Linking Energy System and Macroeconomic Growth Models

Is the Supply Curve Enough?

Nico Bauer

Ottmar Edenhofer

Contents

- Two Models
- Two Approaches
- Results
- Augmenting the Soft-Link
- Intermediate Conclusions
- Artificial Constraints
- Conclusions

Energy System Model

- 2 types of primary energy (fossil, renewable)
- 2 types of final energy (high and low capital costs)
- 2 conversion technologies for each

$$\text{Min!}\, DESC = \int_{t=\tau_1}^{\tau_2} e^{-rt}\left(C_{Inv} + C_{Fuel} + C_{O\&M}\right)dt;$$

s.t.: linear equations;

$E(t)$ exogenous.

PAUL SCHERRER INSTITUT PSI

Nico Bauer
Ottmar Edenhofer

PIK

Macro Growth Model

- Welfare and macro production function
- 2 types of final energy
- 2 capital stocks with depreciation

$$\text{Max!} = \int_{t=\tau_1}^{\tau_2} e^{-\rho t} U\left(F(K,L,E) - I - EE\right) dt;$$

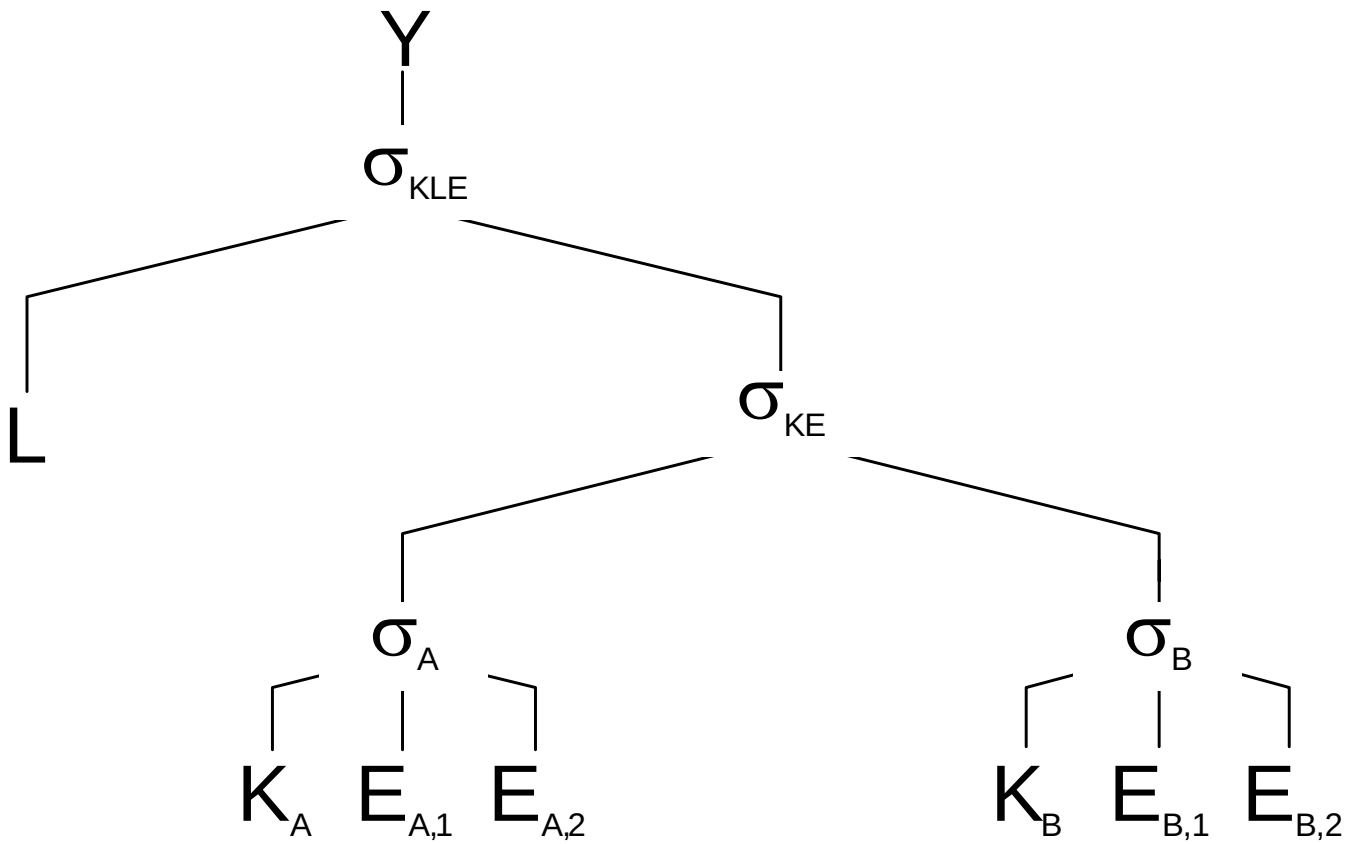
$$\text{s.t.:} \qquad \dot{K} = I - \delta K, \qquad K^0.$$

PAUL SCHERRER INSTITUT

Nico Bauer
Ottmar Edenhofer

P I K

Macro Growth Model



PAUL SCHERRER INSTITUT
PSI

Nico Bauer
Ottmar Edenhofer

PIK

Hard-Link

- Full Integration of ESM into MGM

$$EE = C_{Tot}$$

- Benchmark for comparison

PAUL SCHERRER INSTITUT
PSI

Nico Bauer
Ottmar Edenhofer

P I K

Soft-Link

- 2 energy supply curves in MGM

$$EE(t) = a(t) + \sum_{i=1,2} b_i(t) E_i(t)^c.$$

- Iteration

$$E = \mathrm{M}(a,b); \quad \begin{pmatrix} a \\ b \end{pmatrix} = \mathrm{E}(E).$$

- Approximation of hard-link result

PAUL SCHERRER INSTITUT PSI

Nico Bauer
Ottmar Edenhofer

PIK

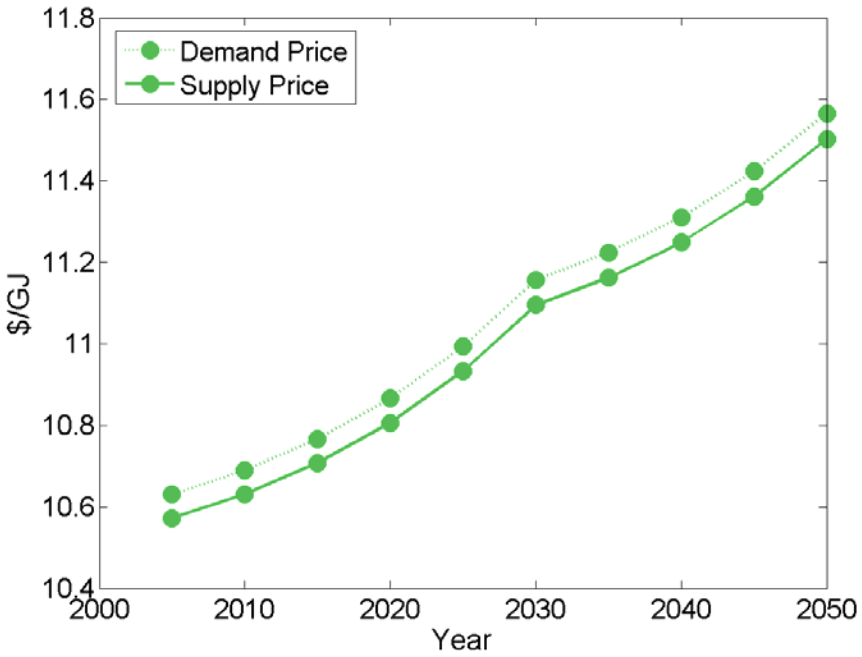
Research Questions

- Soft-link
  - Energy prices?

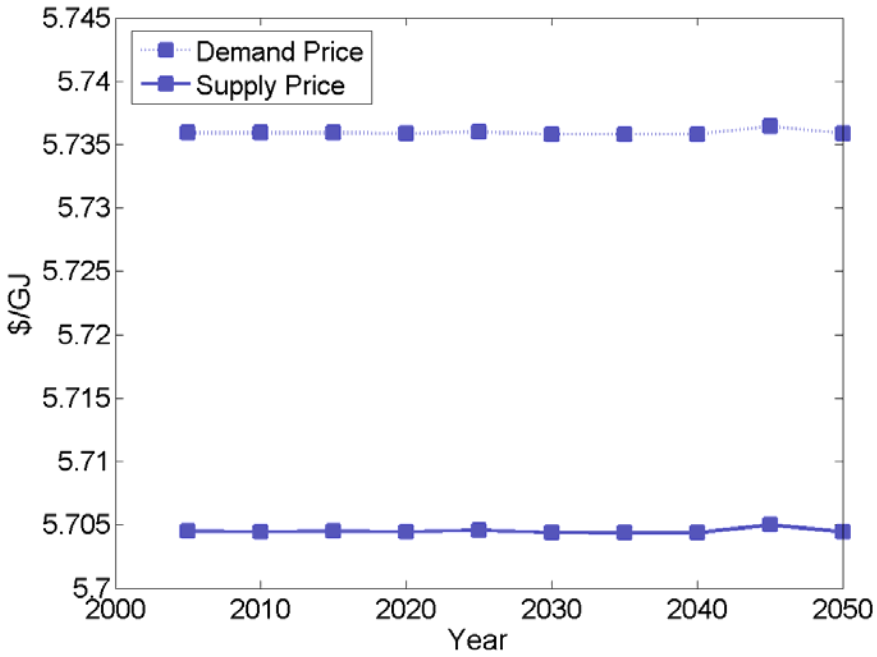
- Hard-link vs. Soft-link
  - Energy prices and quantities?
  - Capital market?

Results – Soft-Link

Price energy type 1



Price energy type 2



PAUL SCHERRER INSTITUT

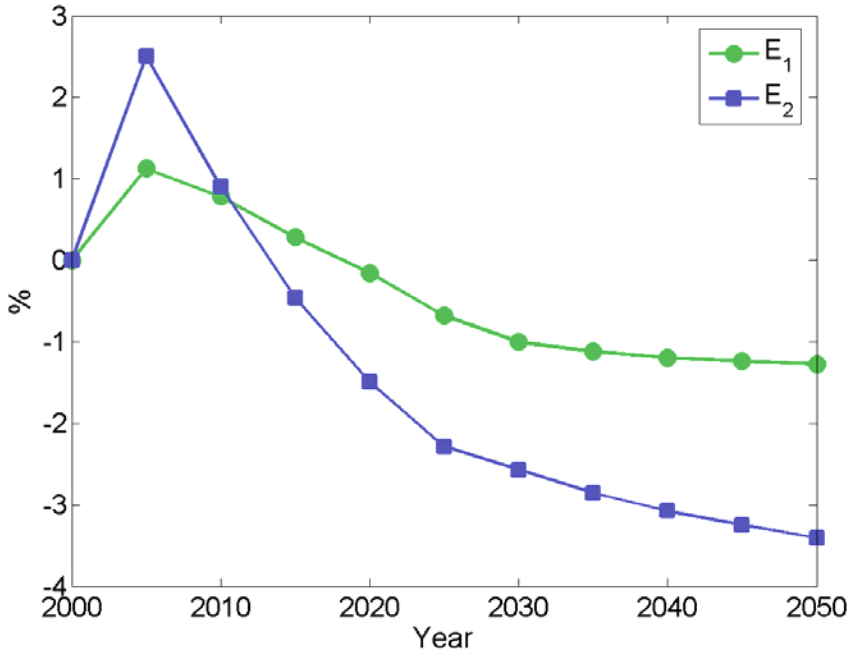
PSI

Nico Bauer
Ottmar Edenhofer

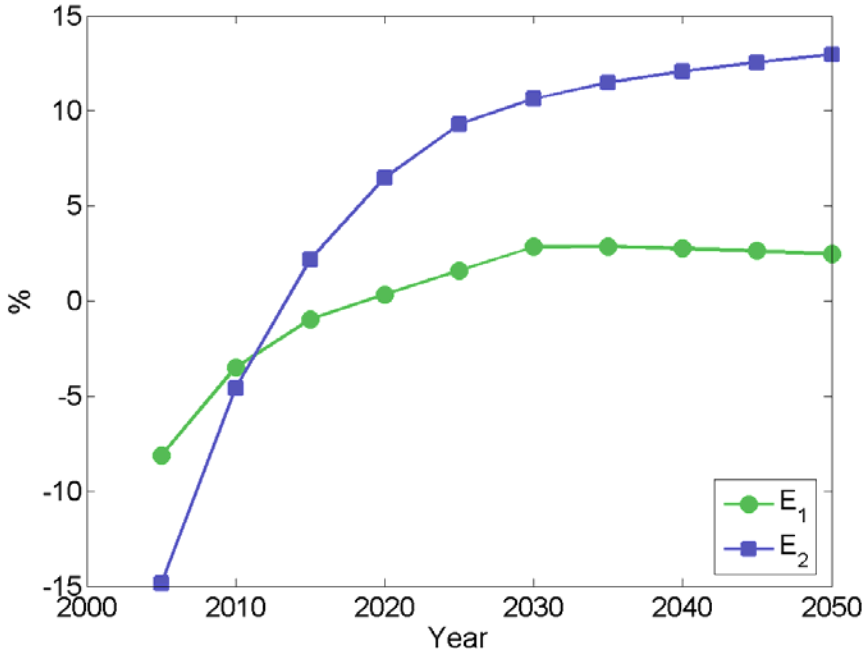
P I K

Results – Hard vs. Soft

Rel. quantity differences



Rel. price differences



PAUL SCHERRER INSTITUT
PSI

Nico Bauer
Ottmar Edenhofer

P I K

Results – Hard vs. Soft

- Own rate of return r_i is technology specific
- Equilibrium interest rate r^*
- Capital market equilibrium

$$I_i \geq 0 \quad \Leftrightarrow \quad r^* = r_i$$
$$I_i = 0 \quad \Leftrightarrow \quad r^* > r_i$$

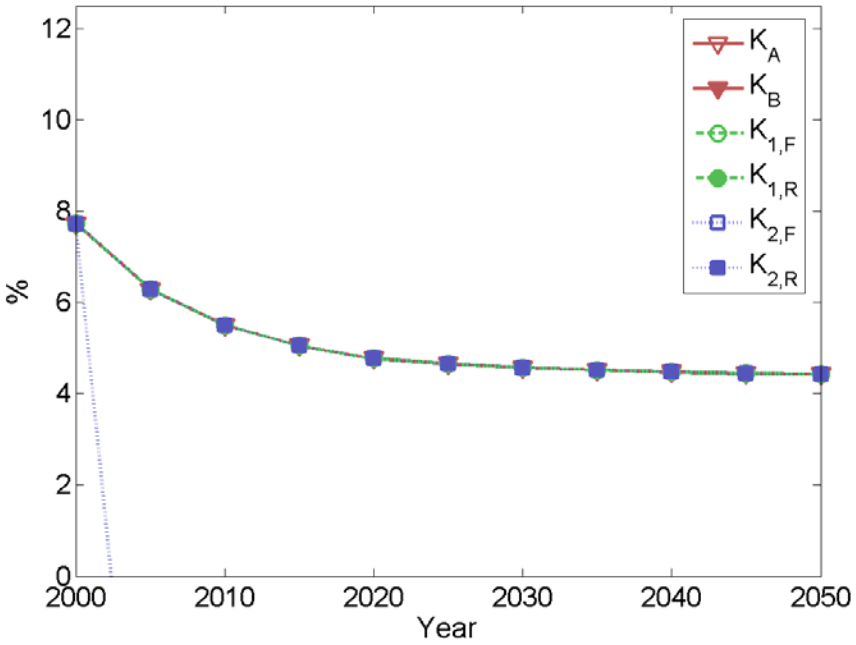
PAUL SCHERRER INSTITUT PSI

Nico Bauer
Ottmar Edenhofer

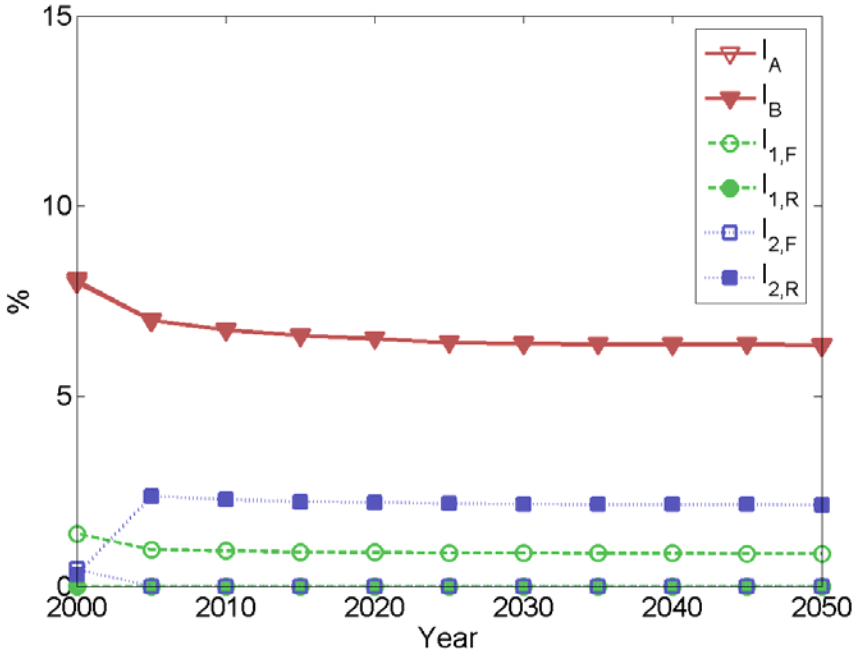
PIK

Results – Hard vs. Soft

r_i for hard-link



I_i/Y for hard-link



PAUL SCHERRER INSTITUT

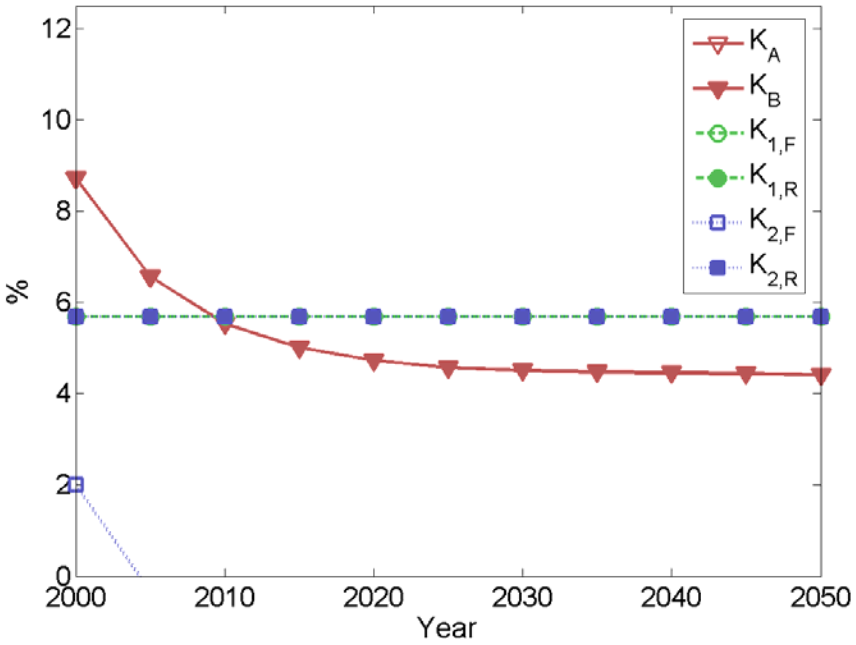
PSI

Nico Bauer
Ottmar Edenhofer

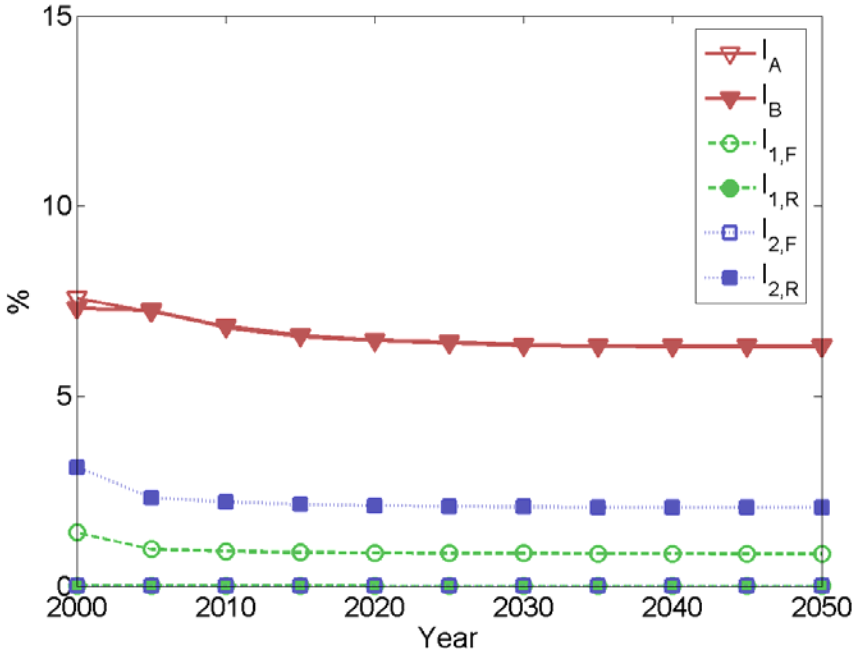
P I K

Results – Hard vs. Soft

r_i for soft-link



I_i/Y for soft-link



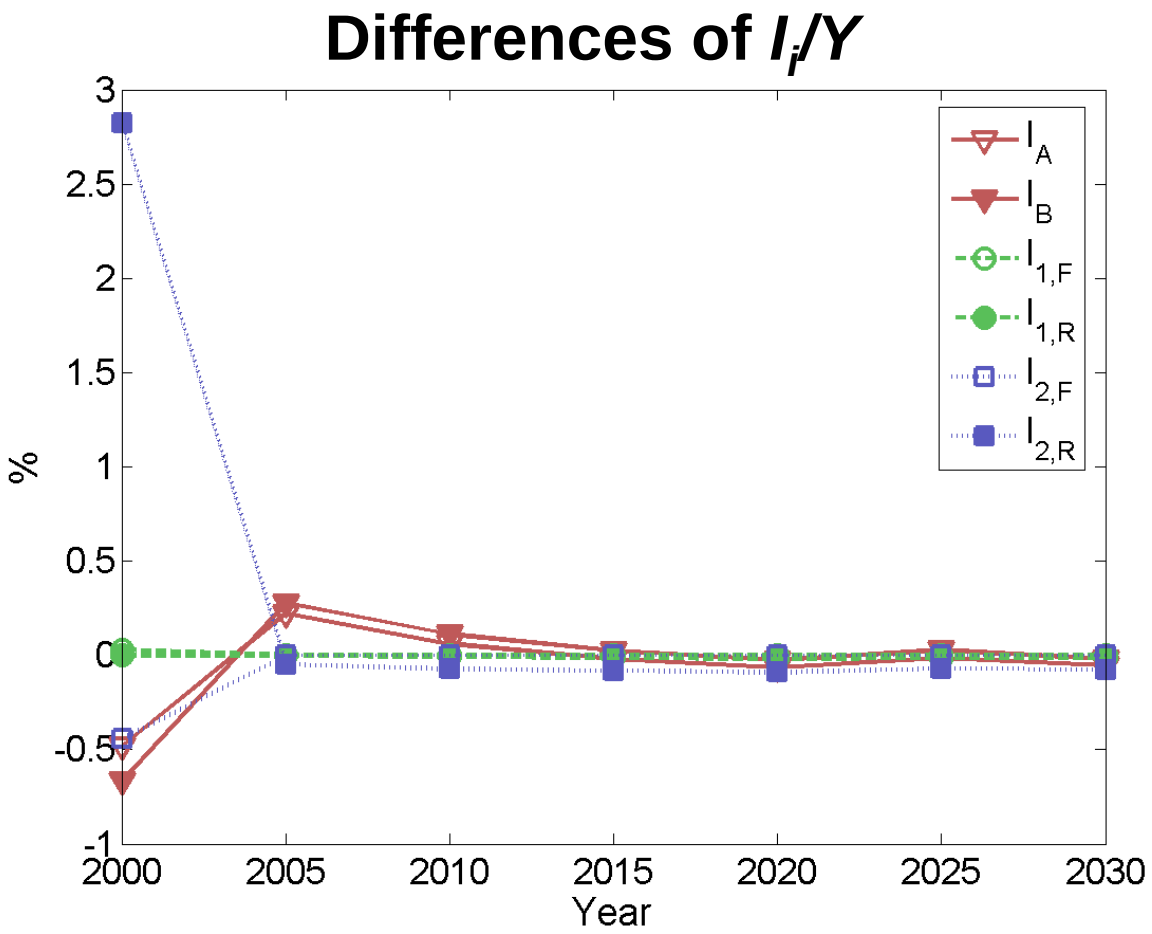
PAUL SCHERRER INSTITUT

PSI

Nico Bauer
Ottmar Edenhofer

P I K

Results – Hard vs. Soft



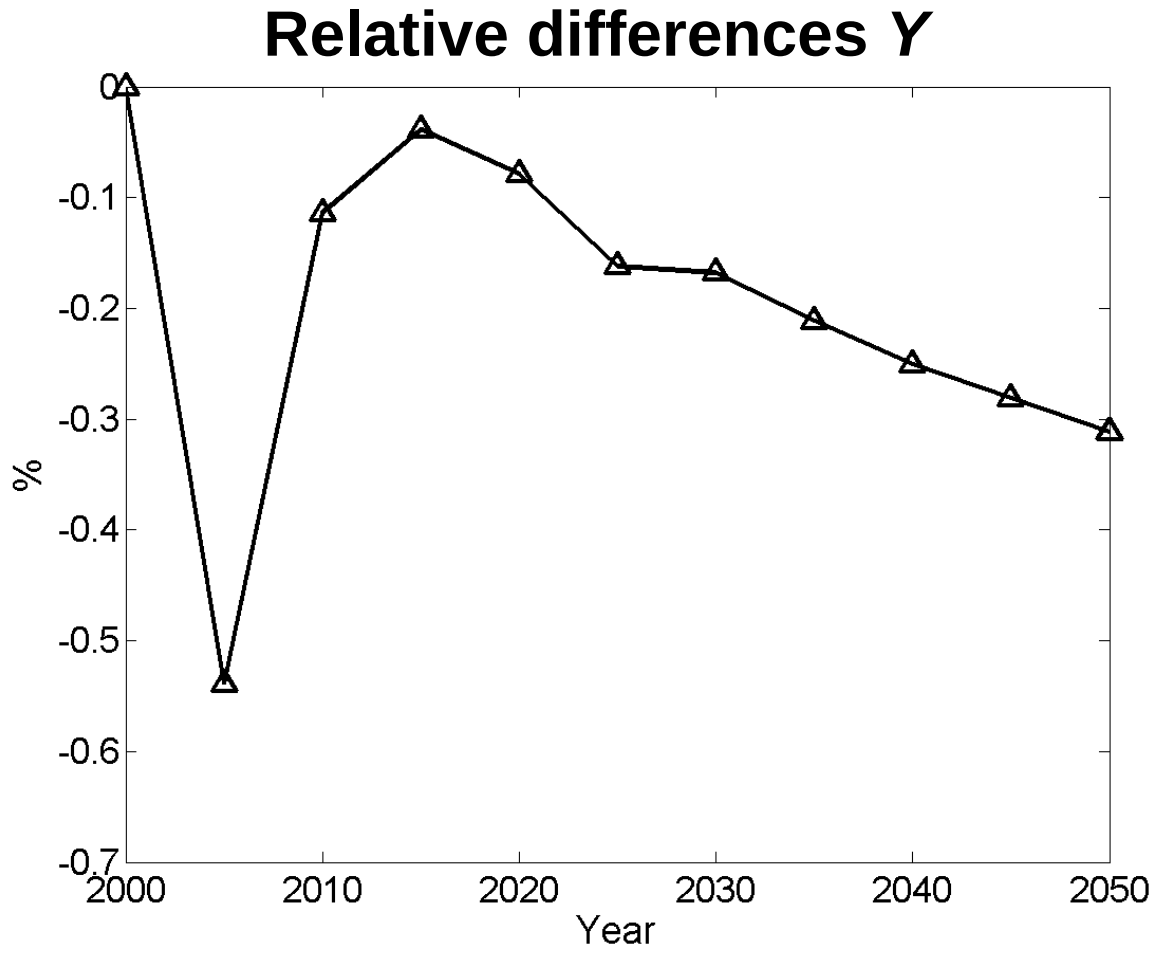
PAUL SCHERRER INSTITUT

PSI

Nico Bauer
Ottmar Edenhofer

PIK

Results – Hard vs. Soft



PAUL SCHERRER INSTITUT
PSI

Nico Bauer
Ottmar Edenhofer

PIK

Improving the Soft-Link

- Extending the information flow

$$\begin{pmatrix} E \\ r \end{pmatrix} = \mathrm{M}\,(a, b);$$

- Considers now capital scarcity

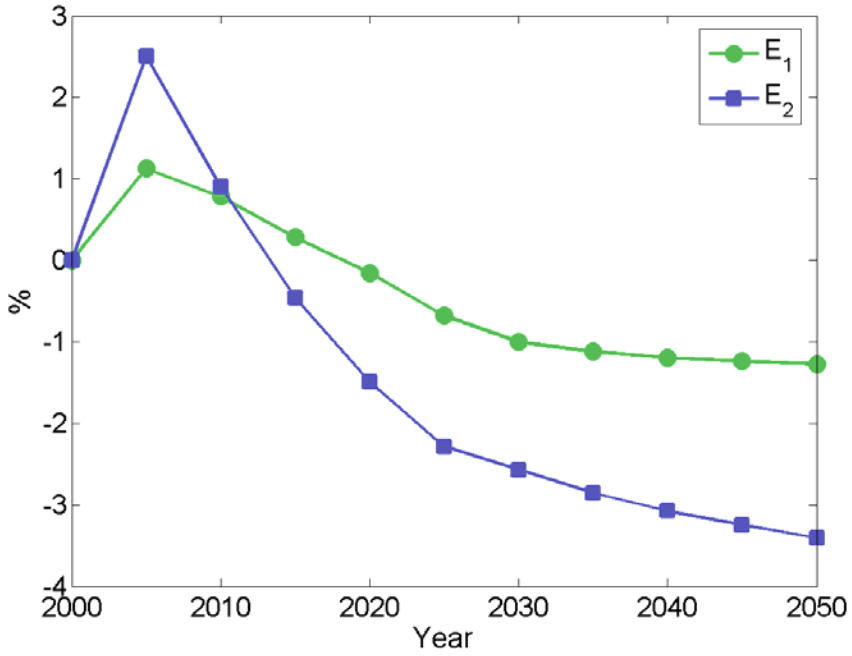
PAUL SCHERRER INSTITUT PSI

Nico Bauer
Ottmar Edenhofer

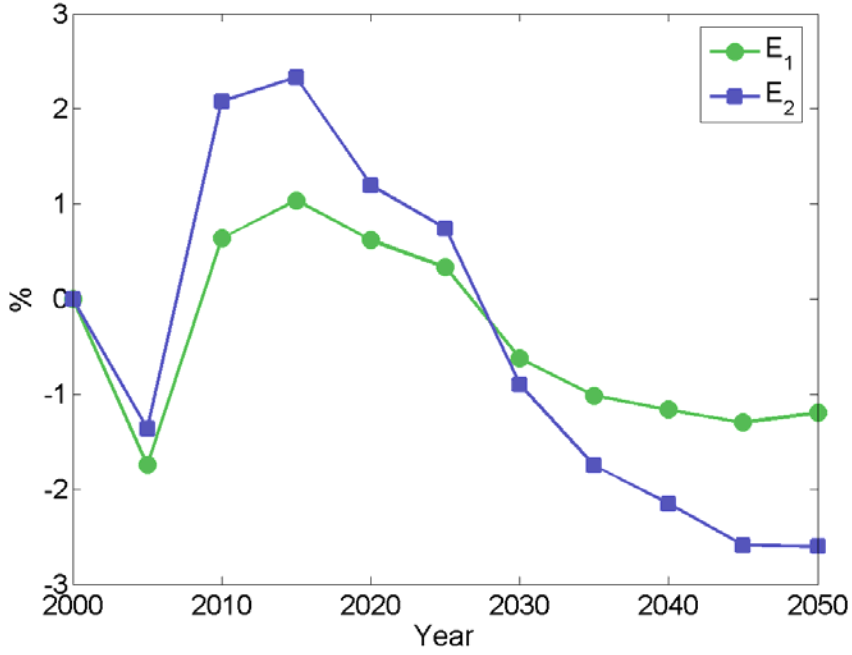
PIK

Augmenting the Soft-Link

Original soft-link



Augmented soft-link



PAUL SCHERRER INSTITUT

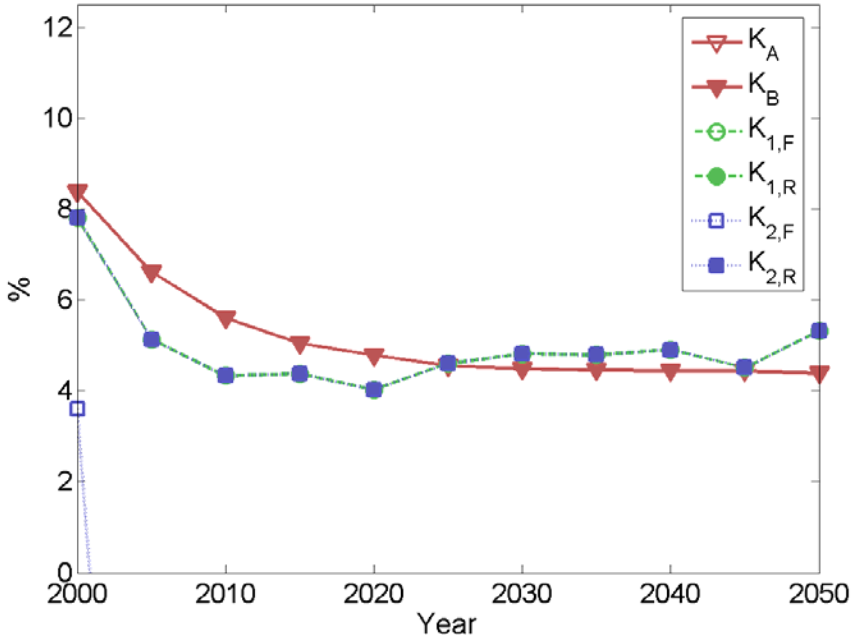
PSI

Nico Bauer
Ottmar Edenhofer

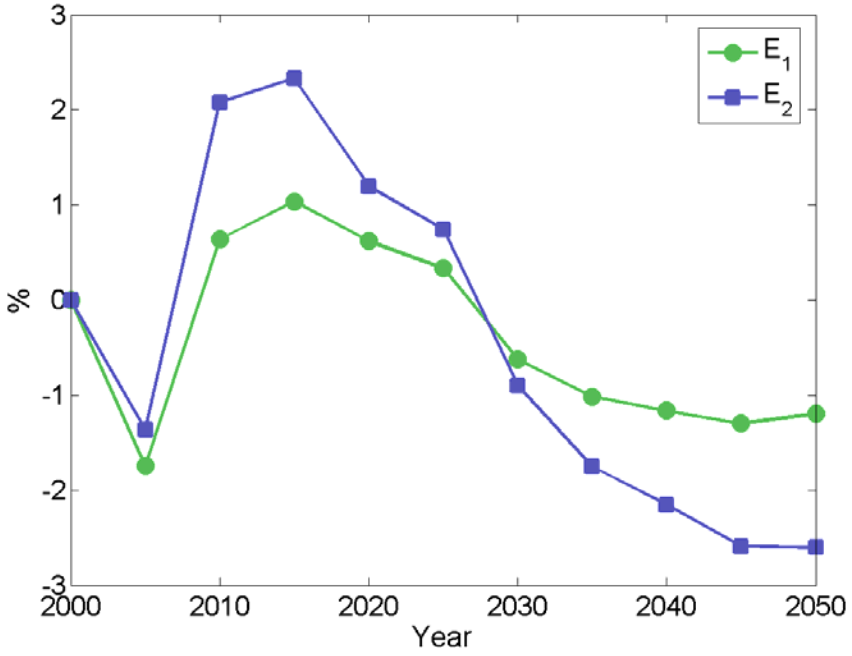
P I K

Augmenting the Soft-Link

Augmented soft-link



Augmented soft-link



PAUL SCHERRER INSTITUT

PSI

Nico Bauer
Ottmar Edenhofer

PIK

Intermediate Conclusions

	Soft-link	Hard-link
Energy market	X	X
Capital market		X

PAUL SCHERRER INSTITUT PSI

Nico Bauer
Ottmar Edenhofer

PIK

Intermediate Conclusions

$$Max\ W = \int_{t=\tau_1}^{\tau_2} e^{-\rho t} U\left(F\left(L, K, E\left(K_E, E_P\right)\right) - I - I_E - \chi E_P\right) dt;$$

$$\dot{K} = I - \delta K, \qquad K^0;$$

$$\dot{K}_E = I_E - \delta_E K_E, \qquad K_E^0.$$

PAUL SCHERRER INSTITUT PSI

Nico Bauer
Ottmar Edenhofer

PIK

Artificial Constraints

$$Max\ W = \int_{t=\tau_1}^{\tau_2} e^{-\rho t} U\left(F\left(L, K, E\left(K_E, E_P\right)\right) - I - I_E - \chi E_P\right) dt;$$

$$\dot{K} = I - \delta K, \qquad K^0;$$

$$\dot{K}_E = I_E - \delta_E K_E, \qquad K_E^0,$$

$$\hat{\lambda} = \rho + \delta - F_K;$$

$$\hat{\lambda}_E = \rho + \delta_E - F_E E_{K_E}$$

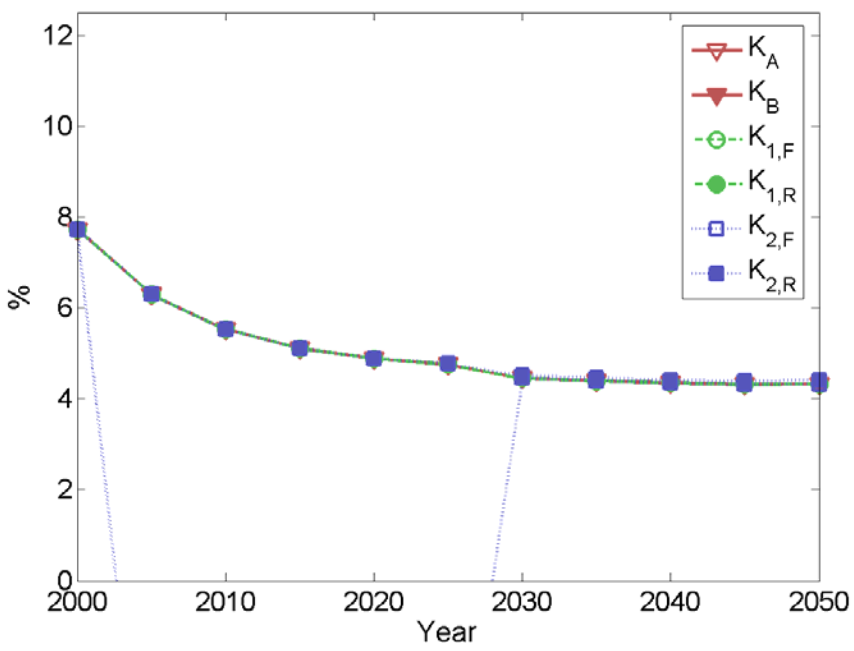
PAUL SCHERRER INSTITUT PSI

Nico Bauer
Ottmar Edenhofer

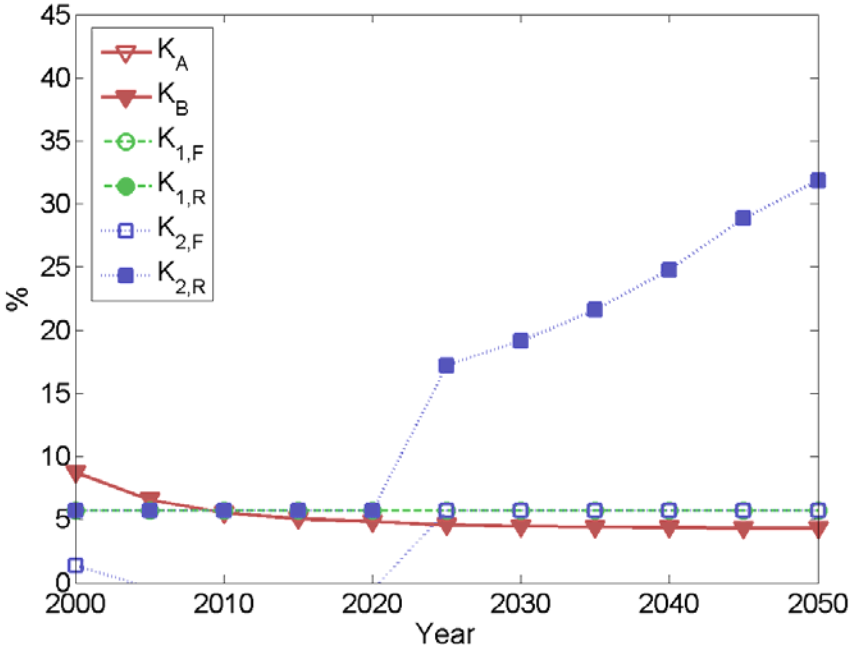
PIK

Artificial Constraints

r_i for hard-link



r_i for soft-link



PAUL SCHERRER INSTITUT

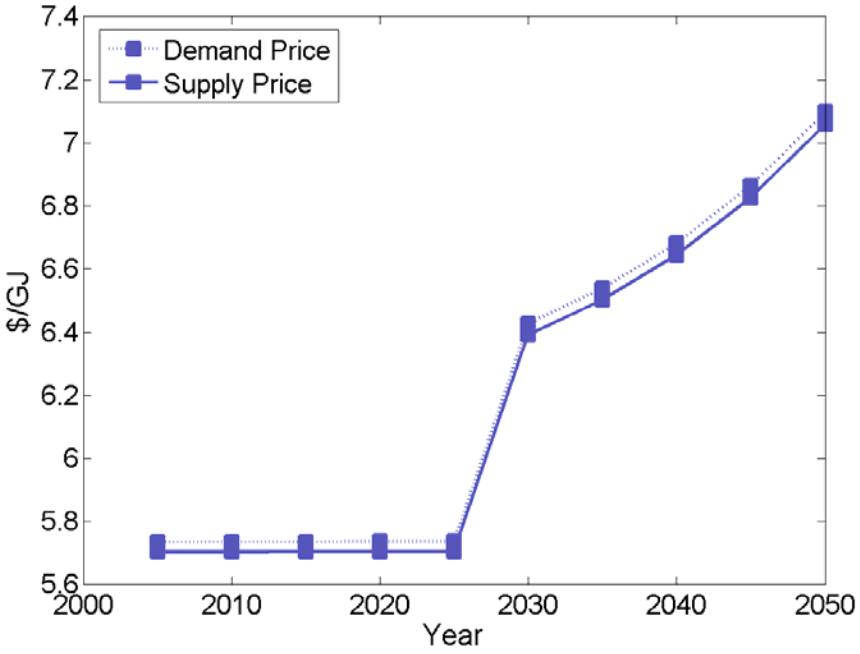
PSI

Nico Bauer
Ottmar Edenhofer

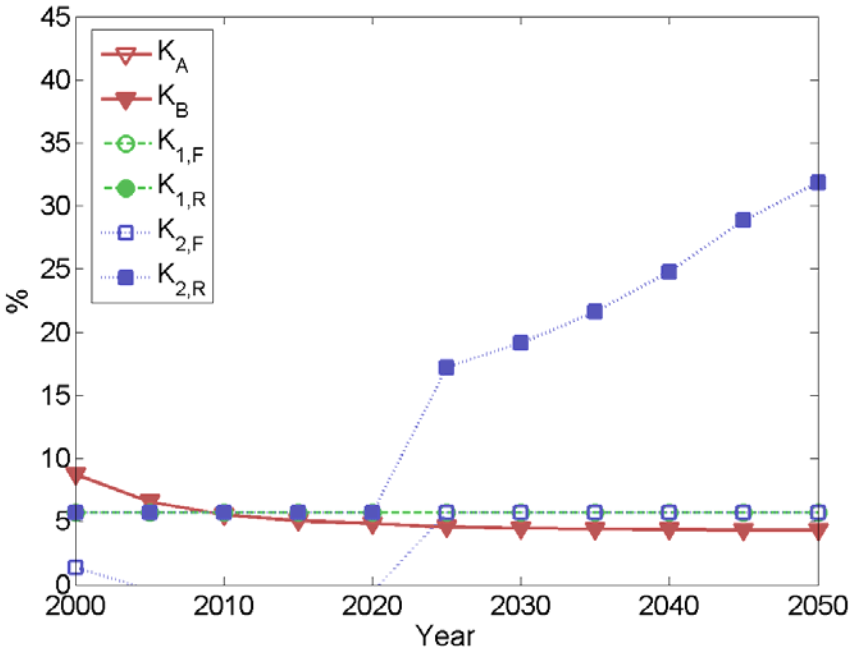
P I K

Artificial Constraints

Price of *E2* in soft-link



r_i for soft-link



PAUL SCHERRER INSTITUT

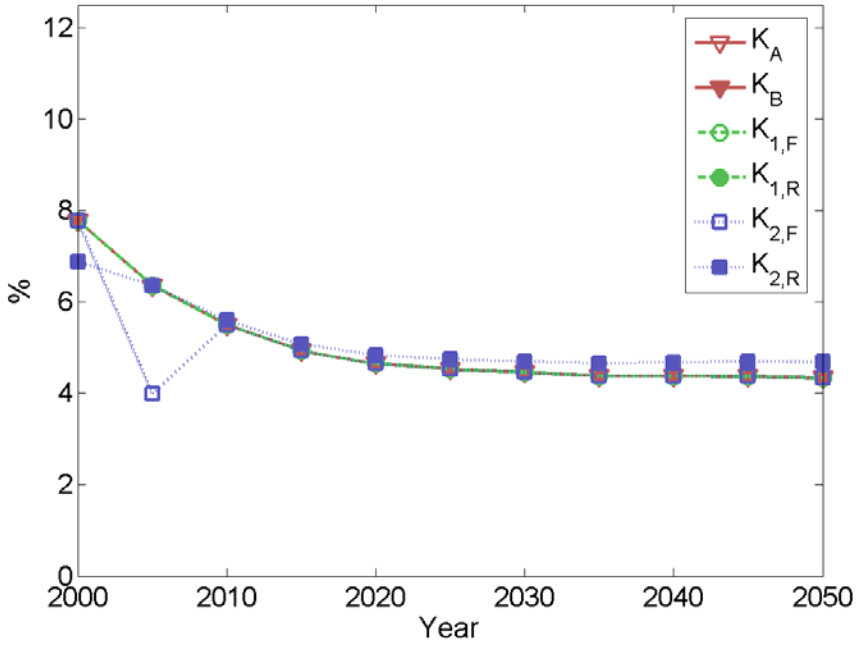
PSI

Nico Bauer
Ottmar Edenhofer

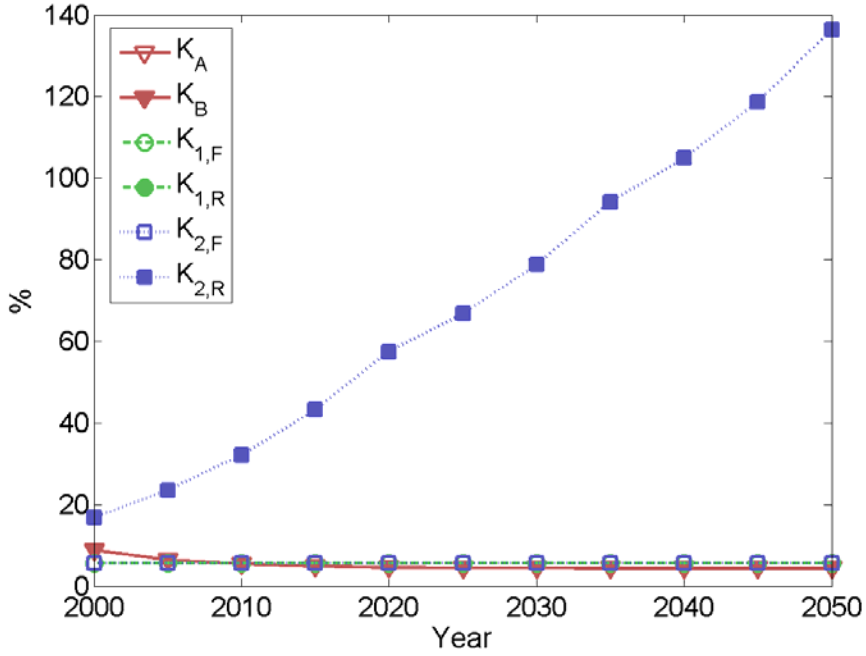
P I K

Artificial Constraints

r_i for hard-link



r_i for soft-link



PAUL SCHERRER INSTITUT

PSI

Nico Bauer
Ottmar Edenhofer

P I K

Artificial Constraints

- Illustration of problem‘s origin

$$\mathrm{H}\left(x, p, t\right) = \sum_{i=1}^{n} p_i\left(t\right) x_i\left(t\right).$$

- Linear production technologies and bounds

- Question: How to merge diminishing returns and equilibrium conditions in large-scale numeric models?

PAUL SCHERRER INSTITUT PSI

Nico Bauer
Ottmar Edenhofer

PIK

Conclusions

- Hard-link guarantees simultaneous equilibrium of capital and energy market
- Soft-link can not approximate
- Augmentation is not successful

PAUL SCHERRER INSTITUT PSI

Nico Bauer
Ottmar Edenhofer

PIK

Conclusions

- Artificial constraints induce also capital market disequilibrium
- Either capital market dis-equilibrium or flip-flop
- Solving the problem in the linear framework is difficult

PAUL SCHERRER INSTITUT PSI

Nico Bauer
Ottmar Edenhofer

PIK