Green innovation and the energy transition

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INTRODUCE INNOVATION IN THE CLIMATE DEBATE

- **Path-Dependence in Green versus Dirty Innovation**
- **Government can avoid disaster by redirecting innovation towards green technologies**
- **Act now**
- **Use several instruments, not just carbon tax**

  - **Aghion, Dechezlepretre, Hemous, Martin, Van Reenen (2016)**
  - **Acemoglu, Aghion, Bursztyn, Hemous (2012)**

Path Dependence

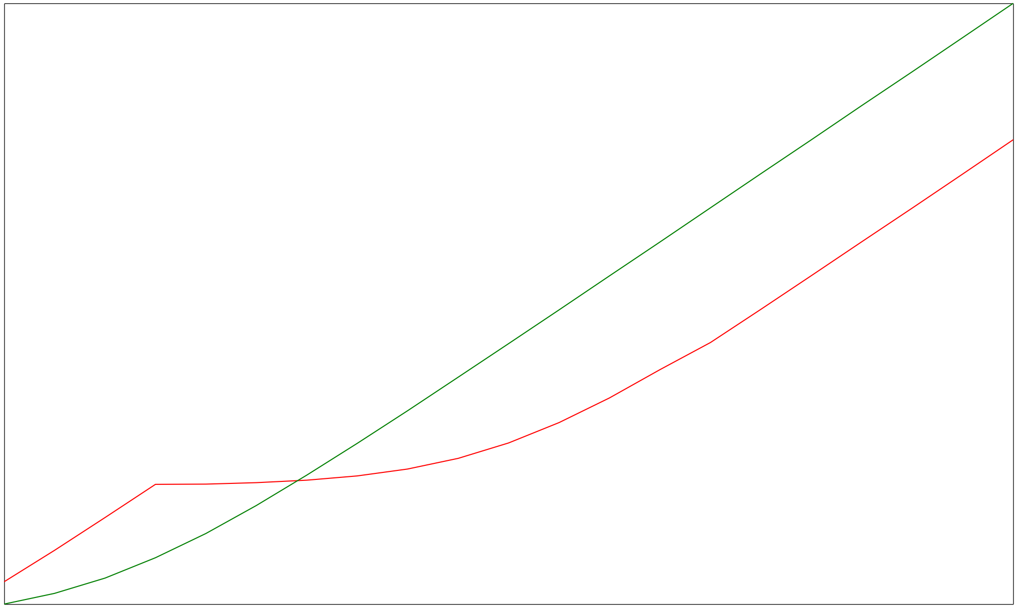
	Clean	Dirty
Fuel Price	0.886**	-0.644***
ln(FP)	(0.362)	(0.143)
Clean Spillover	0.266***	-0.058
$SPILL_C$	(0.087)	(0.066)
Dirty Spillover	-0.160*	0.114
$SPILL_D$	(0.097)	(0.081)
Own Stock Clean	0.303***	0.016
K_C	(0.026)	(0.026)
Own Stock Dirty	0.139***	0.542***
K_D	(0.017)	(0.020)
#Observations	68,240	68,240
#Units (Firms and individuals)	3,412	3,412

Notes: Estimation by Conditional fixed effects (CFX), all regressions include GDP, GDP per capita & time dummies. SEs clustered by unit.

Act now

- Without intervention, innovation is directed towards dirty inputs
- Thus the gap between clean and dirty technology widens
- Hence cost of intervention (reduced growth as long as clean technologies catch up with dirty technologies) increases

Act now: AABH 2012



Several instruments, not just carbon tax

- Two externalities:
  - Environmental externality
  - Knowledge externality (path-dependence)
- Thus need at least two instruments, not just carbon tax

ENERGY TRANSITION
with D. Acemoglu, L. Barrage, D. Hemous

- **Energy transition**
  - Introduce an intermediate source of energy (e.g. shale gas)
  - Should we subsidize production and research in that intermediate source?

- Analyze effects of an exogenous improvement in extraction technology for gas (shale gas boom) on aggregate pollution in short run and long run

- Discrete time economy.
- Final good produced according to:

$$Y_t = e^{-\Gamma S_t} \left((1-\nu)\, Y_{Pt}^{\frac{\lambda-1}{\lambda}} + \nu \left(\widetilde{A}_{Et} E_t \right)^{\frac{\lambda-1}{\lambda}} \right)^{\frac{\lambda}{\lambda-1}},$$

  - Y_{Pt} ~ production input produced via $Y_{Pt} = A_{Pt} L_{Pt}$
  - A_{Pt}, $\tilde{A}_{Et}$ ~ productivity in goods production, energy efficiency
  - S_t is carbon concentration.

Golosov et al. (2014) carbon cycle:

$$S_t = \overline{S} + \sum_{s=0}^{t+T} \left(\varphi_L + (1 - \varphi_L)\, \varphi_0 \,(1 - \varphi_d)^s\right) \left(P_{t-s} + P_{t-s}^{ROW}\right),$$

- Energy composite E_t :

$$E_t = \left(\kappa_c E_{c,t}^{\frac{\varepsilon-1}{\varepsilon}} + \kappa_s E_{s,t}^{\frac{\varepsilon-1}{\varepsilon}} + \kappa_g E_{g,t}^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon-1}} .$$

  - $E_{c,t}$, $E_{s,t}$, and $E_{g,t}$ $\sim$ coal, natural gas, and green energy, resp.

- Production of energy $i \in (c, s, g)$ is given by:

$$E_{i,t} = \min(Q_{it}, R_{it}),$$

  - $Q_{it} \sim$ energy input (e.g., power plant); $R_{it} \sim$ resource (e.g., coal)

- Resource use leads to pollution : $P_{i,t} = \xi_i R_{i,t}$ and $\xi_c > \xi_s > 0 = \xi_g$
  - Green does not pollute, and coal pollutes more than natural gas

- Energy input i ("power plant") is produced according to:

$$Q_{it} = \exp\left(\int_0^1 \ln q_{ijt}\, dj\right)$$

- q_{ijt}: Intermediate inputs (e.g., steam turbine, boiler, etc.)
  - Produced by monopolist j in energy sector i via $q_{ijt} = A_{ijt} l^q_{ijt}$
  - Monopolist's technology γ times more productive than fringe

- Productivity in generation technologies A_{ijt} endogenous

→ Define avg. productivity in power plant type i: $\ln A_{it} = \int_0^1 \ln A_{ijt}\, dj$

- Extraction productivity (exogenous):
  - B_{ct} ~ avg. productivity in coal extraction
  - B_{st} ~ avg. productivity in gas extraction
  - Shale gas boom = exogenous increase in B_{st}

- Denote effective productivity of energy type i as:

$$C_{it} \equiv \left(A_{it}^{-1} + B_{it}^{-1}\right)^{-1}$$

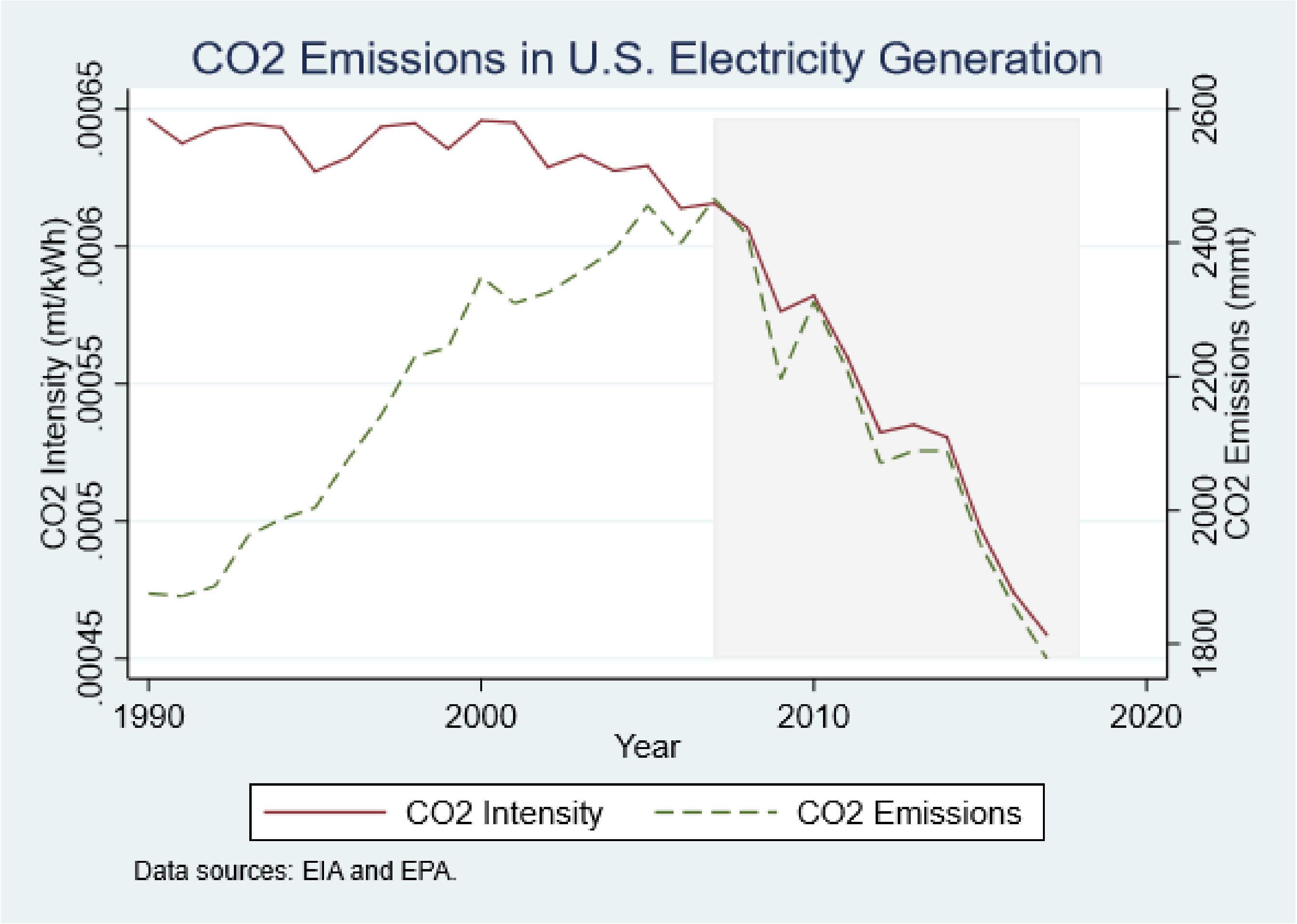
Short-Run Effects

- Absent innovation (short-run), there are two opposite effects of shale gas boom:
  - Substitution effect
  - Scale effect
- Substitution effect dominates if gas sufficiently cleaner than coal

Short-Run Impact Estimates

Total Effects of Improved Shale Extraction Technology B_{s0}			
	$\%\Delta$Emiss.	$\%\Delta$Energy	$\%\Delta CO_2$
	Intensity	Consumption	Emissions
Baseline Parameters			
+10% Increase in B_{s0}	-16.7%	+5.5%	-12.1%
+50% Increase in B_{s0}	-21.0%	+9.6%	-13.4%

Emissions and Emissions Intensity



Long-run effects

- There is a mass 1 of scientists who can decide in which sector to work
  - s_{ft} ~ share working on fossil fuels generation technology
  - s_{gt} ~ share working on green generation technology

- Each scientists has a probability of success given by: $\eta_i s_{it}^{-\psi}$

- A successful innovator obtains a technology on energy input γ times more productive
  - Patents last for 1 period only
  - If there is no innovation, monopoly rights are allocated randomly

- An innovator in the green sector obtains expected profits:

$$\Pi_{gt} = \eta_{gt} s_{gt}^{-\psi} \left(1 - \frac{1}{\gamma}\right) p_{gt} E_{gt}$$

- An innovator in the fossil fuel sector obtains expected profits:

$$\Pi_{ft} = \eta_{ft} s_{ft}^{-\psi} \left(1 - \frac{1}{\gamma}\right) \left(\frac{C_{ct}}{A_{ct}} p_{ct} E_{ct} + \frac{C_{st}}{A_{st}} p_{st} E_{st}\right)$$

  - Innovators in fossil technologies improve both coal and gas generation.
- In equilibrium innovators must be indifferent so that:

$$\Pi_{gt} = \Pi_{ft}$$

$$\left(\frac{s_{gt}}{s_{ft}}\right)^{\psi} \approx \frac{\kappa_g^{\varepsilon} A_{gt-1}^{\varepsilon-1}}{\frac{1}{A_{ct-1}}\kappa_c^{\varepsilon}\left(\frac{1}{A_{ct-1}}+\frac{1}{B_{ct}}\right)^{-\varepsilon}+\frac{1}{A_{st-1}}\kappa_d^{\varepsilon}\left(\frac{1}{A_{st-1}}+\frac{1}{B_{st}}\right)^{-\varepsilon}}$$

Key points:

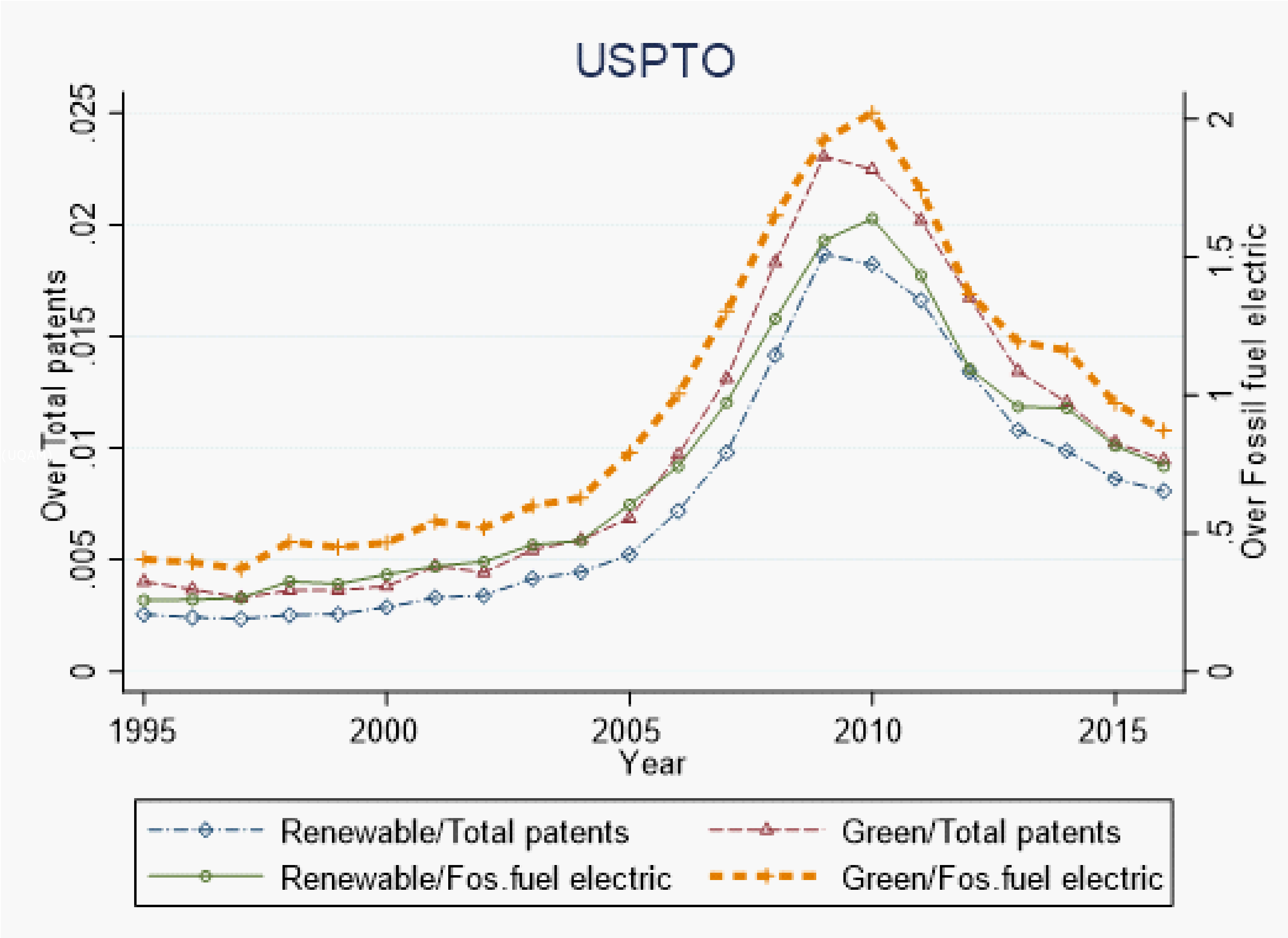
- More advanced sector gets a larger market ⇒ Larger profits from further innovation
  - Better green technology $A_{g(t-1)}$ leads to more green innovation
  - Better gas technology $A_{s(t-1)}$ leads to more fossil innovation (provided that fossil fuels are not too costly to extract relative to generation costs)

- Improvement in gas extraction technology B_{st} :
  - Extraction and power plant are complements ⇒ Higher gas extraction technology B_{st} encourages innovation in gas generation A_{st}

Long-Run Effects

- Shale gas boom directs innovation away from both, coal and clean production technologies into gas production technologies
- In the long-run, it may move the economy from a path with declining CO_2 emissions to a path with increasing CO_2 emissions

Renewable and green innovation



- **Welfare Effect of Shale Gas Boom:**
  Perspective of a US social planner that takes emissions from abroad as given but internalizes foreign damages

- Specify SWF as

$$U_t = \sum_{\tau=t}^{\infty} \frac{1}{(1+\rho_U)^{\tau-t}} \left(\frac{C_\tau^{1-\vartheta}}{1-\vartheta} + v(S_t) \right) \quad (1)$$

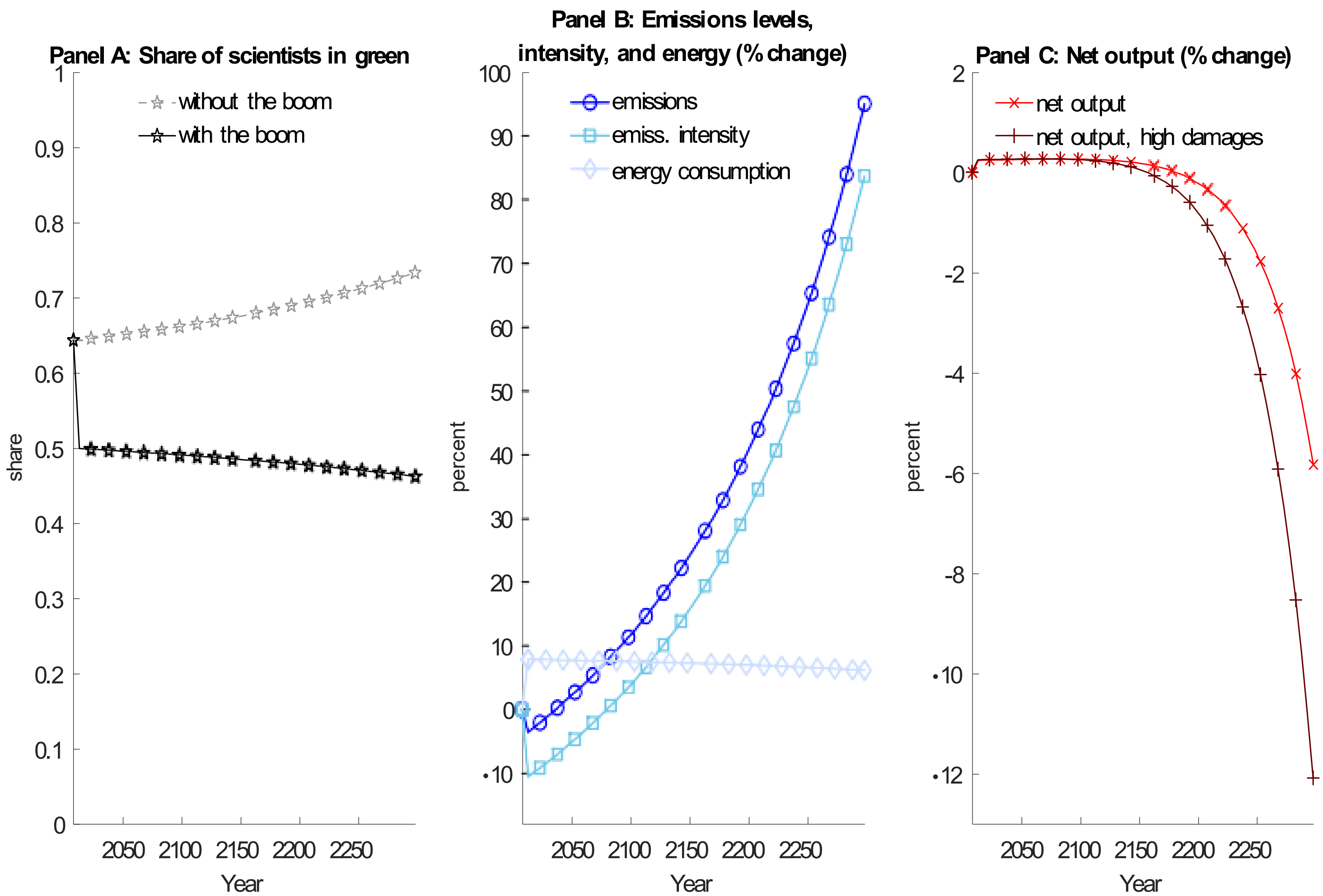
  - S_t is carbon concentration. It affects consumption through damages to output
  - $v(S_t)$ represents welfare costs from climate damages abroad.
  - Carbon cycle modeled as in GHKT.

Calibration

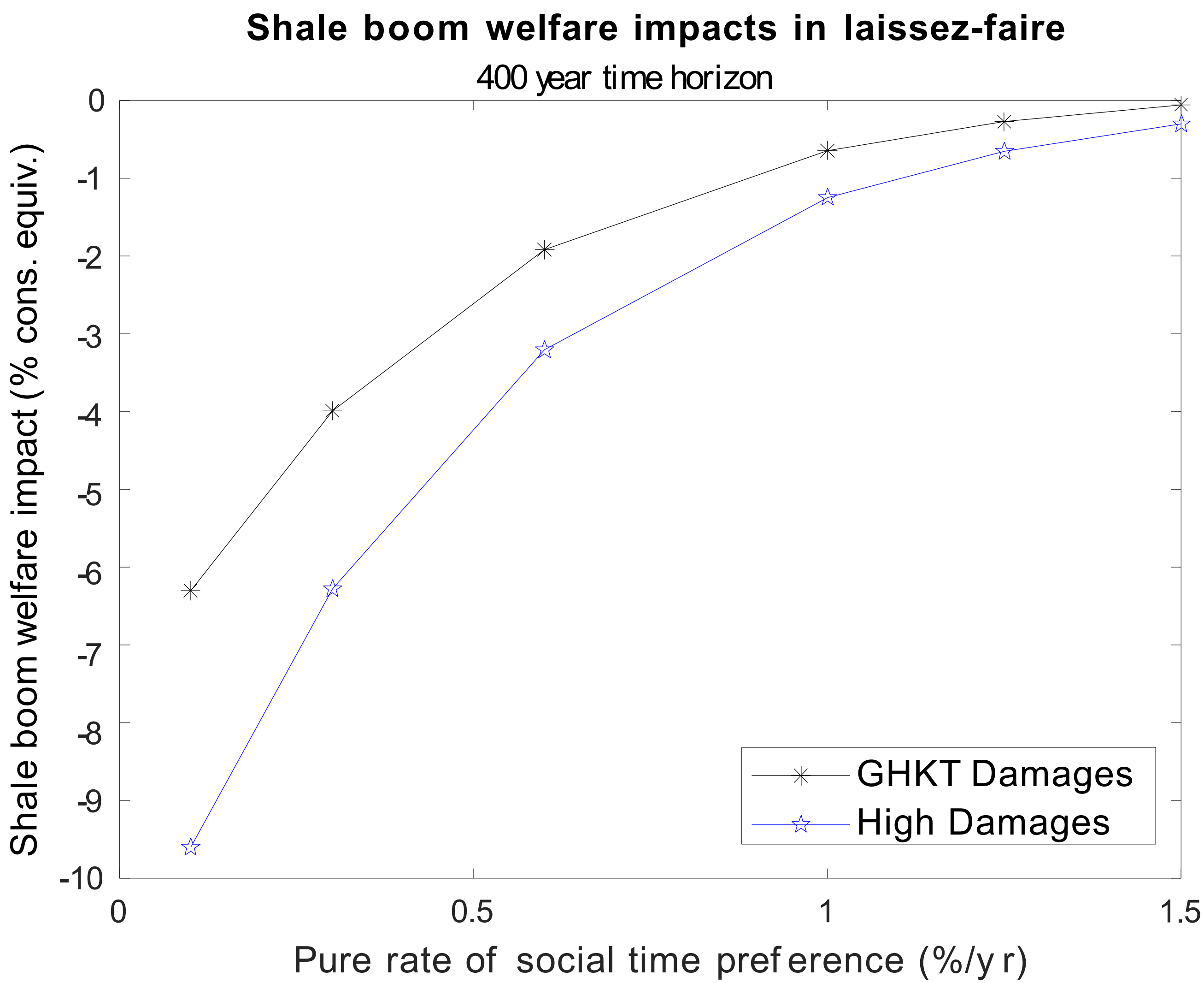
- We proceed in three steps:
  - We construct measures of electricity generation costs using information on electricity (only) production in the US in 2006-2010 for coal, natural gas and green sources
  - We select a number of parameters directly based on prior literature and data sources (epsilon, kappa's)
  - We solve for the remaining parameters and initial equilibrium outcomes (initial A's and B's) so as to match the model with the data.
- 3 key parameters:
  - Elasticity of substitution across electricity sources ε=1.86 (Papageorgiou et al., 2017)
  - Decreasing return to innovation ψ to match elasticity of clean to dirty innovation with respect to natural gas of 0.246
  - Discount rate ρ which we take to be equal to 1.5% in most of our analysis

Effects of shale gas boom

Unmanaged boom



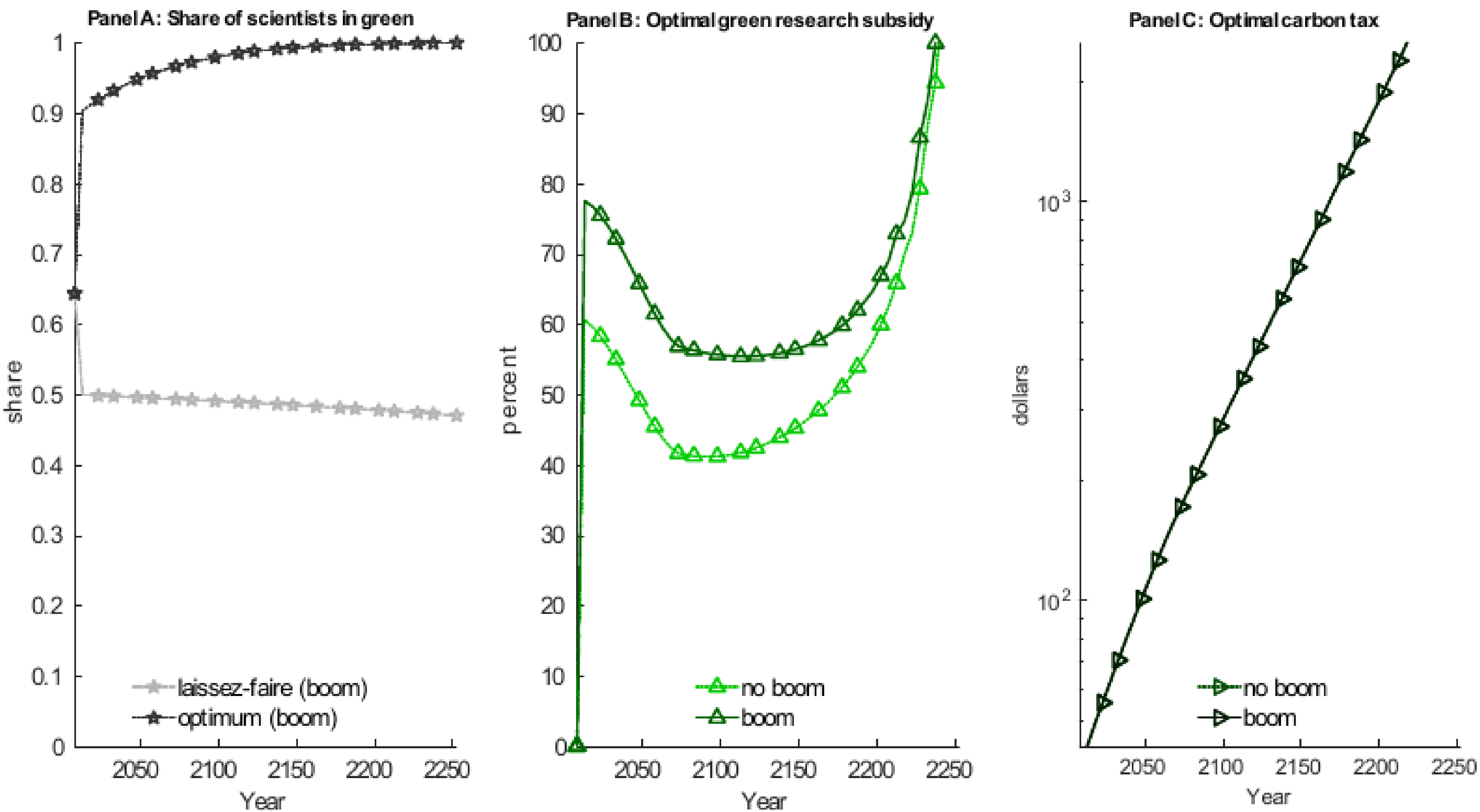
Welfare effects



Optimal policy: Setup

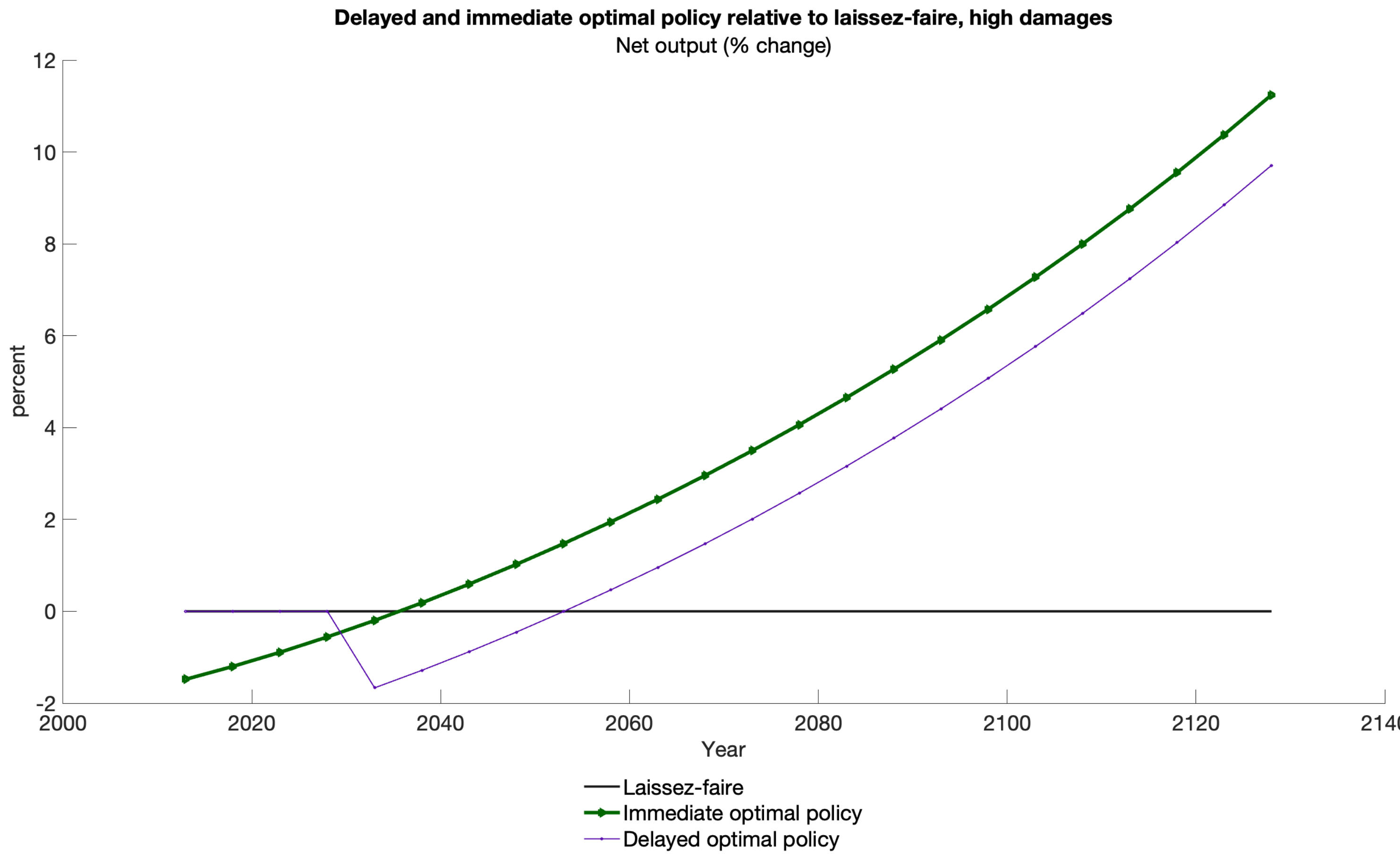
- Consider a social planner who maximizes US welfare but takes emissions from ROW (and outside electricity) as given
- Two externalities $\Rightarrow$ two instruments:
  - Carbon tax to correct for environmental externality
  - Clean research subsidy to take into account that private value of innovation is too short-sighted

Optimal Policy: effect of the boom



Now consider shale gas boom as given

- All simulations here take the shale gas boom as given.
- We look at effect of delaying or not the optimal policy and of using one versus two instruments



Delayed and immediate optimal policy relative to laissez-faire, high damages
Net output (% change)
percent
Year
12
10
8
6
4
2
0
-2
2000
2020
2040
2060
2080
2100
2120
2140
Laissez-faire
Immediate optimal policy
Delayed optimal policy

	Welfare compared to laissez-faire, in percentage points	
	GKHT damages	High damages
Optimal Policy	19.59	49.17
Delayed Policy (20 years)	14.85	34.13

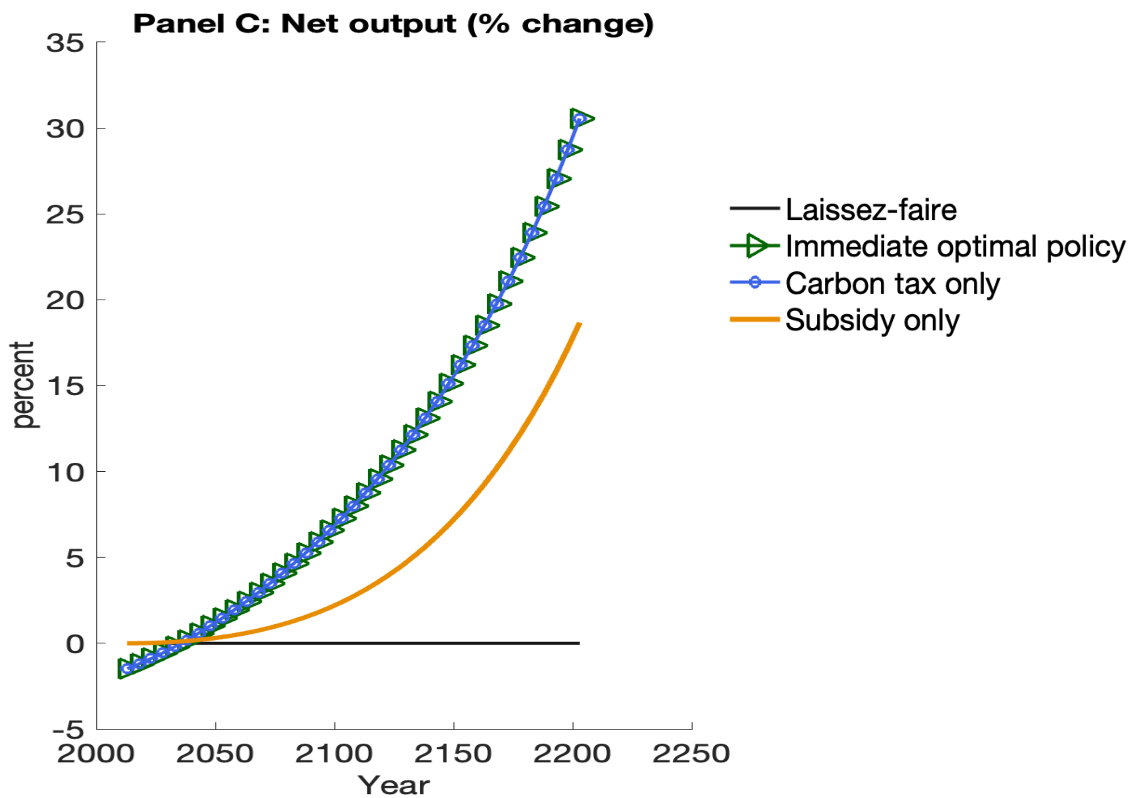
Note: The optimal policy increases welfare by 19.59% compared to laissez-faire, in the GHKT damages case.

	Welfare compared to optimal policy, in percentage points	
	GKHT damages	High damages
Optimal Policy	*reference*	*reference*
Delayed Policy (20 years)	-3.65	-8.45

Note: The delayed policy reduces welfare by 3.65% compared to the optimal policy, in the GHKT damages case.

One versus two instruments

Constrained and optimal policy relative to laissez-faire, high damages



Welfare effects with 1.5% discount rate

	Welfare compared to laissez-faire, in percentage points	
	GKHT damages	High damages
Optimal Policy	20.2	49.2
Delayed Policy (20 years)	14.9	34.1
Tax only	20.2	49.2
Subsidy only	6.2	12.4

Note: The optimal policy increases welfare by 20.2% compared to laissez-faire, in the GHKT damages case.

	Welfare compared to optimal policy, in percentage points	
	GKHT damages	High damages
Optimal Policy	*reference*	*reference*
Delayed Policy (20 years)	-3.7	-8.5
Tax only	0.0	0.0
Subsidy only	-10.4	-21.1

Note: The delayed policy reduces welfare by 3.7% compared to the optimal policy, in the GHKT damages case.

Welfare effects with 1% discount rate

	Welfare compared to laissez-faire, in percentage points	
	GKHT damages	High damages
Optimal Policy	30.4	77.8
Delayed Policy (20 years)	24.0	57.2
Tax only	30.5	77.8
Subsidy only	11.1	22.3

Note: The optimal policy increases welfare by 30.4% compared to laissez-faire, in the GHKT damages case.

	Welfare compared to optimal policy, in percentage points	
	GKHT damages	High damages
Optimal Policy	*reference*	*reference*
Delayed Policy (20 years)	-4.4	-9.0
Tax only	0.0	0.0
Subsidy only	-13.3	-25.3

Note: The delayed policy reduces welfare by 4.4% compared to the optimal policy, in the GHKT damages case.

Conclusion

- Innovation-based climate models suggest that action must be taken urgently and that multiple instruments should be used
- Our calibration confirms the delay cost but so far we find no big loss from using carbon tax only when taking shale gas boom as given
- Yet recall that green research subsidies help mitigate the negative long-run effects of shale gas boom

Conclusion

- **The role for green industrial policy (Aghion, Hemous, Liu)**
- We consider the green / energy transition along the value chain in the presence of Pigovian taxation.
- Complementarities across sectors can lead to multiple equilibria where either clean technologies are adopted along the value chain or where they are not adopted.
- This speaks to the role of industrial policy to coordinate the clean transition.
- With a pigovian tax alone, to remove multiplicity then one would need too large of a tax!

Extra slide

– GKHT damages (from Golosov, Krusell, Hassler, Tsyvinsky, 2014)
  - $v(S_t) \sim 1 - e^{-\gamma_D (S_t - S_0)}$ where S is the quantity of CO2 in the atmosphere
  - γ_D=1.1.(10 to the power -4)

– High damages
  - Increase parameter γ_D to double the projected effects of unmitigated end-of century warming