How DOEs Government Funding Fuel Scientists?

Eugenie Dugoua
LSE

Todd Gerarden
Cornell

Kyle Myers
HBS

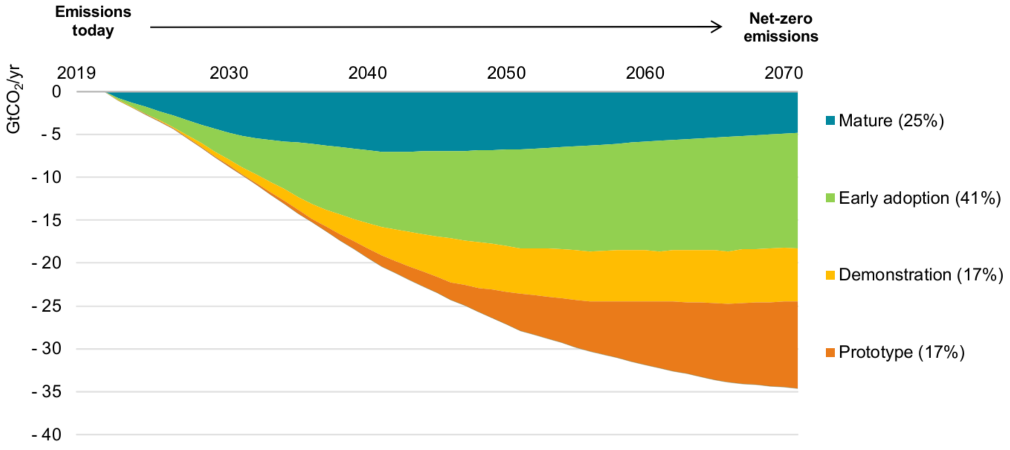
Jacquelyn Pless
MIT Sloan

INRAE Paris

May 18, 2025

Addressing Climate Change will Require Significant Innovation (still)

Figure 3.1 Global energy sector CO_2 emissions reductions by current technology readiness category in the Sustainable Development Scenario relative to the Stated Policies Scenario



Source: Energy Technology Perspectives, IEA (2020)

Innovation Begins with People

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Most innovation policies subsidize firms (R&D tax credits, grants, etc.)

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Frictions in education preventing individuals from investing to become inventor?

- If supply of inventors is inelastic, demand-side policies might just increase wages of high-skilled workers (Goolsbee, 1998)
- **Human capital policies** may be most direct mechanism (Bloom et al., 2019; Akcigit et al., 2020; Van Reenen, 2021)

7

Should the Government Subsidize Supply or Demand in the Market for Scientists and Engineers?

Paul M. Romer, *Graduate School of Business, Stanford University*

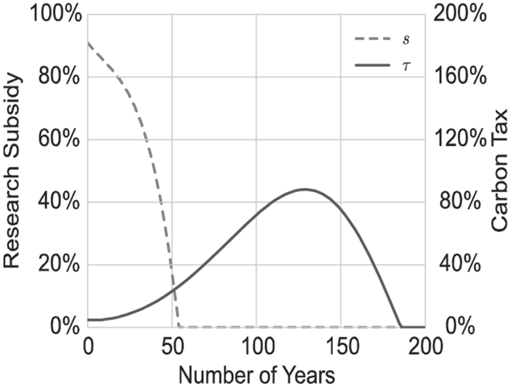
"...innovation policy in the US has erred by subsidizing the private sector demand for scientists and engineers without asking **whether the educational system provides the supply response** necessary for these subsidies to work." (Romer, 2000)

Macro Energy Models often Assume a Fixed Supply of Researchers

Existing macro models

- subsidy affects **shares** of scientists in clean vs dirty
- **but total supply of researchers is fixed**
- **path dependence** and **switching costs** very important [Nowzohour 2020]
- New inventors less elastic than incumbent clean incumbents [Dugoua Gerarden 2024]

Figure 1: Optimal policy path



[Acemoglu et al. 2016]

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- **Data:**
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  - Outcome 2: Energy patenting at the USPTO (PATSTAT)
  - Energy tech-specific DOE budget **requests** and Congress **appropriations** (1987-2022) NEW!

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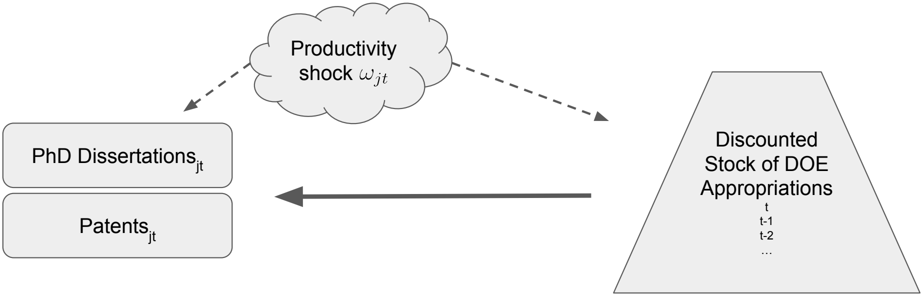
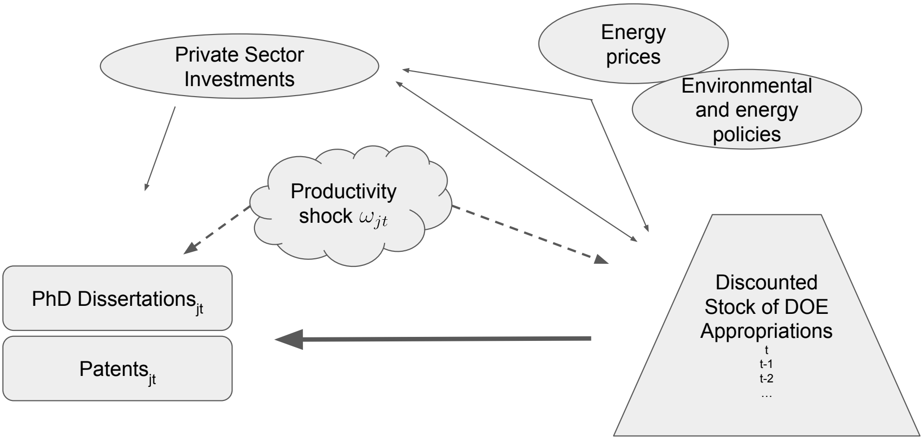
  - Energy tech-specific DOE budget **requests** and Congress **appropriations** (1987-2022)
- **Methods: Exploit funding “windfalls”**
  - Windfalls = Congressional Appropriations - DOE Requests
  - Construct a measure of “unexpected” windfalls to capture quasi-random variation by predicting appropriations based on observables
  - Construct an instrument based on these “unexpected” windfalls

Technology-Specific Appropriations at the DOE

	FY 1990 Approp.	FY 1990 REQUEST
Solar Energy R&D	$89,659	$71,156
Geothermal	18,077	15,409
Electric Energy	17,828	17,313
Energy Storage	12,047	8,589


Productivity shock ω_{jt}
PhD Dissertations$_{jt}$
Patents$_{jt}$
Discounted Stock of DOE Appropriations
t
t-1
t-2
…



Private Sector Investments
Energy prices
Environmental and energy policies
Productivity shock ω_{jt}
PhD Dissertations$_{jt}$
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t
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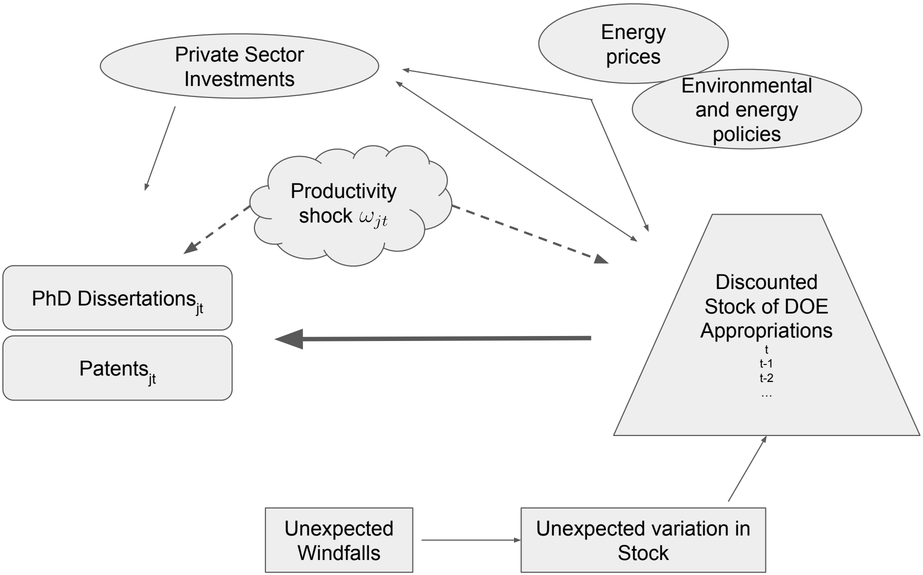

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…
Unexpected Windfalls
Unexpected variation in Stock

Contributions

- **Scientific labour supply responsiveness:** Goolsbee (1998); Myers (2020); Dugoua & Gerarden (2024)
- **Causal estimates of public energy RD&D returns:** first technology-year estimates of productivity from DOE investments - the largest funder of energy RD&D. Prior work has looked at specific program, typically targetting firms.
    - Energy: Howell (2017), Popp (2016)
    - Outside energy: Azoulay et al. (2019), Santoleri et al (2024), Jones (2021)
- **Evaluation of ARRA's innovation impact:**
    - First ex post assessment of the 2009 American Recovery and Reinvestment Act on innovation (in progress).
    - ARRA: largest ever investment in clean energy RD&D (until the IRA \$11 billion)
    - Studies on employment effects, e.g., Popp et al 2020
- **Political economy of energy R&D:** the political economy of carbon pricing has received a lot of attention, innovation policies much less...

Outline

Data: DOE Requests and Appropriations

Data: Dissertations and Patents

Empirical Strategy and Results

Data: DOE Requests and Appropriations

How is funding determined?

For example, for the FY 2002:

Spring 2000: White House issues guidance to agencies

Summer 2000: Agencies develop budget requests

Sep 2000: Agencies submit budgets to White House

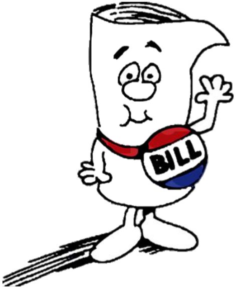
Oct–Dec 2000: White House negotiates with agencies

Jan–Feb 2001: "President's Budget" request sent to Congress

$\Rightarrow$ Document published with justification of the budget estimates

Mar–Sep 2001: Congress debates with White House and agencies

Sep 2001: Congress (hopefully) passes appropriations bills



DEPARTMENT OF THE INTERIOR AND RELATED AGENCIES APPROPRIATIONS FOR 2002

HEARINGS

BEFORE A

SUBCOMMITTEE OF THE

COMMITTEE ON APPROPRIATIONS

HOUSE OF REPRESENTATIVES

ONE HUNDRED SEVENTH CONGRESS

FIRST SESSION

SUBCOMMITTEE ON THE DEPARTMENT OF THE INTERIOR AND RELATED AGENCIES

JOE SKEEN, New Mexico, *Chairman*

RALPH REGULA, Ohio
JIM KOLBE, Arizona
CHARLES H. TAYLOR, North Carolina
GEORGE R. NETHERCUTT, JR., Washington
ZACH WAMP, Tennessee
JACK KINGSTON, Georgia
JOHN E. PETERSON, Pennsylvania

NORMAN D. DICKS, Washington
JOHN P. MURTHA, Pennsylvania
JAMES P. MORAN, Virginia
MAURICE D. HINCHEY, New York
MARTIN OLAV SABO, Minnesota

NOTE: Under Committee Rules, Mr. Young, as Chairman of the Full Committee, and Mr. Obey, as Ranking Minority Member of the Full Committee, are authorized to sit as Members of all Subcommittees.

DEBORAH WEATHERLY, LORETTA BEAUMONT, JOEL KAPLAN, and CHRISTOPHER TOPIK, *Staff Assistants*

PART 3

Justification of the Budget Estimates

Energy Efficiency and Renewable Energy
Funding by Congressional Control ($K)

	FY 2014 Enacted	FY 2014 Current[1]	FY 2015 Enacted	FY 2016 Request	FY 2016 vs FY 2015
Vehicle Technologies	289,737	282,201	280,000	444,000	+164,000
Bioenergy Technologies	232,290	182,327	225,000	246,000	+21,000
Hydrogen and Fuel Cell Technologies	92,928	89,518	97,000	103,000	+6,000
Solar Energy	257,058	254,305	233,000	336,700	+103,700
Wind Energy	88,126	87,035	107,000	145,500	+38,500
Water Power	58,565	57,834	61,000	67,000	+6,000
Geothermal Technologies	45,775	44,802	55,000	96,000	+41,000
Advanced Manufacturing	180,471	175,400	200,000	404,000	+204,000
Federal Energy Management Program	28,248	28,248	27,000	43,088	+16,088
Building Technologies	177,868	173,631	172,000	264,000	+92,000
Weatherization and Intergovernmental Program					
Weatherization Assistance Program					
Weatherization Assistance [2]	170,898	170,898	189,600	223,999	+34,399
Training and Technical Assistance	2,998	2,998	3,000	4,000	+1,000
NREL Site-Wide Facility Support	0	0	400	400	0
Total, Weatherization Assistance Program	173,896	173,896	193,000	228,399	+35,399
State Energy Program[3]	49,970	49,970	50,000	70,100	+20,100
Local Energy Program[4]	0	0	0	20,000	+20,000
Tribal Energy Program[5]	6,996	6,996	0	0	0
Total, Weatherization and Intergovernmental Program	**230,862**	**230,862**	**243,000**	**318,499**	**+75,499**
Program Direction	162,000	162,000	160,000	165,330	+5,330
Strategic Programs	23,540	23,540	21,000	27,870	+6,870
Facilities and Infrastructure	45,973	45,973	56,000	62,000	+6,000
Subtotal, Energy Efficiency and Renewable Energy	**1,913,441**	**1,837,676**	**1,937,000**	**2,722,987**	**+785,987**
Use of Prior Year Balances	-2,382[6]	-2,382[5]	0	0	0

Vehicle Technologies
Funding ($K)

	FY 2014 Enacted[1]	FY 2014 Current[2]	FY 2015 Enacted	FY 2016 Request	FY 2016 vs FY 2015
Vehicle Technologies					
Batteries and Electric Drive Technologies					
Battery Technology R&D	84,949	82,231	82,701	105,400	+22,699
Electric Drive Technologies R&D	23,986	23,218	21,000	39,000	+18,000
Total, Batteries and Electric Drive Technologies	**108,935**	**105,449**	**103,701**	**144,400**	**+40,699**
Vehicle Systems (formerly Vehicle and Systems Simulation and Testing)	**43,474**	**42,848**	**40,393**	**68,100**	**+27,707**
Advanced Combustion Engine R&D	**49,970**	**48,371**	**49,000**	**64,500**	**+15,500**
Materials Technology					
Lightweight Materials Technology	28,982	28,055	28,533	62,500	+33,967
Propulsion Materials Technology	9,155	8,862	7,069	8,000	+931
Total, Materials Technology	**38,137**	**36,917**	**35,602**	**70,500**	**+34,898**
Fuel and Lubricant Technologies	**15,990**	**15,478**	**20,000**	**37,000**	**+17,000**
Outreach, Deployment, and Analysis					
Vehicle Technologies Deployment	23,985	23,985	24,000	49,000	+25,000
Advanced Vehicle Competitions	1,999	1,999	2,500	2,500	+0
Legacy Fleet Improvement	2,898	2,805	0	0	+0
Legislative and Rulemaking	1,899	1,899	1,804	2,000	+196
Biennial Peer Reviews	450	450	0	0	+0
Analysis	0	0	0	3,000	+3,000
Total, Outreach, Deployment, and Analysis	**31,231**	**31,138**	**28,304**	**56,500**	**+28,196**
NREL Site-Wide Facility Support	**2,000**	**2,000**	**3,000**	**3,000**	**+0**
Total, Vehicle Technologies	**289,737**	**282,201**	**280,000**	**444,000**	**+164,000**

Categories of Energy Technologies, j

Energy Technology	Type	Separable in DOE appropriations
solar	clean	Y
wind	clean	Y
marine / hydro	clean	Y
geothermal	clean	Y
hydrogen / fuel cell	clean	Y
nuclear fission	clean	Y
carbon capture and storage	clean	Y
battery / electric vehicle	clean	Y
energy storage	clean	Y
(smart) grid	clean	Y
building	clean	in progress
industry	clean	in progress
nuclear fusion	clean	in progress
biomass/biofuels	grey	Y
energy efficiency	grey	in progress
coal	dirty	Y
natural gas	dirty	Y
oil	dirty	Y
internal combustion engine	dirty	in progress

Data Collection Strategy

- Source documents: DOE Office of Budget; Congressional appropriation documents

  Manual parsing of each document from 2023 back to 1989

- Identify all sub-item activities that relate to RD&D for technology j

  Ignore sub-item if text describes deployment/commercialization activities

- Excludes program direction costs when they cannot be assign to one clear technology
- Excludes direct funding to National Labs when it cannot be assigned to one technology
- Numbers for Requests and Appropriations: choose the number that appears in the latest budget document, as it will be the most representative of what the DOE ultimately requested / Congress ultimately appropriated.

Why do Budget Requests $\neq$ Appropriations? (at the Dept. of Energy)

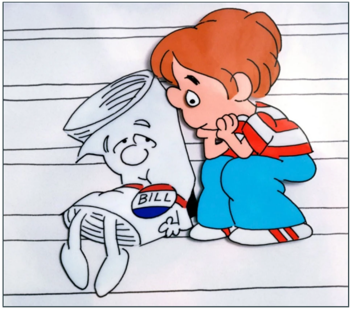
The "budget game"

- Asking/Giving for more/less than what is wanted

Quasi-random factors

- Political skill of secretary / office leadership
- Congress members (esp. appropriations committee)

  Personal or local preferences; lobbying
- Budget shocks elsewhere (e.g., defense)
- Reallocations across line-item budgets

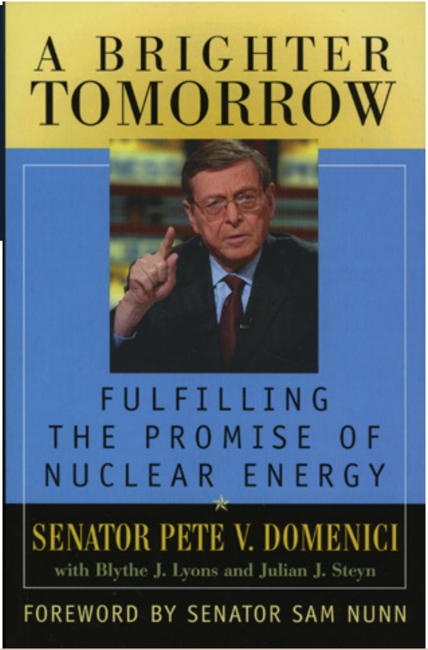


Meet Pete Domenici – New Mexico: Los Alamos and Sandia

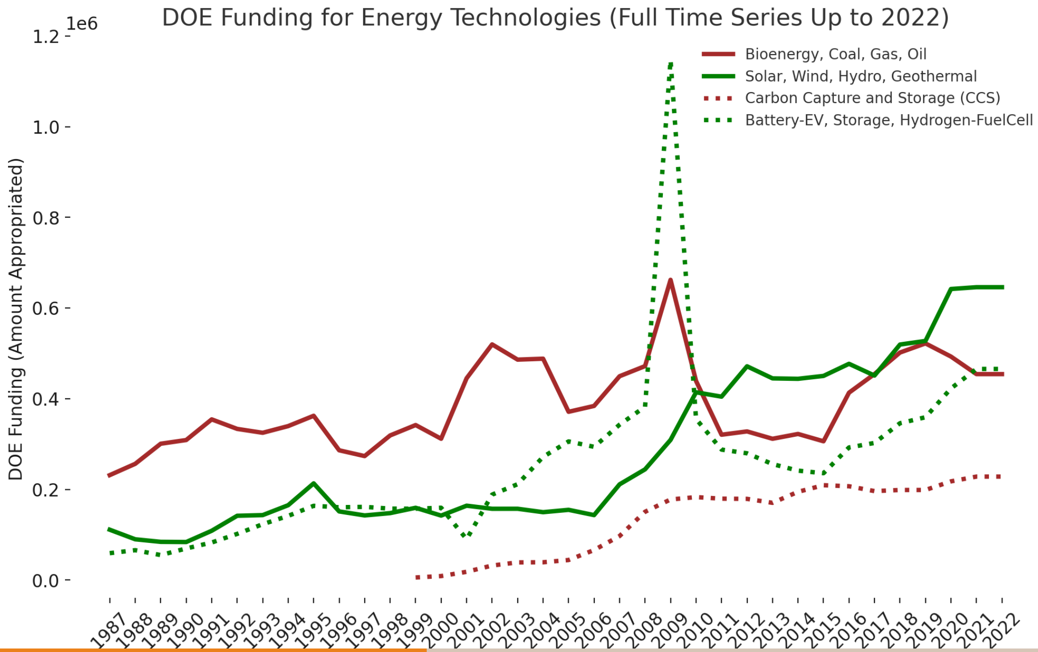
Sen. Pete Domenici: nuclear renaissance man

If there is to be a renaissance in the U.S. nuclear power industry, then Pietro "Pete" Vichy Domenici, the son of Italian immigrants, may be seen as both its Michelango and its Machiavelli. By MSNBC's Mike Stuckey.

Sen. Pete Domenici presides over a September hearing on the Global Nuclear Energy Partnership before the Senate Appropriations



Trends in Technology-Specific Appropriations



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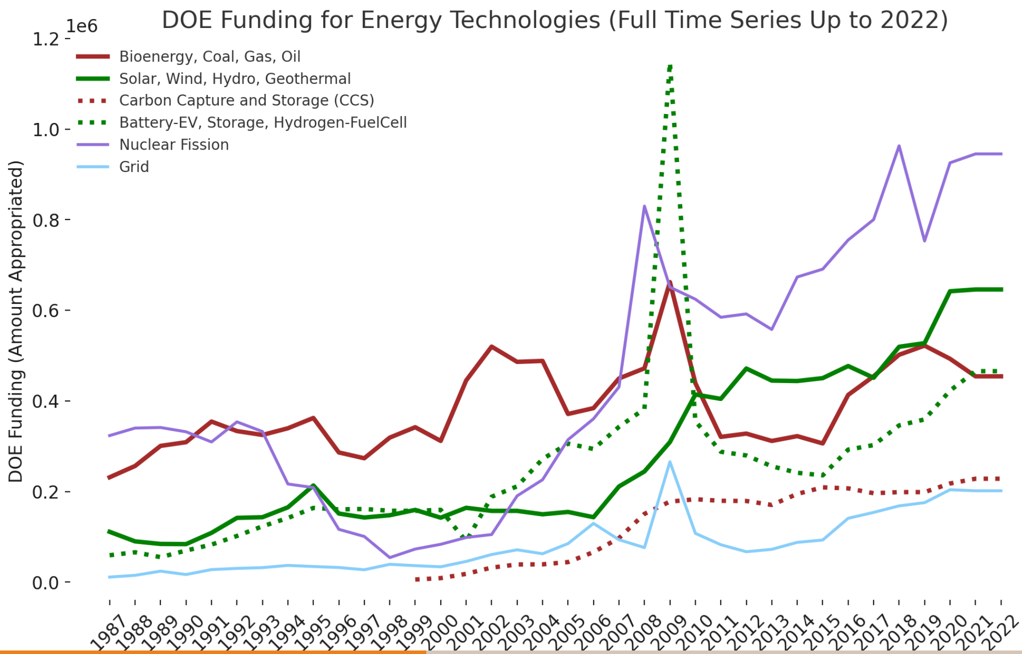

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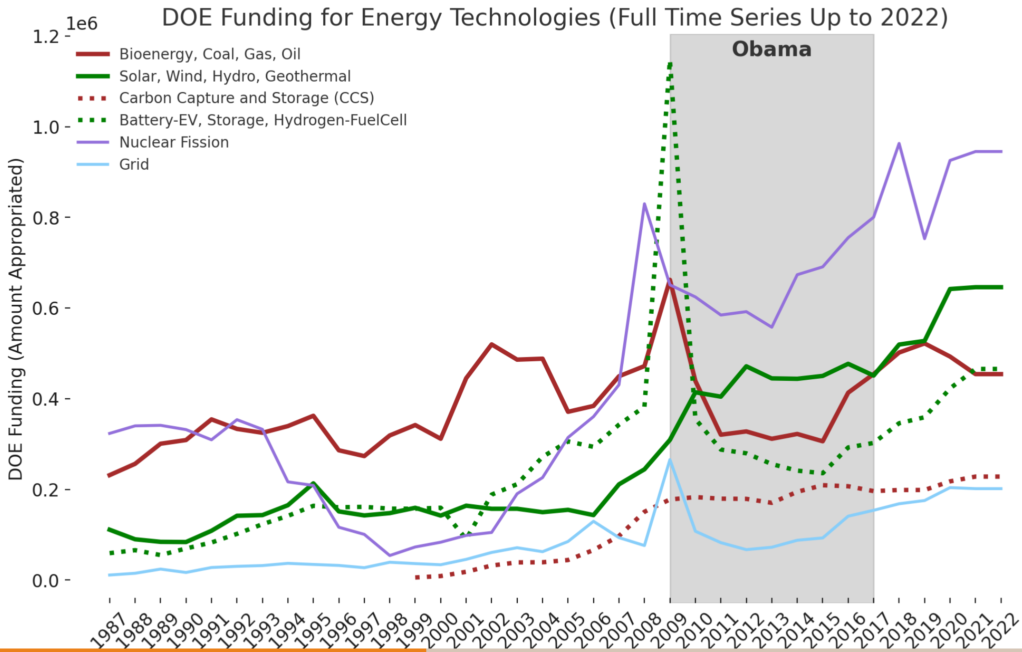

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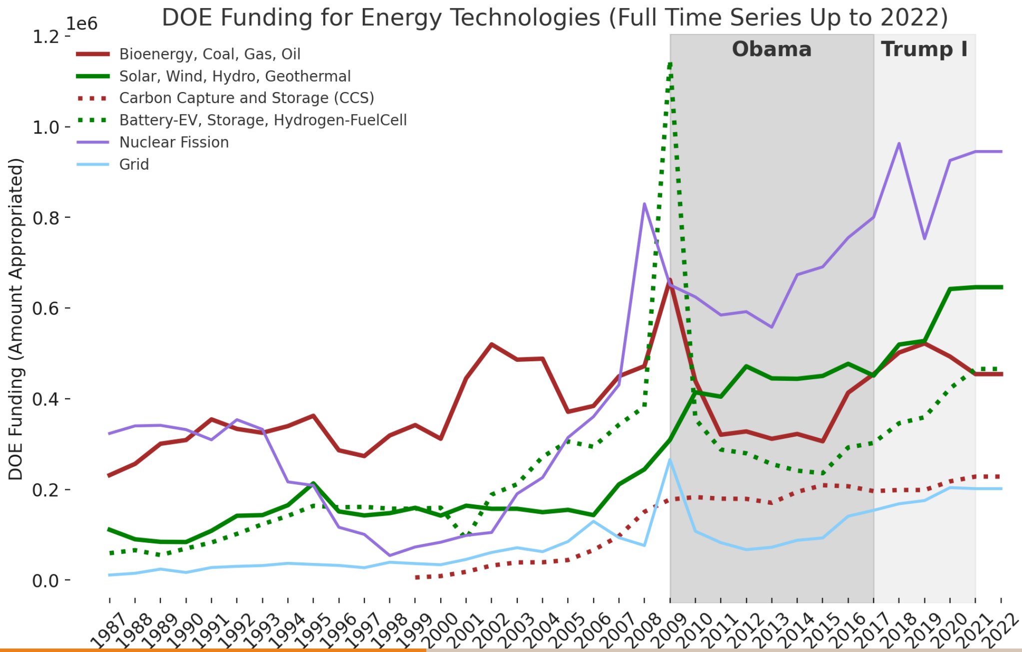
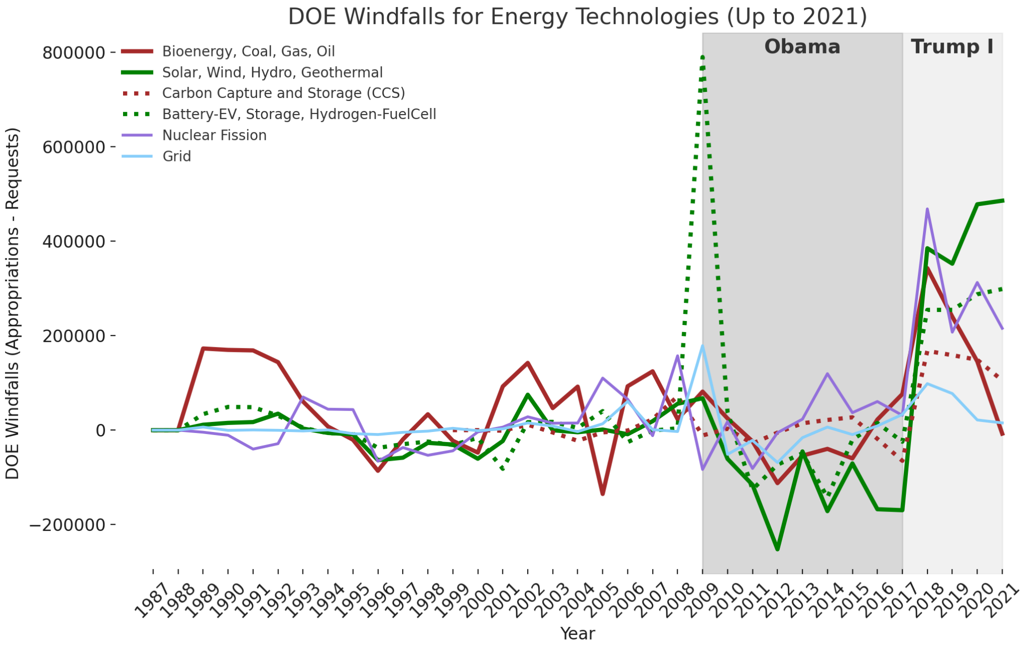


Tech-Specific "Windfalls" (Appropriations - Requests)



FY2011: Congress likes unconventional fossil; DOE not so much

Congress decided to fund a program the DOE did not propose

Unconventional Fossil Energy Technologies

Funding Profile by Subprogram

	FY 2009 Current Appropriation	FY 2009 Current Recovery Act Appropriation	FY 2010 Current Appropriation	FY 2011 Request
Unconventional Fossil Energy Technologies				
Unconventional Fossil Energy Technologies	0	0	20,000	0
Total, Unconventional Fossil Energy Technologies	0	0	20,000	0

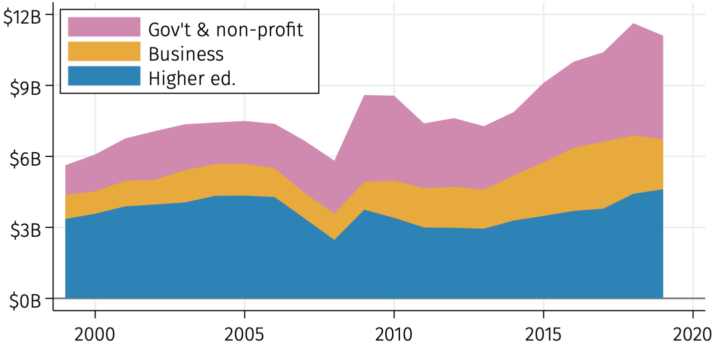
Mission

In FY 2010 Congress recommended the establishment of a new comprehensive program of research, development and technology deployment to focus on the development and production of unconventional oil, gas and coal resources

Consistent with Administration policy to phase out fossil fuel subsidies, the program is requesting no funding in FY 2011.

40-60% of Dept. of Energy Research Funding Goes to Higher Education

Dept. of Energy R&D obligations, by organization type



Source: Survey of Federal Funds for Research and Development

SCALABLE OPEN-AIR PROCESSING OF
ELECTRON TRANSPORT LAYERS FOR
PEROVSKITE SOLAR CELLS

A DISSERTATION
SUBMITTED TO THE DEPARTMENT OF
MATERIALS SCIENCE & ENGINEERING
AND THE COMMITTEE ON GRADUATE STUDIES
OF STANFORD UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

SCALABLE OPEN-AIR PROCESSING OF ELECTRON TRANSPORT LAYERS FOR PEROVSKITE SOLAR CELLS

5.6 Acknowledgements

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

Data: Dissertations and Patents

Dissertations and Patents

- Dissertation Data
  - ProQuest Dissertation Database, 1980-2020
  - Dissertation title/abstract and user-inputted Proquest Class and keywords
  - Focus on STEM disciplines but also excluding biological sciences, astronomy, paleontology...
- Patent Data
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  - Patent CPC codes to track energy technologies

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  - Application-level details and metadata
  - Patent CPC codes to track energy technologies
- Energy Dictionnary
  - Energy term occurrence >0 in title/abstract (after cleaning)
  - Convert to shares if multiple energy terms
  - Aggregate to tech-year counts
- Dictionary vs CPC codes:
  - 36% recall / 62% precision (CPC codes as the "ground truth")

Energy Dictionary

Solar
solar energy
solar power
photovoltaic
solar thermal energy
solar tower
solar cell
solar plant
solar panel

Wind
wind turbine
wind farm
wind energy
wind power

Geothermal
geothermal

Hydro
hydropower
hydro power
hydro energy
hydroelectric
hydro electric
hydro plant

Marine

carbon storage
carbon dioxide capture
carbon dioxide sequestration
carbon dioxide storage
co2 capture
co2 sequestration
co2 storage
carbon dioxide + disposal

Nuclear
nuclear power
nuclear reactor
nuclear energy
nuclear fuel
nuclear engineering
nuclear waste
nuclear accident
nuclear safety
nuclear fission
radioactive waste
nuclear reprocessing

Smart Grid
smart grid
smart power grid
power grid
microgrid
distributed energy

li ion + battery
lithium-ion + battery
pack + battery
module + battery
cell + battery
electrode + battery
storage + battery
electrochemical + battery
cathode + battery
anode + battery
discharge + battery
rechargeability + battery

Fuel Cell
fuel cell

Energy Storage
energy storage
flywheel
supercapacitor

Electric Vehicles
electric vehicle
electric mobility
electrical propulsion units
electric propelled vehicle
electrodynamic brake
electric regenerative braking
charging station

bioethanol
waste heat
waste energy
waste incineration

Energy Efficiency
energy efficiency
energy efficient
energy conservation
energy saving
energy recuperation

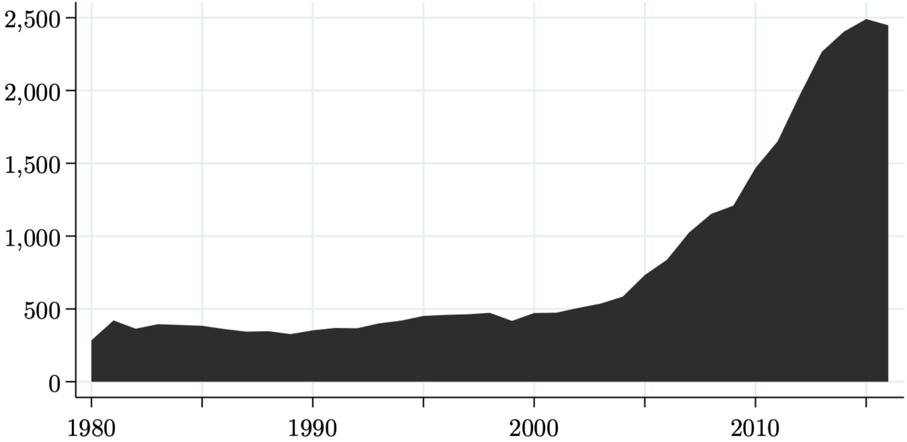
Fossil Fuels
fossil fuel
combustion furnace
liquid fuel
carbonaceous
steam engine
steam accumulator
steam generation
kiln + engineering

Internal Combustion Engine
combustion engine
combustion + energy
gasoline + engine

Oil

Number of New Energy Researchers Increasing

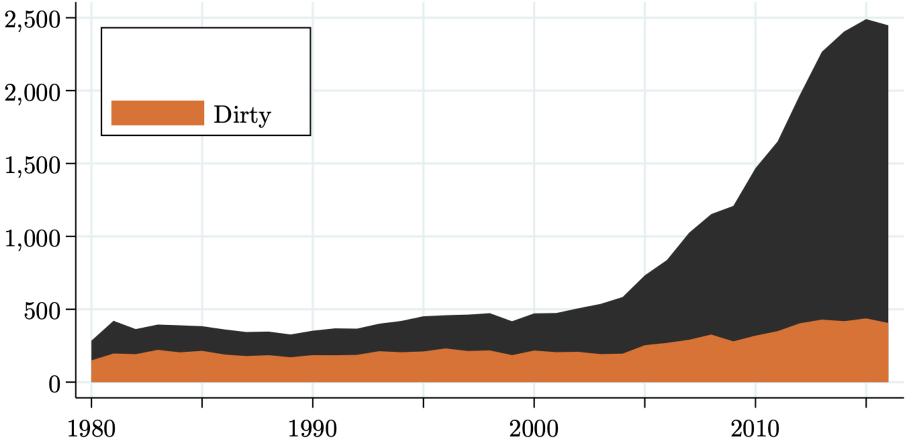
Number of energy-based PhD dissertations



Based on 191 U.S.-based institutions

Number of New Energy Researchers Increasing

Number of energy-based PhD dissertations



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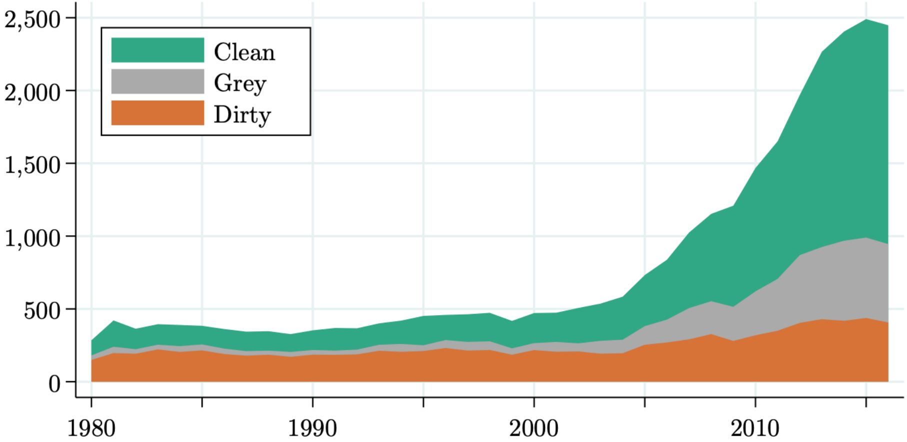
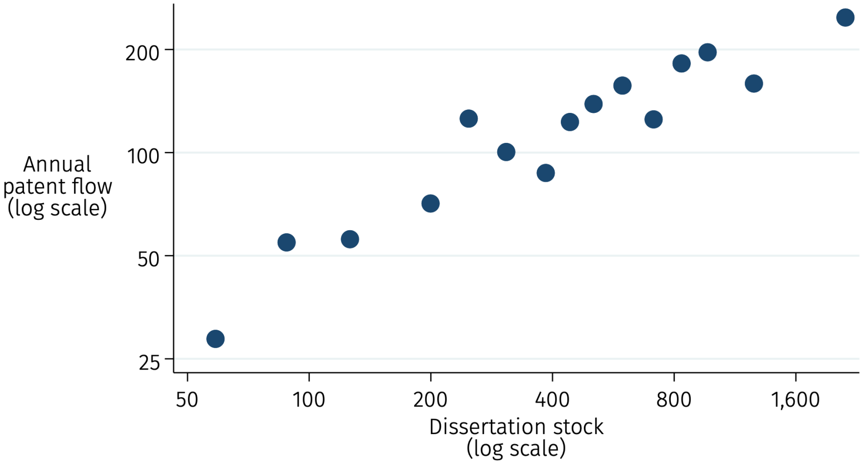


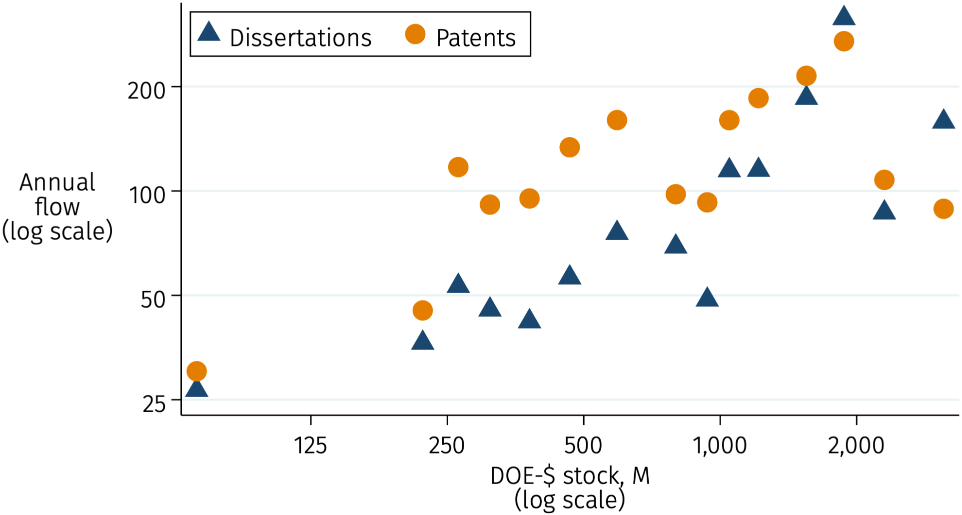
Based on 191 U.S.-based institutions

Stock of Disssertations/Scientists Correlates with Flow of Patents



Note: binned scatterplot, data aggregated to tech-year level

Raw Output-Approp Relationship



Empirical Strategy and Results

Empirical Setting: Estimating the impact of DOE R&D funding

We want to estimate β: the impact of DOE R&D funding on the supply of scientists and innovation.

For energy technology j, year t:

$$\log(\text{Diss}_{jt}^{\text{flow}}) = \alpha + \beta \log\left(\text{Approp}_{jt}^{\text{stock}}\right) + \omega_{jt} + \epsilon_{jt}$$

Diss – count of dissertations (or patents or scientific articles)

Approp – Dept. of Energy R&D appropriations (discounted stock of the previous N years)

β – output elasticity of funding

ω – productivity shock: could lead to omitted variable bias; unobservable to us

ϵ_{jt} – idiosyncratic error

Empirical Setting: We observe both requests and appropriations.

- $\text{Approp}_{jt}^{\text{stock}}$ funding determined through a political budget process:
  - **DOE requests** are made (based on productivity expectations)
  - **Congressional appropriations** typically differ from the requests
- There is some random variation we can leverage for identification in:

$$\text{Windfall}_{jt} = \log(\text{Approp}_{jt}) - \log(\text{Requests}_{jt})$$

- Windfalls may reflect:
  - Random congressional deviations (which may be useful for identification)
  - Systematic responses to DOE requests and strategic budgeting where DOE anticipates Congressional biases. $\Rightarrow$ could reflect expected productivity rather than a purely exogenous shock

Empirical Challenge: Isolating quasi-random variation

Predict Appropriations based on observables:

$$\log \text{Approp}_{jt} = f_{jt}(\log \text{Request}_{jt}, \text{PoliticalParty}_t, \text{Dirty}_j) + e_{jt}$$

- Approp_{jt} is the amount appropriated for tech j in year t (flow)
- $f_{jt}(.)$ is a flexible function which can be tech and/or year specific
- Request_{jt} is the amount requested for tech j in year t (flow)
- PoliticalParty_t are a series of variables capturing whether POTUS/Senate/House are Republican/Democrat and whether POTUS is of the same party as the Senate and/or the House
- Dirty_j: oil, gas, coal

We then use the residual $\hat{e}_{jt}$ to construct an instrument for the stock of appropriations at time t.

Empirical Challenge: Isolating Quasi-Random Variation

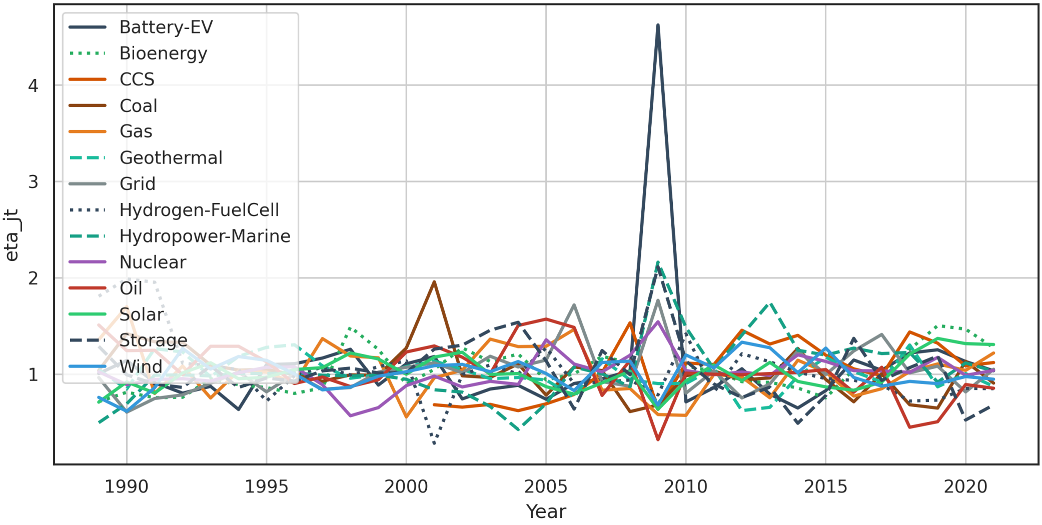
Predict Appropriations based on Observables:

$$\log \text{Approp}_{jt} = f_{jt}(\log \text{Request}_{jt}, \text{PoliticalParty}_t, \text{Dirty}_j) + e_{jt}$$

- Specification 1: $\log \text{Request}_{jt}$ X year f.e., year f.e. ($R^2 = 92\%$)
- Specification 2: $+$ tech f.e. ($R^2 = 93\%$)
- Specification 3: $+$ political variables X dirty indicators ($R^2 = 94\%$)
- Specification 4: $+ \log \text{Request}_{jt}$ X political variables X dirty indicators ($R^2 = 94\%$)
- Specification 5: $+$ square and cube of $\log \text{Request}_{jt}$ ($R^2 = 96\%$)

Residual $\hat{e}_{jt} \approx \log \eta_{jt} \Rightarrow \eta_{jt} = \exp(\hat{e}_{jt}) = \frac{A_{jt}}{\hat{A}_{jt}}$

Predicting Appropriations: Residuals η_{jt} across Technologies over Time



Constructing the Instrument

$$\log \text{Approp}_{jt} = f_{jt}(\log \text{Request}_{jt}, \text{PoliticalParty}_t, \text{Dirty}_j) + e_{jt}$$

- Predicted appropriations: $\hat{\text{Approp}}_{jt}$
- Predicted stock of appropriation:

$$\hat{\text{Approp}}_{jt}^{\text{stock}} = \sum_{\tau} (1-\delta)^{\tau} \hat{\text{Approp}}_{j(t-\tau)} \quad (1)$$

- Instrument:

$$Z = \log \text{Approp}_{jt}^{\text{stock}} - \log \hat{\text{Approp}}_{jt}^{\text{stock}} \quad (2)$$

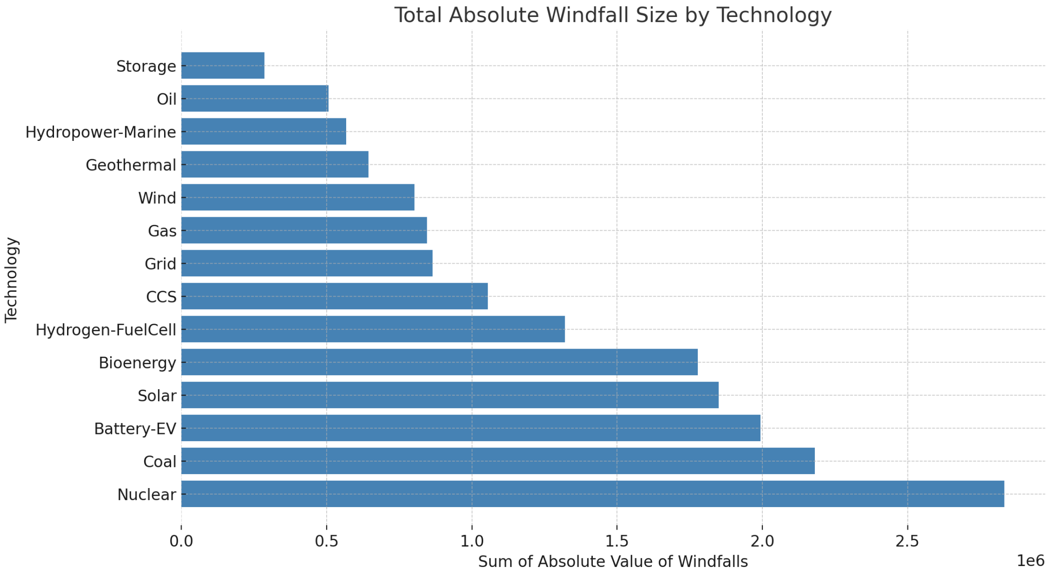
- Assumptions:
  - Some source of quasi-random shocks independent from productivity (e.g. political noise)
  - Congress does not have better information about ω_{jt} than the DOE, i.e. DOE are the experts.

Further Empirical Challenge: Non-Random Exposure?

- Problem: Some technologies or years may be more "treated" (higher windfalls) for systematic reasons
  - e.g., a 1% shock in appropriations implies a much larger dollar value shock for technologies with larger base levels of appropriations

  $\Rightarrow$ A problem of **non-random exposure to random shocks**
- **Solution:** Recenter the instrument to remove the endogenous component following Borusyak & Hull (2023)
- Intuition: Predict the "expected" windfalls and use only deviation from this as the identifying variation

Some technologies have systematically larger windfalls



Construct a recentered instrument using permutations

- Randomly permute $\hat{\eta}_{jt}$ across units to create artificial appropriation values:

$$\tilde{Approp}_{jt}^{(n)} = \hat{Approp}_{jt} \times \exp(\hat{\eta}_{j't'})$$

- Compute the expected approp stock using the recursive accumulation equation:

$$\tilde{\text{Approp}}_{jt}^{\text{stock}(n)} = \delta \text{Approp}_{j(t-1)}^{\text{stock}} + \tilde{Approp}_{jt}^{(n)}$$

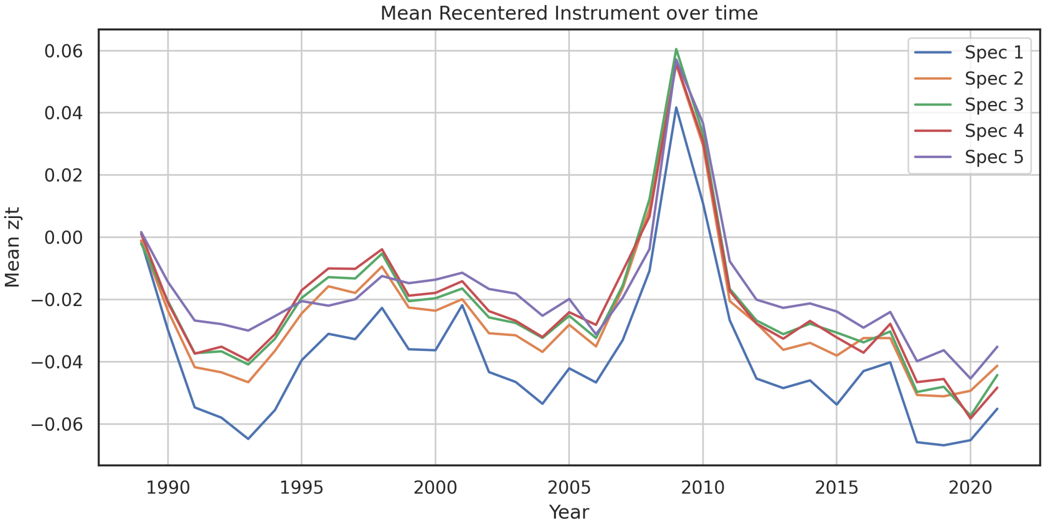
- Average across N permutations:

$$\mu_{jt} = \frac{1}{N} \sum_{n} \log(\tilde{\text{Approp}}_{jt}^{\text{stock}(n)})$$

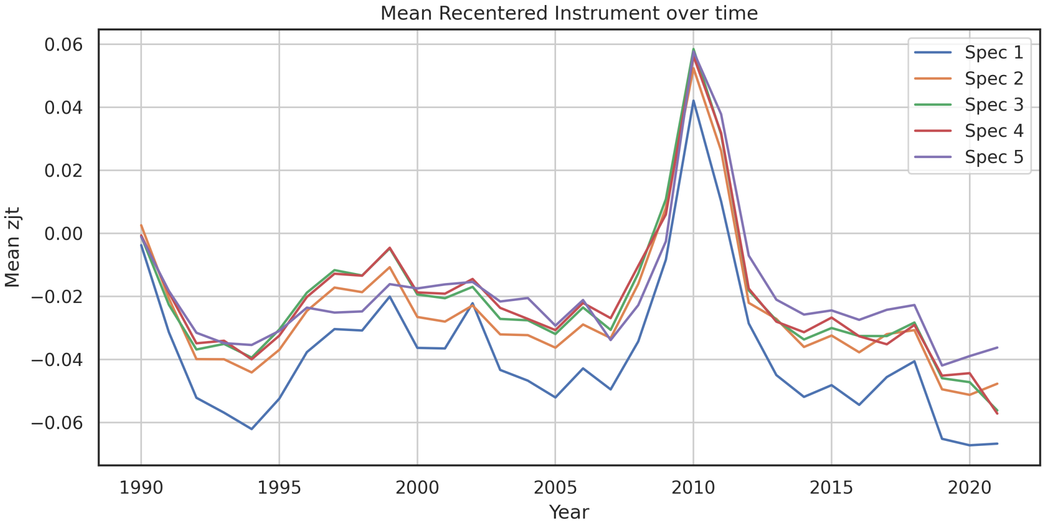
- Final instrument:

$$z_{jt} = \log(\text{Approp}_{jt}^{\text{stock}}) - \mu_{jt}$$

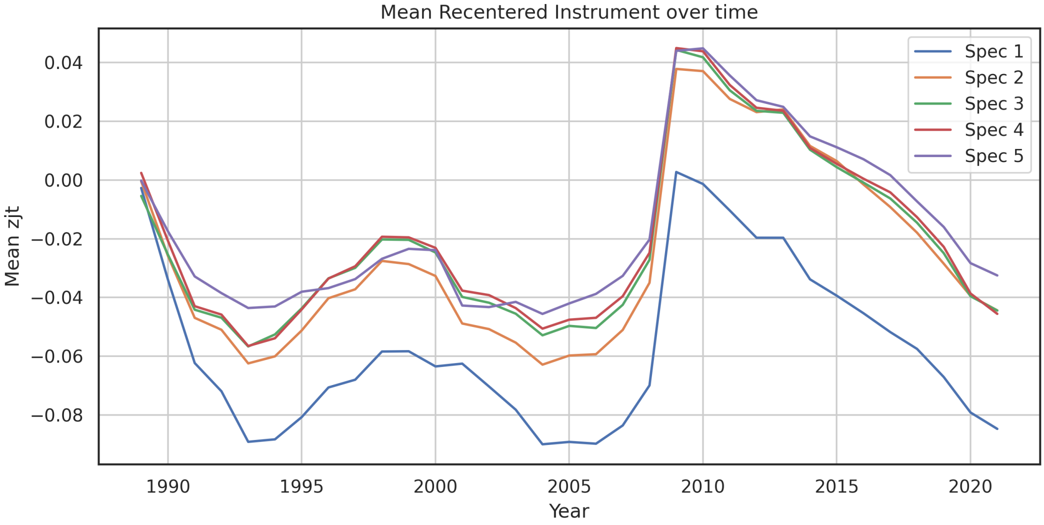
Recentered Instrument: 50% discount rate, τ lag 0



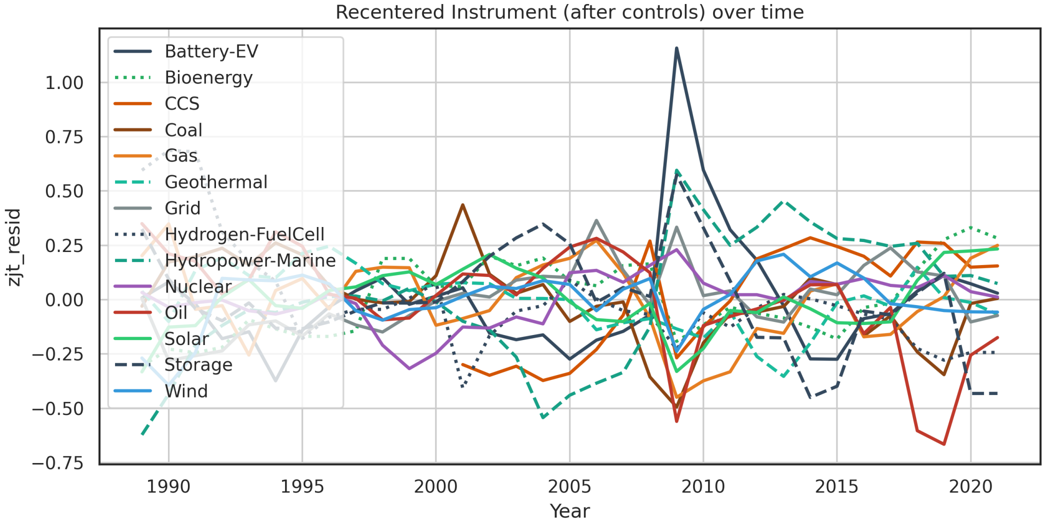
Recentered Instrument: 50% discount rate, τ lag 1



Recentered Instrument: 10% discount rate, τ lag 0



Recentered Instrument (After Controls) Across Tech (50% discount, τ lag 0)



IV estimation

- Second Stage:

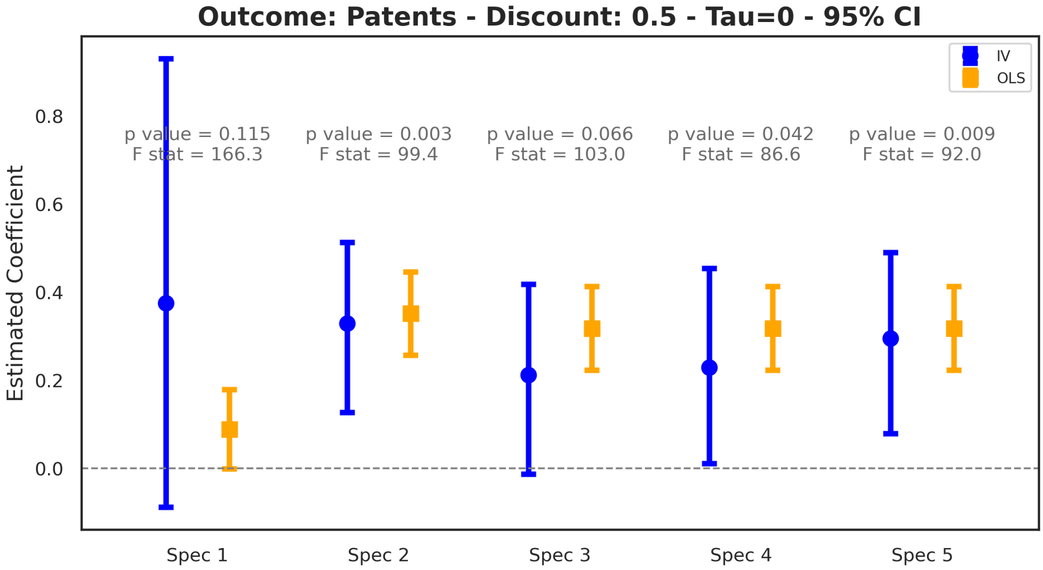
$$\log(\text{Diss}_{jt}^{\text{flow}}) = \beta \log\left(\text{Approp}_{jt}^{\text{stock}}\right) + \textit{Controls} + \epsilon_{jt} \tag{3}$$

- First Stage:

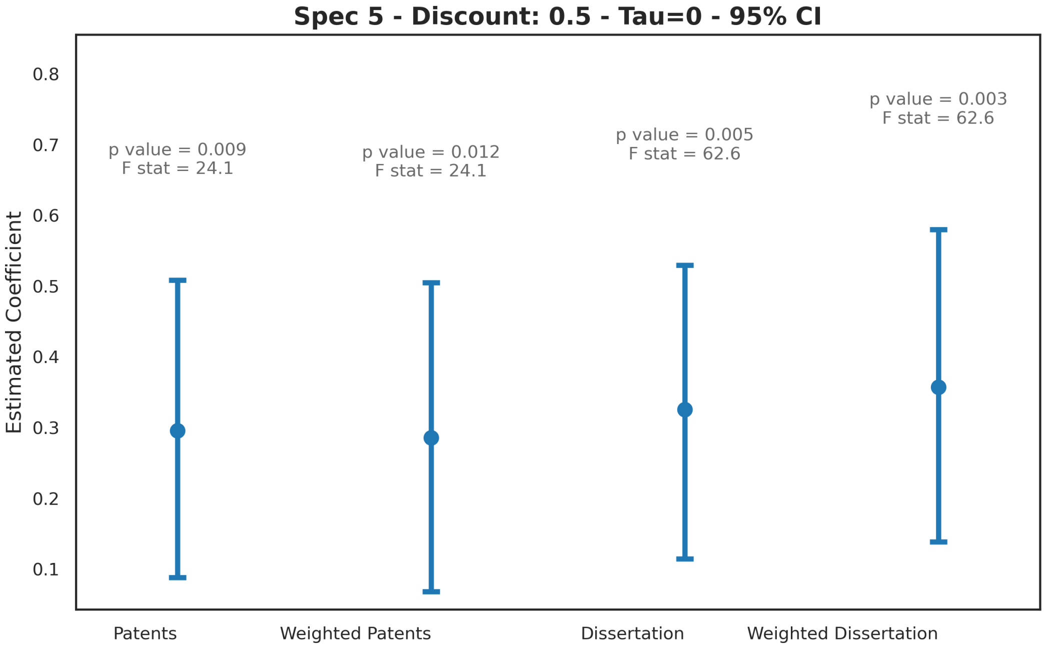
$$\log\left(\text{Approp}_{jt}^{\text{stock}}\right) = \gamma z_{jt} + \textit{Controls} + u_{jt} \tag{4}$$

- Controls:
  - Specification 1: year f.e.
  - Specification 2: + tech f.e.
  - Specification 3: + political variables X dirty indicators
  - Specification 4: (same)
  - Specification 5: (same)
- Inference: BH permutation procedure

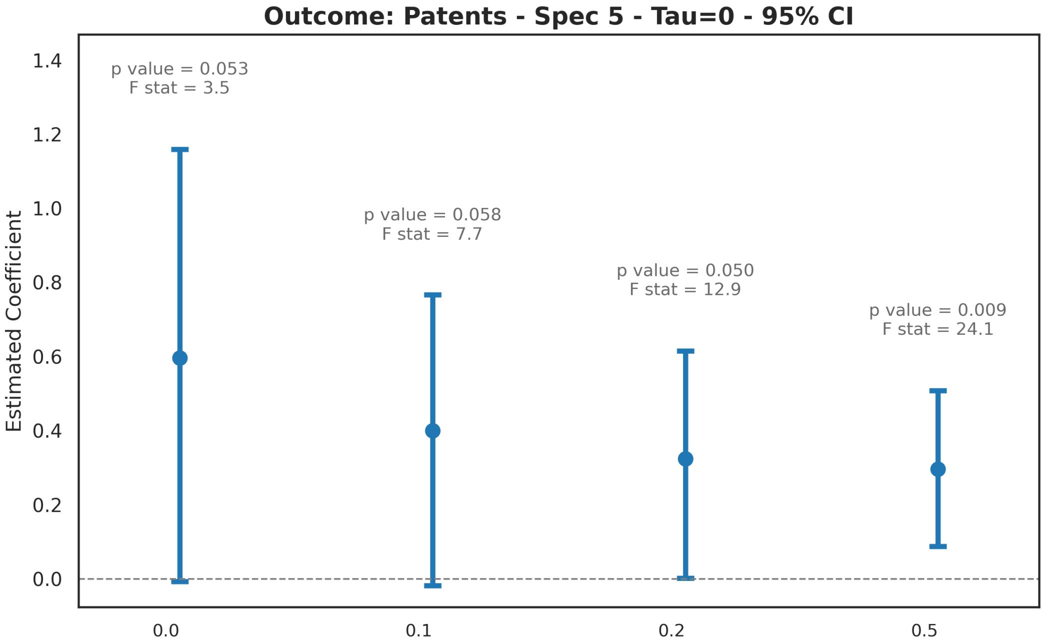
Results Across Specifications



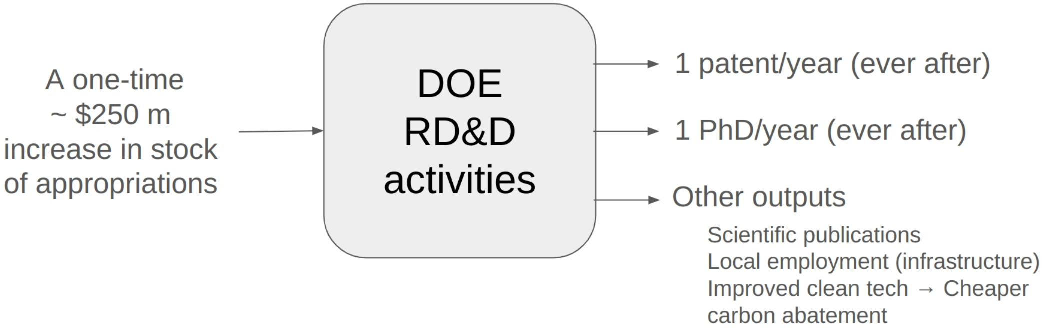
Results Across Outcomes



Results Across Different Discount Rates



Key Take-Aways for Now



Budget Cuts at the DOE → Fewer Scientists and Engineers

The end of DOE as we know it

As more major cuts loom, staff tell Latitude Media that it feels like “a hostile takeover” is happening within the Department of Energy.

MAEVE ALLSUP | LISA MARTINE JENKINS | APRIL 14, 2025

Any question/comment, email me: `e.dugoua@lse.ac.uk`

Thank you!

Eugenie Dugoua
www.eugeniedugoua.com
London School of Economics and Political Sciences

Appendix

Standard Error Computation: Permutation Approach

Estimation Across Permutations

- Re-estimate the main model
- Obtain estimates $\hat{\beta}^{(n)}$ for each permutation n.

Compute Standard Errors

- Compute the empirical standard deviation:

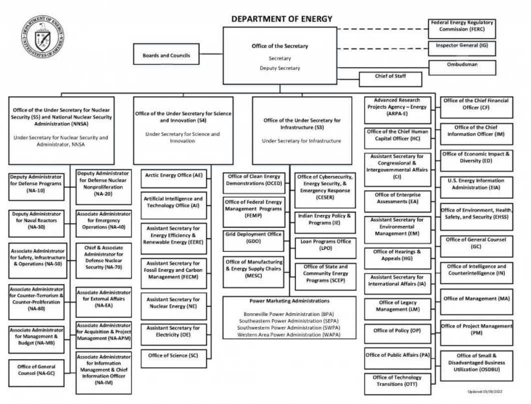
$$SE(\hat{\beta}) = \sqrt{\frac{1}{N}\sum_{n}(\hat{\beta}^{(n)} - \bar{\beta})^2}$$

- Where:

$$\bar{\beta} = \frac{1}{N}\sum_{n}\hat{\beta}^{(n)}$$

The DOE Sprawls across Technologies... and Across Missions (R&D vs non R&D)

- Offices of...
  - Electricity
  - Indian Energy Policy
  - ARPA-E
  - Efficiency & Renewables
  - Environmental Mgmt.
  - Fossil Energy and Carbon Mgmt.
  - Legacy Mgmt.
  - Loan Programs
  - Nuclear Energy
  - Science
  - Cybersecurity & Energy Security
  - A.I. & Technology
- 84 locations (21 labs & centers)
- 14K fed. employees + 95K contractors



Addressing Climate Change will Require Significant Innovation

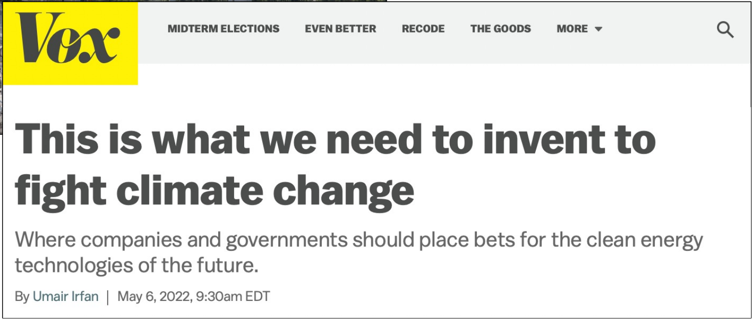
INTERNATIONAL MONETARY FUND

F&D FINANCE & DEVELOPMENT

FIGHTING CLIMATE CHANGE WITH INNOVATION

KELLY LEVIN, ANDREW STEER

SEPTEMBER 2021



Vox

MIDTERM ELECTIONS EVEN BETTER RECODE THE GOODS MORE

This is what we need to invent to fight climate change

Where companies and governments should place bets for the clean energy technologies of the future.

By Umair Irfan | May 6, 2022, 9:30am EDT

Where we could use lots of feedback

- **Is this an interesting question / potential contribution?**
  - Direct funding is important for increasing quant of energy researchers
  - Bringing scientists into energy matters for driving energy innovation
  - Human capital in general matters - and there are frictions in educ

- **Method**: a few potential approaches.
  - **Is tech-year windfall variation convincing?**
    - And if so, funding stocks? (vs. lags vs. moving averages)
  - **Is current prod fn approach convincing? Or...**
    - IV with windfalls? (basically equivalent anyway and weak IV)
    - Use data at grant and dissertation level? (but don't have exog variation)

Connections to literature

Inelasticities in research

- Goolsbee (1998)
- Myers (2020)
- Dugoua & Gerarden (2024)

Human capital & innovation

- Romer 2000; Van Reenan (2020)
- Bianchi and Giorcelli, (2019)
- Akcigit et al., WP (2020)

Innovation in the energy sector

- Johnstone et al. (2010), Newell et al. (1999), Noailly and Smeets (2015), Popp (2002), and Popp and Newell (2012)

Gov't funded research

- Azoulay et al. (2019); Howell (2017); Pless (2022)

Political economy and public finance

- Exploiting noise in political bargaining for evaluating programs

University science & firms

- Cohen, Nelson, Walsh (2002)
- Fleming et al. (2019)

Estimates of the Social Returns to R&D (Jones 2022)

Study	Industry / Context		Social Rate of Return	Social Benefit-Cost Ratio
Alston et al. (2000)	Agriculture (review of 292 studies)		44% (median)	--
Mansfield et al. (1977) and Tewksbury et al. (1980)	Industrial Innovations (37 case studies)		71% (median)	--
Bloom et al. 2013	Publicly-traded firms, All industries		55%	--
Azoulay et al. 2019	Biomedical research from the NIH		--	> 3
Jones and Summers (2020)	Overall U.S. Economy	Baseline estimate Conservative estimate	67% 20%	13.3 5

Energy Efficiency and Renewable Energy Programs
FY 2003 Congressional Budget Request
(in thousands of dollars)

Program	FY 2001 Comparable Appropriation	FY 2002 Original Appropriation	FY 2002 Adjustments	FY 2002 Comparable Appropriation	FY 2003 Request
Building Technology, State and Community Sector	$293,341	$380,270	$0	$380,270	$408,791
Federal Energy Management Program	$25,661	$23,300	$0	$23,300	$27,880
Industrial Sector	$145,986	$148,924	$0	$148,924	$138,359
Transportation Sector	$251,462	$252,715	$0	$252,715	$222,664
Power Technologies (DER)	$47,346	$63,846	$0	$63,846	$63,904
Policy and Management	$46,046	$43,750	$2,665	$46,415	$42,706
Subtotal Energy Conservation	$809,842	$912,805	$2,665	$915,470	$904,304
Renewable Energy Resources	$370,453	$385,589	$817	$386,406	$407,720
Subtotal Energy Supply	$370,453	$385,589	$817	$386,406	$407,720
Total Program Funding	$1,180,295	$1,298,394	$3,482	$1,301,876	$1,312,024
PODRA and Prior Year Balances	$0	$0	$0	$0	$0
Transfer from Biomass Energy Development (non add)	$(2,000)	$0	$0	$0	$0
Total Budget Authority	$1,180,295	$1,298,394	$3,482	$1,301,876	$1,312,024
Total Excluding Full Funding for Federal Retirement	$1,176,764	$1,298,394	$0	$1,298,394	$1,308,651

The FY 2001 and FY 2002 columns of the FY 2003 Congressional Request include funding in the amount of $3,531,000 and $3,482,000 respectively, for the Government's share of increased costs associated with pension and annuitant health care benefits. These funds are comparable to FY 2003 funding of $3,373,000. (Note: The data is presented on a comparable basis as if the legislation had been enacted and implemented in FY 2001.)

In addition, reflects FY 2002 Interior and Related Agencies Appropriation (P.L.107-63) language directing that 50 percent of Energy Efficiency Science Initiative funds for FY 2002 ($6,000,000) and beyond shall be made available to the DOE Fossil Energy Research and Development account.
For Renewable Energy, budget adjustments have been made for full funding of Federal Retirements as well as a $10,411,000 Energy Supply Account (Energy and Water Development Appropriation) general reduction. Other FY 2001 adjustments were made for establishment of separate Power Technologies (DER) program budget starting in FY 2002 as well as SBIR/STTR transfers.

How the DOE decides on Requests

Example from FY 1997:

"In a time of fiscal austerity"... Early 1990s recession, strong pressure to reduce government spending.

The challenge DOE faces in FY 1997 is to produce beneficial new technologies with fewer resources, maintaining the vital contribution of energy efficiency and renewable energy in the Administration's and Congress' vision. To accomplish this goal, DOE's FY 1997 Budget Request proposes funding for programs that will leverage significant non-Federal investments and will produce high economic, environmental and energy-security benefits, while accelerating the entry of U.S. technologies into the global marketplace.

Energy Efficiency and Renewable Energy Programs represent an appropriate government role in technology R&D

If the marketplace functioned perfectly, Federal initiatives might not be needed to help the private sector research and develop promising new energy technologies. But changes in the marketplace, industrial restructuring and the nature of technology development have all acted to discourage investments in technology R&D in many areas. These changes include:

These changes do not mean that the federal government should have a role in <u>all</u> technology R&D. However, carefully targeted federal involvement in close partnership with the private sector can help the marketplace function more efficiently and facilitate the development of American competitive advantage in technologies that might otherwise be developed by our global competitors. The federal government should consider funding a technology if:

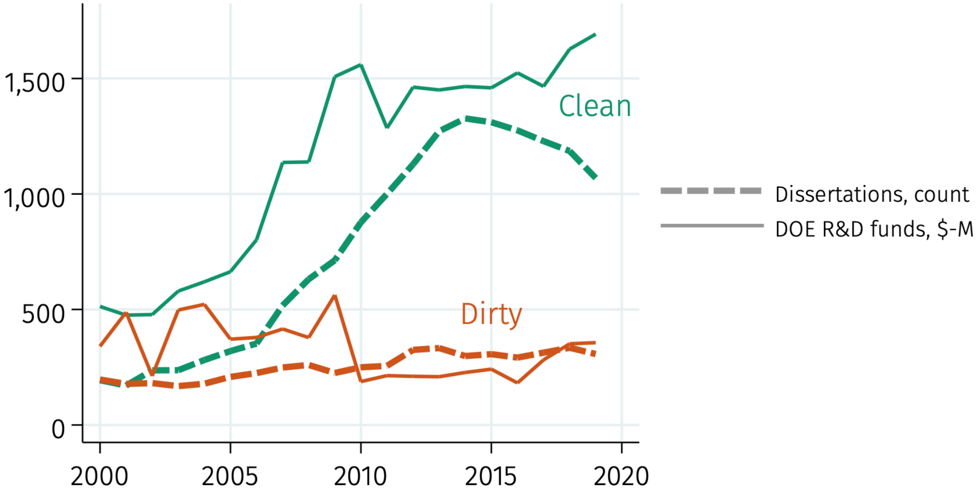
- there is a high social rate of return;
- it fulfills a strategic national need; and,
- the private sector cannot develop it alone.

Stock of Disssertations/Scientists Correlates with Flow of Patents

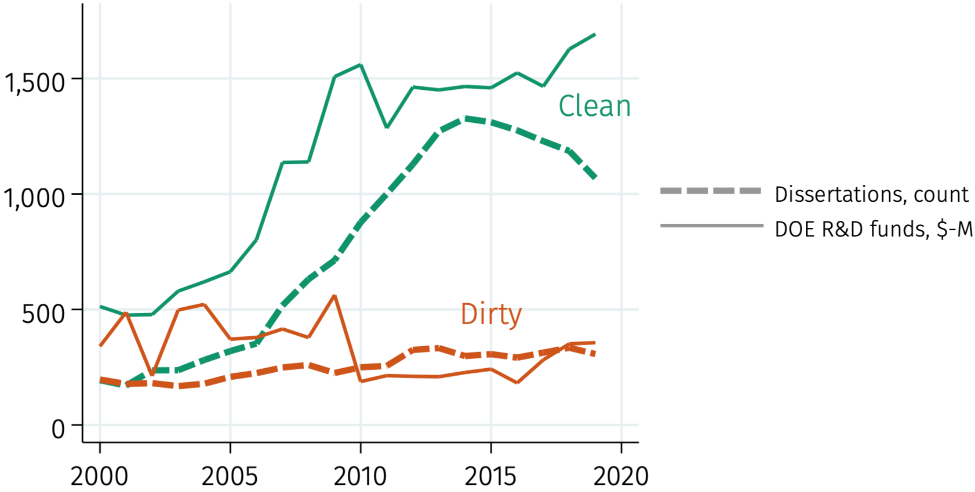
$$\log(\text{Patent}_{jt,\text{ flow}}) = \beta \log(\text{Diss}_{jt,\text{ stock}}) + \text{...FE...} + \epsilon_{jt}$$

	(1)	(2)	(3)	(4)
Diss, stock	0.931***		0.570***	
	(0.113)		(0.178)	
... $\times$ dirty		0.914***		0.786
		(0.0957)		(1.173)
... $\times$ clean		1.002***		0.610**
		(0.0997)		(0.265)
N jt obs.	231	231	231	231
year-t FE	Y	Y	Y	Y
tech-j FE			Y	Y

Trends in Dissertations Mirror Trends in Funding

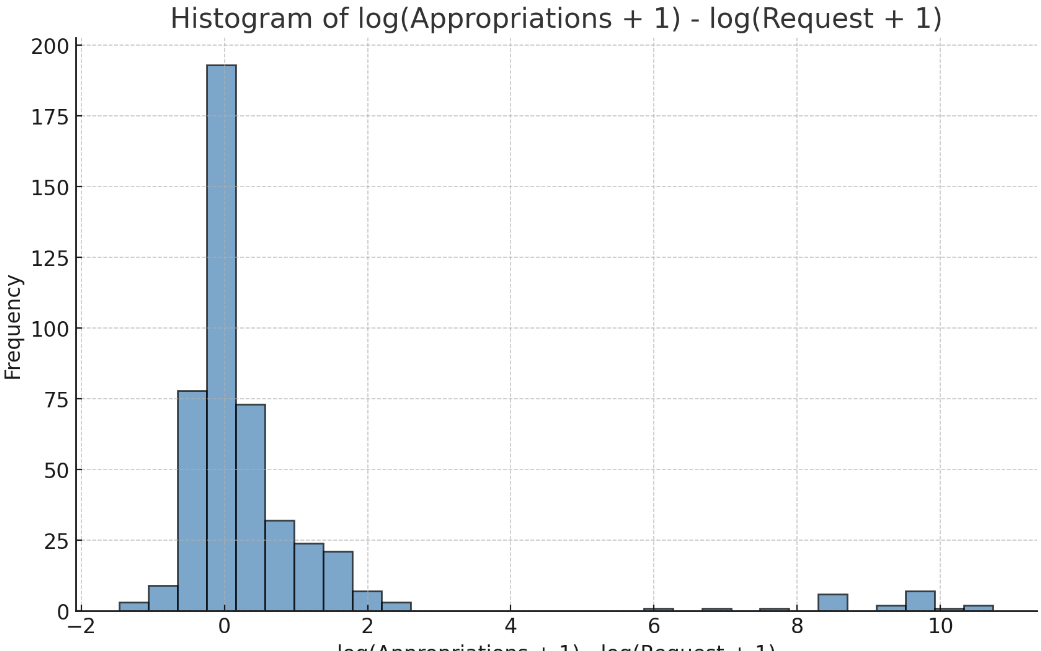


Trends in Dissertations Mirror Trends in Funding



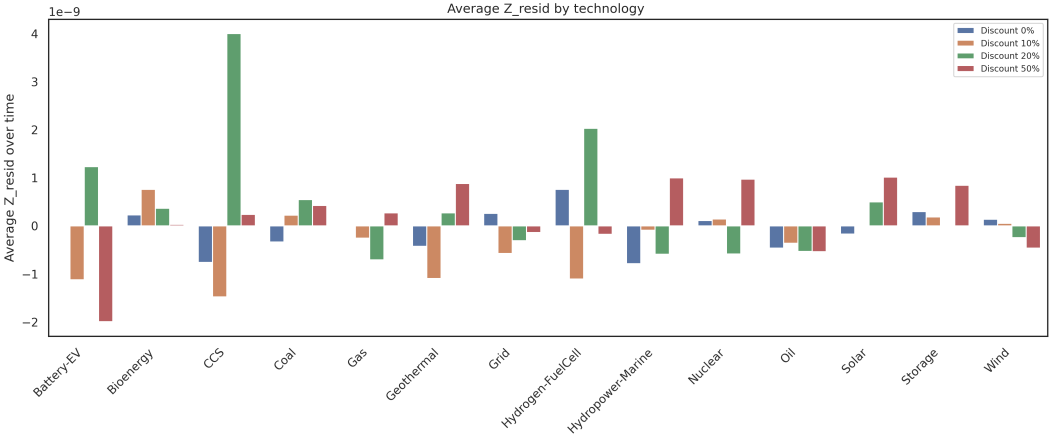
Challenge: other factors may drive both funding and patents and dissertations

Some technologies have systematically larger windfalls



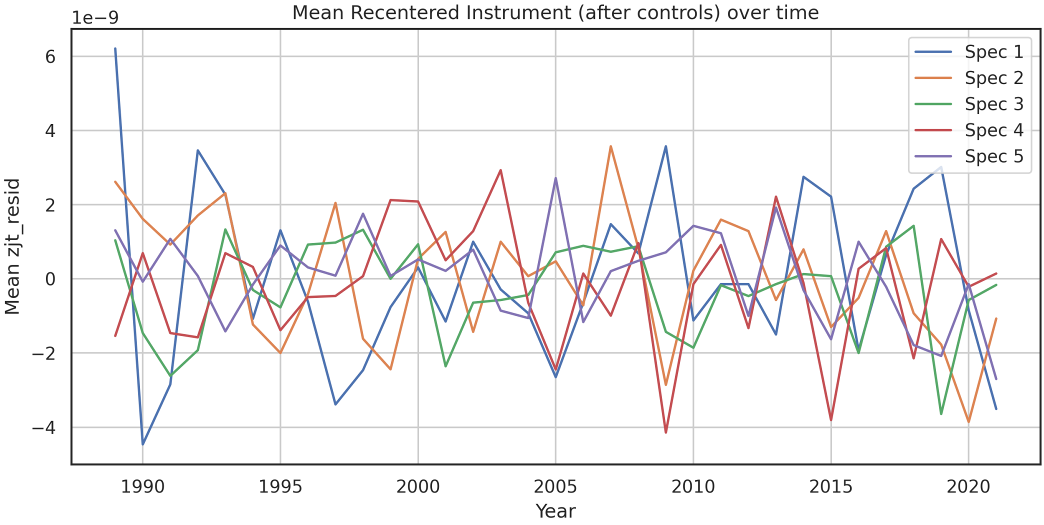
Identifying Variation: Recentered Instrument (residualized after controls)

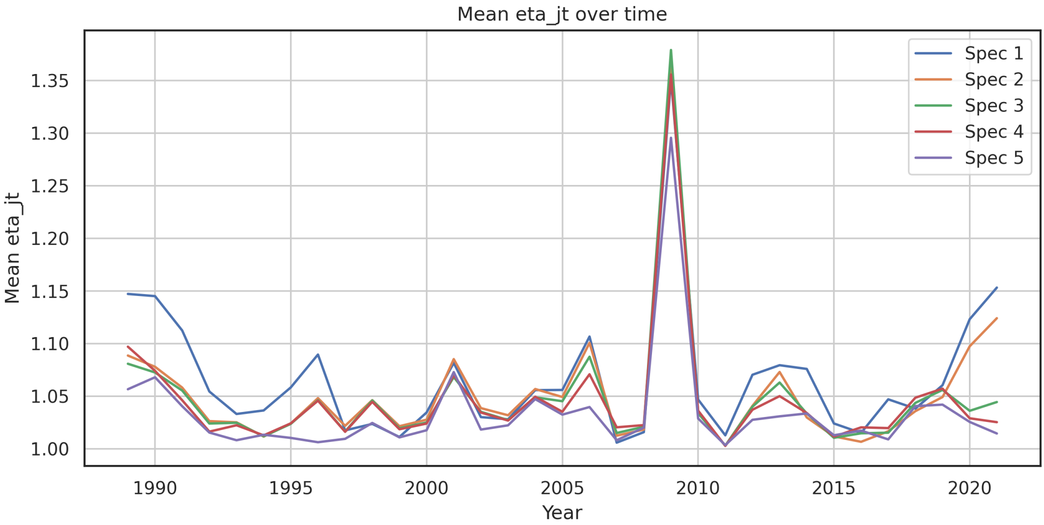
Average over time for each tech for different discount rates
For Specification 5 and τ lag 0



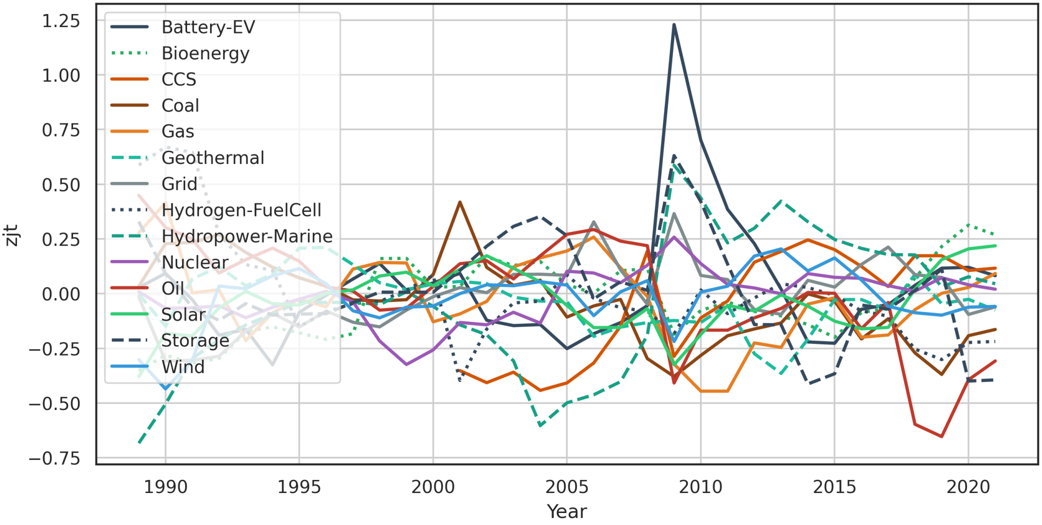
Identifying Variation: Recentered Instrument (residualized after controls)

Average over all technologies for different specifications
50% discount rate, τ lag 0




Mean eta_jt over time
Spec 1
Spec 2
Spec 3
Spec 4
Spec 5
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
Mean eta_jt
1990
1995
2000
2005
2010
2015
2020
Year

Recentered Instrument Acr0ss Tech (50% discount rate, τ lag 0)



Key Take-Aways for now

For energy technology j, year t:

$$\log(\text{Diss}_{jt}^{\text{flow}}) = \alpha + \beta \log\left(\text{Approp}_{jt}^{\text{stock}}\right) + \omega_{jt} + \epsilon_{jt}$$

- β is around 0.2-0.4 for both patents and dissertations
  - Cost per dissertation: \$3-6 million
  - Cost per patent: \$1-2.5 million

    If mean (commercial) value of patents is \$10 million,

    $\Rightarrow$ Benefit-cost ratio of 1.6 to 3.3 (not including social value from emission reduction)