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Optimal R&D Investments and the Cost of GHG Stabilization when Knowledge Spills across Sectors

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Outline of Presentation

- **Empirical evidence on spillovers and motivation of the analysis**
- **Spillovers in the Witch model with directed technical change**
- **Major findings**
- **Concluding remarks**

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Spillovers: empirical evidence

- Most Empirical works find that estimated **R&D spillovers** are **significant and positive**

- Both **Domestic and International** knowledge **spillovers** have a **significant impact on innovations** and **productivity**

- **Spillovers** are **mainly domestic** (more national than international in scope)

- **Inter-sectoral spillovers** are extremely significant

Why to include spillovers?

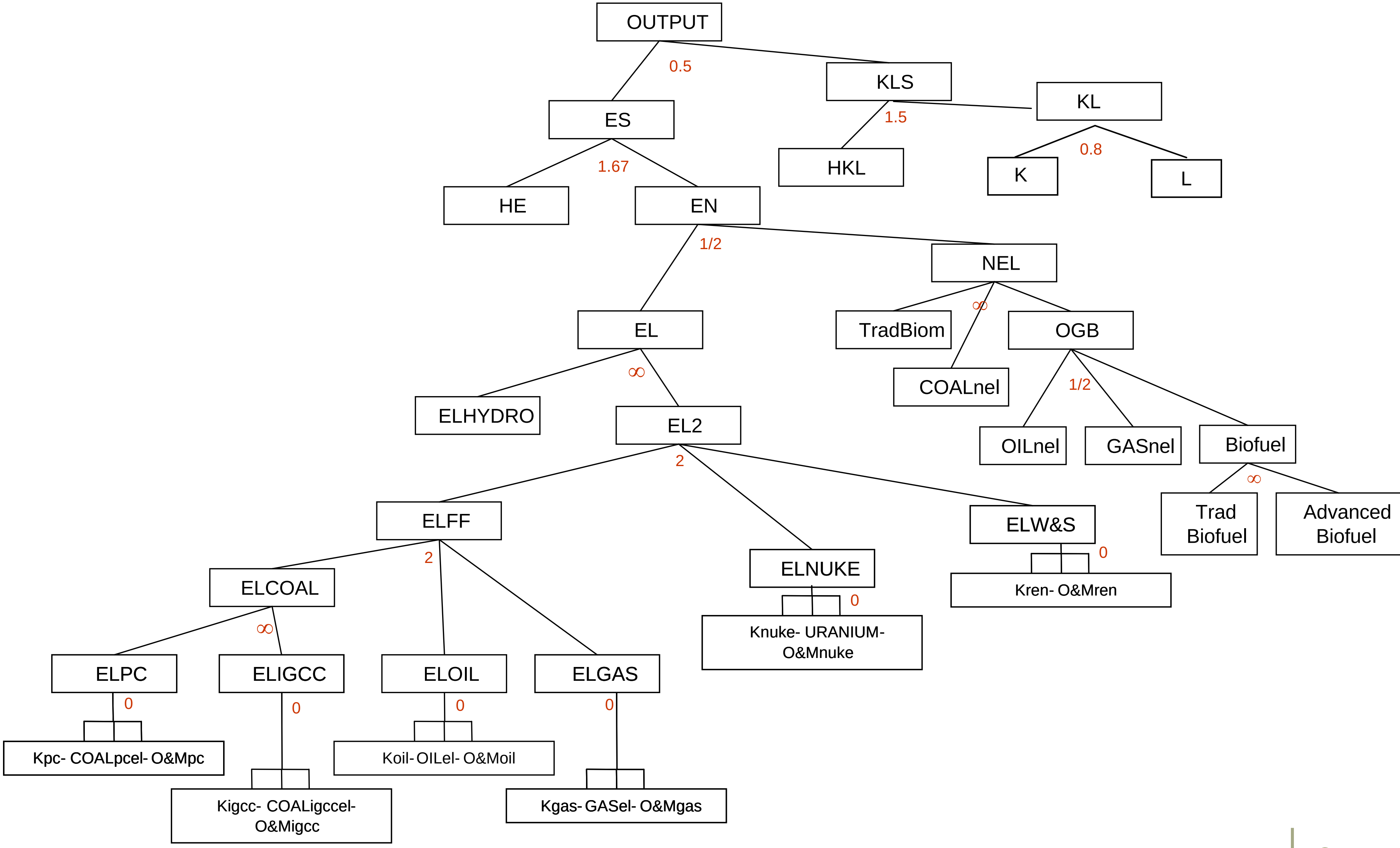
- Even if the description of technical change in integrated model for climate policy analysis has greatly improved, **current approaches rarely include knowledge externalities**.

- **Without spillovers**, models unrealistically assume that advance of technological frontiers of different sectors are mutually independent and **omit** to consider **the interactions among different drivers** of technical change.

Motivation of the analysis

- We introduce **inter-sectoral spillovers** in the WITCH model with directed technical change, i.e. R&D expenditures are **factor specific** and can be directed towards increasing **energy-efficiency** or towards rising **productivity of non-energy inputs**.
- The directed technical change approach allows to explicitly modeling spillovers across the two R&D capital stocks. We can thus study **the effect** that modeling **inter-sectoral knowledge spillovers** has on the **advances of the technological frontier** and on **the costs of climate policy**.

WITCH with Directed Technical Change


OUTPUT

0.5

KLS

KL

ES

1.5

HKL

0.8

K

L

1.67

HE

EN

1/2

NEL

∞

TradBiom

OGB

EL

COALnel

∞

ELHYDRO

EL2

1/2

OILnel

GASnel

Biofuel

2

∞

ELFF

ELW&S

Trad Biofuel

Advanced Biofuel

2

ELNUKE

0

Kren- O&Mren

ELCOAL

0

Knuke- URANIUM- O&Mnuke

∞

ELPC

ELIGCC

ELOIL

ELGAS

0

0

0

0

Kpc- COALpcel- O&Mpc

Koil- OILel- O&Moil

Kigcc- COALigccel- O&Migcc

Kgas- GASel- O&Mgas

Production Function

Output is produced combining **capital-labour services** (KLS) and **energy services** (ES) and is reduced by **climate damage**:

$$Y(n,t) = \frac{TFP(n,t)\left[\alpha_Y(n)\cdot KLS^{\rho_Y} + (1-\alpha_Y(n))\cdot ES(n,t)^{\rho_Y}\right]^{1/\rho_Y}}{\Omega(n,t)} \qquad (1)$$

KLS is produced combining the **capital-labour** (KL) aggregate and the stock of **capital-labor knowledge** (HKL):

$$KLS(n,t) = \left[\alpha_{HKL}(n)HKL(n,t)^{\rho_{KLS}} + \alpha_{KL}(n)KL(n,t)^{\rho_{KLS}}\right]^{1/\rho_{KLS}} \qquad (2)$$

$$KL(n,t) = \left[\alpha_K(n)K(n,t)^{\rho_{KL}} + \alpha_L(n)L(n,t)^{\rho_{KL}}\right]^{1/\rho_{KL}} \qquad (3)$$

ES is produced aggregating the **energy** (EN) and the stock of **energy knowledge** (HE):

$$ES(n,t) = \left[\alpha_{HE}(n)HE(n,t)^{\rho_{ES}} + \alpha_{EN}(n)EN(n,t)^{\rho_{ES}}\right]^{1/\rho_{ES}} \qquad (4)$$

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R&D Sector

Knowledge stocks are increased by the flow of **new ideas** and are subject to **depreciation**

$$HKL(n,t+1) = HKL(n,t)(1-\delta) + Z_{HKL}(n,t) \tag{5}$$

$$HE(n,t+1) = HE(n,t)(1-\delta) + Z_{HE}(n,t) \tag{6}$$

Production of new ideas follows an “innovation possibility frontier” specification with **intra-sectoral and inter-sectoral spillovers** and **diminishing returns**:

$$Z_{HKL}(n,t) = f\, I_{HKL}(n,t)^{g}\, HKL(n,t)^{h}\, HE(n,t)^{i} \tag{7}$$

$$Z_{HE}(n,t) = a\, I_{HE}(n,t)^{b}\, HE(n,t)^{c}\, HKL(n,t)^{d} \tag{8}$$

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Calibration of the Innovation possibility frontier

Relative contribution of different sources of Knowledge to Productivity

	Domestic own-sector	Domestic other-sectors	International
Keller (2002)	51%	30%	19%
Frantzen (2002)	24%-41%	23%-39%	36%-38%

	Domestic private	Domestic spillovers	Domestic Intra-sectoral	Domestic Inter-sectoral	International Spillovers
Malerba (2007)	14%-21%		32%-65%	11%-16%	10%-35%
Bottazzi, Peri (2007)	24%-46%	30%-0.62%			15%-38%

$$Z_{HKL}\left(n,t\right) = f\, I_{HKL}(n,t)^{0.18}\, HKL(n,t)^{0.37}\, HE(n,t)^{0.16}$$

$$Z_{HE}\left(n,t\right) = a\, I_{HE}(n,t)^{0.18}\, HE(n,t)^{0.37}\, HKL(n,t)^{0.16}$$

Business as Usual

	2005	2025	2045	2065	2085	2105
GWP (Trillions, 2005 USD)	44	87	150	224	300	365
World Population (billions)	6.5	8.0	9.0	9.5	9.5	9.0
Energy Intensity of Output	10.1	7.3	5.5	4.3	3.6	3.1
Carbon Intensity of Primary Energy	0.018	0.018	0.019	0.020	0.021	0.020
Concentrations of GHG (ppmv)	427	506	623	753	881	996
R&D expenditure (%GWP)	1.682%	1.756%	1.760%	1.762%	1.744%	1.661%
Non-energy R&D (%GWP)	1.666%	1.742%	1.746%	1.748%	1.731%	1.648%
Energy R&D (%GWP)	0.016%	0.014%	0.014%	0.014%	0.013%	0.012%
Energy R&D (%Total Investment in R&D)	0.924%	0.818%	0.789%	0.775%	0.760%	0.742%

- **GWP increases** over the whole century at a declining rate
- **Energy Intensity declines**
- **Carbon Intensity increases**
- **Carbon emission increases**
- **R&D expenditures**, as share of GWP, slightly **increase** because of **increasing** path of **Non-Energy R&D** investments, while **Energy R&D** expenditures, as share of GWP, **decline**

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Stabilization policy

	GWP	Consumption	Investment			
			Final good	Non_Energy R&D	Energy R&D	Backstop R&D
Baseline	4399	3459	829	76	0.61	0.80
Stabilization	4333	3435	784	71	1.11	2.88
	-1.50%	*-0.68%*	*-5.42%*	-6.81%	*81.81%*	*72.25%*

- **GWP, Consumption, Investment in Capital and Non-energy R&D, all decline**

- Investment in **Energy Efficiency R&D and Backstop R&D sharply increases**

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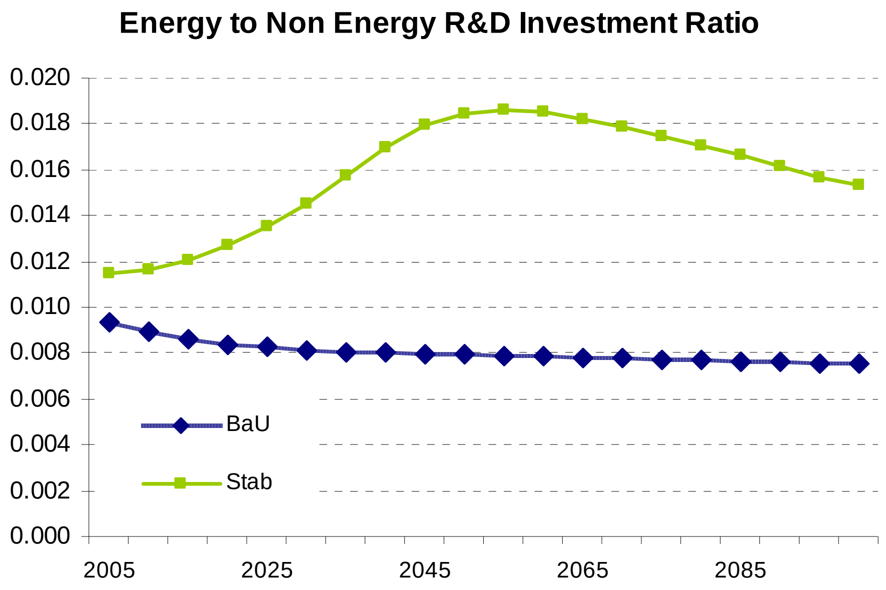
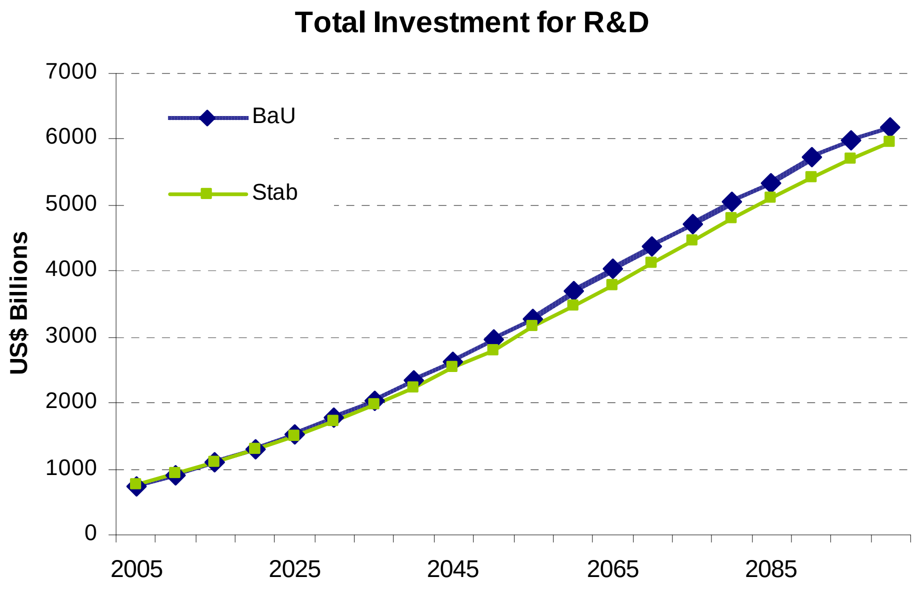
R&D Investment





- The **Energy to Non-Energy** R&D investment ratio switches from a declining to a **rising path** both because of the increase in Energy investment and the decline of Non-Energy investment
- As a result **Total R&D** investment **declines**

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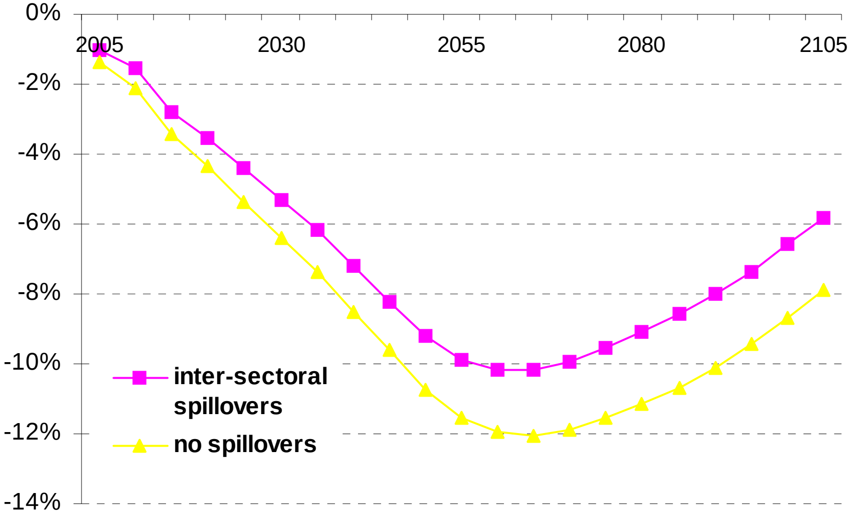
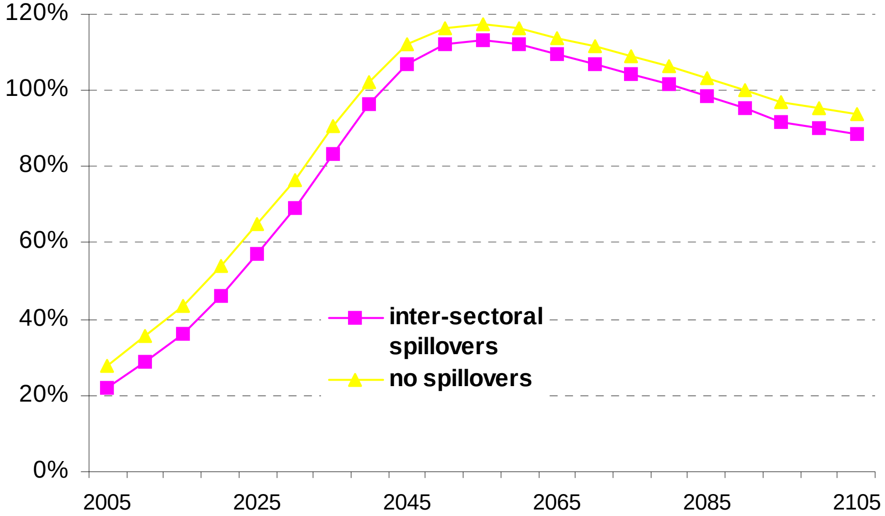
R&D dynamics

Percentage change of Investments in Non-Energy R&D: stabilization wrt bau



Percentage change of Investments in Energy R&D: stabilization wrt bau



- **Non-Energy R&D decreases less** and **Energy R&D increases less** with respect to the model without knowledge externalities

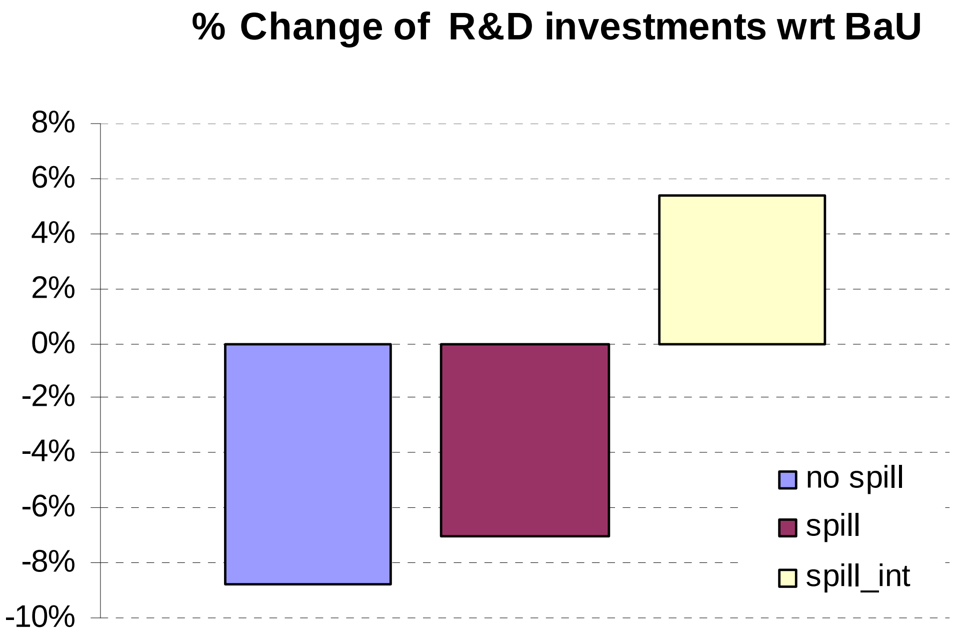
R&D dynamics

$$Z_{HKL}\left(n,t\right) = f\, I_{HKL}(n,t)^{0.18}\, HKL(n,t)^{0.37}\, HE(n,t)^{0.16}$$

$$Z_{HE}\left(n,t\right) = a\, I_{HE}(n,t)^{0.18}\, HE(n,t)^{0.37}\, HKL(n,t)^{0.16}$$

- The **increase in energy knowledge** increases the **marginal product of investment** in **Energy R&D**
- The **decrease in Non-Energy knowledge** decreases the **marginal product of Non-Energy R&D**

Change of R&D investments



- If spillovers are internalized **total R&D investments increase** because of a greater increase in Energy R&D and a lower contraction in Non-Energy R&D than when spillovers are either not internalized or not modelled

The Cost of the Stabilization Policy

	No Spillovers	Spillovers	Stabilization Policy and Spillovers Internalized
Stabilization Cost	1.66%	1.50%	0.98%

- When **spillovers** are **introduced** the **cost of policy decreases.**

- **When spillovers** are **internalized** the **cost of policy decreases the most**.

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Concluding remarks

- Even in a model with intersectoral spillovers **Total R&D drops** because of the **sharp reduction** in **Non-energy R&D** investment
- However **domestic spillovers reduce** the **impact** of the **mitigation policy** on R&D investments
- As a result, the cost (in terms of GWP losses) of the mitigation policy is reduced
- There is the potential for a **synergy** between **mitigation policy** and **policy** that overcomes **market failures in the R&D sector**