreign innovation (mostly disregarded in the analysis)

Analytical model

- Innovation (cont.):
  - Assume that scientists (innovators) only earn profit in the first period
    - Following Acemoglu et al. (2012)
  - Derive following arbitrage condition (equal profit from clean and dirty R&D):

$$\frac{\ell_{ct}}{\ell_{dt}} = \left(\frac{(1+s_{ct})\eta_c \left(P_{ct} R_{ct}^{\alpha_2}\right)^{\frac{1}{1-\alpha_1}} A_{ct-1}}{(1+s_{dt})\eta_d \left(P_{dt} R_{dt}^{\alpha_2}\right)^{\frac{1}{1-\alpha_1}} A_{dt-1}} \right)^{\frac{1}{1-\varpi}} .$$

    - s_{jt}: R&D subsidy

- Proposition 1.

  More researchers will be allocated to a sector *j*

  i. the higher is the current final product price P_{jt}

  ii. the lower is the current private resource cost $c_{jt} + \tau_{jt}$

  iii. the higher is the existing level of technology A_{jt-1}

Analytical model

- The social planner maximizes NPV of energy production:

$$\max_{L_{jt},\ell_{jt},R_{jt},Y_{jt}} \sum_{t=0}^{\infty} \frac{1}{(1+r)^t} \left[\sum_j P_{jt}Y_{jt} - \psi \left(\int_0^1 x_{cit} di + \int_0^1 x_{dit} di \right) - c_{dt}R_{dt} - \bar{c}R_{ct} \right]$$

- This gives the following condition for optimal allocation of scientists:

$$\frac{\ell_{ct}^S}{\ell_{dt}^S} = \left(\frac{\frac{A_{ct-1}}{A_{ct}} \sum_{k=0}^{\infty} (\frac{1}{1+r})^k P_{c,t+k} Y_{c,t+k}}{\frac{A_{dt-1}}{A_{dt}} \sum_{k=0}^{\infty} (\frac{1}{1+r})^k P_{d,t+k} Y_{d,t+k}} \right)^{\frac{1}{1-\varpi}},$$

- Compared with BaU-condition (with s_{jt} = 0 and $\eta_c = \eta_d$):

$$\frac{\ell_{ct}^M}{\ell_{dt}^M} = \left(\frac{\frac{A_{ct-1}}{A_{ct}} P_{ct} Y_{ct}}{\frac{A_{dt-1}}{A_{dt}} P_{dt} Y_{dt}} \right)^{\frac{1}{1-\varpi}}$$

Analytical results

- Message:

  While the innovation market only considers current profits from energy production, the social planner also considers future profits

- What are the implications for R&D subsidies and direction of technical change?
  - Distinguish between *technology effect* and *price effect*

Analytical results

- Technology effect:

Proposition 2 *Along an optimal subsidy path where the socially optimal $A_{j,t+k}$ are induced in the market while the price $P_{j,t+k}$ and the resource cost $\chi_{d,t+k}$ are fixed for $j \in c, d$ for all k, the optimal subsidy s^*_{jt} at time t is increasing in the socially optimal allocation of scientists $\ell^S_{j,t+k}$ for any $k > 0$.*

- In plain words: The more scientists should do clean R&D in the *future*, the higher is the optimal subsidy to clean R&D *today*
  - Scientists of today do not take into account the knowledge spillover for the future
    - Standing on shoulders
- Thus: If the clean transition is coming (or should come), it should be accelerated

Analytical results

- Price effect:

Proposition 3 *For fixed technology* $\hat{A}_{j,t+k}$ *and resource cost* $\chi_{d,t+k}$ *for* $j \in c, d$ *for all* k*, the optimal subsidy* s^*_{jt} *at time* t *is:*

i) unchanged if the percentage fall in prices $P_{j,t+k}$ *is the same for all* k*;*

ii) lower if the percentage fall in prices $P_{j,t+k}$ *is larger for at least one* k *than the price fall at time* t *(and the price fall is at least equal to the price fall at time* t *for all other* k*);*

iii) higher if the percentage fall in the price $P_{j,t+k}$ *is larger at time* t *than the price fall for any* k*.*

- In plain words: A gradually declining price of dirty energy in the future implies a higher optimal subsidy to clean R&D *today*
  - Future drop in profitability of dirty energy is not taken into account in the market

Analytical results

- Cost effect: Similar (but opposite) as Proposition 3 → Proposition 4
- In plain words: Gradually higher extraction costs imply a higher optimal subsidy to clean R&D *today*

- Corollary on extraction tax:

Corollary 1 *For fixed technology $\hat{A}_{j,t+k}$ and price $P_{j,t+k}$ for $j \in c, d$ for all k, the optimal subsidy s^*_{jt} at time t is higher if the percentage rise in the extraction tax $\tau_{d,t+k}$ is larger at time t than the rise for any $k > 0$.*

- In plain words: Introducing (or increasing) extraction tax *today* implies a *lower* optimal subsidy to clean R&D *today*

Resource curse

- Our definition:

Definition 1 *The economy is in a state of (technology) resource curse if along the* laissez fair *growth path, more researchers are allocated to dirty innovation than clean innovation in each period, i.e.,* $\ell_{dt}^{M} > \ell_{ct}^{M}$ $\forall t$*, while there exist alternative development paths that give higher wealth as given by (16) in which more researchers are allocated to clean innovation than dirty innovation from a period* T *onwards, i.e.,* $\ell_{dt} < \ell_{ct}$ $\forall t > T$.

Numerical simulations

- Straightforward parameterization of the analytical model
  - Mostly based on previous studies
  - 5-years periods simulated for 150 years (display 100 years)
- Consider four scenarios that differ according to:
  - Technology distance between clean and dirty (A_c vs. A_d)
    - How much behind is clean technology? 40% vs. 60% below initially
  - Future price path for dirty energy
    - Constant: "Business as usual"
    - Declining: "Global climate policy" (5% reduction per period)

		Technology distance	
		Large	Small
Dirty price	Constant	S I	S III
	Declining	S II	S IV

- Consider four policy cases
  - Laissez fair (BaU); First best with optimal R&D subsidy and extraction tax; Second-best policies with either subsidy or tax

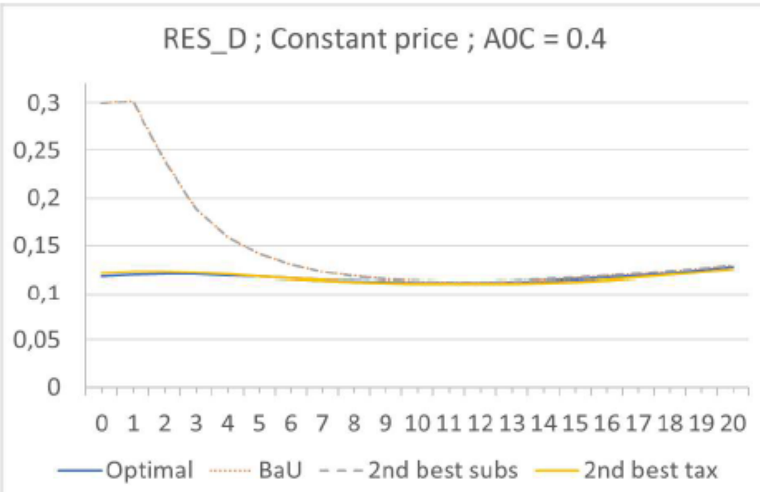
Scenarios: 4 different types of outcome

1. Steady course
   – Keeping on extracting fossil fuels is *optimal* since the increasing extraction cost can be counteracted by focusing R&D effort in the dirty energy sector
2. Resource curse due to global climate policy
   – Keeping on extracting fossil fuels is *not optimal* when the fossil fuels price decreases, but the private sector does not shift to clean R&D
3. Resource curse with no global climate policy
   – Keeping on extracting fossil fuels is *not optimal* even if the fossil fuels price stays constant, but the private sector does not shift to clean R&D
4. Induced change in course due to climate policy
   – Keeping on extracting fossil fuels is *not optimal*, and the private sector shifts R&D efforts to the clean energy sector without intervention from the government

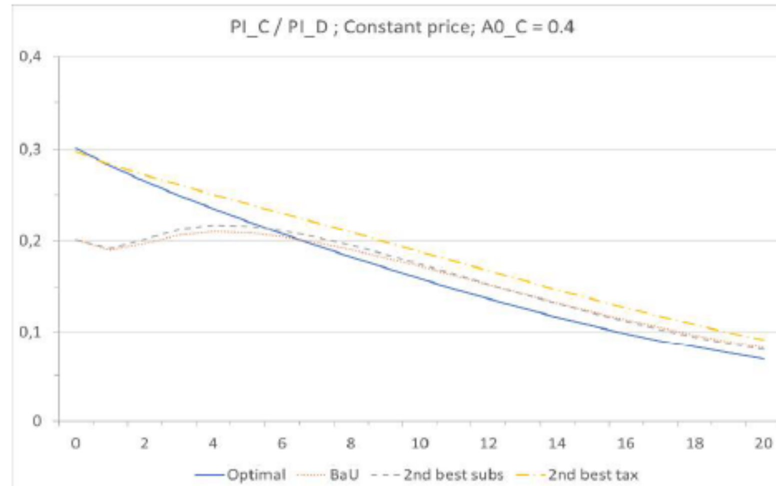
		Technology distance	
		Large	Small
Dirty price	Constant	S I	S III
	Declining	S II	S IV

Scenario I: Steady course

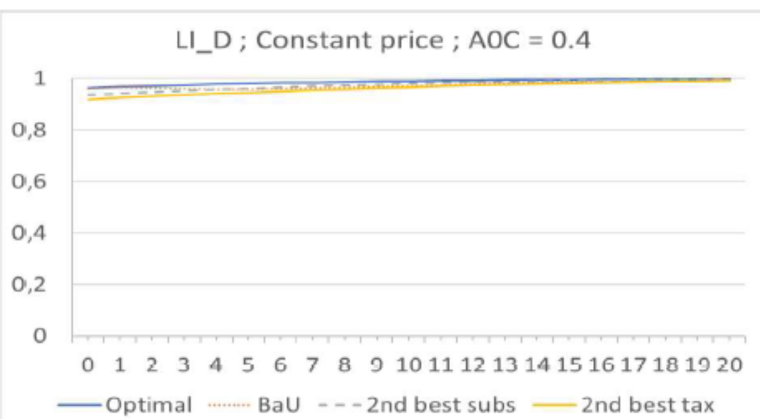
Panel a) Petroleum resource extraction



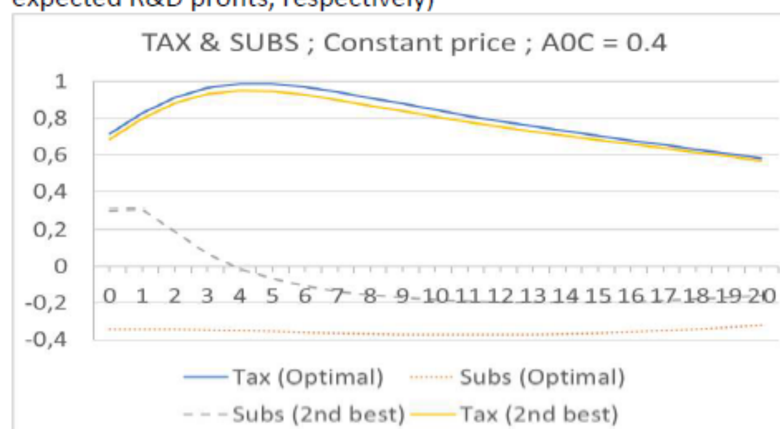
Panel b) Relative profits in clean versus dirty energy production



Panel c) Allocation of researchers to dirty R&D



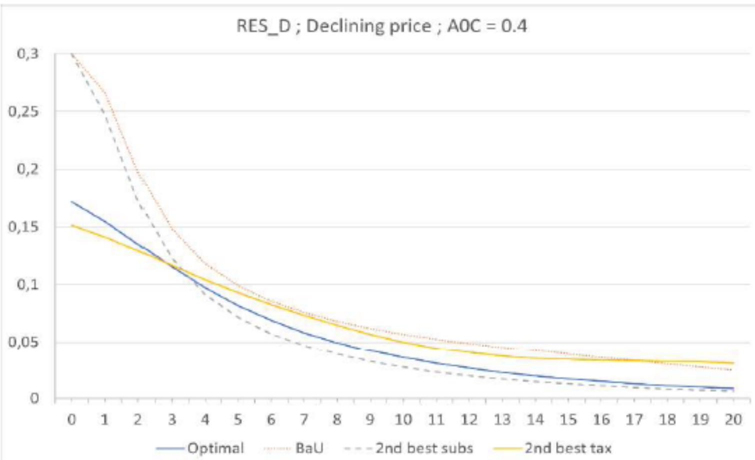
Panel d) Tax and subsidy levels (as shares of resource costs and expected R&D profits, respectively)



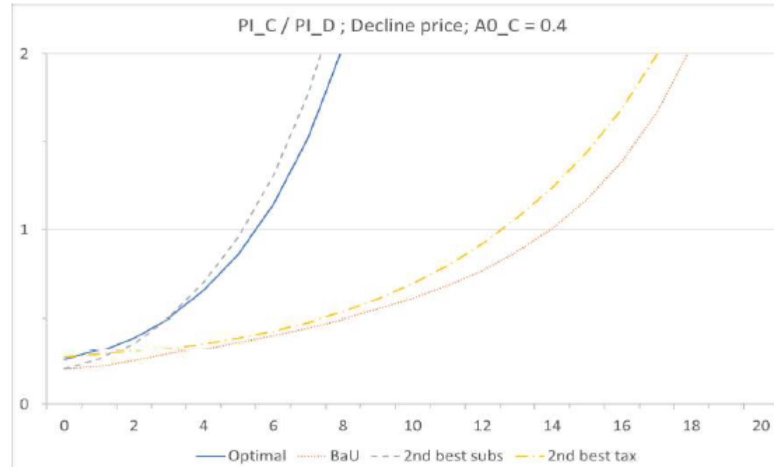
		Technology distance	
		Large	Small
Dirty price	Constant	S I	S III
	Declining	S II	S IV

Scenario II:
Resource curse due to global climate policy

Panel a) Petroleum resource extraction



Panel b) Relative profits in clean versus dirty energy production



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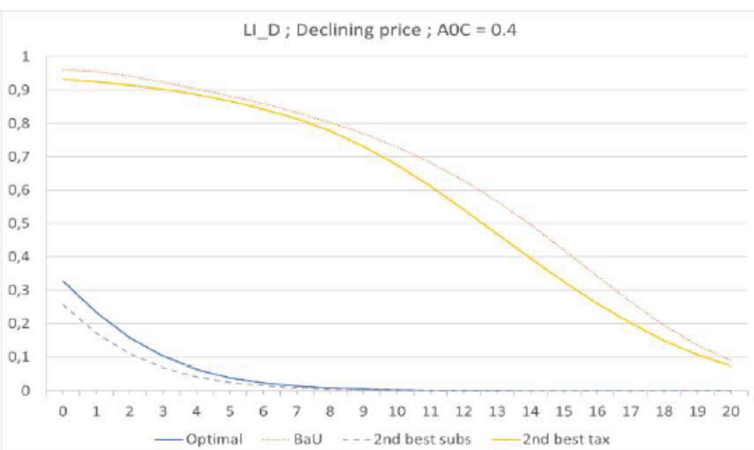
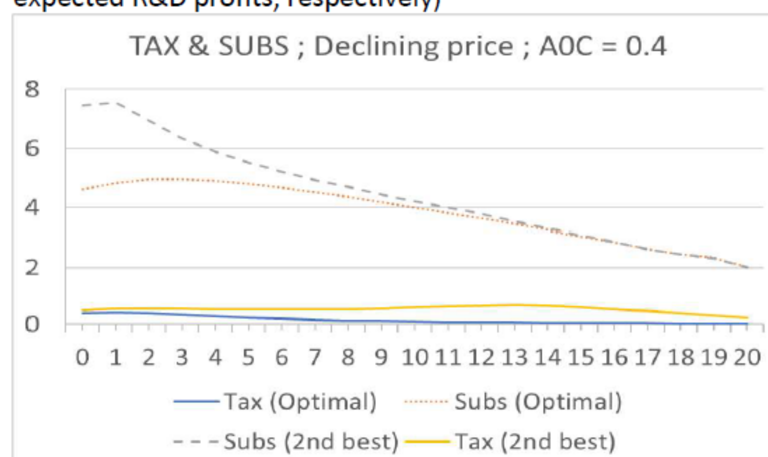


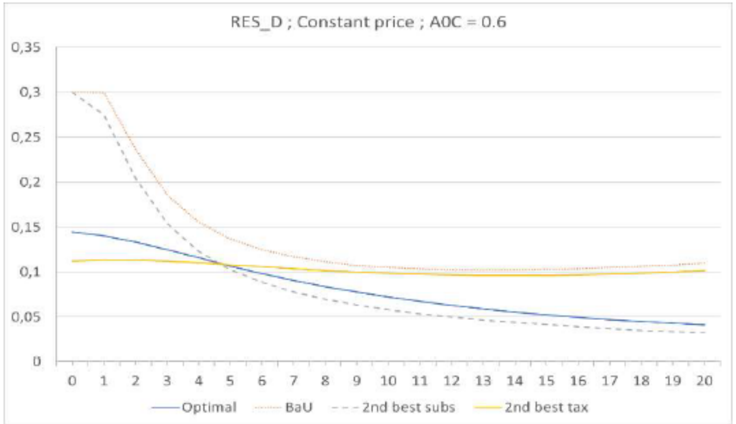
Panel d) Tax and subsidy levels (as shares of resource costs and expected R&D profits, respectively)



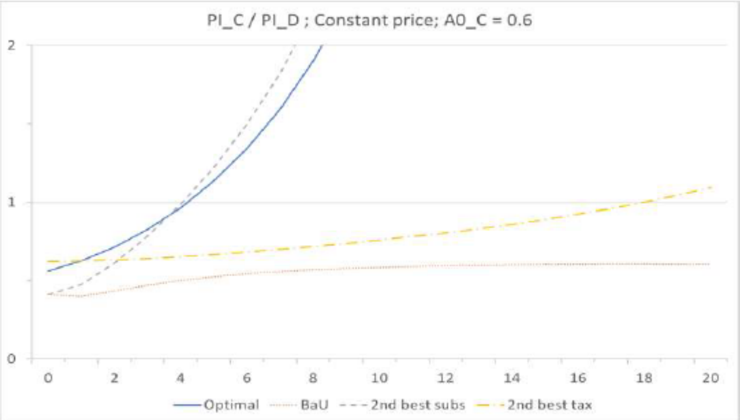
		Technology distance	
		Large	Small
Dirty price	Constant	S I	S III
	Declining	S II	S IV

Scenario III:
Resource curse with no global climate policy

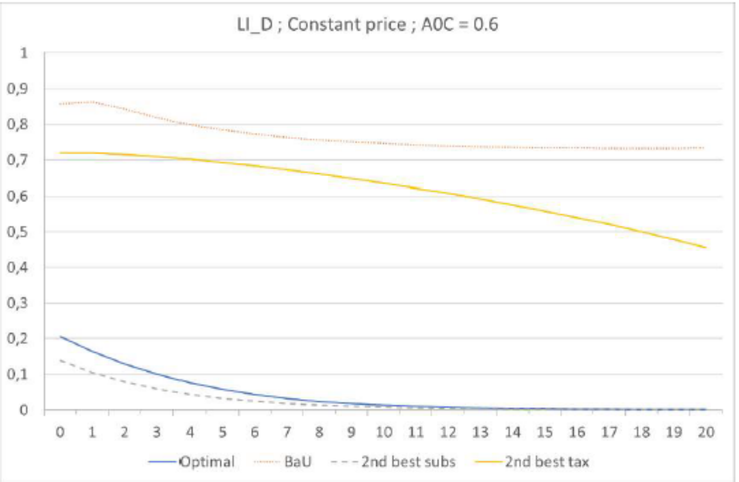
Panel a) Petroleum resource extraction



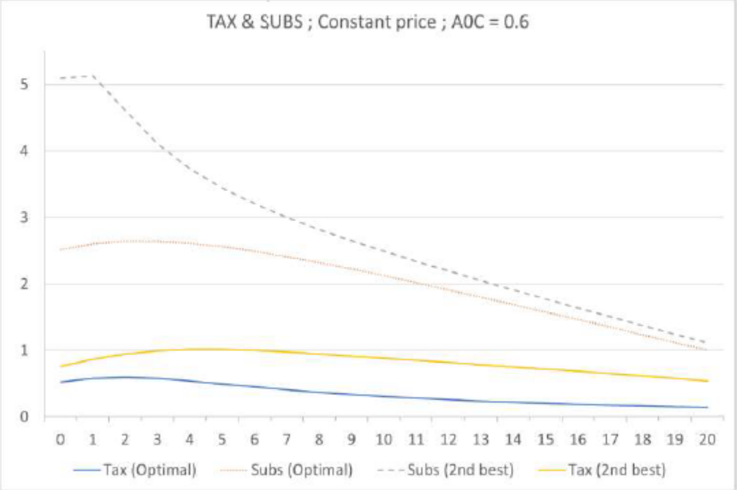
Panel b) Relative profits in clean versus dirty energy production



Panel c) Allocation of researchers to dirty R&D



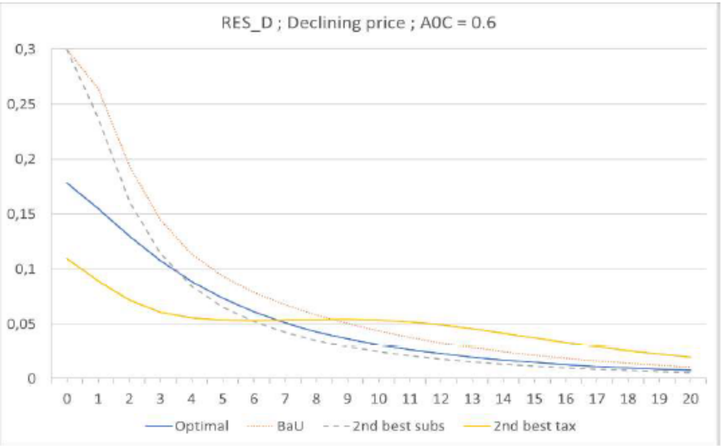
Panel d) Tax and subsidy levels (as shares of resource costs and expected R&D profits, respectively)



		Technology distance	
		Large	Small
Dirty price	Constant	S I	S III
	Declining	S II	S IV

Scenario IV:
Induced change in course due to climate policy

Panel a) Petroleum resource extraction



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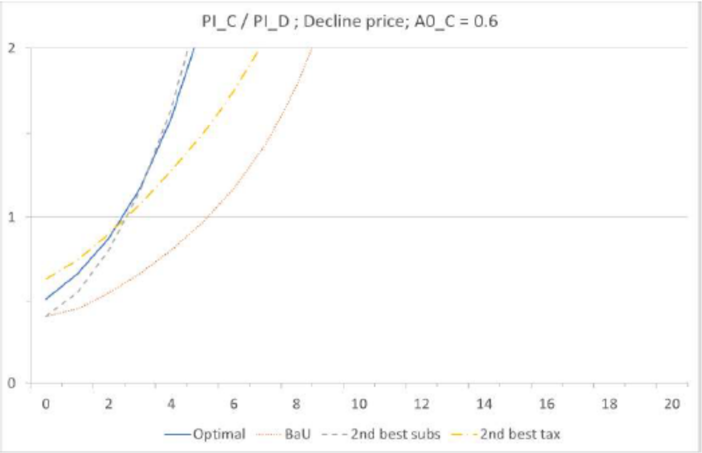

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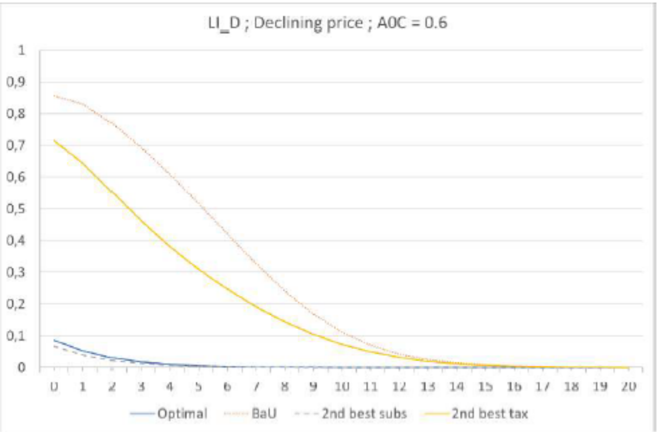

Panel d) Tax and subsidy levels (as shares of resource costs and expected R&D profits, respectively)

Wealth effects

Scenarios	I	II	III	IV
BaU	3.52	2.40	4.17	3.65
Optimal	3.96	2.89	5.00	4.43
2nd best subsidy	3.53	2.82	4.84	4.37
2nd best tax	3.95	2.56	4.59	3.91
(Optimal-BaU)/BaU	12.5%	20.4%	20.0%	21.4%
(2nd subsidy-BaU)/(optimal-BaU)	0.3%	85.6%	80.5%	92.6%
(2nd tax-BaU)/(optimal-BaU)	97.9%	31.3%	50.7%	33.4%

- Most interesting comparison: Between 2nd best subsidy and 2nd best tax
- Scenario I: Tax clearly most important
- Scenarios II-IV: Subsidy much more important (almost 1st best in S IV)

Arrival of innovation from abroad

- So far: Only domestic innovation
- What if innovation arrives exogenously from abroad?
  - Assume equal impulse for dirty and clean
  - Assume (approx.) equal impulse from domestic and foreign innovation
  - Assume (approx.) same total impulse as with only domestic innovation
- Two main insights:
  - No longer optimal with subsidies to dirty R&D in Scenario I
  - R&D subsidies are less important than before
    - In some scenarios the extraction tax is more important

Summing up

- Technological progress is path dependent

  → May be need to direct technical change (Acemoglu et al., 2012)

- Abundance of fossil fuel resources may exacerbate the need to direct technical change
  - Future profitability may be hampered by increasing extraction costs and global climate policy

→ May risk a resource curse

- Some discussion points / caveats:
  - How short- or farsighted are innovators and extractors?
  - Are clean and dirty technologies completely different types, or are there spillovers?

THANKS FOR THE ATTENTION!