Virtual Seminar on Climate Economics

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The Macroeconomics of Clean Energy Subsidies

Greg Casey[1] Woongchan Jeon[2] Christian Traeger[3]

[1]Williams College

[2]ETH Zurich

[3]U. Oslo

Virtual Seminar on Climate Economics
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Bob Kopp
@bobkopp

Environmental economists should probably take a moment of humble reflection to ask whether the discipline's focus on first-best carbon pricing mechanisms contributed to how long it has taken to get US climate legislation

8:17 PM · Aug 7, 2022

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This paper: policymakers can only affect the price of clean energy

Use macro climate-economy model to:

1. Characterize constrained-efficient subsidy
   - When do clean energy subsidies decrease emissions and improve welfare?
2. Quantify impact of Inflation Reduction Act (IRA)
   - Emissions & welfare relative to no policy?
   - 'Impacts of IRA' for short
3. Quantify constrained-efficient subsidy
   - Emissions & welfare relative to no policy?
   - Emissions & welfare relative to dirty energy tax?

Macro models suggest limited effectiveness of clean energy subsidies

1. Constrained-efficient subsidy = *indirect externality*
   - *Indirect externality* = (impact of clean on dirty) $\times$ (MC_{ext} of dirty)
   - Subsidies $\downarrow$ emissions $\iff$ clean and dirty energy gross substitutes
   - Substitutability not relevant for Pigouvian tax
2. Small impacts of subsidies in IRA
   - Standard values suggest subsidies $\uparrow$ emissions (gross complements)
3. Carbon tax yields order of magnitude $\downarrow$ emissions and $\uparrow$ welfare relative to constrained-efficient subsidy

Related literature and contribution

MACRO CLIMATE MODELS: Nordhaus and Boyer (2003), Nordhaus and Barrage (2023), Golosov et al (2014), Hassler et al (2016, 2018), Traeger (forthcoming)

- **Contribution**: Clean energy subsidies

SECOND-BEST IN STATIC/CGE MODELS: Palmer and Burtaw (2005), Fullerton and Wolverton (2005), Bennear and Stavins (2007), Goulder and Parry (2008), Holland et al (2009, 2012), Kalhul et al., (2013), Newell et al (2019).

- **Contribution**: Characterize best subsidy, quantification in dynamic model

MACRO & SECOND-BEST: Rezai and van der Ploeg (2017), Hassler et al (2020, 2021), Bistline et al (forthcoming)

- **Contribution**: Characterize best subsidy, quantify IRA & best subsidy

Outline

Study a (really) simple model to get intuition

- Gross output: $q = f(l, e_d, e_c)$
  - labor (l), dirty energy (e_d), clean energy (e_c)
  - CRS, Inada conditions
  - $f_j > 0$ and $f_{jj} < 0$, $j = l, c, d$
  - Price normalized to one
- Inelastic labor supply: $l = 1$
- Energy extracted from environment using final good
  - Real extraction costs: p_d, p_c
- Final output: $y = f(l, e_d, e_c) - p_c e_c - p_d e_d$
- Utility: $U = u(y) - m e_d$
- Policy: Can tax or subsidize e_c ($\tau_c > 0$ is a tax)

Competitive equilibrium (CE) determined by firm optimization

Firm solves:

$$\max_{l,e_d,e_c} f(l,e_d,e_c) - p_d e_d - (p_c+\tau_c)e_c - wl,$$

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First order conditions determine equilibrium ($l = 1$):

$$f_d(1, e_d, e_c) = p_d$$
$$f_c(1, e_d, e_c) = p_c + \tau_c$$

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Key result:

$$\frac{de_d}{de_c} = \frac{f_{cd}}{-f_{dd}} \equiv D'(e_c)$$

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$$\frac{de_d}{de_c} > 0 \iff f_{cd} > 0$$

Constrained social planner can subsidize/tax clean energy

Choose τ_c to maximize U, subject to CE.

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$$\max_{e_c}\; u\Big(f(1, D(e_c), e_c) - p_d D(e_c) - p_c e_c\Big) - mD(e_c).$$

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First order condition:

$$\underbrace{f_c(1, e_c^*, D(e_c^*)) - p_c}_{\frac{\partial y}{\partial e_c}} + \underbrace{(f_d(1, e_c^*, D(e_c^*)) - p_d)}_{\frac{\partial y}{\partial e_d}} \underbrace{D'(e_c^*)}_{\frac{de_d}{de_c}} = \underbrace{\frac{m}{u'(y)}}_{\text{MC}_{\text{ext}}} \underbrace{D'(e_c^*)}_{\frac{de_d}{de_c}}.$$

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Substitute from competitive equilibrium:

$$\underbrace{f_c(1, e_c^*, D(e_c^*)) - p_c}_{=\tau_c^*} + \underbrace{\left(f_d(1, e_c^*, D(e_c^*)) - p_d\right) D'(e_c^*)}_{=0} = \underbrace{\frac{m}{u'(y)} D'(e_c^*)}_{\text{indirect externality}} \; .$$

Constrained-efficient subsidy

$$\tau_c^* = \frac{m}{u'(y)} \frac{de_d}{de_c} = \left(\frac{m}{u'(y)} \right) \left(\frac{f_{cd}}{-f_{dd}} \right)$$

So, $\tau_c^* > 0 \iff f_{cd} > 0$.

- Clean energy subsidy/tax = *indirect externality*
- Best to tax clean energy when $\frac{de_d}{de_c} > 0$
- Best to subsidize clean energy when $\frac{de_d}{de_c} < 0$

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- Clean energy subsidy/tax = *indirect externality*
- Best to tax clean energy when $\frac{de_d}{de_c} > 0$
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Note, f_{cd} wouldn't matter for optimal carbon tax.

What about non-optimal subsidies?

$$\frac{dU}{d\tau_c}\frac{1}{u'(y)}\Big|_{\tau_c=0} = \frac{m}{u'(y)}\frac{de_d}{d\tau_c} = \frac{m}{u'(y)}\frac{de_d}{de_c}\frac{de_c}{d\tau_c} = \frac{m}{u'(y)}\frac{f_{cd}}{-f_{dd}}\frac{de_c}{d\tau_c}.$$

- The no-policy equilibrium maximizes y.
- But, it has too much dirty energy: $\partial U/\partial e_d < 0$.
- Envelope theorem: marginal $\uparrow$ U $\iff$ marginal $\downarrow e_d$.
- If $f_{cd} > 0$, then $de_d/de_c > 0$ and a subsidy decreases welfare.

Learning-by-doing (LBD) doesn't change intuition

- LBD common justification for clean energy subsidies
  - But, separate market failure
  - Separate instruments to implement optimal allocation

- LBD: $\uparrow e_c \rightarrow \downarrow p_c$

- Maybe good for welfare (better tech), but not environment

- If $f_{cd} > 0$, still $de_d/de_c > 0$
  - Clean subsidy still increases dirty energy use.
  - Impact of subsidy is now bigger, because stronger response of $\frac{de_c}{d\tau_c}$

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  - Clean subsidy still increases dirty energy use.
  - Impact of subsidy is now bigger, because stronger response of $\frac{de_c}{d\tau_c}$
- (Also, no need to raise revenue in this model.)

Outline

1. General characterization in simple model
2. Functional forms in simple model
3. Dynamic model
4. Conclusion

Use nested CES-in-CD to map results to model parameters

Standard approach in macro climate-economy models:

$$
\begin{aligned}
q &= g(l, e) = l^{1-\nu} e^{\nu} \\
e &= h(e_d, e_c) = \left(\omega e_d^{\frac{\epsilon-1}{\epsilon}} + (1-\omega) e_c^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}} \\
\Rightarrow q &= f(l, e_d, e_c) = g(l, h(e_d, e_c)).
\end{aligned}
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Key parameters:

$$
\begin{aligned}
\frac{\partial \ln \frac{e_d}{e_c}}{\partial \ln \frac{p_d}{p_c}} &= -\epsilon \\
\frac{\partial \ln e}{\partial \ln p_e} &= -(1-\nu)^{-1}
\end{aligned}
$$

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With these functional forms

$$
f_{cd} > 0 \iff \epsilon < (1-\nu)^{-1}.
$$

Use nested CES-in-CD to map results to model parameters

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\Rightarrow q &= f(l, e_d, e_c) = g(l, h(e_d, e_c)).
\end{aligned}
$$

With these functional forms:

$$
\frac{d \ln e_d}{d \ln(p_c + \tau_c)} = \left(\epsilon - (1-\nu)^{-1}\right) \frac{(p_c + \tau_c) e_c}{(p_c + \tau_c) e_c + p_d e_d}.
$$

- Energy mix: ϵ determines $\Delta(e_d/e)$
- Energy use: ν determines Δe

Use nested CES-in-CD to match results to data

- ν measured from national accounts: 4%-8%
  - Hassler et al (2021); Casey (forthcoming)
- Cutoff value for ϵ : $1.04 - 1.09$.
- Standard value of $\epsilon = 0.95 \Rightarrow \tau_c^* > 0$
  - Meta-study by Stern (2012)
  - Used in Golosov et al (2014); Hassler et al (2016, 2018)
  - Close to cutoff $\Rightarrow \frac{de_d}{d\tau_c}$ is small
- Alternate value of ϵ is $\approx 2 \Rightarrow \tau_c^* < 0$
  - Papageorgiou et al (2017)
  - Electricity sector + average of other sectors
  - Acemoglu et al (2023) summarize as $\epsilon = 1.85$
  - How close to cutoff?

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  - How close to cutoff?
- Key results:
  - Standard parameters imply detrimental impacts of subsidies
  - Reasonable parameter values reverse sign of impact signs
  - Either way, impacts likely to be small

Outline

Aggregate climate-economy model of US economy

- Simple model intuition hold in dynamic setting?
- Emissions & welfare impacts of subsidies in Inflation Reduction Act?
  - Compare to no policy
- Constrained-efficient subsidy? Compare to ...
  - No policy
  - IRA
  - Dirty energy tax

Model equations: production

$$
\begin{aligned}
Y_t &= K_{y,t}^{\alpha} E_{y,t}^{\nu} \left(A_{y,t} L_{y,t}\right)^{1-\alpha-\nu} \\
E_t &= \left(\omega^{\frac{1}{\epsilon}} Z_{d,t}^{\frac{\epsilon-1}{\epsilon}} + (1-\omega)^{\frac{1}{\epsilon}} Z_{c,t}^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\epsilon}{\epsilon-1}} \\
Z_{j,t} &= K_{j,t}^{\alpha} E_{j,t}^{\nu} (A_{j,t} L_{j,t})^{1-\alpha-\nu}, \quad j = c, d \\
A_{j,t+1} &= (1+g_j) A_{j,t}, \quad j = y, c, d
\end{aligned}
$$

- 10-year periods
- Symmetric productions functions for easy solution method
- Capital in energy production (differs from GHKT)
- Parameters:
  $\epsilon \in \{0.95, 1.85\}, \ \nu = 0.08, \ \alpha = 0.27, \ \omega = 0.60, \ g_j = 2\%$/year

Model equations: utility

$$U = \sum_{t=0}^{\infty} \beta^t \left(L_t \ln(C_t) - m \sum_{v=0}^{t} \eta_v Z_{d,v} \right)$$

$$\eta_t = (1 + g_\eta)\eta_{t-1}$$

$$C_t + K_{t+1} = w_t L_t + (1 + r_t - \delta)K_t$$

- Linear utility similar to GHKT (2014), but with endogenous savings
- Linear utility $\rightarrow$ ignore earlier/ROW emissions
- SCC $\times$ 2020 emission = 4% of GDP (Rennert et al, 2020)
- Parameters: $g_\eta = -2.3\%$/year, $m = 0.60$, $\beta = 0.77$, $\delta = 6.0\%$/year

Closing the model

$$
\begin{aligned}
K_t &= K_{y,t} + K_{d,t} + K_{c,t} \\
L_t &= L_{y,t} + L_{d,t} + L_{c,t} \\
K_{t+1} &= Y_t - C_t + (1-\delta)K_t \\
L_{t+1} &= (1+n)L_t.
\end{aligned}
$$

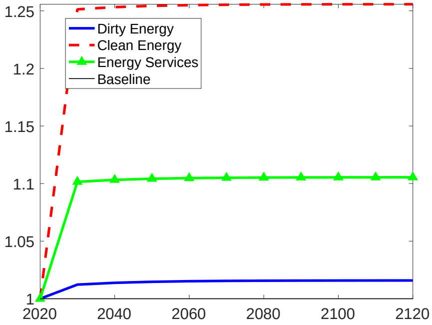
- Parameter: $n = 1.1\%$/year.

Overall, fairly 'off-the-shelf' macro model

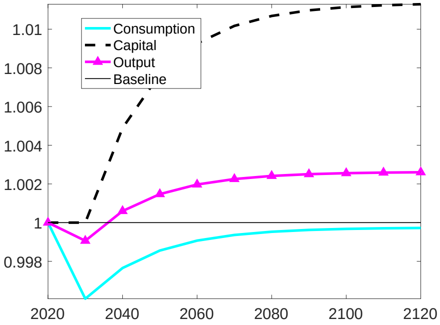
Inflation Reduction Act

- Need to ignore nuances. Goal is order of magnitude and sign.
- Model everything as a 20% production tax credit
  - $0.80p_{c,t}$ paid by energy service producer
  - Lump sum taxes and transfers
- Bistline et al (forthcoming): IRA will lower the prices of utility-scale solar, onshore wind and offshore wind by 20%, 12%, and 23%, respectively
- Announced and implemented in 2030. Permanent.
- Compare to baseline where economy remains on no-policy BGP

IRA impacts with $\epsilon = 0.95$



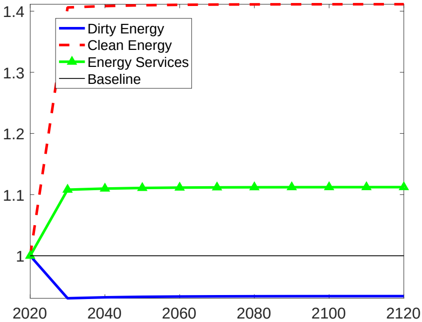
(a) Energy Use



(b) Macro Dynamics

- Effects on dirty energy small, because close to $\epsilon = (1-\nu)^{-1}$.
- $\uparrow$ dirty energy $+\downarrow$ consumption $\Rightarrow \downarrow$ welfare (0.15% CEV).

IRA impacts with $\epsilon = 1.85$



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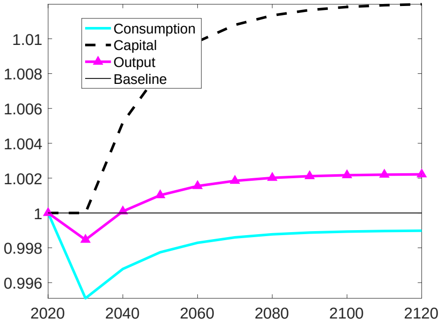


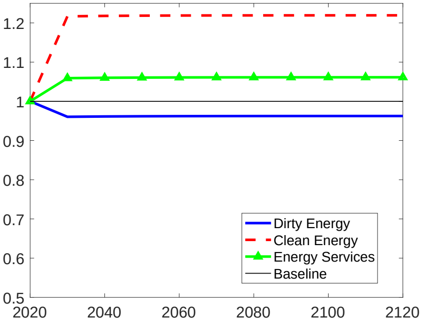
(b) Macro Dynamics

- $\epsilon > (1-\nu)^{-1} \Rightarrow$ emissions $\downarrow$ 6.5%
- Welfare increase by 0.02% CEV

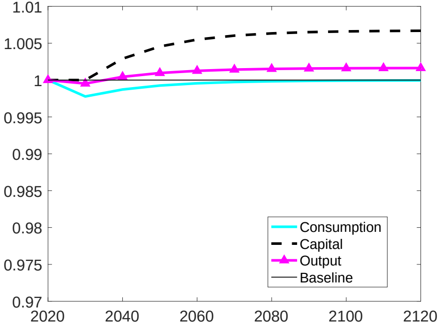
Constrained-efficient subsidies

- Emissions & welfare impacts of IRA are small, possibly detrimental
- Poor choice of subsidy level or ineffective instrument?
- What is the best we can do with subsidies?
- Use $\epsilon = 1.85$
- Find constrained-efficiency subsidy
  - Compare to no policy, IRA, dirty energy tax
  - Check grid: 80%, 79%, ...

Constrained-efficiency subsidy is 12% (vs 20% in IRA)



(a) Energy Use



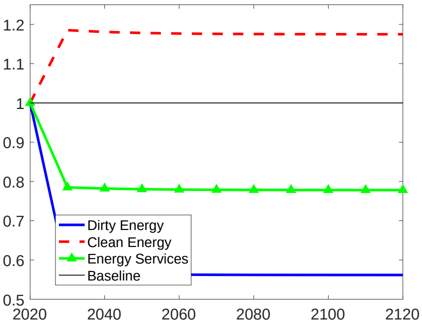
(b) Macro Dynamics

- Emissions ↓ 4%
- Welfare ↑ 0.06% CEV (vs no policy)

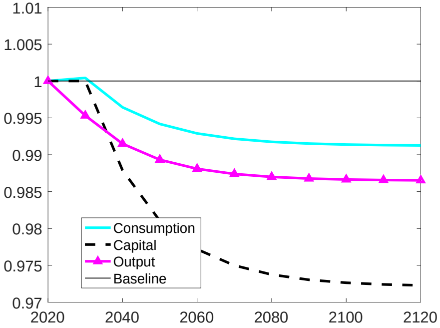
Dirty energy tax

- Clean subsidies have small welfare impact
  - Just low climate damages?
  - Benefit relative to carbon pricing?
- Compare best subsidy to best tax
  - $\epsilon = 1.85$
- Similar constraints: constant tax on dirty energy
  - Check grid: 0%, 1%, ...

Constrained-efficient dirty energy tax is 49%



(a) Energy Use



(b) Macro Dynamics

- Qualitatively different energy and macro dynamics
- Dirty energy ↓ 45%
- Welfare ↑ 0.7% CEV (vs no policy)

Comparison to engineering models

- Bistline et al (2023, forthcoming): REGEN suggest IRA reduces emissions by $\approx$11% relative to no policy.

- Possible to read this as supporting $\epsilon > 1.85$

- But, another important difference: treatment of energy demand.
  - Partially-exogenous in REGEN
  - $\Rightarrow$ overstates emissions reductions

Outline

Conclusion: climate policy when can't affect dirty energy prices

- Best subsidy = indirect externality
- Are clean and dirty substitutes or complements?
- Complements at standard parameter values ⇒ subsidies increase emissions
  - but EoS highly uncertain
- Even with a high elasticity:
  - limited impact of IRA on emissions
  - dirty energy tax much more effective than best subsidy

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Standard macro climate-economy models:
big return to moving to carbon pricing

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Standard macro climate-economy models:
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Email: gpc2@williams.edu

Outline

5. What is a plausible elasticity?

What determines ϵ?

In general, macro elasticities depend on:

- Average of sector-level elasticities
- Heterogeneity between sector-level elasticities
- Substitution between sectors

For clean-dirty EoS:

- Elasticity within electric power sector
- Average ease of electrification within end-use sectors
- Substitution between end-use sectors

What is a plausible elasticity?

$$e = \left(\omega^{\frac{1}{\epsilon}} e_d^{\frac{\epsilon-1}{\epsilon}} + (1-\omega)^{\frac{1}{\epsilon}} e_c^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}}$$

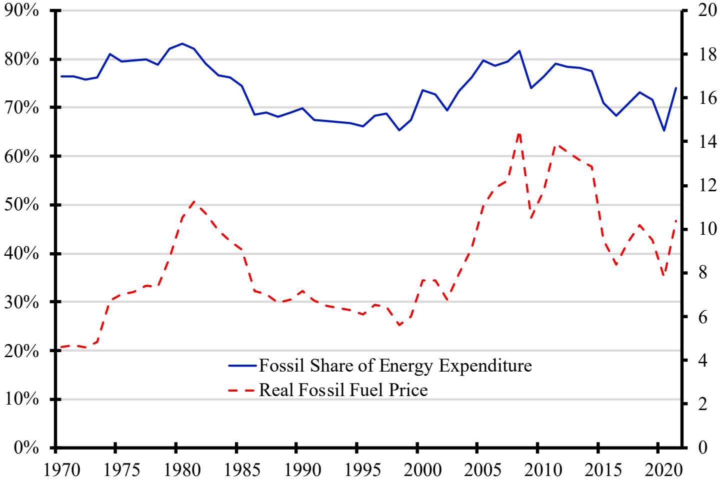
$\Longrightarrow$

$$\ln \frac{s_d}{1-s_d} = \text{constant} + (\epsilon - 1) \ln \frac{p_c}{p_d},$$

where

$$s_{d,t} := \frac{p_d e_d}{p_e e}.$$

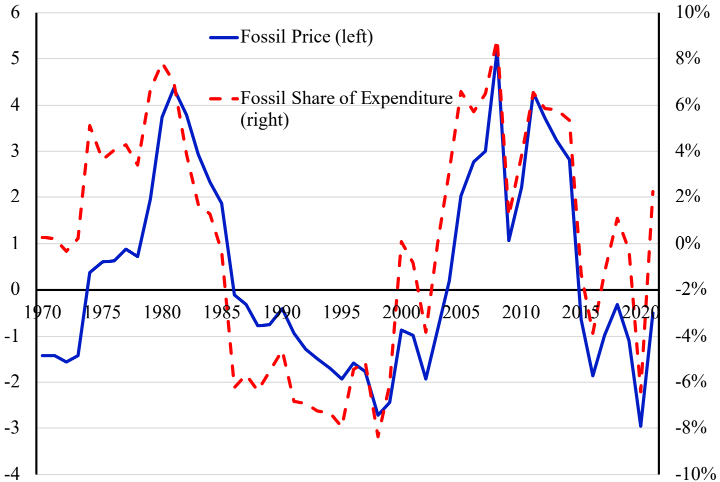
Dirty share fairly constant despite rising price



Source: Casey and Gao (2023)

With constant p_c, trend implies $\epsilon = 1.05$

Short-run elasticity appears even lower



Source: Casey and Gao (2023)